EPA 560/6-76-005

PCBs IN THE UNITED STATES INDUSTRIAL USE AND ENVIRONMENTAL DISTRIBUTION

TASK I

FEBRUARY 25, 1976

FINAL REPORT

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF TOXIC SUBSTANCES
WASHINGTON, D.C. 20460

NWMAR115681

NWMAR115682

EPA 560/6-76-005

PCBs IN THE UNITED STATES INDUSTRIAL USE AND ENVIRONMENTAL DISTRIBUTION

Task I

EPA Contract No. 68-01-3259

EPA Project Officer: Thomas Kopp

For

Environmental Protection Agency

Office of Toxic Substances
4th and M Streets, S.W.
Washington, D. C. 20460

February 25, 1976

U.S. Environmental Protection Agency
Region 5 Library (PL-12J)
77 West Jackson Blvd., 12th Floor
Chicago, IL 60604-3590

NWMAR115683

REVIEW NOTICE

This report has been reviewed by the Office of Toxic Substances, EPA and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ENVIRON... ...TION AGENCY

NWMAR115684

ABSTRACT

This document presents the current state of knowledge about the production, usage, and distribution of polychlorinated biphenyls (PCBs) in the United States. The information presented is derived from detailed studies on the production and first tier user industries, the past and present generation and disposition of PCB-containing wastes, environmental transport and cumulative loads, potential alternatives to PCBs usage, inadvertent losses to and potential formation in the environment, and current regulatory authorities for PCBs control. These results indicated that, although PCBs content of industrial wastes can be reduced through various approaches (treatment, substitution, etc.), there exists a potentially severe future hazard in the form of large amounts of PCBs currently contained in land disposal sites. Further definition of this and other aspects of the PCBs problem, and determination of ways to minimize the hazard, are recommended.

NWMAR115685

TABLE OF CONTENTS

		Page
SECTION I - INTRODUCTION		1
1.0	OVERVIEW OF THE PCBs PROBLEM	1
2.0	OBJECTIVE AND SCOPE OF THE REPORT	2
SECTION II - SUMMARY		4
1.0	PRODUCTION, USAGE, AND DISTRIBUTION OF PCBs	4
	1.1 Overview of PCBs Industrial Usage in the United States	4
	1.2 Cumulative PCBs Production and Usage in the United States	5
	1.3 Current Distribution of PCBs Usage and Associated Wastes	8
	1.4 Land Disposal and Environmental Load	8
	1.5 Foreign Production of PCBs	10
2.0	CHARACTERIZATION OF INDUSTRY PRACTICE AND WASTE HANDLING FOR THE PCBs PRODUCER AND MAJOR FIRST-TIER USERS	10
	2.1 Manufacture of PCBs and PCB-Containing Capacitors and Transformers	10
	2.2 Treatment and Disposal of Industrial Wastes Containing PCBs	12
	2.2.1 Incineration	13
	2.2.2 Treatment of PCB-Contaminated Wastewater	13
	2.3 Characterization of the Investment Casting Industry	15
	2.4 Transformer Service Industry	16
3.0	SUBSTITUTES AND USE ALTERNATIVES FOR PCBs	16
	3.1 Substitutes for PCBs in Capacitors	16
	3.2 Substitutes for PCBs in Transformers	17
	3.3 Alternatives to Other PCBs Applications	19
4.0	SOURCES OF INADVERTENT ENTRY OF PCBs INTO THE ENVIRONMENT.	19
	4.1 Paper Recycling	19
	4.2 Effluent Contamination by PCBs in Other Industries	20
	4.3 Inadvertent Production of PCBs in the Environment	20

NWMAR115686

TABLE OF CONTENTS (Con't)

Page

SECTION II (Con't)

5.0 TRANSPORT AND DISTRIBUTION OF PCBs IN THE ENVIRONMENT . . . 21

6.0 REGULATORY ACTIONS ON PCBs. 23

SECTION III - CONCLUSIONS AND RECOMMENDATIONS 25

1.0 CONCLUSIONS 25

2.0 RECOMMENDATIONS 28

SECTION IV - CHEMICAL AND PHYSICAL PROPERTIES OF CHLORINATED BIPHENYLS 31

1.0 INTRODUCTION 31

1.1 The Chemistry of the Chlorinated Biphenyls 31
1.2 Commercial Production and Chemical Makeup of the Aroclors 34
1.3 Physical Properties of the PCB Aroclors 39

1.3.1 Physical Properties of Industrial and Technical Interest 39
1.3.2 Physical Properties of Environmental Interest . 41

1.4 Chemical Properties of the Chlorobiphenyls 49
1.5 Photochemical Reactions Involving the PCBs 49
1.6 Metabolic Chemistry of the Chlorobiphenyls 51

SECTION V - INDUSTRIAL CHARACTERIZATIONS. 54

1.0 INTRODUCTION 54

2.0 MANUFACTURING PROCESS - POLYCHLORINATED BIPHENYLS (PCBs) . 54

2.1 Process Description 54
2.2 Raw Wastes 57
2.3 Plant Water Usage 59
2.4 Wastewater Treatment and Housekeeping 60

2.4.1 Treatment Facility for the Effluent from Sauget Complex. 64

2.5 Plant Effluents 64

3.0 PCB USER INDUSTRIES 65

3.1 Askarel Capacitor Manufacturing Industry 65

NWMAR115687

TABLE OF CONTENTS (Con't)

Page

3.1.1 Askarel Capacitor Manufacturing Plants 67

3.1.1.1 Askarel Handling. 70
3.1.1.2 Process Description 71
3.1.1.3 Raw Wastes. 76
3.1.1.4 Water Use 76
3.1.1.5 Wastewater Treatment 80
3.1.1.6 Effluent Composition 80

3.2 Askarel Transformer Manufacturing Industry 84

3.2.1 Transformer Manufacturing Plants 88

3.2.1.1 Askarel Handling. 88
3.2.1.2 Process Description 91

3.2.1.2.1 Assembly and Askarel Filling Procedure for the Distribution and Power Transformer . . . 92

3.2.1.3 Raw Wastes. 98
3.2.1.4 Water Use 98
3.2.1.5 Wastewater Treatment 101
3.2.1.6 Effluent Composition 103

3.2.2 Askarel Transformer Repair Industry 103

3.2.2.1 Transformer Inspection and Maintenance. 103
3.2.2.2 Repair of Failed Transformers 108
3.2.2.3 PCB Usage in the Transformer Repair Industry 114
3.2.2.4 Transformer Service Life 115
3.2.2.5 Usage Rate of PCBs in Transformer Repair 115

3.3 Investment Casting. 115

3.3.1 Background 116
3.3.2 Investment Casting Technologies 118

3.3.2.1 Principles of Investment Casting . . . 118
3.3.2.2 Foundry Process - Use of PCT and PCB Filled Waxes 122
3.3.2.3 Waste Streams 125

3.3.3 Wax Manufacturing. 127
3.3.4 Recommendations. 128

3.4 Secondary Fiber Recovery (Paper Recycling) 128

NWMAR115688

TABLE OF CONTENTS (Con't)

Page

3.4.1 Historical Use of PCBs in the Paper Industry. . 129
3.4.2 Fiber Recovery Mill Process 135

3.5 Industrial Use of PCBs as Hydraulic and Heat Transfer Fluids. 140

3.5.1 General 140
3.5.2 Use of Imported PCBs by Joy Manufacturing . . . 141

3.6 Recent Use of PCBs in Product Development Activities . 141

SECTION VI - WASTE TREATMENT TECHNOLOGIES 145

1.0 INTRODUCTION. 145

1.1 Summary of Waste Management Problem Areas 145

1.1.1 Waste Liquid PCBs and Contaminated Scrap Oil . 145
1.1.2 PCBs in Wastewater 146
1.1.3 PCB-Contaminated Solid Wastes 146

1.1.3.1 Burnable Solid Waste Materials Containing PCBs 146
1.1.3.2 Nonburnable Solid Waste Materials Containing, or Contaminated with PCBs 147

1.1.4 Air Emissions of PCBs 147

1.2 Summary of Current PCBs Waste Control Practices . . . 147

1.2.1 Control of Waste Liquid PCBs and Contaminated Scrap Oils 147
1.2.2 Control of PCBs in Wastewaters 148
1.2.3 Control of Solid Wastes Contaiminated with PCBs 149
1.2.4 Control of Air Emissions of PCBs 150

2.0 CANDIDATE PCBs WASTE TREATMENT TECHNOLOGIES CONSIDERED. . . 151

2.1 Treatment of Waste Liquid PCBs and Contaminated Scrap Oils. 152

2.1.1 Incineration 153
2.1.2 Sanitary or Scientific Landfill 154

2.2 Treatment of Wastewaters containing PCBs 154

2.2.1 Carbon Adsorption 154

2.2.1.1 PCBs Adsorption Testing by Carborundum Company 156

NWMAR115689

TABLE OF CONTENTS (Con't)

Page

SECTION VI (Con't)

2.2.1.2 PCBs Adsorption Testing by ICI-US . . . 158
2.2.1.3 PCBs Adsorption Testing by Calgon Corp. 160
2.2.1.3.1 Adsorption Treatment of Wastewater. 164
2.2.1.3.2 Reactivation of the Granular Carbon. 165
2.2.1.3.3 Carbon Transport 166
2.2.1.3.4 Materials of Construction . 166
2.2.1.4 Carbon Regeneration Alternatives - Wet Catalytic Oxidation 166
2.2.1.5 Further Applications Data 168
2.2.2 Ultraviolet-Assisted Ozonation 168
2.2.2.1 Molecular Responses to Ultraviolet Energy 169
2.2.2.2 Photodegradation of PCBs 170
2.2.2.3 Experimental Factors in UV-Assisted Ozone Oxidation of PCBs 172
2.2.2.4 Destruction of PCBs and Refractory Organics at Houston Research, Inc. . . 173
2.2.2.4.1 PCB Destruction Data 173
2.2.2.4.2 Operating Data Obtained from Refractory Organics Tests . 173
2.2.2.5 Destruction of PCBs and Refractory Organics at Westgate Research Corp.. . 177
2.2.2.5.1 PCBs Destruction Data. . . . 177
2.2.2.5.2 Pilot-Scale Tests of Refractory Organics Decomposition. 181
2.2.2.6 Laboratory Test Results from AiResearch Corp.. 185
2.2.2.7 Comments on UV/Ozone Tests 186
2.2.3 Non-Carbon Adsorbents for PCBs 186
2.2.3.1 The Amberlite XAD Series of Macroreticular Resins. 187

NWMAR115690

TABLE OF CONTENTS (Con't)

Page

SECTION VI (Con't)

2.2.3.1.1 PCBs Adsorption Testing . . . 187
2.2.3.1.2 Process Concept for Resin Adsorption of PCBs 187

2.3 Treatment of PCBs - Contaminated Solid Wastes. 190

2.3.1 Incineration. 190
2.3.2 Sanitary Landfill 190

2.4 Treatment of Air Emissions 190

2.4.1 Condensation Methods 190
2.4.2 Granular Adsorption Methods 190
2.4.3 Catalytic Oxidation of Organics in Evaporated Effluents. 191

2.5 The Potential for Zero Discharge 191

3.0 RATIONALE AND SELECTIONS OF CURRENTLY RECOMMENDED WASTE TREATMENT METHODS 192

3.1 Incineration Recommended for Liquid PCBs and Scrap Oils. 192
3.2 Carbon Adsorption and UV-Assisted Ozonation Recommended for PCBs in Wastewater. 193
3.3 Incineration and Landfill Recommended for Contaminated Solids. 194
3.4 Dry Carbon Filter Adsorption Recommended for Control of Air Emissions 195

SECTION VII - PRODUCTION AND DISTRIBUTION 198

1.0 PRODUCTION AND CURRENT USE. 198

1.1 Domestic Production of PCBs and PCTs 198
1.2 Foreign Production and Distribution of PCBs 207
1.3 Summary of Recent PCBs and PCTs Imports 207

2.0 FIFTEEN YEAR EXTRAPOLATIONS FOR PCB PRODUCTION AND USE IN ELECTRICAL EQUIPMENT 210

3.0 OVERALL MATERIAL BALANCE 215

SECTION VIII - SUBSTITUTES FOR PCBs 220

1.0 INTRODUCTION. 220

NWMAR115691

TABLE OF CONTENTS (Con't)

Page

SECTION VIII (Con't)

2.0 ELECTRICAL CAPACITORS 220

2.1 Function of the Dielectric Material 221
2.2 Practical Capacitors 224
2.3 Required Properties of Dielectric Liquid 225
2.4 The Use of PCBs in Capacitors 226

2.4.1 Properties of PCB Capacitor Dielectric Liquid . . 226
2.4.2 Advantages and Disadvantages of PCBs in Capacitors 228
2.4.3 Usage of PCBs in Capacitors 228

2.5 Alternatives to the Use of PCBs in Capacitors 229

2.5.1 Substitutes for PCBs 229

2.5.1.1 Phthalate Esters 230
2.5.1.1.1 Dioctyl Phthalate:(DOP) . . . 230
2.5.1.1.2 Diisononyl Phthalate 230

2.5.1.2 Alkylated PCB. 231
2.5.1.3 Alkylated Chlorodiphenyl Oxide 232
2.5.1.4 Silicones. 233
2.5.1.5 Diaryl Sulfone 233

2.5.2 Elimination of Dielectric Liquids in Capacitors . 233

2.6 The Use of PCB Capacitors in Electrical Equipment. . . . 235

2.6.1 Power Factor Correction 235

2.6.1.1 High Voltage Power Factor Capacitors . . 239
2.6.1.2 Low Voltage Power Factor Capacitors . . 239
2.6.1.3 Lighting Ballast Capacitors 240

2.6.2 Motor Starting Circuits 242
2.6.3 Electronic Filter Capacitors 244

2.7 Institutional Barriers to Substitutes for PCBs in Capacitors. 244

2.7.1 Performance Acceptability 245
2.7.2 Fire Safety 246

2.7.2.1 Utility Use of Power Factor Correction Capacitors. 246
2.7.2.2 Industrial Use of Power Factor Correction Capacitors 247
2.7.2.3 Lighting and Appliance Capacitors . . . 247

NWMAR115692

Page

SECTION VIII (Con't)

3.0 ELECTRICAL TRANSFORMERS 248

3.1 Heat Generation in Electrical Circuits 248
3.2 The Nature and Purpose of Transformers 250
3.3 Desired Properties for Transformer Heat Transfer Fluids. 251
3.4 Use of PCBs in Electrical Transformers 252
3.5 Present Alternates to the Use of PCBs in Transformers . 254

3.5.1 Mineral Oil-Filled Transformers 254
3.5.2 Open Air Cooled Transformers. 255
3.5.3 Closed Gas Filled Transformers 257

3.6 Current Alternatives to the Use of PCB Cooled Transformers 258

3.6.1 Vault Usage Requirements for Transformers 258
3.6.2 Vault Construction Requirements for Transformers. 259
3.6.3 Transformer Vault Construction Costs. 261

3.7 Substitutes for PCBs in Transformers 263

3.7.1 Fluorocarbons 264
3.7.2 Silicones 264
3.7.3 High Flash Point Mineral Oils 267
3.7.4 High Flash Point Synthetic Hydrocarbons 267

3.8 Institutional Barriers to the Use of Substitutes for PCBs. 268
3.9 Relative Merits of Alternatives to New Askarel Transformers 271

3.9.1 Distribution Transformers 271
3.9.2 Power Transformers. 271
3.9.3 Precipitator Transformers 273
3.9.4 Railroad Transformers 273

3.10 Replacement of Askarels in Existing Transformers 274

3.10.1 PCB Losses Due to Transformer Failures 274
3.10.2 Environmental Effects of an Askarel Replacement Program. 275
3.10.3 Effect of Leaving Askarel Transformers in Service 276

4.0 INVESTMENT CASTING

4.1 Function of the Filler Material. 277
4.2 Use of PCBs in Investment Casting 278
4.3 Advantages and Disadvantages of the Use of Deka PCBs in Investment Casting. 278

NWMAR115693

Page

SECTION VIII (Con't)

4.4 Alternatives to the Use of Deka PCBs 279
4.4.1 Replacement Filler Materials. 279
4.4.1.1 Isophthalic Acid 279
4.4.1.2 Polystyrene. 280
4.4.2 Unfilled Waxes. 280
4.5 Conclusions - Substitutes for PCB in Investment Casting. 280

SECTION IX - PCBs RELEASE AND CUMULATIVE ENVIRONMENTAL LOADS 286
1.0 ESTIMATES OF FREE PCBs IN THE ENVIRONMENT 286
1.1 PCBs Losses to the Environment Since 1930, by Use and by Chlorine Content of Molecule. 286
1.2 Total PCBs Accumulation and Current Rates 287
1.3 Current PCBs Disposal in Landfills and Dumps 291
1.4 Release of PCBs via Industrial Effluents (Waterborne). . 294
1.5 Spills of PCBs During Transport. 294

SECTION X - INADVERTENT AMBIENT REACTIONS AS ROUTES OF ENTRY OF PCBs INTO THE ENVIRONMENT 297
1.0 INTRODUCTION. 297
2.0 COMMERCIAL BACKGROUND, PRODUCTION AND PROPERTIES OF BIPHENYL. 297
2.1 Origins and Commercial Usage Background. 297
2.2 Production Methods and Rates for Biphenyl 298
2.3 Properties and Characteristics of Biphenyl 300
3.0 PROVEN BIPHENYL REACTIONS YIELDING PCBs 301
3.1 Chlorination of Biphenyl 301
3.2 Reactions Combining Phenyls to Produce Biphenyls 302
4.0 BIPHENYL USAGE IN HEAT TRANSFER FLUIDS, DYES AND PACKAGING. . 303
4.1 Heat Transfer Fluids 303
4.2 Dye Carriers for Polyesters and Polyolefins. 303
4.3 Biphenyl as a Mold Preventive in Packaging 304
4.4 General Biphenyl Occurrence in the Environment 305
5.0 PCBs GENERATION AND WASTEWATER EXPERIMENTS IN A MAJOR U.S. BIPHENYL USAGE LOCALITY. 305
6.0 POTENTIAL DEGRADATION AND SUBSEQUENT REACTION OF DDT AND RELATED COMPOUNDS IN THE ENVIRONMENT TO FORM PCBs. 307

NWMAR115694

TABLE OF CONTENTS (Con't)

Page

SECTION X (Con't)

7.0 COMPARISON OF POTENTIAL INADVERTENT AMBIENT REACTIONS 308

8.0 PCBs FOUND IN THE EFFLUENTS OF THE MACHINERY AND MECHANICAL PRODUCTS MANUFACTURING INDUSTRY. 309

SECTION XI - MOVEMENT OF PCBs IN THE ENVIRONMENT - GENERAL DISTRIBUTION MODEL. 314

1.0 INTRODUCTION. 314

2.0 RATIONALE FOR MODEL DEVELOPMENT 315

2.1 Time Dependence of the PCB Input Rate [B(t)] 316

3.0 APPLICATION OF THE MODEL TO LAKE MICHIGAN 317

4.0 RESULTS AND CONCLUSIONS 319

4.1 Results. 319
4.2 Conclusions. 320

SECTION XII - REGULATORY ACTIONS ON PCBs. 322

1.0 INTRODUCTION. 322

1.1 Measures Taken by the Manufacturers. 322
1.2 Measures Taken by the U.S. Government. 323

1.2.1 Food, Drug and Cosmetic Act (21 U.S.C. 301 et seg.). 323
1.2.2 The Egg, Meat and Poultry Acts 324
1.2.3 The Clean Air Act (42 U.S.C. 1857 et seg.). . . . 324
1.2.4 Federal Water Pollution Control Act (33 U.S.C. 466 et seg.) 325
1.2.5 The Refuse Act of 1899 (33 U.S.C. 407). 326
1.2.6 The Occupational Safety and Health Act (29 U.S.C. 651-678) 326
1.2.7 Act to Regulate Transportation of Explosives and Other Dangerous Articles (18 U.S.C. 831-835) 326
1.2.8 Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (7 U.S.C. 135-135K). 327
1.2.9 Needs for Federal Control 327

1.3 International Decisions and Agreement. 328
1.4 Measures Taken by Foreign Governments 330

1.4.1 Measures Taken by Manufacturers - Limitations of Sales. 330

NWMAR115695

Page

SECTION XII (Con't)

1.4.2 Measures Taken by Some Governments 331

1.4.2.1 PCB Producing Countries 331
1.4.2.2 Non-Producing Countries 332

1.5 U.S. Customs Regulations 333

APPENDIX A - PCB ADSORPTION TESTING BY XAD-4 RESIN A-1

APPENDIX B - MACRORETICULAR RESINS FROM ROHN AND HAAS CO. B-1

APPENDIX C - NON-CARBON ADSORBTION AND OTHER RESEARCH STAGE PCB TREATMENT TECHNOLOGIES C-1

APPENDIX D - MASS BALANCE MODEL FOR PCB DISTRIBUTION D-1

APPENDIX E - BACKGROUND DATA USED TO CONSTRUCT THE MODEL FOR PCBs IN LAKE MICHIGAN E-1

APPENDIX F - TOXICOLOGICAL ASPECTS. F-1

NWMAR115696

LIST OF TABLES

		Page
SECTION II		
1.2-1	Estimates of Cumulative PCBs Production, Usage, and Gross Environmental Distribution in the United States Over the Period 1930-1975 in Millions of Pounds . . .	7
1.3-1	Estimated Production, Usage, and Losses of PCBs in the United States During 1974 in Millions of Pounds . . .	9
SECTION IV		
1.1-1	Empirical Formulation, Molecular Weights and Chlorine Percentage in PCBs	35
1.2-1	Approximate Molecular Composition of Selected Aroclors	36
1.2-2	High Resolution Gas Chromatography of Aroclor 1248 . .	37
1.3.1-1	Chemical and Physical Properties of Representative Aroclors	40
1.3.1-2	Electrical Properties of Some Aroclors	42
1.3.2-1	Solubility, Vapor Pressure and Halflife for Vaporization from Water of Selected Aroclors at 25°C.	43
1.3.2-2	Vaporization Rates of Aroclors	45
1.3.2-3	Percent Loss in Area of Seven Chromatogram Peaks of Aroclor After Heating.	46
1.3.2-4	Solubility of Chlorobiphenyls in Water	47
1.3.2-5	Relative Peak Heights (Peak 5 = 100) in Saturated Aqueous Solutions of Aroclor 1254.	48
SECTION V		
3.1.1-1	U.S. Capacitor Manufacturing Industry Using PCBs . . .	69
3.1.1.3-1	Non-Product PCB Discharges	77
3.1.1.3-2	Quantity of Waste Loads.	78
3.1.1.6-1	Range of Flow Rates & PCB Concentration in Effluents from Capacitor Manufacturing Plants.	81
3.1.1.6-2	Comparison of Discharges	82
3.1.1.6-3	Intake Water PCB Concentration	83
3.2.1-1	U.S. Transformer Manufacturing Industry Using PCBs . .	89
3.2.1.3-1	Non-Product PCB Discharges	99

NWMAR115697

LIST OF TABLES (Con't)

		Page
SECTION V (Con't)		
3.2.1.6-1	PCB Concentration in Effluents from Transformer Manufacturing Plants	104
3.2.1.6-2	Influent and Effluent Compositions of Plant 103 . . .	105
3.4-1	PCB Concentrations in Wisconsin Paper Plant Effluents.	130
3.4.1-1	History of Aroclor 1242 Consumption in the Manufacture of NCR Carbonless Paper for the Years 1957 through 1971	131
3.4.1-2	History of NCR Carbonless Paper Production for the Years 1957 through 1971	132
3.4.1-3	Ratio of Aroclor 1242 Consumption for Carbonless to NCR Carbonless Estimated Production.	133
3.4.2-1	Composition of Raw Water and Claifier Effluent	139
SECTION VI		
2.2.1.1-1	Carborundum Co. Tests of PCBs (Aroclor 1254) Removal from Water by an Experimental Activated Carbon . . .	157
2.2.1.2-1	ICI-US Tests of PCBs (Aroclor 1254) Removal from Water by Two Types of Commercial Carbons	159
2.2.1.3-1	Results of Calgon Corp. Laboratory Isotherm Tests for Carbon Removal of PCBs	162
2.2.2.5.1-1	UV Ozonolysis Destruction of Typical Capacitor and Transformer PCBs at Westgate Research.	180
2.2.2.5.2-1	Simulated Two-Stage, Continuous UV-Ozonation of a 5 Component Mix at Westgate Research Corp.	184
SECTION VII		
1.1-1	PCB & PCT Manufacture and PCB Sales Monsanto Industrial Chemicals Company (1957 thru 1964)	199
1.1-2	PCB & PCT Manufacture and PCB Sales Monsanto Industrial Chemicals Company (1965 thru 1974)	
1.1-3	PCB Manufacture and Sales Monsanto Industrial Chemicals Company (First Quarter - 1975)	205
1.1-4	End-Uses of PCTs and PCBs by Type	206

NWMAR115698

LIST OF TABLES (Con't)

		Page
SECTION VII (Con't)		
1.2-1	Production, Trade and Use of PCBs OECD Member Countries (1973)	208
1.3-1	Preliminary Summary of PCBs Import Data for 1971-75 Versus Monsanto Production and Sales Data.	209
2-1	Total PCB Breakdown by Use (1966-1975)	212
SECTION VIII		
3.8-1	Properties of Transformer Liquids Tested by RTE Corporation.	270
3.9-1	Relative Merits of Alternatives to the Use of Askarel Transformers in New Applications	272
SECTION IX		
1.1-1	PCB Environmental Load by Aroclor Type	288
1.1-2	Cumulative Environmental PCB Load by Chlorine Content.	289
1.1-3	Computed Spectrum of Chlorine Content for Wild PCBs. .	290
SECTION X		
2.3-1	Physical Constants of Biphenyl	300
8-1	PCBs Concentration in the Effluents of the Machinery & Mechanical Products Manufacturing.	311
SECTION XI		
2.1-1	Summary of PCB Input Sources (1973-1974) to Lake Michigan	317
3.0-1	Overall PCBs Balance for Lake Michigan Area During the Period 1930-1975	318
3.0-2	Derived PCB Concentrations in Lake Michigan Water and Biota Over the Period 1930-1975.	318

NWMAR115699

LIST OF FIGURES

		Page
SECTION II		
1.0-1	U.S. Production and Usage of PCBs Summary Over 1972-75	6
SECTION IV		
1.2-1	Moieties from Which Principal Chlorobiphenyl Isomers are Formed	38
SECTION V		
2.1-1A	Preparation of Crude Chlorinated Biphenyls-Monsanto Krummrich Plant	55
2.1-1B	Distillation of Crude Products-Monsanto Krummrich Plant	55
2.2-1	Non-Product PCB Discharges at Monsanto's Krummrich Plant	58
2.4-1	Process Flow Diagram of the John Zink Incinerator at Monsanto's Krummrich Plant	61
3.1.1-1	Medium Size Industrial Capacitor	68
3.1.1.2-1	Generalized Flow Diagram for the Manufacturing of Large Capacitors	72
3.1.1.2-2	Generalized Flow Diagram for the Manufacturing of Small Capacitors	73
3.2.1-1	Substation Transformer	90
3.2.1.2.1-1	Transformer Filling With Vapor Phase Predrying of Interiors	93
3.2.1.2.1-2	Transformer Filling With Oven or Vacuum Chamber Predrying of Transformer Internals	96
3.2.1.2.1-3	Transformer Filling Operation With Oven Predrying of Assembled Hardware	97
3.2.1.3-1	Non-Product PCB Discharges	99
3.2.1.5-1	Process Flow Diagram for Thermal Oxidizer Incinerator at Plant 103	102

NWMAR115700

LIST OF FIGURES (Continued)

		Page
SECTION V (Continued)		
3.2.2.2-1	Transformer Maintenance & Servicing	110
3.2.2.2-2	Transformer Repair.	111
3.3.2.1-1	Investment Shell Process	119
3.3.2.2-1	Flow Chart of PCBs Usage in Investment Casting . .	123
3.3.2.3-1	Idealized Flow Chart for an Investment Casting Foundry, Showing Waste Streams	126
3.4.2-1	Mill Fiber Recovery Process and Water Effluents . .	136
SECTION VI		
2.2.1.3-1	Equilibrium Carbon Adsorption of PCBs From Water at Low Concentrations (Calgon Data)	163
2.2.2.4.1-1	Lab Scale Apparatus for Reaction and Mass Transfer Studies at Houston Research, Inc.	174
2.2.2.4.1-2	Aroclor 1254 Destruction by UV-Assisted Ozonation	175
2.2.2.4.2-1	Ozone Oxidation of Acetic Acid, Effect of UV and Temperature (Initial CH_3COOH-105 mg/l, O_3(1) = 3.5 mg/l)	176
2.2.2.4.2-2	Ozone/UV Oxidation of Acetic Acid; Effect of Increased Radiation Input	178
2.2.2.5.2-1	The Effect of UV Path Length on TOC Destruction . .	182
2.2.2.5.2-2	Schematic of Bench Reaction System at Westgate Research Corp.	183
2.2.3.1.2-1	PCBs Removal Process Concept Flow Sheet by Rohm and Haas Company	189
SECTION VII		
1.1-1	U.S. Production of PCBs and PCTs and Domestic Sales and Exports of PCBs	201
1.1-2	U.S. Domestic Sales of PCBs by End Use Applications	202

NWMAR115701

SECTION VII (Continued

		Page
1.1-3	U.S. Domestic Sales of PCBs by Type	203
2-1	Unbiased Extrapolations of Least-Square Linear Curves for PCB Production and Use in Electrical Equipment	214

NWMAR115702

ACKNOWLEDGEMENTS

The preparation of this report was accomplished through the efforts of the staff of Versar Inc., Springfield, Virginia, under the overall direction of Dr. Robert L. Durfee, Vice President.

The considerable aid furnished by personnel of the Environmental Protection Agency, Office of the Toxic Substances, is acknowledged. Mr. Tom Kopp served as Project Officer and provided guidance for the project effort.

Appreciation is extended to The Electric Industries Association, The National Electrical Manufacturers Association, The Investment Casting Institute, The Wisconsin Paper Council, and the many individual companies who gave us invaluable assistance and cooperation in this program.

Appreciation is also extended to the individuals of the Staff of Versar Inc., for their contributions and assistance during this program. Specifically, our thanks to:

Mr. James D. Barden, Environmental Engineer
Mrs. Gayaneh Y. Contos, Senior Chemical Engineer
Dr. E. Ellsworth Hackman III, Senior Scientist
Dr. Mohammad N. Khattak, Analytical and Environmental Chemist
Miss Susan A. Perlin, Environmental Engineer
Mr. Bennett Y. Ryan, Ecologist
Mr. Robert A. Westin, Senior Chemical Engineer
Dr. Frank C. Whitmore, Senior Scientist

Also our acknowledgement and appreciation is given to the secretarial staff of Versar Inc., for their efforts in the typing of drafts, necessary revisions and final preparation of this document. Our special thanks to:

Mrs. Nancy C. Downie
Mrs. B. Lynn Waller
Mrs. Lillette A. Steeves

NWMAR115703

SECTION I
INTRODUCTION

1.0 OVERVIEW OF THE PCBs PROBLEM

The term polychlorinated biphenyls (PCBs) refers to a family of organic chemicals which have been produced and marketed in this country for 45 years as a series of relatively complex mixtures under the trade name Aroclor. Each of these mixtures contains a number of chlorinated biphenyl isomers out of an overall range of chlorine content from one chlorine to ten chlorines per molecule. In general, higher chlorine content corresponds to greater resistance to chemical (and biochemical) degradation.

PCBs are among the stable organic compounds known, and, in addition, they exhibit other properties which render them extremely advantageous for use as dielectric and heat transfer fluids. These properties include low solubility in water, low vapor pressure, low flammability, high heat capacity, low electrical conductivity, favorable dielectric constant, and suitable viscosity-temperature relationships. Because of these properties, and also because PCBs exhibit little acute toxicity (toxic effects from high level, short term exposure), this family of materials has been extensively used in many industrial applications, primarily in "closed" or "semi-closed" systems such as electrical transformers and capacitors, heat transfer systems, and hydraulic systems. Most of the PCBs marketed to U.S. industry are still in service, primarily in electrical equipment. The remainder has entered the general environment; a significant fraction of this amount is present in air, water, soil, and sediment, but most of the PCBs in the environment are believed to be in landfills and dumps across the country.

In the late 1960's it became apparent that, although PCBs exhibit little acute toxicity, they are accumulated in the tissues of many biological species and do exhibit chronic (long-term) toxicity to many species even when the exposure is to very low concentrations. The effects of chronic PCB exposure may be considered as roughly comparable to those of DDT.

NWMAR115704

The recognition of this problem resulted in a major program designed to lessen the environmental stress arising from widespread use and dissemination of PCBs; by mid-1971, the Monsanto Industrial Chemicals Co., the sole U.S. producer, had voluntarily terminated sales of Aroclors (PCBs and polychlorinated triphenyls, or PCTs) for all but closed electrical systems uses. Monsanto also, in the same time frame, offered incineration services for waste liquid PCBs and terminated production of the most highly chlorinated Aroclors.

During 1972 and 1973, the Food and Drug Administration developed limitations on PCBs concentrations, designed to eliminate interstate transport of PCB contaminated foodstuffs, for a number of important dietary items and packaging materials used for foods. These limitations also reinforced the elimination of PCBs usage in the U.S. except for closed electrical systems.

After approximately five years of the voluntary industrial restrictions, and about three years following the FDA limitations, a National Conference on PCBs was held in Chicago during November, 1975, under the joint sponsorship of EPA and other Government agencies. By that time it had become apparent that, although dietary intake of PCBs had declined (apparently as a result of the FDA actions plus cooperation of the food and food packaging industries), improved analytical techniques plus more extensive monitoring efforts had revealed PCBs contamination at environmentally significant levels to be more widespread than originally thought.

Results presented at the Chicago meeting indicated PCB levels in the environment, on an overall basis, to have been more or less constant since 1971, although there were local instances of both increases and decreases in PCB levels. It thus appears that, unlike DDT, elimination of PCBs from dissipative uses has not resulted in a significant reduction in environmental load.

2.0 OBJECTIVE AND SCOPE OF THE REPORT

It was against the above background that the work upon which this report is based was performed. The objective of this report is to present the current state of knowledge about PCBs production, distribution, usage, and losses to

NWMAR115705

the environment in the United States. Many, but not all, of the facets of the PCBs problem are addressed; many of the estimates presented are based on engineering and scientific judgement instead of hard data, simply because hard data in these areas are not available. We hope that all assumptions and judgements in the report are clearly identified as such, and that sufficient supporting information, where available, is presented to justify the choices made.

While this report attempts to shed some light on the possible reasons why PCB levels in the environment are not decreasing as rapidly as had been hoped, its scope also includes a detailed presentation of past and present production and usage of PCBs in the United States, an analysis of PCB distribution and environmental transport as applied to Lake Michigan, a treatment in detail of potential substitutes and use alternatives, a discussion of the technical aspects of substitution, and discussions of various other aspects of the overall problem. Toxicological and human health aspects are not addressed; nor are the various current activities of EPA, other Government agencies, and individual states toward reducing entry of PCBs into the environment.

The information and data contained in the report were collected from personal interviews and telephone conversations with representatives of many of the firms handling or using PCBs, from trade associations, from the open literature, and from local, state, and Federal Government personnel, researchers, and other parties having interest in and information concerning the PCBs problem. Ten visits to plants were made; these covered the categories of PCBs production, small and large capacitor manufacturing, transformer manufacturing, investment casting, and waste disposal contracting (waste PCBs). The degree of cooperation, and therefore the accuracy of the data obtained, varied widely from industry to industry. Electric utilities provided key information, as did also other users or distributors of products containing PCBs.

NWMAR115706

SECTION II

SUMMARY

1.0 PRODUCTION, USAGE, AND DISTRIBUTION OF PCBs

1.1 Overview of PCBs Industrial Usage in the United States

Over the past four years the domestic production and use of polychlorinated biphenyls (PCBs) have been approximately constant with averages of 40 million pounds per year for production and 33 million pounds per year for domestic sales. During this period Monsanto Industrial Chemicals Corp., the sole domestic producer, has supplied approximately 99 per cent of the domestic market. Monsanto sells several PCB mixtures under the generic trade name Aroclor, and purchase has been limited to intended use in nominally closed electrical systems (transformers and capacitors) since 1971 under voluntary restrictions imposed by Monsanto.

The remainder of the domestic usage depends on imported PCBs, most of which originate in Italy and the remainder in France. Decachlorobiphenyl is imported from Italy for use in investment casting wax, and the material imported from France is used in cooling systems of mining machinery.

Of the domestic sales of PCBs, 65 to 70 per cent are to manufacturers of capacitors, and the remainder to manufacturers of transformers. Transformers, which contain 2,000 to 2,500 pounds of PCBs on the average (present as a 60 to 70 per cent component of mixtures with trichlorobenzene called Askarels) are used primarily to change voltages during the transmission and distribution of electrical power. Approximately five per cent of the transformers in service in this country contain PCBs; most transformers contain mineral oil instead of PCBs. Capacitors containing PCBs are of two general types; small capacitors which are built into electrical appliances such as fluorescent lights, TV sets and small motors, and large capacitors which are used as separate units in electrical power distribution systems and with large industrial machinery such as electric motors and welding machines. PCBs are used in about 95 per cent of U.S.-produced liquid impregnated capacitors (most small capacitors in radios and other electronic equipment are solid-state units).

NWMAR115707

PCBs are typically used in transformers where protection against fire is of paramount importance. Use of PCBs in capacitors is based on a number of factors, but fire protection and service life appear to be the most important. Industry codes, such as the National Electrical Code, specify the use of PCB-filled transformers and capacitors under a number of conditions. These codes will serve as institutional barriers to rapid reductions in PCBs usage, but at present there are also technical barriers to substitution of other materials for PCBs in electrical equipment.

The above overview of current PCBs usage in the U.S. is summarized by Figure 1.0-1, which traces domestic PCBs production and importation through first tier usage and distribution of PCBs - containing products.

1.2 Cumulative PCBs Production and Usage in the United States

Estimates developed for total PCBs production and utilization in the U.S. since their introduction to industry in 1929-30 are presented in Table 1.2-1. These data define the estimated proportions of PCBs used in various applications, and an accounting, based on available data plus estimates, of the current distribution of this material. Of the roughly 1.25 billion pounds purchased by U.S. industry, it is estimated that only 55 million pounds, or 4.4 per cent, have been destroyed by incineration or by degradation in the environment. About 60 per cent of the total domestic sales is still in service, almost all in capacitors and transformers. The remainder, about 44 million pounds, are in the environment; it is estimated that 290 million pounds are in landfills or dumps and 150 million pounds are "free" in the general environment (air, water, soil, sediments) and presumably available to the biota.

Some of the values in Table 1.2-1 are relatively well-established, while others are gross estimates resulting from a lack of data in the area. The estimated reliability for each value presented is shown on the table. For instance, the PCBs usage in carbonless copy paper is a firm value obtained from the only producer (NCR), where as the amount of PCBs environmentally degraded could conceivably range from a low value to the total of mono-, di-, and trichlorobiphenyl utilized but not still in service. The value for U.S. production could not be

NWMAR115708

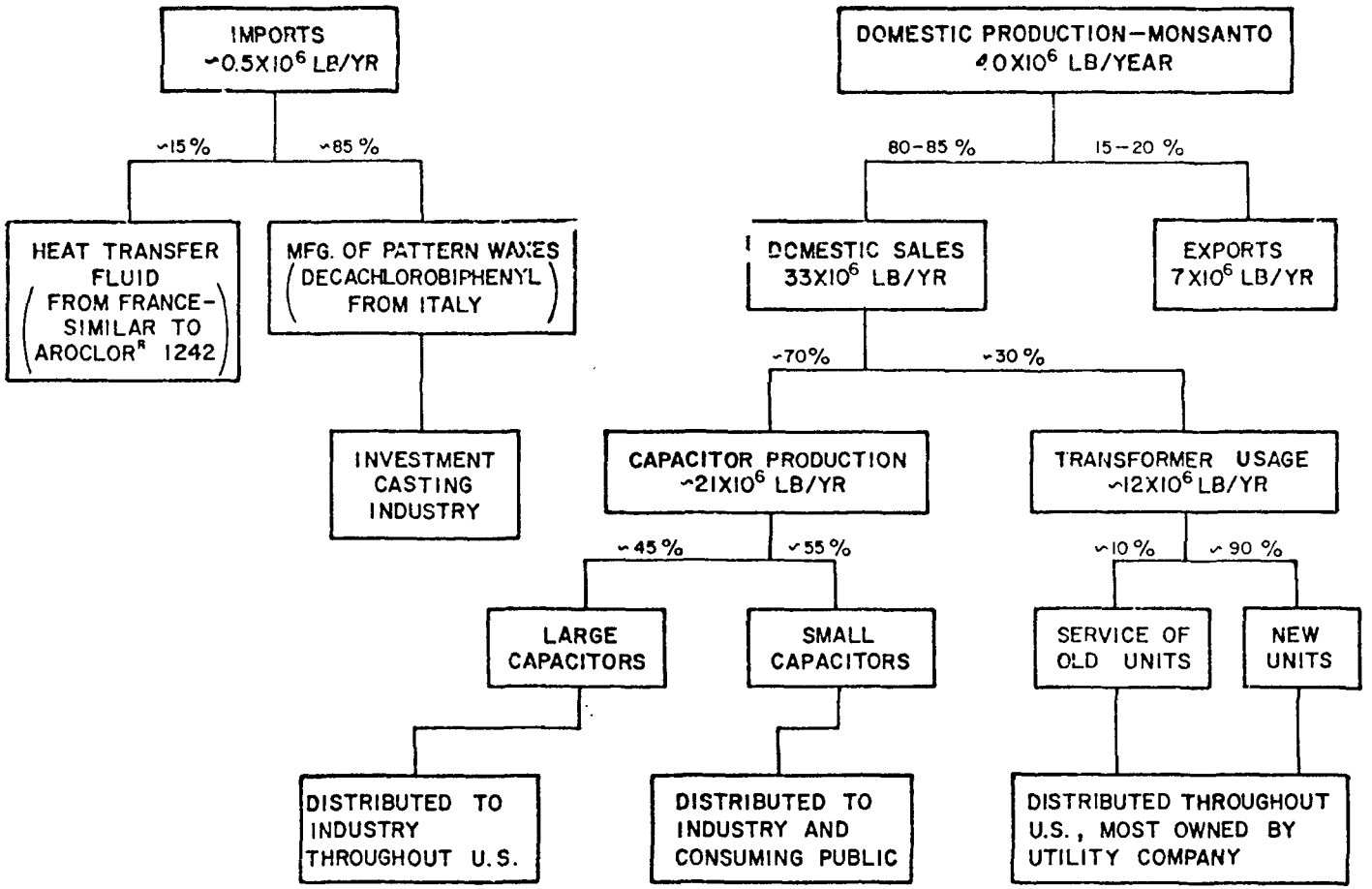


FIGURE 1.0-1. U.S. PRODUCTION AND USAGE OF PCBs
SUMMARY OVER 1972-75

NWMAR115709

Table 1.2-1

Estimates of Cumulative PCBs Production, Usage, and Gross Environmental Distribution in the United States Over the Period 1930-1975 in Millions of Pounds

	Commercial Production	Commercial Sales	Industrial Purchases of PCB	PCBs Currently in Service	PCBs Currently in Environment	PCBs Destroyed	Estimated Reliability of Values
U.S. PCB Production	1,400						+ 5% - 20%
Total U.S. PCB Imports	3						± 30%
U.S. PCB Domestic Usage		1,253					+ 5% - 20%
Total U.S. PCB Exports		150					± 20%
PCB by Use Category:							
Petroleum Additives			1				± 50%
Heat Transfer			20				± 10%
Misc. Industrial			27				± 15%
Carbonless Copy Paper			45				± 5%
Hydraulics and Lubricants			80				± 10%
Other Plasticizer Uses			115				± 15%
Capacitors			630	450			± 20%
Transformers			335	300			± 20%
Uses Other than Electrical				8			± 60%
PCB Degraded or Incinerated:							
Environmentally Degraded						30	± 70%
Incinerated						25	± 10%
Landfills and PCBs in Dumps:							
Cap. and Trans. Production Wastes					110		± 20%
Obsolete Fle. Equipment					80		± 40%
Other (paper, plastic, etc.)					100		± 40%
Free PCBs in the Environment (soil, water, air, sediment)					150		± 30%
Total	1,403	1,403	1,253	758	440	55	

NWMAR115710

much over 1.45 billion pounds nor less than 1.1 billion pounds, based on analysis of other available or estimated data; hence, the estimated confidence interval for this value on Table 1.2-1 of +5 per cent and -20 per cent.

One of the more important conclusions from this work is the estimation of about two times the amount of PCBs in landfills and dumps as compared to the amount of PCBs already free in the environment. The material in land disposal sites may be considered a threat to become widely dispersed over a long period of time. The length of time required can only be guessed at, but is probably short in comparison to the time required for degradation of the PCBs by natural processes. Thus, release of the land disposal material through slow vaporization and leaching could very well worsen an already severe environmental problem.

1.3 Current Distribution of PCBs Usage and Associated Wastes

A material balance for PCBs production, sales, distribution, and wastes in 1974 is presented in Table 1.3-1. Reliability of the values were estimated as for the previous table. The amounts estimated to be land disposed, totaling 1.18 million pounds, do not include land disposal of previously used PCBs. However, the amounts listed under scrap PCBs incinerated account for all PCBs incineration in the U.S. during 1974 at the recommended temperature-time conditions (> 2000°F; > 1.5 seconds residence time). Of the total of 2.61 million pounds incinerated, the Monsanto facility accounted for over half. Other companies currently providing incineration services include General Electric, Rollins Environmental Services, and Chem-Trol Pollution Services, but the total number of such facilities known to be available in the U.S. is six.

1.4 Land Disposal and Environmental Load

The 1.18 million pounds per year of land-destined wastes estimated above is only a small portion of the total PCBs entering landfills and dumps yearly; the current estimated yearly rate of PCBs entering land disposal sites is about 12 million pounds. The largest source of this material is capacitors which have failed or become obsolete, or which are contained in obsolete equipment. Other important sources are industrial solid wastes from PCBs production and first-tier usage, and the total of other (non-electrical) municipal and industrial solid wastes.

NWMAR115711

2.2.1 Incineration

The most advanced treatment technology in use is incineration. The PCBs manufacturer and one user have plant scale facilities capable of destroying PCBs with very high efficiency. There are at least two commercial services available, with four incinerator locations in the Eastern and Southern U.S., for PCBs incineration.

Incineration is primarily applicable to waste PCBs and scrap oils contaminated with PCBs. Incinerators for PCBs destruction have the capacity of "burning" some contaminated wastewater but, of course, the proportion of that water to the exothermic oil burning must be kept low. Only one commercial incineration service (Rollins) can routinely handle all kinds of PCBs contaminated transformer and capacitor components, sludges, fuller's earth and other solids, as long as they can be contained in a 47 gallon fiber drum. One PCB user company incinerates transformer internals for purposes of metal recovery.

Waste liquid PCBs and scrap oils (contaminated PCBs) are best handled, as a guideline, by high temperature (2000-2400°F) and long residence time (2-3 seconds) incineration. However, because of incinerator design variables, the conditions should be chosen in each case to lead to 99.999% destruction. The best incinerator combination for handling wastes from these industries is a rotary burner fired by a liquid burner, and followed by an afterburner and scrubber system for HCl and particulate control. The rotary burner can be designed to handle a variety of solid materials, and the liquid burner can handle both the oily and water type wastes.

2.2.2 Treatment of PCB-Contaminated Wastewater

There is no commercial scale wastewater treatment for PCBs removal being practiced beyond those of gravity settling of the heavy PCBs layers as a sludge from the bottom of sumps or tanks, and skimming of a contaminated oil-layer from the water surfaces.

Adequate methodology is available for those plants wishing to control the release of PCBs to the environment. Currently available technologies can

NWMAR115712

be applied to the efficient removal of PCBs from wastes, or their destruction with the other wastes. The PCBs content of wastewaters can be lowered to the 1 ppb level or below by removal of solids (and oil layers, where applicable), followed by adsorption of PCBs onto carbon, macroreticular polymer resins or possibly other adsorbents.

Carbon adsorption is currently the best available technology for plant scale treatment of PCBs wastewaters. This conclusion is based on laboratory tests with PCBs in water, and on the long background of plant scale use of carbon adsorption for removal of organics from water.

Polymeric resins (AMBERLITES) were found in laboratory tests to be approximately as effective as carbon in removing PCBs from water. Further pilot scale testing is needed with this newer (than carbon) technology to accurately assess its potential.

Ultraviolet catalyzed ozonation was determined to be the best method, demonstrated on a laboratory scale, for destruction of PCBs in wastewaters when the streams occur in large volume, on a relatively continuous flow basis and with PCBs at the ppb concentration levels. This technology has the potential for conversion of PCBs to CO_2, H_2O and HCl. However, significant development and optimization work would be required before application of the process becomes practical. In addition, the potential exists for production of toxic degradation products by UV-ozonation.

Although still in the laboratory stage, catalytic reduction of PCBs offers the possibility of reduction to biphenyl and HCl; and catalytic oxidation is another process which offers a potential for destruction of PCBs to CO_2, H_2O and HCl.

It is believed that wastewater treatment systems employing activated carbon and possibly UV-ozonation could produce effluents which would be at or below the limits of detectability for PCBs with current analytical techniques. However, since no full scale systems for the treatment of PCBs are in operation at this time, this possibility cannot be confirmed.

NWMAR115713

units are cleaned and sealed, and then the sealed units are degreased, painted, and tested. Transformers and the largest types of capacitors are filled individually after evacuation; this produces relatively less chance of PCBs loss than the flood-filling process.

Of the 38 plants in the above categories, 10 discharge their effluents into the water ways while the remainder discharge into the sewage treatment plants. All plants in these categories have discharges under heavy rainfall conditions. There are three types of waste materials generated at these plants that require treatment and proper handling in order to minimize the PCB into the environment. These are:

(a) Waste waters containing trace quantities of PCBs (10 to 500 ppb PCBs);
(b) Waste PCBs, scrap oils and small quantities of process water highly contaminated with PCBs; and
(c) Burnable and non-burnable solid materials contaminated with PCBs.

Quantitative estimates of these wastes are given below:

	Waste Loads, Daily Average		
	PCB Discharge in Waterways or Sewers	Land-Destined PCB Wastes	Scrap Oils to Incineration
PCB Manufacturer	3.06 lbs	301 lbs	1425 lbs
Capacitor Industries	5.86 lbs	4440 lbs	3968 lbs
Transformer Industries	0.17 lbs	Unknown	1750 lbs

The above waste loads represent current industrial practice. It may be assumed that, prior to knowledge of the adverse environmental effects of PCBs, much of the types of material currently landfilled or incinerated was not disposed of properly and thus entered the environment directly.

As yet, very little is being done at these plants to control air emissions. The general industry assumption is that the vapor pressure of PCBs is so low that there will be essentially no air contamination. A few facilities, however, were reported to be filtering and chilling exhaust air from PCBs impregnation areas,

NWMAR115714

and plant personnel are beginning to realize that evaporation of PCBs may make a significant contribution to general contamination of the plant area.

Since most water used at these facilities is for non-contact cooling purposes, at most plants it is possible to significantly reduce the effluent volume by segregation of wastewaters, recycling and proper housekeeping measures. Most user plants and the PCB producing plants have already undertaken PCBs containment programs in order to minimize the entry of PCBs into the environment. While the emissions of PCBs to water are expected to decrease due to improved pollution abatement of waterborne wastes, the release of PCBs to air and land may increase. One potential source of increasing air emissions is the increase in incineration due to proper handling of wastes which were previously discharged into the waterways or sewers. The quantities of land-destined wastes are expected to increase due to improved housekeeping measures.

Rivers receiving PCBs discharges for a number of years vary greatly in PCBs content with time, apparently depending upon PCB content in storm water runoff and the degree to which contaminated bottom sediments are agitated and suspended. Whereever there have been PCB operations in the past, there are probably high concentrations in local waterways bottom sediments.

Over the past 45 years, waste PCBs from transformer and capacitor operations have been used as local road oiling compounds. Sometimes they were discarded in dumps adjacent to manufacturing facilities. These are sources of long term leaching of PCBs into waterways, particularly with storm water runoff.

2.2 Treatment and Disposal of Industrial Wastes Containing PCBs

A study was performed to determine and compare the methods available for the treatment of PCB-containing wastes from the PCBs production, capacitor manufacturing, and transformer manufacturing industry categories. A full treatment of this technology, including cost estimates for treatment, may be found in the Task II Report under Contract 68-01-3259. Much of the technical portion of this work is reproduced herein and summarized below.

NWMAR115715

Table 1.3-1

Estimated Production, Usage, and Losses of PCBs in the United States during 1974 in Millions of Pounds

	Production or Imports	Commercial Sales	Industrial Purchases by Category	Amount Disposed or Lost	Estimated Reliability of Values
Domestic Production	40.466*				± 10%
Total Imports	0.45				± 50%
Monsanto Domestic Sales		34.406*			± 10%
Exports		5.395*			± 10%
Import Sales		0.45			± 50%
From Mfg. Inventory, etc.		0.665*			± 10%
PCBs Usage by Product Category					
Capacitors			22.0		± 20%
Transformers			12.0		± 20%
Investment Casting Wax			0.4		± 20%
Other			0.05		± 70%
PCBs Disposal to Land (assume PCBs to be 30% of total solid wastes)					
From PCBs manufacture				0.03	± 50%
From capacitor industry				0.48	± 50%
From transformer industry				0.27	± 50%
From investment casting				0.4	± 30%
Incineration of Scrap PCBs					
From PCBs manufacture				0.52	± 15%
From capacitor industry				1.45	± 20%
From transformer industry				0.64	± 20%
Industrial Discharges to Water and Sewers (as PCBs)					
From PCBs manufacture				0.0011**	± 40%
From capacitor industry				0.0021**	± 60%
From transformer industry				0.0001**	± 60%
Spills during Transport				0.01	± 50%
Totals	40.916	40.916	35.45	3.80	

* From Monsanto data

** Developed from data supplied by industry. Most analyses for PCBs concentrations in industrial wastewaters are probably not more accurate than ± 50 per cent.

NWMAR115716

The total current environmental load of "Free" PCBs was estimated to be about 150 million pounds. An analysis of environment load (Free PCBs) average chlorine content per molecule indicated that, if mono-, di-, and trichloro isomers were disregarded, the average chlorine content of Free PCBs would be within seven per cent of the value for Aroclor 1254.

1.5 Foreign Production of PCBs

Known current producers of PCBs besides the United States include the United Kingdom, Czechoslovakia, France, Germany, Spain, and the U.S.S.R. Japan was a producer until 1972. In 1973, total foreign production of PCBs is estimated at 43 million pounds, corresponding to a 50 per cent reduction since 1971. On this basis, the U.S. production appears to be about half of the world total. Usage of PCBs in all countries is expected to decrease further as a result of recent findings on adverse environmental effects and potential human health hazards from PCBs, and this usage is expected to be essentially confined to use in capacitors and transformers.

2.0 CHARACTERIZATION OF INDUSTRY PRACTICE AND WASTE HANDLING FOR THE PCBs PRODUCER AND MAJOR FIRST-TIER USERS

2.1 Manufacture of PCBs and PCB-Containing Capacitors and Transformers

PCBs are produced domestically only by Monsanto at Sauget, Illinois. The process involves the batch chlorination of biphenyl and subsequent separation and purification of the desired chlorinated biphenyl fractions. The degree of chlorination is determined by the contact time in the reactor. Depending on the distance and size of shipment, transport is via tank car, tank truck, or common carrier (drums).

There are 17 capacitor plants and 18 transformer plants utilizing PCBs in the United States. Manufacture of both types of units involves initial preparation of internal and external cases, filling with PCBs under vacuum, cleaning and degreasing, and performance testing. The greatest PCB wastes occur in the filling operations. Filling of small capacitors (less than 2 pounds of PCBs) and most large capacitors is performed in chambers holding many small capacitors or fewer large ones. The chamber and the capacitors are evacuated and then flood-filled with the PCB liquid. Excess liquid is removed from the chamber, the filled

NWMAR115717

Unfortunately, no methodology is presently available which can guarantee "zero discharge" of PCBs to the environment. "Zero discharge" objectives can be best met now by eliminating discharge streams and developing recycle systems. All streams that are high in pollutants and cannot be treated for reuse, including rainwater runoffs, could be collected and incinerated under a "zero discharge" objective.

2.3 Characterization of the Investment Casting Industry

Investment casting is a lost-wax process by which metal castings which are of intricate shapes or which require close dimensional tolerances are mass-produced. The pattern wax, some of which contains PCB filler, is molded and then used to make a ceramic shell (investment) whose internal dimensions are those of the desired product. The wax is typically melted from the shell, and the shell is fired (sintered), which removes the last traces of the wax. Then molten metal is poured into the mold (shell) and cooled to form the castings.

There are currently 135 investment casting foundries and four major investment casting wax manufacturing plants in the United States. The Yates Manufacturing Company, Chicago, Ill., is the sole known U.S. supplier of decachlorobiphenyl (deka) waxes. The deka content is 30 per cent of the total wax by weight. Yates currently imports deka from Italy and manufactures between 1 and 1.5 million pounds of deka wax annually. Very little is known about the wax manufacturing process. Wax manufacturers are also believed to use polychlorinated terphenyls (PCTs) imported from France.

The major losses of the virgin and used waxes appear to occur during the dewaxing of the ceramic mold. The mold is fired in a furnace to set the mold and remove the wax. Depending on furnace conditions, the deka or PCT in the wax is either burned or released to the atmosphere. The magnitude of these emissions is not known.

Most foundries recover the drained pattern wax and reuse it several times. It is estimated that the purchased wax is used an average of 2.5 times. Little of the wax is destroyed in the process; therefore, it is considered probable that the investment casting foundries store or dispose of relatively large amounts of used PCB- or PCT-containing wax.

NWMAR115718

2.4 Transformer Service Industry

Most servicing of transformers is performed by electrical repair shops rather than by the utility or the owner of the transformer. Thirteen companies were identified as offering transformer service at a total of 131 locations. Servicing of askarel-filled transformers may include the filtering of the askarel to remove degradation products and moisture or the replacement of the askarel with new liquid. PCB wastes include filter media, scrapped askarel, and miscellaneous solvents, rags, etc. The proper disposal of these wastes is specified by a voluntary NEMA standard. Liquid PCBs are incinerated in most, but not all, cases. The total usage of PCBs by the transformer repair industry is about 800,000 lb/year, or about seven per cent of the amount used to manufacture new transformers.

3.0 SUBSTITUTES AND USE ALTERNATIVES FOR PCBs

Potential substitute materials and use or process alternatives which would eliminate or reduce the current requirements for PCBs were investigated. Important points from this study are summarized below.

3.1 Substitutes for PCBs in Capacitors

PCBs (primarily Aroclor 1016) are currently used in almost all U.S.-made capacitors for AC service (liquid-filled capacitors) and are uniquely suited for this application because of their high dielectric constant, high resistance to current flow and electrical breakdown, chemical stability, and non-flammability. A number of different liquid materials now under development or testing have been proposed as substitutes for PCBs in capacitors, including phthalate esters, synthetic hydrocarbons, alkylated chlorodiphenyl oxide, alkylated PCBs, diaryl sulfones, and silicones.

Since each of these materials is relatively more flammable than Aroclor 1016, it appears that use of any liquid substitute will probably pose more of a fire hazard than use of PCBs. Vulnerability of capacitor manufacturers to liability for damages from capacitor failure is a major factor in industry acceptance of a substitute capacitor fluid. The conservative code structure now in force could also pose significant barriers to reduction or elimination of PCBs usage in

NWMAR115719

capacitors. In addition, data on electrical performance, toxicity to humans, and environmental effects of the potential substitutes are not presently sufficient to allow meaningful comparisons with PCBs.

Dry AC capacitors (film-type) are in the development stage. These capacitors are significantly larger than liquid-filled capacitors and are limited to a maximum of 280 volts. Satisfactory dry film capacitors will not be available until there are two separate technological breakthroughs: 1) the development of a plastic film that combines a high dielectric constant with a low loss-tangent; and 2) the development of winding techniques that exclude all air from the winding of the capacitor.

Although it is considered probable that satisfactory substitutes for PCBs will be developed within the next 5 years, no such material is presently available and much additional research remains to be done. On the other hand, a significant portion of the large capacitors used by utilities, and some in industry, are situated out-of-doors. These could be replaced by capacitors containing a more flammable fluid without significantly increasing the risk of fire.

Although direct replacement of existing PCB-filled capacitors with units containing substitutes appears possible for many large capacitors, anticipated size differences will present severe problems in retrofitting. The new fluids also cannot be directly substituted for PCBs in existing capacitors. In addition, disposal of obsolete or replaced units will probably be in landfills for many years to come. It is probable that the best replacement scheme for capacitors, assuming cessation of PCBs production and use, would be use of non-PCB replacements as units become obsolete or fail.

3.2 Substitutes for PCBs in Transformers

Aroclors 1242 and 1254 are currently used in about five per cent of U.S.-built transformers; most transformers are cooled with mineral oil. Transformers filled with askarel (60-70 per cent PCBs) are often specified for use in buildings and in hazardous locations where minimization of the fire hazard is of paramount importance. The National Fire Code requires that oil-filled units, and askarel-filled units rated for service over 35 kV, be enclosed in fireproof vaults when

NWMAR115720

used in buildings. For units below 35 kV, the higher cost (by 20 to 30 per cent) of an askarel unit is more than offset by the savings on vault construction.

Open, air-cooled transformers are limited to a clean, dry environments, but are being increasingly used in commercial buildings. Closed, gas-cooled transformers are more expensive than askarel units. Both of the above types have voltage limitations and much less overload capacity than the askarel-filled type.

Several substitute liquids have been suggested for use in transformers which are less flammable than the currently used mineral oil, but which are more flammable than askarel. The most promising are a silicone oil and a synthetic paraffinic hydrocarbon. These liquids are characterized as being self extinguishing - i.e., they do not continue to burn after being ignited by a momentary electrical arc. Proposals have been submitted to the National Electrical Code to allow the use of these self extinguishing materials under those conditions where askarels are presently specified. Because of the relative lack of service experience with these liquids, it is unlikely that these proposals will be accepted. The next Code revision (1978) will probably continue to recognize only askarel and "oil filled" transformers.

It is likely that the "self extinguishing" liquids will prove to be satisfactory alternatives to PCBs. Substantial experience on the performance of the liquids will be required before the code requirements will be changed to allow their use. The restrictive Electrical Code, which has been incorporated into the OSHA Standards, may act to inhibit the accumulation of this data and thereby act to postpone the general acceptance of these substitutes for PCBs.

The major conclusion from this portion of the study was that technically acceptable alternatives to the use of PCBs in transformers exist and that their use should not result in a significant increase in fire hazards from transformer failure. At present the selection of PCB (askarel) transformers appears to be based primarily on cost rather than technical considerations.

As with capacitors, direct replacement of PCBs in existing transformers would present potentially severe problems. These include the extreme difficulty of removing more than 90-95 per cent of the PCBs, even by repeated flushing with

NWMAR115721

a compatible solvent (trichlorobenzene), and the requirements of incinerating such large quantities of PCBs and contaminated solvent.

3.3 Alternatives to Other PCBs Applications

On a preliminary basis, there appear to be no overriding technical (or institutional) barriers to the use of alternatives to decachlorobiphenyl filler in investment casting waxes. (This also appears to be the case for the polychlorinated terphenyls.) Potential alternatives include use of materials such as isophthalic acid as the filler and use of the new low-shrinkage unfilled waxes. A cost increase of about ten per cent is projected for each of the above alternatives.

Since the voluntary restriction by Monsanto in 1971 of PCBs sales for use in closed electrical systems only, PCBs have largely been eliminated from usage in hydraulic and heat transfer systems. Adequate substitutes were generally available at the time of the Monsanto restriction, and the present usage of PCBs (believed to be minor) should be replaceable by alternatives with minimal disadvantage.

4.0 SOURCES OF INADVERTENT ENTRY OF PCBs INTO THE ENVIRONMENT

4.1 Paper Recycling

Over the period 1957 to 1971, approximately 45 million pounds of Aroclor 1242 was used by a single producer (NCR) in the production of carbonless copy paper. Some fraction of this material has entered the paper recycling stream and is apparently a major source of observed PCBs contamination of effluents from the secondary fiber recovery industry. PCBs were also added to paper in inks and possibly in other additives; this material was probably Aroclor 1254.

Thus, in its effort to conserve resources profitably, the secondary fiber recovery (paper recycling) industry is inadvertently releasing previously used and "stored" PCBs into the general environment, primarily to water. Reliable estimates of the amounts of PCBs so released are not available, and, although the significance of this release should diminish as office files are emptied, the amounts remaining to be released are not known.

NWMAR115722

Results from an analysis of PCBs entering Lake Michigan, discussed later in Section 5.0, indicate that, although there is a significant concentration of paper recycling activities in the area of this lake, the contribution of paper mills to the total PCBs input to Lake Michigan is small in comparison to atmospheric fallout. However, effluents containing amounts of PCBs which are very small compared to the total environmental load can be extremely important on a local basis, and further investigation of this problem is urged.

It should be noted that water usage in the paper recycling industry is high and effluent PCB concentrations are typically 5 to 10 ppb. The cost of PCBs removal would therefore probably be higher per unit of profit than for the other industry categories described herein.

4.2 Effluent Contamination by PCBs in Other Industries

High concentrations of PCBs were recently reported in effluents from a number of plants engaged in the manufacture of machinery and mechanical products. These measurements have not been verified to data. PCBs were, in the past, used extensively in hydraulic and heat transfer systems, in lubricants, and in paints and plastics, so that it is not inconsistent that effluents from the machinery manufacturing industry contain PCBs. PCB contamination of effluents is known to have occurred via slow release of old deposits in sewers and elsewhere, although industrial usage in semi-open applications is believed to be continuing at a low level.

4.3 Inadvertent Production of PCBs in the Environment

Three general types of reactions were considered as potential sources of inadvertent production of PCBs. Of the three, the one considered most likely to occur is chlorination of biphenyl in wastewater during treatment. This refers specifically to the discharge of wastewater containing biphenyl to a municipal sewer and the subsequent chlorination of the material in the treatment plant.

Biphenyl is used extensively as a dye carrier for the dyeing of synthetic fibers; in this application, much of the biphenyl leaves the process as waste. The estimated U.S. industrial usage of biphenyl is about 50 million pounds per year, of which at least half is used in dyeing operations. Although chlorination of

NWMAR115723

biphenyl in sewage treatment appears likely, the extent of neither the initial chlorination nor further chlorination is known. Further investigation of biphenyl chlorination as a possible source of PCBs is recommended.

Chlorinated biphenyls have been produced by the decomposition of DDT, although this requires recombination of phenyl radicals from cleavage of two DDT molecules. Significant production of PCBs in the environment by this mechanism is considered unlikely. Formation of PCBs via chlorination of the product formed from the combination of two substituted benzenes is also considered of less potential significance than direct chlorination of biphenyl in wastewater.

5.0 TRANSPORT AND DISTRIBUTION OF PCBs IN THE ENVIRONMENT

A first order mass balance model was developed and used to study the transport and distribution of PCBs in the environment. The total environmental load of "free" PCBs was regarded as a "pool" of mixed PCBs. In applying the model, the pool was assumed to exhibit properties roughly similar to those of Aroclor 1254. The model was applied to Lake Michigan; the boundaries of the region studied were taken to be the drainage basin of the lake. Lake Michigan is a nearly closed body of water of sufficient size to allow averaging of properties and of sufficient interest that some pertinent data were available.

The estimated total input of PCBs to Lake Michigan (1973-1974) was 13,400 lb/yr, of which 1,600 lb/yr came from point sources (summation of industrial and municipal discharges reaching the lake), 6,400 lb/yr represented fallout directly onto the lake, and 5,400 lb/yr was derived from fallout on the drainage basin (assumed to be 50 per cent of total fallout on the basin). Thus, it is estimated that about 88 per cent of the PCBs currently entering Lake Michigan arise from fallout.

Application of the model produced the following cumulative values for the period 1930 to 1975 (input function assumed proportional to domestic sales):

Total input	1.49×10^5 lb
Total in solution	1.0×10^5 lb
Total in biota	3.64×10^3 lb
Total in sediments	1.7×10^4 lb

NWMAR115724

Total in outflow	9.07×10^3 lb
Total evaporated	1.93×10^4 lb

Since degradation of PCBs in the lake was assumed to be zero, the closing of the material balance depended upon total evaporation from the lake being 1.93×10^4 pounds, or about 13 per cent of the total input. This value is in excellent agreement with values derived both from kinetic theory and from co-distillation theory; this result substantiates both the model form and the material balance above.

Average water and biota concentrations derived from the analysis (using a bioconcentration factor over water of 4×10^4) are, for recent years:

	Water Conc. (ppt)	Biota Conc. (ppb)
1960	1.60	64
1965	2.92	117
1970	5.35	214
1975	9.10	364

The above agrees well with available data on lake and biotic concentrations since 1970.

Mean residence times of PCBs in air and water, and the transport mechanisms which operate at the various phase interfaces, are very important to the understanding of environmental transport and distribution. Lifetime values are extremely sensitive to the assumptions required for their calculation (required because of the lack of adequate experimental data). Estimates derived from work by others range from 20 days to eight years for the average lifetime to fallout of airborne PCBs. Residence times to evaporation in Lake Michigan appear to be on the order of ten hours, based on theoretical calculations, whereas residence times to evaporation from sea water may be one to two orders of magnitude lower.

The picture of gross PCBs transport consistent with all of the above findings is the one dominated by air transport. Terrestial components, including fresh water, are partial sinks responding primarily to input from fallout. Losses are to evaporation and to rivers, which enter the oceans where further (possibly rapid)

NWMAR115725

evaporation occurs. Degradation of PCBs, which was assumed to be zero in the Lake Michigan analysis, appears too slow to have a significant effect. Industrial and municipal effluents and air emissions are sources of both old and new PCBs; large amounts enter landfills and a small fraction enters the cycle through leaching and evaporation.

If the above is even partially correct, then one possible answer to the question of why the restriction on uses beginning in 1971 has not caused the hoped for diminution in PCBs distribution is as follows:

(1) The systems which cause concern with regard to PCBs (freshwater systems and associated biota) serve as sinks for PCBs;
(2) Other possible sinks are not available or are ineffective in retaining PCBs; and
(3) The environmental degradation of PCBs is too slow to be significant over a five year period.

Further work in many aspects of PCBs transport and distribution are needed in order to estimate the real magnitude of the future environmental problem from these materials. Such work should also assist in identifying potential methods for reducing the environmental load of PCBs.

6.0 REGULATORY ACTIONS ON PCBs

Four government agencies, the Monsanto Company and NEMA comprise the regulatory forces currently restricting the use and distribution of PCBs. EPA, OSHA, FDA and USDA have, between them, authority to regulate and monitor food levels, disposal into waterways, industrial housekeeping, and safety practices in the work place. Each of these available authorities has a limited focus and is inadequate to prevent more PCBs from entering the environment.

There are currently no regulations to restrict the importation of PCBs as a chemical for use in applications banned by the Monsanto Company. As a result, PCB is being imported by a few companies for use in several "open-end" or "nominally-closed" applications.

NWMAR115726

Several producing nations have voluntarily limited sales of PCBs. Since 1972, Japan has banned production and importation of PCBs. The United Kingdom has barred sales of PCBs to all applications except usage as dielectric fluids, while Germany has lessened this restrictive measure to include use in heat transfer and hydraulic systems. Among non-producing countries, Sweden and Norway have stringent regulations. In Sweden, only the Environmental Protection Board can authorize the use of PCBs or compounds containing PCBs, while in Norway only the Ministry of Social Affairs can authorize the use of PCBs.

NWMAR115727

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

1.0 Conclusions

Conclusions which have resulted directly from the work reported herein are presented below. Some of these have been discussed briefly in the preceding section, but each is believed to be justified by information contained in the text of the report and the appendices.

(1) It is estimated that approximately 1.25 billion pounds of PCBs have been sold for industrial use in the U.S. since initiation of production around 1930.

(2) Of this amount, at least 95 per cent are still in existence; most is in service in capacitors and transformers, but about 290 million pounds are believed to reside in landfills and dumps and about 150 million are believed to be "free" in the environment. The magnitude of these values indicates that there is a strong future threat from PCBs present in land disposal sites.

(3) In 1974, U.S. usage of PCBs sold by Monsanto, the sole domestic producer, was distributed between capacitor manufacture (22 million pounds) and transformer manufacture (12 million pounds). Imported materials amounted to about one per cent of U.S. industrial purchases of PCBs in 1974; about 400,000 pounds (of decachlorobiphenyl) were used in investment casting and and an estimated 50,000 pounds of new material were used in specialized heat transfer systems.

(4) Waterborne effluents from PCBs production and first-tier use currently release amounts to the environment which are very small in comparison to the amounts entering land disposal sites from these industries. However, these effluents can have severe local impacts, as evidenced by the current PCBs problem in the Hudson River.

NWMAR115728

(5) Monsanto and portions of the electrical equipment industry utilizing PCBs have greatly reduced PCB releases to water and land over the past few years, primarily through improvement of plant housekeeping, improved waste collection and handling, and disposal of liquid wastes through incineration.

(6) There is no plant-scale process used at present for the specific purpose of removing PCBs from industrial wastewater.

(7) The best available treatment technology for removal of PCBs from wastewater is carbon adsorption coupled with solids and oil/grease removal. Carbon treatment can produce end-of-pipe PCBs concentrations of one ppb or less. Other adsorbents, such as resins, also appear effective to this extent.

(8) The most promising method, of those water treatment technologies under development, for PCBs destruction is ultraviolet-catalyzed ozonation.

(9) Incineration is an effective method of disposal for liquid PCBs. Landfilling is the only generally available disposal method for PCBs-contaminated solid wastes, but incineration of these wastes is technically feasible.

(10) "Zero discharge" to water of PCBs from production and first-tier use is available only through extensive water reuse plus extensive incineration of lightly contaminated wastewaters.

(11) Significant amounts of solid PCB (decachlorobiphenyl, or deka) wastes are stored or disposed of on land by the investment casting industry. Air emissions of deka may also be significant in amount, but no evidence of potential health hazards from this material has been reported.

(12) The total present usage of PCBs for open and semi-closed applications is not known but is believed to be small in comparison to closed electrical system usage. A few capacitor manufacturing

NWMAR115729

plants report recent use of PCBs in vacuum pumps, and a significant amount of carbonless copy paper containing PCBs must still be in inventory and in files.

(13) Chlorination of waste biphenyl in industrial wastewaters discharged into municipal sewers is a potential mechanism for inadvertent production of PCBs.

(14) PCBs are uniquely suited to the requirements of capacitors for AC service. Although a number of potential substitutes for this application are under development and test, they are all more flammable than Aroclor 1016 and neither their performance in service nor their potential toxicity to man and other species have been evaluated sufficiently to allow a definitive comparison with 1016.

(15) Alternatives to PCBs usage in new transformers are available. In addition, testing of promising substitute fluids (termed "self-extinguishing") is underway; these fluids may gain industry-wide acceptance within three years as substitutes for PCB fluids. At present, specification of PCB-filled transformers appears to be based primarily on cost considerations.

(16) No technical barriers to substitution for PCBs (deka) in investment casting waxes are apparent. Several potential alternatives have been previously used by this industry.

(17) Atmospheric fallout is a major source of PCBs input to fresh water systems. In Lake Michigan, the PCBs contribution at present appears to be much larger than the total of PCBs inputs from point sources such as municipal sewage treatment and paper recycling.

(18) The importance of atmospheric transport of PCBs relative to other potential inputs to water indicates that the availability of environmental sinks from PCBs is limited, possibly due to short residence times to evaporation in sea water.

NWMAR115730

(19) At present, regulatory authority over PCBs in the United States is insufficient to significantly reduce future PCBs inputs to the environment, although inputs directly to the waterways from industrial sources can be reduced from their present level. Current disposal practices, except for incineration, tend to delay instead of prevent the PCBs entry into the "free" (available to the biota) state, and these practices are regulated only minimally.

2.0 RECOMMENDATIONS

During December, 1975 and January, 1976, EPA Administrator Russell Train called for a cooperative effort between Government and industry to eventually eliminate PCBs from production and usage in the United States. The recommendations listed below were developed with this objective in mind, although each recommendation also reflects the still existing needs for further definition of the current and future PCBs problem and for the development of methods for reducing the potential damage to human health and the environment.

(1) The current distribution and losses to the environment of PCBs should be defined more accurately. Study is needed for the following aspects of past and present usage:

   (a) Present extent and distribution of usage in semi-closed systems such as heat transfer and hydraulic systems (dissemination of information concerning PCBs effects and available substitutes will result in voluntary reduction of PCBs usage);
   (b) Definition of past and present usage in investment casting, including quantification of air emissions, disposal on land, and waterborne contamination;
   (c) Present distribution and projected future trends for PCBs in the pulp and paper industry, especially the secondary fiber recovery portion; and

NWMAR115731

(d) Extent of inadvertent PCBs contamination in effluents from other industries which are currently not purchasers of PCBs.

(2) The basic transport properties of PCBs, particularly those relating to evaporation and atmospheric fallout, should be studied in depth. This and other information should be used to investigate global transport characteristics of PCBs and to predict the potential magnitude of the global PCBs problem. Potential sinks and destruction methods for PCBs should be investigated.

(3) The type of analysis presented herein for Lake Michigan should be further expanded and refined for application to other important fresh water systems. The model should be extended to a prediction of future effects and the influence of possible reductions in PCBs usage.

(4) Transport of PCBs from landfills should be investigated; in particular, potential methods for delaying or reducing PCBs release from landfills should be studied.

(5) Development and testing of potential substitutes for PCBs in capacitors, transformers, and investment casting waxes should be encouraged strongly. Technical and institutional barriers to the use of alternatives should be attacked on all possible fronts as soon as possible. Extensive toxicological testing of proposed substitute materials should be performed prior to acceptance.

(6) Methods for treatment of PCBs-contaminated water effluent should be developed and applied. Research and development activities on directly destructive treatment methods, such as UV-assisted ozonation and catalytic oxidation or reduction should be encouraged, but further work on adsorptive techniques is also needed.

NWMAR115732

(7) Alternative approaches and schedules for PCBs elimination from U.S. commerce should be evaluated with regard to technical feasibility, institutional acceptability, and economic and environmental impact. Based on these considerations, an optimized path to PCBs elimination should be developed.

(8) Possible inadvertent formation of PCBs in the environment should be studied; in particular, it is recommended that the chlorination of biphenyl in wastewaters be evaluated as a potential source of PCBs.

NWMAR115733

SECTION IV

CHEMICAL AND PHYSICAL PROPERTIES OF CHLORINATED BIPHENYLS

1.0 INTRODUCTION

The purpose of this section is to present a précis of the salient characteristics of the commercial preparations of the polychlorinated biphenyls which have generated concern as environmental pollutants. The emphasis is directed to those properties that have led to the relatively widespread use of these materials. In addition, attention will also be directed to those physical and chemical properties that contribute to the environmental effects arising from the general distribution of these materials. The discussion is not meant to be exhaustive, but rather to offer the basic technical information that is used to support the other sections of the total report. The most complete compilation of the relevant information that has been published to date is that by Hutzinger et al (O. Hutzinger, S. Safe, and V. Zitko, "The Chemistry of PCBs", CRC Press, 1974) and the authors express their debt to this publication.

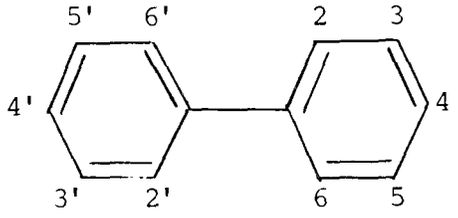
1.1 The Chemistry of the Chlorinated Biphenyls

The polychlorinated biphenyls (PCBs) constitute a large class of compounds produced by the partial (or complete) chlorination of the biphenyl molecule. Since their introduction in 1929 in commercial quantities, these compounds, or rather commercial mixtures of various members of the class, have been applied in a considerable variety of industrial applications. The unique physical and chemical properties of these compounds, including low vapor pressure at ambient temperatures; resistance to combustion; remarkable chemical stability; high dielectric constant and high specific electrical resistivity have been utilized in such applications as electrical insulating fluids; fire resistant heat transfer and hydraulic fluids; lubricants for use at high temperatures and pressures in critical applications and as a constituent in a variety of elastomers, adhesives, paints, lacquers, varnishes, pigments and waxes.

NWMAR115734

PCBs and mixtures of chlorobiphenyls have been produced in a number of countries and marketed under several trade names including Aroclor, Clophen, Phenoclor, Kanechlor and Fenclor. The essential characteristics of all these mixtures, which depend in detail on the specific mixtures of chlorobiphenyls that make up the specific preparation, are sufficiently alike that it will suffice to discuss all in terms of the Aroclors, which is the trade name of the preparations of Monsanto Chemical Company. In those special cases wherein there is some particular property peculiar to one of the foreign PCB mixtures, a note will be made.

A great deal of confusion has appeared in the literature because of the nomenclature that is used to describe the commercial preparations and the individual authenticated chlorobiphenyls. In order to clarify the nomenclature to be used herein, it is appropriate to digress briefly as follows. The biphenyl molecule has a total of ten (10) carbon-hydrogen bonds at which chlorine substitution can be accommodated. A schematic representation of the biphenyl molecule with the various positions at which substitution can be accomplished numbered in the American Chemical Society standard notation is presented below:



ACS Convention for Numerical Assignments
of Biphenyl Substitution

In the interest of a common usage, the following rules will be followed in this report:

a. When referring to a mixture of different species, as occurs in the commercial products, we will use the term polychlorinated biphenyls or the acronym PCB.

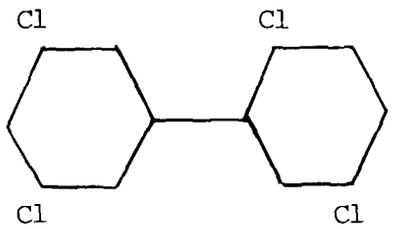
NWMAR115735

b. Those species of chlorinated compounds that arise from a specified number of chlorine substituents on the biphenyl molecule will be referred to as chlorobiphenyls with a suitable numerical prefix to define the number of substituted chlorines; i.e., dichlorobiphenyl. Thus, there are a total of ten (10) chlorobiphenyls that might appear in the commerical mixtures.

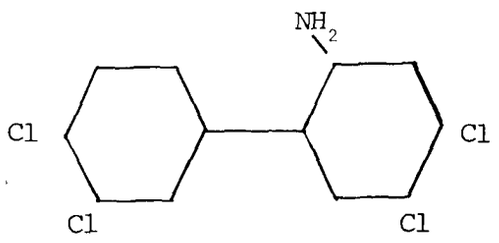
c. Those specific compounds that represent the class of compounds formed by a specific number of substituent chlorine atoms but differ in the locations at which substitution has taken place are referred to as isomers.

Thus, in terms of the above, the proper manner of referring to a commercial PCB mixture is as a "mixture of chlorobiphenyls containing various proportions of the iosmers of each".

To illustrate the utility of the numbering system indicated previously, the correct names of the compounds shown below are:



2,3',5,5'-tetrachlorobiphenyl



3',4,4',5-tetrachloro-2-biphenylamine

NWMAR115736

The ten chlorobiphenyls and some of the salient chemical data are listed in Table 1.1-1; note that the total of all the isomers of the chlorobiphenyls are 209 separate compounds.

1.2 Commercial Production and Chemical Makeup of the Aroclors

The commercial process by which the PCBs are made involves the chlorination of biphenyl with anhydrous chlorine in the presence of a catalyst which may be either iron filings or ferric chloride. The crude product is generally purified to remove color, traces of hydrogen chloride, and the catalyst by treatment with alkali and subsequent distillation. The resulting product is then a more or less complex mixture of the chlorobiphenyls, the precise composition depending on the conditions under which chlorination was carried out. The approximate composition of selected Aroclors is given in Table 1.2-1.

By way of explanation, the products made by Monsanto under the tradename Aroclor are designated as to the starting material, with biphenyl represented by the 12 prefix, and with the approximate chlorine percentage by the second set of digits; i.e., Aroclor 1248 is a chlorinated biphenyl containing approximately 48 percent chlorine.

From the data presented in Table 1.1-1 and 1.2-1, it might be inferred that all of the isomers of the individual chlorobiphenyls are to be found in each of the commercial mixtures. To illustrate the actual situation, Aroclor 1248, which is made up primarily of the di-, tri-, tetra-, penta- and hexa- chlorobiphenyls, could be expected to contain something of the order of 140-150 separate isomers. In point of fact, there are less than 50 identifiable peaks observed in the high resolution gas chromatogram of typical specimens of Aroclor 1248 as is illustrated in Table 1.2-2.

The observations relative to the high resolution studies of the commercial Aroclor mixtures have been summarized by Hutzinger, et al (ibid), in the form of Figure 1.2-1 which indicates the structural units of which the significant isomers are constructed.

NWMAR115737

Table 1.1-1
Empirical Formulation, Molecular Weights
and Chlorine Percentage in PCBs

Empirical formula chlorobiphenyls	Molecular weight*	Percent chlorine*	No. of isomers
$C_{12}H_{10}$	154	0	1
$C_{12}H_9Cl$	188	18.6	3
$C_{12}H_8Cl_2$	222	31.5	12
$C_{12}H_7Cl_3$	256	41.0	24
$C_{12}H_6Cl_4$	290	48.3	42
$C_{12}H_5Cl_5$	324	54.0	46
$C_{12}H_4Cl_6$	358	58.7	42
$C_{12}H_3Cl_7$	392	62.5	24
$C_{12}H_2Cl_8$	426	65.7	12
$C_{12}HCl_9$	460	68.5	3
$C_{12}Cl_{10}$	494	79.9	1

*Based on Cl^{35}

NWMAR115738

Table 1.2-1

Approximate Molecular Composition
of Selected Aroclors

Chlorobiphenyl	Aroclor Type or Grade (percent composition)					
	1221	1242	1248	1254	1260	1016
$C_{12}H_{10}$	11	<0.1		<0.1		<0.1
$C_{12}H_9Cl$	51	1		<0.1		1
$C_{12}H_8Cl_2$	32	16	2	0.5		20
$C_{12}H_7Cl_3$	4	49	18	1		57
$C_{12}H_6Cl_4$	2	25	40	21		21
$C_{12}H_5Cl_5$	0.5	8	36	48	12	1
$C_{12}H_4Cl_6$	ND	1	4	23	38	<0.1
$C_{12}H_3Cl_7$	ND	<0.1		6	41	ND
$C_{12}H_2Cl_8$	ND	ND		ND	8	ND
$C_{12}H_1Cl_9$	ND	ND		ND	1	ND
$C_{12}Cl_{10}$	ND	ND		ND		ND

NWMAR115739

Table 1.2-2

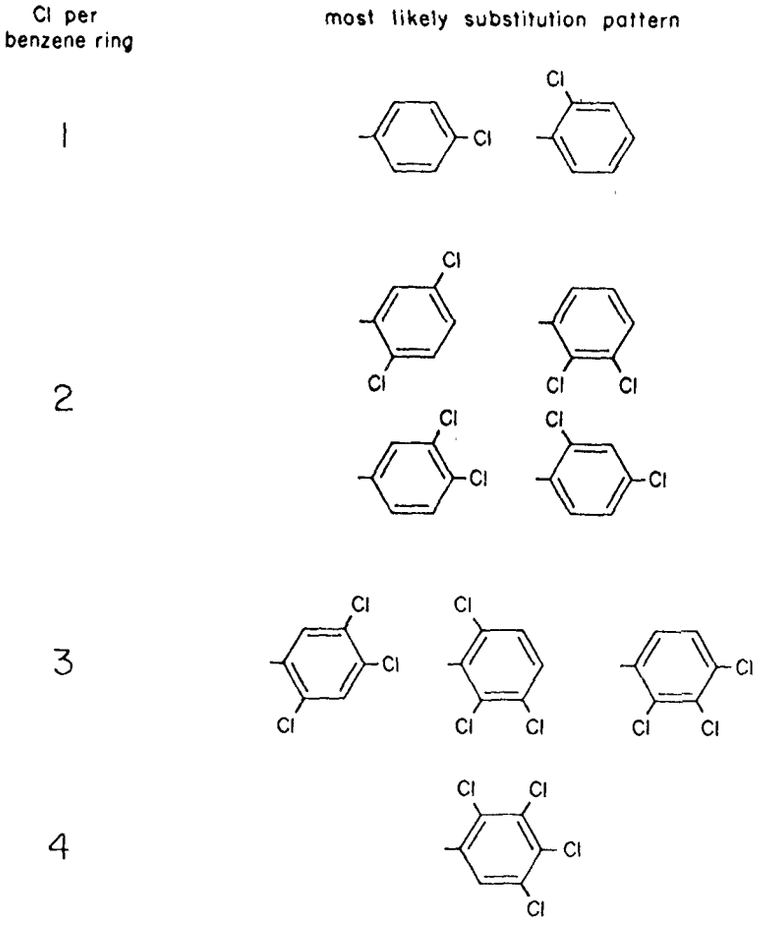
High Resolution Gas Chromatography of Aroclor 1248

Peak number*	No. of Cl	% In Aroclor 1248	% In fatty tissue
1			
2			
3			
4	2	0.4	
5	3	1.0	0.9
6	2	3.2	1.4
7	3	11.2	0.9
8	3	3.2	2.4
9	3	3.1	0.5
10	3	2.0	0.2
11/12	3,4	1.4	4.8
13	3,4	1.4	0.8
14	3,4	0.8	0
15	3	8.5	1.6
16	3	9.7	1.6
17	3	2.1	0.8
18	3,4	7.4	0.5
19	3,4	7.4	-
20	3,4	6.0	7.0
21	3,4	4.5	4.1
22	4	3.1	0.3
23	4	2.6	0.4
24	3,4,5	0.8	-
25	4,5	1.2	1.0
26	4,5	1.0	-
27	4	0.2	-
28	4	5.0	5.3
29	4	3.3	2.0
30	4	2.0	0.4
31	4	2.1	0.5
32	4,5	1.0	2.9
33	4,5	0.5	29.0
34	4,5	0.5	1.4
35	4,5	0.8	-
36	5	1.0	1.7
37	5	0.4	1.4
38	6	<0.1	0.1
39	4	<0.1	0.1
40	6	0.2	11.0
41/42	5	0.3	1.1
43	5,6	0.2	8.0
44	6	<0.1	5.3
45	6	0.2	0.9
46	6,7	(0.7)	(1.1)

NWMAR115740

Figure 1.2-1

Moieties from Which Principal
Chlorobiphenyl Isomers are Formed



The most common substitution patterns for the chlorobiphenyls found in PCB preparations. Only one phenyl-ring is shown. The most abundant tetrachlorobiphenyls, for example, are those from the dichlorophenyl-moieties shown. One di- and one trichlorophenyl- would give most abundant penta-chlorobiphenyls, etc.

NWMAR115741

Several comments are necessary at this point: The importance of such detailed determination and identification of the isomers characteristic of the commercial PCBs lies in the observations, to be discussed below, that bio-accumulated chlorobiphenyls show what appear to be significant differences in the distributions of the individual isomers from the source materials. The most probable explanation for these observations seem to be that at least some of the chlorobiphenyls are metabolized principally to hydro-chlorobiphenyls. Only after very complete isomeric spectra are available can such effects be properly studied.

Secondly, the detailed study of the PCBs has shown that there are no major compounds in these mixtures aside from the chlorobiphenyls. On the other hand, products formed by the addition (rather than by substitution) of chlorine to the biphenyl molecule in laboratory studies, yield significant concentrations of partially saturated structures. These structures are apparently either not formed under the conditions of chlorination that prevail during the industrial processing or alternatively are destroyed during the purification steps of the process. In contrast to the Aroclors, some of the foreign products have shown traces of polychlorinated naphthalenes and polychlorodibenzofurans; a fact that may have considerable toxicological significance in view of the rather more toxic nature of these latter products. However, recent information published by FDA indicates that impurities of chlorodibenzofurans have been also detected in Aroclors.

1.3 Physical Properties of the PCB Aroclors

The relevant physical properties of the Aroclor mixtures naturally separate into two groups; those properties that have led to the widespread industrial use of these materials, and those properties that result in the introduction of these materials into the environment with what appears to be considerable potential danger.

1.3.1 Physical Properties of Industrial and Technical Interest

The most useful compilation of the physical properties of the various Aroclors that has so far appeared in the literature is that given by Hutzinger, et al (ibid), a portion of which is herein reproduced (with minor changes) as Table 1.3.1-1.

NWMAR115742

NR - not reported
* - same chlorine content as deca chlorobiphenyl
** - polychlorinated terphenyls

Table 1.3.1-1

Chemical and Physical Properties of Representative Aroclors

Property	Aroclor 1221	Aroclor 1232	Aroclor 1016	Aroclor 1242	Aroclor 1248	Aroclor 1254	Aroclor 1260	Aroclor 1262	Aroclor 1268	Aroclor 1270*	Aroclor 5442	Aroclor 5460**
Appearance	Clear, mobile oil	Clear, mobile oil	Clear, mobile oil	Clear, mobile oil	Clear, mobile oil	Light-yellow viscous liquid	Light-yellow soft, sticky resin	Light-yellow sticky viscous resin	White to off-white powder	White crystalline powder	Yellow, transparent sticky resin	Clear yellow-to-amber brittle resin
Color, maximum	100 APHA	100 APHA		100 APHA	100 APHA	100 APHA	150 APHA	150 APHA	1.5 NPA (molten)			
Chlorine, percent	20.5-21.5	31.4-32.5	~41	42	48	54	60	61.5-62.5	68	71	42	60
Acidity, mg KOH/g maximum	0.014	0.014		0.015	0.010	0.010	0.014	0.014	0.05			
Moisture, ppm, maximum	-	-		50	50	50	50	-	-			
Ave. coefficient of expansion, cc/cc/°C	0.00071 (15°-40°C)	0.00073 (25°-100°C)		0.00068 (25°-65°C)	0.00070 (25°-65°C)	0.00066 (25°-65°C)	0.00067 (20°-100°C)	0.00064 (25°-65°C)	0.00067 (20°-100°C)			
Specific gravity	1.182-1.192 (25°/15.5°C)	1.270-1.280 (25°/15.5°C)	1.362-1.372 (25°/15.5°C)	1.381-1.392 (25°/15.5°C)	1.405-1.415 (65°/15.5°C)	1.495-1.505 (65°/15.5°C)	1 555-1.566 (90°/15.5°C)	1.572-1.583 (90°/15.5°C)	1.804-1.811 (25°/25°C)	1.934-1.960 (25°/25°C)	1.470 (25°/25°)	1.670 (25°/25°)
Density, lb/gal, 25°C	9.85	10.55	11.40	11.50	12.04	12.82	13.50	13.72	15.09	16.30	12.25	13.90
Distillation range, °C, corrected (ASTM D-20, modified)	275-320	290-325	323-356	325-366	340-375	365-390	385-420	390-425	435-450	450-460	215-300	280-335
Evaporation loss, %, 100°C, 6 hr (ASTM D-6, mod.)	1.0-1.5	1.0-1.5		0-0.4	0-0.3	0-0.2	0-0.1	0-0.1	0-0.06			
163°C, 5 hr				3.0-3.6	3.0-4.0	1.1-1.3	0.5-0.8	0.5-0.6	0.1-0.2			
Flash point °C (Cleveland Open °F Cup)	141-150 286-302	152-154 305-310	170	176-180 348-356	193-196 379-384	none to boiling point	none to boiling point	none to boiling point	none to boiling point	none	247	none
Fire point °C (Cleveland Open °F) Cup)	176 349	238 460	none to boiling point	none to boiling point	none to boiling point	none to boiling point	none to boiling point	none to boiling point	none to boiling point	none	>350	none
Pour point °C (ASTM E-97) °F	1 (crystals) 34 (crystals)	-35.5 -32		-19 2	-7 19.4	10 50	31 88	35-38 99	-		46	—
Softening point °C (ASTM E-28) °F	-	-		-	-	-	-	-	150-170 302-338 (hold point)	249-300	46-52	98-105.5
Refractive index, n D-20 20°C	1.617-1.618	1.620-1.622	1.622-1.624 (@ 25°C)	1.627-1.629	1.630-1.631	1.629-1.641	1.647-1.649	1.6501-1.6517	-			1.660-1.665
Viscosity, SUS Saybolt Universal (ASTM D-88)												
100°F (37.8°C)	39-41	44-51	71-81	82-92	185-240	1800-2500		600-850 (160°F; 71°C)	-			
130°F (54.5°C)	35-37	39-41	NR	49-56	73-80	260-340	3200-4500	86-100				
210°F (98.9°C)	30-31	31-32	NR	34-35	36-37	44-48	72-78					
Average no. of Cl/mol	1.15	2.04	NR	3.10	3.30	4.96	6.30	6.80	8.70	NR	NR	NR

NWMAR115743

In addition to the chemical stability and resistance to combustion illustrated in Table 1.3.1-1, the electrical properties of the PCB Aroclors are of extreme significance in the utilization of these materials. A compilation of the relevant data is presented as Table 1.3.1-2, which illustrates the nature of the problem that is encountered when one undertakes a search for a suitable substitute for these compounds in such segments of the electrical industry as the manufacture of capacitors. Specifically, the dielectric constants for most dielectric liquids lie in the range up to perhaps half of that of the polychlorinated biphenyls.

1.3.2 Physical Properties of Environmental Interest

The essentially world-wide distribution of the chlorinated hydrocarbons such as the PCBs suggest that a major route by which such compounds are transported is through the atmosphere either in the form of vapor or perhaps sorbed onto dust particles. In addition, it is observed that there is a widespread accumulation of these compounds within the biota ranging from the smallest on up the food chain until truly enormous loads are found in the highest members of the chain. Since this bioaccumulation also includes the aquatic biota, the possibility of considerable transport via the solubility of these compounds in water must also be taken into account. Table 1.3.2-1 lists some of the vapor pressure and solubility data for several of the Aroclors (D. MacKay and A. W. Wolkoff, Env. Sci. and Tech., 7, 611 ff (1973)).

The analysis of co-evaporation (MacKay, ibid) of dilute solutions of the Aroclors by equilibrium thermodynamics suggests that, because of the very high activity coefficients of the chlorobiphenyls in water, the potential for evaporation is quite high enough that this mechanism is a major portal by which such compounds enter the atmosphere. The fourth column of Table 1.3.2-1 indicates the theoretical time for a fifty percent reduction in the concentration of the Aroclor from a saturated water solution (pure water plus PCBs), assuming the water depth to be 1 meter thick. Clearly, the results of this analysis need to be experimentally verified.

NWMAR115744

Table 1-3.1-2
Electrical Properties of Some Aroclors

Aroclor	Dielectric constant at 1000 cycles[a] 25°C	100°C	Volume resistivity,[b] 8 cm at 100°C 500 V, de	Dielectric strength,[c] kV	Power factor,[a] 100°C, 1000 cycles, %
1232	5.7	4.6			
1242	5.8	4.9	above 500 x 10^9	>35	<0.1
1248	5.6	4.6	above 500 x 10^9	>35	<0.1
1254	5.0	4.3	above 500 x 10^9	>35	<0.1
1260	4.3	3.7	above 500 x 10^9	>35	<0.1
1268	2.5				
5442*	3.0	4.9	above 500 x 10^9	--	--
5460*	2.5	3.7	---	--	--

[a]ASTM D-150-47T

[b]ASTM D-257-46

[c]ASTM D-149-44

*Polychlorinated terphenyls

NWMAR115745

Table 1.3.2-1

Solubility, Vapor Presure and Halflife for
Vaporization from Water of Selected Aroclors at 25°C

PCB Type	Solubility (mg/l)	Vapor Pressure (mm Hg)	Theoretical halflife for vaporization from 1 m. water column
Aroclor 1242	0.24	4.06×10^{-4}	5.96 hr.
Aroclor 1248	5.4×10^{-2}	4.94×10^{-4}	58.3 min.
Aroclor 1254	1.2×10^{-2}	7.71×10^{-5}	1.2 min.
Aroclor 1260	2.7×10^{-3}	4.05×10^{-5}	28.8 min.

NWMAR115746

As pointed out above, not only is each of the Aroclors a mixture of several chlorobiphenyls, but there are a number of isomers present for each of the chlorobiphenyls. Thus, the solubility of an Aroclor, or the vapor pressure of an Aroclor, represents an average over the various species that make up the mixture. To illustrate the effect of the structural complexity, Table 1.3.2-2 (Hutzinger, ibid) details the measured vaporization rates of the several Aroclors. On the other hand, the changes in the mixture corresponding to Aroclor 1254 on extended heating are displayed in Table 1.3.2-3 (Hutzinger, ibid).

The possible implications of these data lie in the fact that much of the Aroclor that is found in typical environmental samples seems to demonstrate lesser amounts of the lower chlorine number chlorobiphenyls than is characteristic of freshly manufactured samples. This observation has frequently been attributed to possible metabolism of the more lightly chlorinated species coupled with enhanced fixation of the higher chlorinated species.

A partial listing of the measured solubility in water of identified authentic chlorobiphenyls is shown in Table 1.3.2-4 (Hutzinger, ibid) and the effect of the solubility differences of the individual chlorobiphenyls on the constitution of Aroclor 1254 solutions is illustrated in Table 1.3.2-5 (Hutzinger, ibid).

A factor that is most probably of considerable importance in the admission of such compounds as the PCBs into the environment is a measure of the partition coefficients between such interface systems as soil-air; soil-water; lipids-water; and, more generally, water-solid particles. At the present time there seems to be very little actual data available in direct form, although much should be possible to infer from the effects of various combinations of stationary phase and support in gas chromatography on the retention index. An interesting and probably significant point of datum has been presented by D. R. Branson of the Dow Chemical Co., who reports that the distribution of 2,2',5 trichlorobiphenyl between sludge-water-air was 92%-3%-5%, respectively.

NWMAR115747

Table 1.3.2-2

Vaporization Rates of Aroclors

Aroclor (Surface area: 12.28 cm^2)	Wt. loss (g)	Exposure at 100°C (hr)	Vaporization rate ($g/cm^2/hr$)
1221	0.5125	24	0.00174
1232	0.2572	24	0.000874
1242	0.0995	24	0.000338
1248	0.0448	24	0.000152
1254	0.0156	24	0.000053
1262	0.0039	24	0.000013
1260	0.0026	24	0.000009
1270 (Deca)	0.0015	24	0.000005

NWMAR115748

Table 1.3.2-3

Percent Loss in Area of Seven Chromatogram Peaks of Aroclor After Heating

Aroclor 1254 peak	% Peak Remaining After Heating with water 25 min	with water 60 min	without water 10 min
1	34	17	13
2	59	26	15
3	78	27	20
4	60	46	20
5	86	49	27
6	100	85	28
7	100	67	16

NWMAR115749

Table 1.3.2-4

Solubility of Chlorobiphenyls in Water

Compound	Solubility mg/l (ppm)
Monochlorobiphenyls	
2-	5.9
3-	3.5
4-	1.19
Dichlorobiphenyls	
2,4-	1.40
2,2'-	1.50
2,4'-	1.88
4,4'-	0.08
Trichlorobiphenyls	
2,4,4'-	0.085
2',3,4-	0.078
Tetrachlorobiphenyls	
2,2',5,5'-	0.046
2,2',3,3'-	0.034
2,2',3,5'-	0.170
2,2',4,4'-	0.068
2,3',4,4'-	0.058
2,3',4',5-	0.041
3,3',4,4'-	0.175
Pentachlorobiphenyls	
2,2',3,4,5'-	0.022
2,2',4,5,5'-	0.031
Hexachlorobiphenyl	
2,2',4,4',5,5'-	0.0088
Octachlorobiphenyl	
2,2',3,3',4,4',5,5'-	0.0070
Decachlorobiphenyl	0.015
4,4'-Dichlorobiphenyl	
+Tween 80 0.1%	5.9
+Tween 80 1%	>10.0
+Humic acid extract	0.07

NWMAR115750

Table 1.3.2-5

Relative Peak Heights (Peak 5 = 100) in Saturated Aqueous Solutions of Aroclor 1254

Peak No.	Saturated aqueous solution (26°C)	Saturated aqueous solution (4°C)	Aroclor 1254 standard
1	172	144	35
2	91	72	16
3	47	41	30
4	14	9	1
5	100	100	100
6	33	28	23
7	57	59	55
8	5	5	10
9	21	24	25
10	8	13	31
11	4	4	6
12	11	24	50
13	6	10	11

NWMAR115751

1.4 Chemical Properties of the Chlorobiphenyls

Considerable detail on the most important chemical reactions that are known to occur with the chlorobiphenyls is presented in Chapter 5 of the treatise on "The Chemistry of the PCB" by Hutzinger, et al. Suffice it to say here that oxidation and hydrolysis can be carried out, but only under conditions which are considerably more rigorous than would be obtained in industrial applications. This relative stability is, of course, one of the most attractive features of these compounds in technological practice.

The class of reactions to which the chlorobiphenyls are susceptible and which is of most interest in terms of their possible toxicological significance are those which result in cyclization. Of particular interest in this context is 2,2' dichlorobiphenyl, which on cyclization yields the compound dichlorodibenzofuran. The toxicological data on these two compounds indicates the nature of this change: the LD_o for oral doses to rats is of the order of 250 mg/kg for the dibenzofuran whereas the corresponding toxicity for the chlorobiphenyl is in excess of 4000 mg/kg. (Data from the "Toxic Substances List", HEW, 1973).

The close proximity of the 2 and 2' substituents on the biphenyl molecule facilitates intermolecular cyclization reactions under a variety of conditions. Of special interest is the observation that alkali fusion of 2-chloro-2'-hydroxybiphenyl and the dehydration of 2,2'-dihydroxychlorobiphenyl yield the corresponding chlorodibenzofurans; hydroxylation of the chlorobiphenyls is the common initial step in the metabolism of these compounds. The immediate biological significance of this is unknown at this time since the chlorodibenzofurans have not been isolated from animal experiments.

1.5 Photochemical Reactions Involving the PCBs

A great deal of effort has been directed to the study of the effects of ultraviolet (UV) radiation on the chlorobiphenyls since photodestruction is believed to be a possible major mechanism for the environmental decay of chlorohydrocarbon pesticides such as DDT. There has been much speculation as to the role that UV photodisintegration might play in terms of the chlorinated biphenyls. The earlier work was carried out using mercury vapor UV sources with the result

NWMAR115752

that, because of the significantly harder radiation (mercury source 250 nm, solar radiation at surface of the earth with an effective cutoff at 290 nm), cross section and reaction paths are difficult to extrapolate to environmental situations. In more recent times, such irradiation studies have been carried out using General Electric "Black Light" sources which much more nearly approximate the spectral distribution of solar radiation.

A number of types of effects have been observed including partial dechlorination and even, in some cases, the formation of very viscous semi-solids that apparently arise from complex polymerizations. Again, the extension of the experimental results to environmental conditions is somewhat limited in value since the majority of the irradiation studies have been carried out in solvents other than water. The very low solubility of even the least chlorinated chlorobiphenyls in water makes the experimental study of aqueous solutions especially difficult, particularly when the information of concern is the quantitative evaluation of the reaction products that are formed. It must be said, at this time, that the probability of UV disassociation being a major source for the environmental decay of the chlorobiphenyls seems to be significantly less than that for the chlorinated hydrocarbon pesticides.

Since it is assumed that a major portion of the chlorinated biphenyls are transported and distributed throughout the world through the medium of adsorption on dust particles or as a vapor, it follows that studies of the stability of thin sorbed films or of vapors of the chlorinated biphenyls against long term UV irradiation are of importance. The earlier attempts to discover the presence of reaction products resulting from long term exposure of selected chlorobiphenyls to solar radiation were subject to the differential evaporation of the less chlorinated species; this result seriously biased the observations. The recent experiments that have been conducted within quartz containers seem to obviate evaporation problems and, further, seem to indicate that the mono- and dichlorobiphenyls are essentially completely destroyed when exposed to hard UV for times of the order of weeks or months. Problems of detection sensitivity continue to plague attempts to elucidate the detailed mechanisms and pathways.

NWMAR115753

Studies of thin films of chlorobiphenyls sorbed onto appropriate surfaces have also been carried out within a quartz enclosure. To date, the major objection to such experiments, in terms of extrapolation to environmental conditions, seems to be that the concentration, or rather the absolute density of the surface layer, is sufficiently high that the activated species remain in contact for sufficiently long times as to allow the formation of products that might well be very rare events in corresponding environmental concentrations.

At this time there appears to be significant research being directed to the determination of the stability of chlorobiphenyls against ultraviolet radiation and that it is to be expected that the situation which obtains in typical environmental conditions will be greatly illuminated in the near future.

1.6 Metabolic Chemistry of the Chlorobiphenyls

The very combination of physical and chemical properties that have made the chlorobiphenyls and their technical mixtures of such wide technical interest also result in these compounds being of significance as environmental pollutants, especially in terms of their impact on the biota. The very low chemical activity, coupled with high lipid-water partition coefficients, apparently contribute to the bioaccumulation whereby the chlorobiphenyls, pecially the more highly chlorinated species, tend to become fixed within the body fats and particularly in higher members of the food chain. There is evidence that this fixed load of refractory chlorinated organic materials, or the circulating levels of the same compounds that must accompany such fixed loads, represents a serious hazard to the bearer or progeny. The toxic consequences of body burdens of chlorobiphenyls is more fully discussed in the section of this report concerned with toxicology of the chlorobiphenyls.

The mechanisms by which an organism can deal with ingested refractory compounds are naturally separated into physical and chemical processes. The physical processes are primarily associated with the requirements of free energy across the boundary between differing phases such as a water-lipid boundary, or a cell wall, etc. Since there does not exist a significant body of partition coefficient data for various combinations of interfaces, little of a quantitative nature can be stated as to the biological significance of such physical processes.

NWMAR115754

On the other hand, as is pointed out in Section 2.4, hydroxylation is a rather easily accomplished process for at least the less chlorinated chlorobiphenyls. Thus, it might be assumed that one should observe the hydroxylated chlorobiphenyls as intermediate metabolic products in a variety of organisms. Experimental data is available to indicate that such hydroxylation processes are indeed exhibited by a wide variety of organisms. The principle species related differences seem to be in the rate at which such processes are found to occur — very rapidly in rodents and very slowly in fish. In addition, once the target chlorobiphenyl has been hydroxylated to a more or less degree, there appear to be available a wide variety of species-specific addition processes which could make use of the hydroxylated molecule. Interestingly, there is to date no evidence of biologically or metabolically induced cyclization; it thus appears likely that the chlorodibenzofurans are not biologically formed.

The salient observations to date on the metabolism of chlorobiphenyls might best be summarized as follows:

a. When the challenge to the animal is a technical mixture of chlorobiphenyls, there is a preferential storage of the more highly chlorinated species, with the result that the homologue spectrum of stored PCBs often represents a more heavily chlorinated mixture than the original test mixture.

b. There is conflicting and often species-dependent data as to the mechanism by which the less chlorinated species are differentiated; whether the processes involve metabolism, physical partitioning, or some combination of such processes has not been settled.

NWMAR115755

c. Conflicting and confusing evidence exists indicating marked differences in accumulation and differentiation between specific isomers especially at the middle levels of chlorination. These differences also seem to be species-dependent in a number of cases.

d. There is significant evidence that PCB metabolism proceeds through an intermediate step of hydroxylation (often this appears to be the terminal step whereby the increased aqueous solubility of the hydroxylated species accomplishes the end of its removal).

e. There are several observations indicating that isomerization can be accomplished during metabolic reactions. In this context, the results of Bagley and Cromartie (Bagley, G.E. and E. Cromartie, J. Chrom. 75, 219-226, (1973)), with the elimination of Aroclor 1254 in the Bobwhite, are most pertinent.

In conclusion, there has been much work directed to the study of the mechanisms whereby living organisms are able to eliminate chlorinated biphenyls from their system. In spite of this effort and because of the inherent complexity of this subject, the nature of these mechanisms remains a mystery.

NWMAR115756

SECTION V

INDUSTRIAL CHARACTERIZATIONS

1.0 INTRODUCTION

This section discusses polychlorinated biphenyls (PCBs) production and each PCBs user (capacitor, transformer, investment casting, paper recycling and miscellaneous) manufacturing process. When known, for each operation the following information is given:

- Name and the location of companies in each category;
- A description of the processes at the facilities studied and pertinent flow diagrams, where appropriate;
- Raw waste load data per ton of PCB used and sources of these wastes;
- Water usage data in terms of gallons per day;
- Treatment and housekeeping measures practiced at the facilities and on-going PCB containment programs;
- Plant waste effluents found and their composition.

2.0 MANUFACTURING PROCESS - POLYCHLORINATED BIPHENYLS (PCBs)

2.1 Process Description

Monsanto, the sole domestic manufacturer of PCBs, manufactures this chemical in their Sauget, Illinois plant. The basic raw material is biphenyl which is manufactured from pure benzene in another Monsanto plant. The PCB manufacturing operation is conducted in two steps. First, biphenyl is chlorinated with anhydrous chlorine in the presence of ferric chloride to produce crude PCBs and then the crude PCBs are distilled to obtain the finished product. A schematic flow diagram of this process is given in Figure 2.1-1A and B.

NWMAR115757

FIGURE 2.1-1A. PREPARATION OF CRUDE CHLORINATED BIPHENYLS-MONSANTO KRUMMRICH PLANT

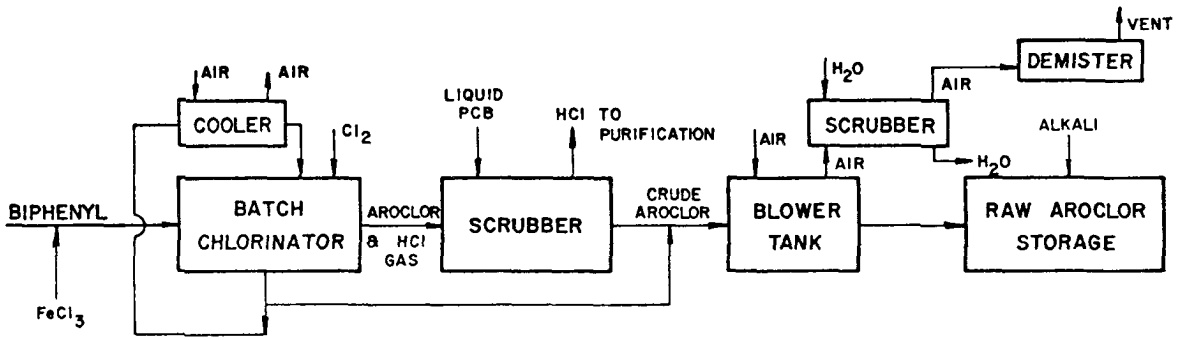
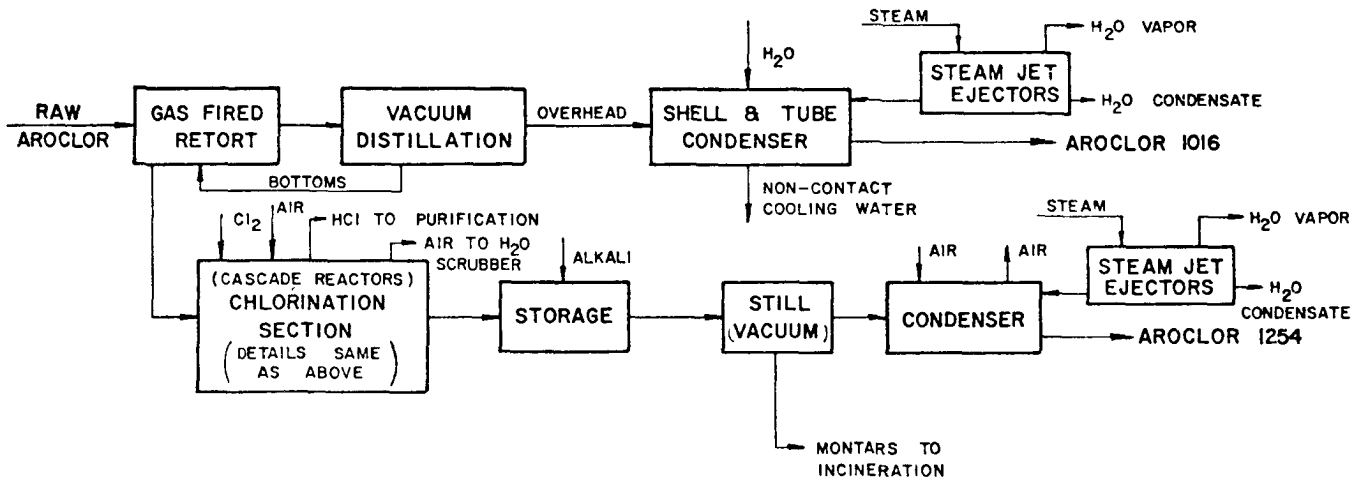


FIGURE 2.1-1B. DISTILLATION OF CRUDE PRODUCTS-MONSANTO KRUMMRICH PLANT



NWMAR115758

The reaction section consists of 6 reactors (3 batch and 3 cascade). Currently, Monsanto manufactures four different types of Aroclors (1242, 1016, 1254 and 1221). For the manufacture of any given product, the chlorinator is charged with proper quantities of biphenyl and catalyst and heated above the melting point of biphenyl. The flow of vaporized chlorine is then started and the charge is circulated with a pump. Throughout the chlorination, the temperature is kept above the melting point of the mixture, but below 150°C to avoid excessive sublimation and plugging of the line discharging the hydrogen chlorine produced by the chlorination. The reaction pressure is maintained near atmospheric. The degree of chlorination is principally determined by the time of contact with anhydrous chlorine. The contact time varies from 12 to 36 hours for the manufacture of different Aroclor types. The degree of chlorination is measured by the specific gravity of the mixture or the ball and ring softening point when the product is viscous.

The vapors from the chlorinator (HCl containing PCBs) are scrubbed with liquid Aroclor and the gaseous HCl is sent to another plant at the Sauget complex for purification. The crude product is held at an elevated temperature and blown with dry air for several hours, after which it is sent to the raw Aroclor storage tank where a few tenths of 1 percent of alkali are stirred with the material to react with any remaining hydrogen chloride or ferric chloride. The air from the blower tank is scrubbed with water and vented to the atmosphere through a demister.

The raw Aroclor is subsequently batch distilled under reduced pressure to remove the color, and the traces of hydrogen chloride and ferric chloride. The methods of purification are different for the different types of end products. Raw Aroclor 1254, 1242 and 1221, each are distilled in stills under reduced pressure, achieved via steam jet ejectors; the condensate from the still is the finished product while the bottoms are the Montars which are drummed and sent to incineration.

The distillation section for the 1016 product consists of a gas fired retort and a vacuum distillation tower. The latter is used to allow the separation of the higher chlorinated, less biodegradable compounds from the relatively

NWMAR115759

lower chlorinated and more biodegradable ones. The raw Aroclor (42% chlorinated material) is fed into the reboiler. The vacuum in the tower is maintained at about 100 mm Hg by steam jet ejectors. The steam is partially condensed and the condensate is discharged into the plant discharge sump. The first cut from this tower is recycled back to the retort. At a preset overhead temperature the 1016 product is collected and sent to the product storage. The high boiling residue from the tower is sent to a subsequent chlorination cycle and the resulting raw Aroclor is distilled in a still. The overhead from this still is the finished product. The bottoms from this tower are the Montars. The spent ferric chloride catalyst, used in PCB manufacturing, is sent to incineration with Montar residues.

For special orders, in order to increase electrical resistivity, the Aroclors are stirred at an elevated temperature with a few tenths of 1% of well-dried fuller's earth and then filtered through paper.

All Aroclors are stored at 150°F. Steam coils are used on the storage tanks for heating these tanks.

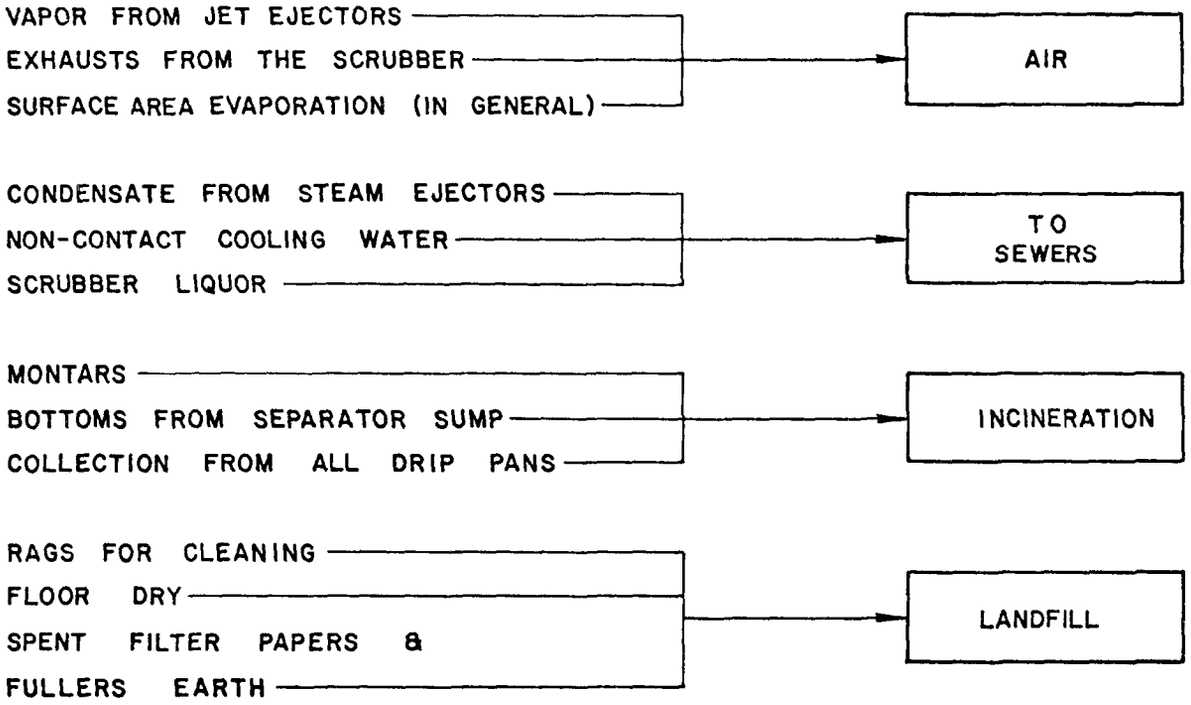
2.2 Raw Wastes

The raw wastes from the manufacturing area consist of the liquor from the scrubber, the condensate from the steam jet ejectors, water used for showers and eye baths, miscellaneous floor wash downs, waste oil collected in drip pans and drums, and montars which are the bottom cut from their stills. The composition and the quantities of the individual waste stream are not monitored. All effluent streams generated in the manufacturing area are directed into the sumps in this area. The waste oil collected in the drip pans and the Montars are emptied into 55 gallon drums and sent to incineration.

The raw wastes generated in the incinerator consist of the venturi scrubber liquor and the water phase from the separator sump in the incinerator area. The composition of the combined stream is monitored. However, the composition of the individual streams is not known. Non-product PCB discharges are shown in Figure 2.2-1. It has been estimated that this plant generates

NWMAR115760

FIGURE 2.2-1. NON-PRODUCT PCB DISCHARGES AT MONSANTO'S KRUMMRICH PLANT



NWMAR115761

about 25 lbs of scrap oil and Montar per ton of PCB produced. Additionally, the quantities of material sent to landfill approximates to 5.4 lbs per ton of PCB produced. Further, Monsanto reports that the plant's PCB contribution to the air is under 1 lb/day.

2.3 Plant Water Usage

On the average, the PCB plant uses a maximum of 388,800 gallons of water and a maximum of 360,000 lbs of steam daily. Water is used for non-contact cooling purposes in shell and tube condensers, in a water scrubber, for floor washings, for showers and in eye baths. Steam is used in the steam jet ejectors and for steam tracing purposes. The plant uses municipal water and purchased steam.

The process water from this facility consists of the liquor from their scrubber and the steam condensates which are discharged in one of the two sumps in the manufacturing area.

Additionally, 273,600 gallons of water are used in the incinerator daily for quenching the hot gases from the fire box. The resulting weak muriatic acid in the quench pot is used in the venturi scrubber and in the packed tower.

The type and quantities of water used and discharged at this plant are summarized below:

Water Balance

. Manufacturing Plant

	Quantities, GPD	
	Used	Discharged
Process Water		
in water scrubber	14,400	14,400
misc. floor wash downs	7,200	7,200
condensate from steam jet ejectors	--	14,400

NWMAR115762

Water Balance (Con't)

. Manufacturing Plant

	Quantities, GPD	
	Used	Discharged
Non contact cooling water	360,000	360,000
showers, eye bath	7,200	7,200
condensate from steam tracers	--	28,800
Total	388,800	432,000

. Incinerator

water used for hot gas quenching	273,600	273,600
water phase from the sump	--	14,400
Total	273,600	288,000

2.4 Wastewater Treatment and Housekeeping

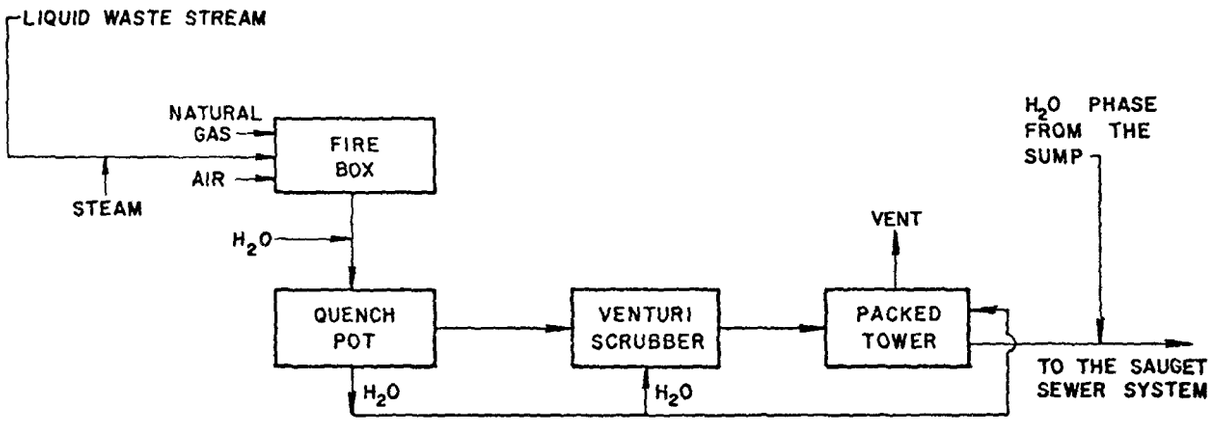
Monsanto reports significant environmental controls at their Krummrich, Sauget plant. Since 1969, they have invested more than 22 man-years of work and millions of dollars in this program. The in-house goals have reduced the PCB discharges into water to about three pounds per day.

A John Zink designed incinerator was erected at Sauget in 1970 to safely dispose of PCBs. A schematic flow diagram of this operation is given in Figure 2.4-1. Aroclor is steam atomized and fed into the fire box. Natural gas is used for combustion and the feed is incinerated at temperature above 2200°F at 5 percent excess oxygen with a retention time of 2-3 seconds. The gases are quenched with water and the exhausts from the quench pot are passed through a high-energy venturi scrubber, then through a packed column which is irrigated by the weak muriatic acid originating from the quench pot. Exhausts are then vented to atmosphere through a demister. These exhausts as well as the effluent from the incinerator section are monitored.

In the incineration area, drainage is directed to trenches and piping which flow into a 10,000 gallon underground concrete basin. The water

NWMAR115763

FIGURE 2.4-1. PROCESS FLOW DIAGRAM OF THE JOHN ZINK INCINERATOR AT MONSANTO'S KRUMMRICH PLANT



NVVMAR1157

layer from this basin is pumped continuously, combined with the scrubber liquor, metered, monitored and discharged into the sanitary sewers of the Sauget complex and from there it is sent to the East St. Louis municipal sewers. The organic phase from the sump is periodically pumped into waste storage tanks for incineration.

The incineration unit has a rated design capacity of 10 million pounds per year. However, since the start of its operation this unit has achieved a service factor of about 0.60. Monsanto reports that this incinerator can achieve a maximum of 6 million pounds of capacity annually; the unit is plagued with various mechanical problems.

Monsanto uses their incinerator to process both their own wastes and as a service to other industries. The service charge for incineration is an average of 5¢ per lb of material, but the cost appears to be increasing.

The incinerator feed is brought into the plant either by truck in 55 gallon sealed drums, by tank trucks or by rail. The drums are opened, picked up by a fork lift and emptied into a concrete pit. The tank truck carrying the waste liquids enters the incinerator area and the liquid waste is then pumped from the truck into the pit. The material in this pit is periodically pumped via a vertical certrifugal pump into one of the four 20,000 gallon incinerator waste feed tanks.

The rail car is brought into a designated area close to the incinerator site. The material from the rail car is normally pumped into a long term, 500,000 gallon storage tank. The material from this tank is pumped into the incinerator feed tanks located on the incinerator pad when required.

Drainage is provided along the rail tracks. These drains empty into the 10,000 gallon sump located under the incinerator pad.

In the manufacturing area, Monsanto has taken a number of significant steps to prevent loss of PCBs to the environment. Drainage is directed to trenches and piping, and then to one of two concrete 3,000-gallon underground settling basins. This insures PCB containment in case of accidental spill or

NWMAR115765

equipment failure. Relief valve lines and atmospheric vents are routed through catch tanks, or are redirected to settling basins.

When small quantities of PCBs are collected in the settling basins of the manufacturing area they are later pumped into 55 gallon drums, and eventually incinerated. The overflow from these sumps is combined with the non-contact cooling water used at the plant, monitored and then discharged into the Sauget complex's sanitary sewer and from there to the East St. Louis municipal system.

PCBs are packed and shipped in galvanized-steel 55 gallon drums, or in railroad tank cars. All tank cars are top loaded. In the drum filling area spills are cleaned via rags or floor dry and these materials are drummed and sent to landfill located in the town of Sauget.

In the PCB truck or rail car loading area, drainage is directed into a small concrete pit. The material accumulated in this pit is periodically pumped into the basins located in the manufacturing area.

Nitrogen blanketing is provided on storage tanks to eliminate any "breathing" of the tanks and resultant PCB escape.

Mist eliminators have been installed in vapor lines to eliminate the possibility of PCBs leaving the manufacturing area through these lines.

Finally, underground sewers have been replaced with above-ground sewers, and repaired or combined with others, so that the effluent from the department can be monitored. In addition, this step will prevent any unknown buildup of PCBs in the sewer systems or any contamination of PCBs into other sewers.

A high housekeeping level is maintained in the plant itself. Housekeeping responsibilities which the operators have assumed are as follows:

- All pumps are checked for leakage on every shift. Drip pans that collect leaks are emptied into scrap PCB drums.

NWMAR115766

- All leaks are reported and documented so that corrections can be made and settling basins observed.
- "Floor Dry" is used to absorb any PCBs that have spilled or leaked. If it becomes necessary to flush PCBs to the settling basin, a minimum amount of water is used.
- Sampling drums and scrap PCB drums are quickly palletized, labelled and transferred to the incineration area.

2.4.1 Treatment Facility for the Effluent from Sauget Complex

The processing and incineration departments' aqueous effluent enters the plant sewer system, and this system discharges into the Sauget Village waste sewer system. The combined streams then flow to the village primary treatment plant. The village treatment plant is under expansion to a secondary chemical treatment plant, scheduled for 1976 completion.

Additionally, evaluations are being conducted to include the village plant discharge in a projected regional biological treatment plant.

2.5 Plant Effluents

This plant has no point source discharge from their operation. There is a single discharge from the manufacturing operation (the combined stream of process and non-contact cooling water) to the main sewer system of the Sauget complex and there is a second discharge from the incinerator area to the same sewer system. The composition of these streams as reported by Monsanto are as follows:

	Effluent from the Manufacturing Operation	Effluent from the Incineration area
flow rate, gpd	432,000	288,000
PCBs, ppm	0.75	0.15
PCBs, lbs/day	2.70	0.36

NWMAR115767

the resultant line current would virtually eliminate home "plug-ins" and would still further overburden a seriously threatened national power network. Almost all air conditioner pump motors are of the split-winding type on which the capacitor provides phase differential for the so-called start winding, thus delivering good starting torque. The proper size capacitor permits high (90%) power factor after start-up.

E. Industrial Electronics

This market category is a catchall covering many varied applications, two important ones being motor run and power supply applications. Motor run applications are for pumps, fans, and farm feed equipment, and do not differ significantly from air conditioning applications. The power supply market uses capacitors principally to provide high power factor, but through careful design the capacitor can also provide wave shaping where desired.

3.1.1 Askarel Capacitor Manufacturing Plants

There are seventeen companies in the U.S. which manufacture askarel capacitors at nineteen plants. The name and the location of these plants are given in Table 3.1.1-1. Some plants manufacture industrial capacitors only and others manufacture power capacitors.

Ten major companies were contacted. Detailed information was obtained on six plants. Four plants were visited. The data herein represents approximately 50 percent of 1974 PCB usage in capacitor application. The PCB usage in this category was approximately 22,000,000 lbs. in 1974. The PCB usage in individual plants is considered by these companies to be confidential information. The range of PCB usage at these plants was 64,000 fold in 1974. Plant ages range from five to thirty-seven years.

Capacitors used in lighting and air conditioning applications contain 0.05 to 1.0 lbs. of Aroclor. The largest power capacitors contain about 77 lbs. of Aroclor. The most popular size contains 36 lbs. A sketch of a medium size industrial capacitor is shown in Figure 3.1.1-1. Capacitors are not rebuilt and returned to service after failure. They are disposed of and replaced by new units. G.E. reports that high voltage utility capacitors, low voltage

NWMAR115768

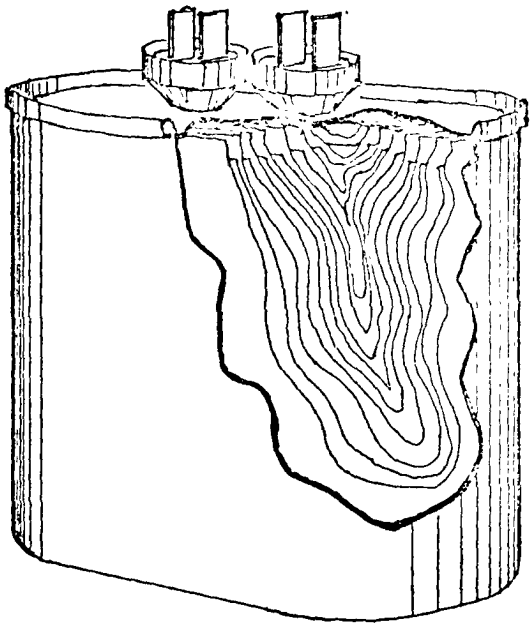


FIGURE 3.1.1-1. MEDIUM SIZE
INDUSTRIAL CAPACITOR

NWMAR11576

Table 3.1.1-1

U.S. Capacitor Manufacturing Industry Using PCBs

Company Name (In order of PCBs Usage)	Location of the Plant
General Electric Company	Hudson Falls, N.Y. Ft. Edward, N.Y.
Westinghouse Electric Corp.	Bloomington, Ind.
Aerovox	New Bedford, Mass.
Universal Manufacturing Corp.	Bridgeport, Conn. Totowa, N.J.
Cornell Dubilier	New Bedford, Mass.
P.R. Mallory & Co., Inc.	Waynesboro, Tenn.
Sangamo Electric Co.	Pickens, S.Carolina
Sprague Electric Co.	North Adams, Mass.
Electric Utility Co.	LaSalle, Ill.
Capacitor Specialists Inc.	Escondido, Calif.
JARD Corp.	Bennington, Vt.
York Electronics	Brooklyn, N.Y.
McGraw-Edison	Greenwood, S. Carolina
RF Interonics	Bayshore, L.I., N.Y.
Axel Electronic, Inc.	Jamaica, N.Y.
Tobe Deutschmann Labs.	Canton, Mass.
Cine-Chrome Lab, Inc.	Palo Alto, Calif.

NWMAR115770

power capacitors, and induction heating capacitors are manufactured at a rate of 200,000 per year, about 2 to 3% of which are replacements; the balance are for new installations. The current market for capacitors used in lighting applications is about 44,000,000 units annually of which 10% are estimated to be replacement ballasts. The current market for capacitors in air conditioning application is above 12,000,000 units annually, with 5% of these estimated to be for replacement usage. The market for capacitors in industrial electronics applications is estimated at 23,000,000 units per year with no estimate as to the relative size of the replacement market.

3.1.1.1 Askarel Handling

In most plants PCBs are shipped via tank car to a rail siding several miles from the plant. Individual plants provide a designated tank truck for the transfer of the PCBs from the rail yard to the manufacturing plant. To large plants, PCBs are brought via rail cars into the plant site.

In most plants PCBs are unloaded and transferred to the PCB storage tank without the benefits of any curbs or dikes. At a very few plants, the unloading operation of the PCBs from the tank car to the storage facility is confined and the receiving area is roofed and diked.

PCBs from the raw storage PCB tanks are filtered through fuller's earth and stored in finished product storage tanks. PCBs are next pumped from the storage tanks to the impregantion areas for use. Excess PCBs from these areas are recycled back to a designated tank and from there either filtered and reused or, if defective, are pumped into the scrap storage tank.

Spent fuller's earth employed at these plants is either drummed and stored at the plant site or is sent to a landfill.

NWMAR115771

It has been reported that these effluents are clear liquids with essentially no suspended solids. The incinerator effluent may contain some amounts of chloride. However, no information is available on the chloride content.

3.0 PCB USER INDUSTRIES

3.1 Askarel Capacitor Manufacturing Industry

Presently 90-95 percent of all impregnated capacitors manufactured in the U.S. are of the PCB type. Two important types of capacitors are phase correctors on power lines and ballast capacitors for fluorescent lighting. Aroclor 1016 is the principal PCB used in this application; at some plants Aroclor 1242 and 1221 are also being used in limited quantities. The principal types of Aroclor impregnated capacitors and their applications are given below.

A. High Voltage Power

Generally AC capacitors are used to improve the power factor of a circuit. Power factor is the ratio of true power in watts to the apparent power as obtained by multiplying the current flowing to the load by the circuit voltage. The power factor correction can be made directly at the load or at utility substations. In the latter case high voltage units will be designed for 4,800 to 13,800 volt service. To the utility engineer the use of capacitors is purely a matter of economics. The main benefits that result from the use of capacitors are:

1. Reduction of losses associated with the delivery of electrical power to the point of use.
2. Reduction of the investment required in equipment for delivering electrical power to the point of use, which may be broken down into:
   a. Reduction of line current for the same kilowatt load.
   b. Reduction of the kva rating of equipment required to handle the same kilowatt load.

NWMAR115772

c. Reduction of the transmission line voltage drop for a given kilowatt load.

d. Control of delivered voltage if the capacitor kva is varied.

Electric utilities also use capacitor banks in series with distribution circuits to improve voltage regulation.

B. Low Voltage Power

Capacitors installed in industrial plants at the demand site (typically large motors and welders) are designed for 230 to 575-volt service. Capacitors installed near the loads are the most efficient way to supply the magnetizing current to produce the flux necessary for the operation of inductive devices. Rates for the sale of power are generally structured to encourage power factor correction at the site, eliminating the need for the electric utility to transmit both power-producing current and magnetizing current all the way from the generator to the plant site.

The same considerations apply to induction heating applications, the principal difference being that capacitors for this application are designed for operation at 960 to 9600 Hz.

C. Lighting

Capacitors improve the efficiency of lighting systems. A fluorescent or mercury vapor lamp can be ballasted without the use of a capacitor, but the power factor of the lighting system would then be in the range of 50 to 60%. For commercial or industrial lighting with either fluorescent or high intensity discharge lamps, the use of a capacitor in the circuit provides part of the lamp ballasting and brings system power factor into the range of 90 to 95%.

D. Air Conditioning

As in the lighting applications, the capacitor improves system efficiency. Air conditioners could be made to operate without capacitors, as do home refrigerators, but because of the higher capacity required for air conditioners,

NWMAR115773

3.1.1.2 Process Description

Most plants in this category manufacture either large power capacitors or small (including less than 2 lbs. of PCBs) industrial type units. The large capacitors are either flood filled or manifold filled. All small capacitors are flood filled either in a vacuum tank or in an automatic "carousel" arrangement where loading and unloading occurs at one station, and the capacitors in each cell are progressively dried, evacuated and filled.

A generalized schematic flow diagram for the manufacture of large capacitors and small industrial capacitors are given in Figures 3.1.1.2-1 and 3.1.1.2-2, respectively. The basic manufacturing operation at these plants can be divided into two major operations.

a) Non PCB related operations consist of the following steps:

- Fabrication of capacitor cans, covers and brackets from sheet aluminum or steel. Smaller plants, however, purchase capacitor casings, capacitor terminals, connectors and foil.
- Vapor degreasing or detergent washing of metal components. At some plants, ultrasonic cleaning is used to clean smaller components.
- Roll winding the capacitor paper or polypropylene film with aluminum foil.
- Complete assembly of capacitor components and sealing the covers. In some units fill holes are provided for PCB introduction; in others PCBs are introduced through bushings or a valve.
- Leak testing via mass spectrometer and pressure testing prior to vacuum drying.

b) PCB related operations

Three completely different impregnating techniques are employed by this industry.

NWMAR115774

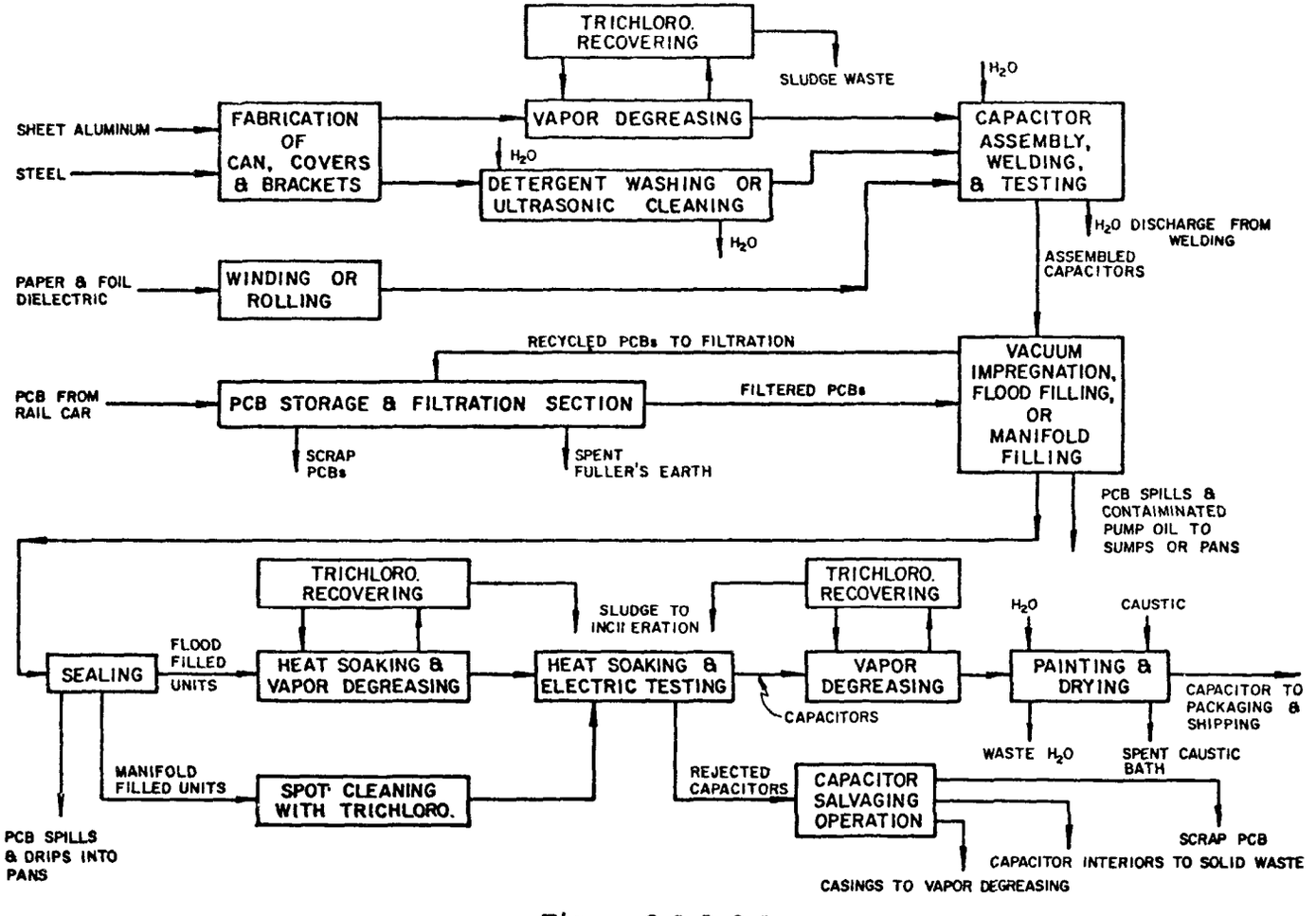


Figure 3.1.1.2-1

GENERALIZED FLOW DIAGRAM FOR THE MANUFACTURING OF LARGE CAPACITORS

NWMAR1157755

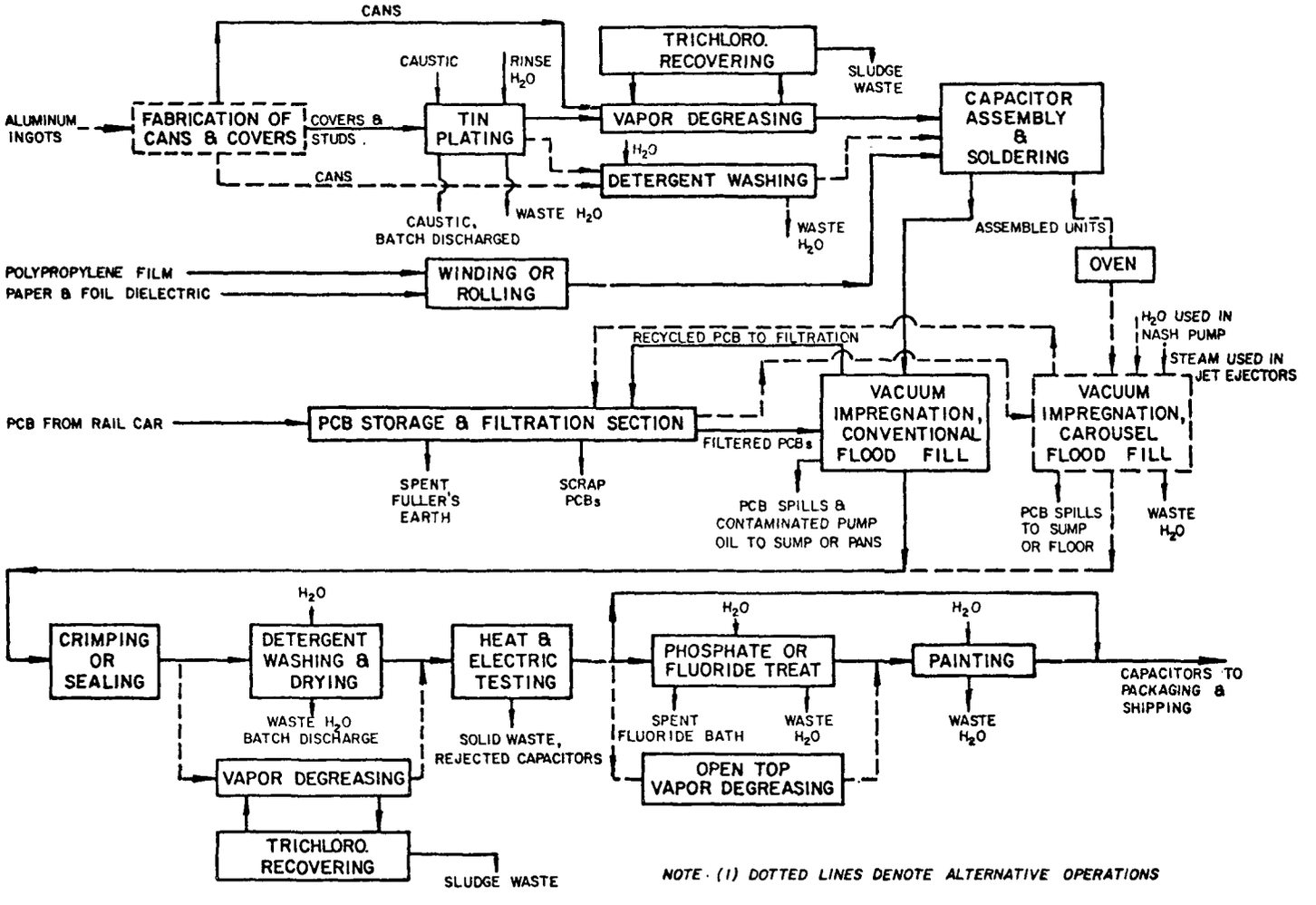


Figure 3.1.1.2-2
GENERALIZED FLOW DIAGRAM FOR THE MANUFACTURING OF SMALL CAPACITORS

NWMAR115776

(1) Conventional flood filling of capacitors

This type of filling operation is used for impregnating large power and small industrial capacitors. Here the capacitors are arranged in baskets or in large tanks which are subsequently transferred into vacuum chambers. Vacuum is then drawn and the capacitors are kept under vacuum at an elevated temperature for a specific period of time in order to evaporate the moisture from the capacitor interiors. The temperature of the tank is next lowered and PCBs are introduced under vacuum. The capacitors are allowed to soak for some time after which they are transferred to the sealing or crimping station via mobile car, sealed, and excess PCBs are then drained. The sealed capacitors are next sent to vapor degreasing or detergent washing for cleaning the exterior of these units. The clean units are heat soaked and heat tested in an oven and then sent to 100% electrical testing.

Subsequent to electric testing, the capacitors with steel casings are pretreated prior to painting. The pretreatment is either vapor degreasing for painting in an electro-static field or it is several stages of phosphatizing and rinsing operations, prior to automatic spray painting, where water is used to scrub the vapors generated during painting. Most capacitors with aluminum casings are marketed unpainted. However, at some plants a portion of capacitors with aluminum casings are fluoride treated and then spray painted. The capacitors are next either air dried or dried in an infrared oven prior to packaging and shipping.

(2) Automatic Flood Filling Operation (Carousel)

In this method of capacitor impregnation, the assembled units are placed in ovens for the removal of moisture from the capacitor interiors. The baskets containing these capacitors are next transferred to the carousel chamber which is at the loading position. The carousel passes through 13 subsequent cycles consisting of

NWMAR115777

various degrees of vacuum applications and then subsequent PCB filling and soaking positions. The PCBs are next drained out of the chamber, and the capacitor baskets are removed from the vacuum chamber and tilted to drain excess PCBs into a sump located adjacent to the carousel loading and unloading station. The capacitors are next transferred to the crimping or sealing stations. From this point on the remainder of the manufacturing steps are identical to those employed in conventional flood filling operation.

In general, vacuum in conventional flood filling operations is achieved via mechanical pumps, whereas vacuum in each automatic flood filling station is achieved via a vacuum pump and several stages of steam jet ejectors.

Rejected industrial capacitors are disposed of in 55 gallon drums either directly or after disecting. Rejected power capacitors which are flood filled are returned to the salvaging operation. Here the capacitor covers are cut on an end mill, the PCBs drained and the interiors examined to find the cause of the electrical failure. Where possible the rejected units are then repaired and reprocessed. Otherwise, the capacitor interior is discarded in a designated solid waste drum. The capacitor casing is sent to vapor degreasing and it is subsequently sold to a scrap dealer.

(3) Manifold Filling Operation

At some plants, large capacitors are filled by this method. Here, the capacitors are completely assembled, sealed and vacuum tested; then each unit is filled individually under vacuum through a manifold. The capacitor valve is next sealed, the exteriors spot cleaned with trichloroethylene and then these units are transferred into an oven where they are heat soaked for a given period of time prior to electrical testing. Those capacitors which pass the electrical tests successfully are vapor degreased, painted, dried, packaged and shipped. The rejects are returned to the filling station where

NWMAR115778

the majority of the PCBs are retrieved through the fill valve under vacuum. The rejects are next transferred to the salvage operation.

Mechanical pumps are used throughout the system to achieve vacuum.

3.1.1.3 Raw Wastes

The raw wastes originating from these plants consist of scrap PCBs collected in sumps, drums and drip pans, contaminated vacuum pump oils, the fractionator bottoms from the trichloroethylene recovery, the caustic bath used, at some plants, for purposes of paint stripping, spent detergent wash and rinse water from capacitor or component cleaning operations, rinse water used in the welding and plating operations, steam condensate from jet ejectors, the seal water used in vacuum pumps, water used in phosphatizing and fluoride baths, water spray used in the paint booths, boiler blow downs and cooling tower blow downs.

Furthermore, in at least one plant in this category, water infiltrating at a subgrade elevator shaft creates an additional waste stream.

Solid wastes from these plants consists of scrap capacitors or capacitor interiors, floor dry and rags and newspapers used for cleaning spills, spent fuller's earth and other filtering media used for PCBs filtration and waterless cleaners used at some plants for hand cleaning purposes.

Non-product PCB discharges, their source and disposition are given in Table 3.1.1.3-1. Adequate data to quantify the various wastes generated at these plants is not available. Information on waste loads reported by some plants are given in Table 3.1.1.3-2.

3.1.1.4 Water Use

The water used at these plants is in the range of 12,500 to 1,260,000 gallons per day. In most plants, water is used primarily for once-through non-contact cooling in vapor degreasers, in pumps and in vacuum tanks. Plant 101 recycles their non-contact cooling water through a cooling tower.

NWMAR115779

TABLE 3.1.1.3-1. NON-PRODUCT PCB DISCHARGES

Source	Plants 100	101	102	104	105	106
Vacuum pump exhaust	Air	Air	Air	Air	Air	Air
Evaporation & ventilation	Air	Air	Air	Air	Air	Air
Vapors from last stage of jet ejectors	None	None	None	None	Air	None
Personal hygiene	Sewer	Sewer	Septic tank	Incineration[1]	Incineration[1]	Sewer
Laundry water	None	None	Septic tank	None	None	None
Water phase from pump oil/water separator	Sewer	None	None	None	None	None
Sanitary & domestic water	Sewer	Sewer	Septic tank	Sewer	Septic tank leach field system	Sewer
PCB contaminated water	River	-	Treatment plant then river	River	River	Sewer
Non-contact cooling water	River	Recycled	Treatment plant then river	River	River	Sewer
Rainfall & surface runoff	River	Storm sewer	Treatment plant then river	River	River	Storm Sewer
Rinse water from component detergent washing	None	Dry well	None	River[2]	None	None
Water used in non-PCB electrolytic capacitor operations	None	None	Treatment plant then river	None	None	None
Ground water infiltration	None	None	None	Decant then to river	None	None
Controlled sink drains[3]	None	Sewer	None	River	River	None
Rinse water used in the caustic bath & welding	None	None	None	River	None	None
Water used in paint scrubbing	None	None	None	Decant then to river	River	None
Phosphatizing bath & rinse	None	None	None	None	River	None
Scrap oil in drip pans, drums & sumps	Incineration	Incineration	Incineration	Incineration	Incineration	Incineration
Spent fuller's earth, clay & filter cartridge	Incineration	None	Incineration	Stored on site	Stored on site	Landfill
Rinse water from dry-well	None	Incineration	None	None	None	None
Fractionator bottoms (sludge) from trichloro recovery	Incineration	None	Incineration[4]	Incineration	Incineration	Incineration
Spent detergent wash of capacitor exteriors	None	Landfill	None	None	Incineration	None
Spent fluoride wash	None	None	None	None	Incineration	None
Reject capacitors or capacitor internals	Landfill	Landfill	Landfill	Stored on site	Stored on site	Landfill
Newspaper, floor dry & rags	Landfill	Landfill	Landfill	Stored on site	Stored on site	Landfill
Caustic bath	None	None	None	Stored on site	None	None

Notes: [1]Sinks at the impregnation areas are contained; water from the sumps are sent to incineration.
[2]Rinse water from non-PCB, component washing operation.
[3]Employees are advised to use waterless hand cleaning material prior to washing their hands.
[4]Only liquids from this operation are sent to incineration. The sludge from this operation is sent to a municipal landfill.

NWMAR115780

TABLE 3.1.1.3-2 QUANTITY OF WASTE LOADS
(lbs/ton of PCB used)

	Plants					
	100	101	102	104	105	106
Land Destined Waste	73 (1)	129	65	- (4)	- (4)	- (5)
Wastes to Incineration	100	56	98	109	127	300
Spent Fuller's Earth to Incineration	4.1	None (2)	- (3)	-	-	Unknown

Notes:

(1) Reported as PCBs. We estimate an additional 175 lbs/ton of PCB contaminated solid material which is being landfilled locally.

(2) PCBs are filtered through packed Porocell cylindrical filters. The filter media has an estimated life cycle of 20 years.

(3) This plant uses clay for PCB filtration. The quantity of spent clay sent to incineration is not known.

(4) These plants store their solid wastes consisting of spent fuller's earth, rejected capacitors, rags and floor dry, on site. Plant 104 generates ten 55-gallon drums of waste and plant 105 forty 55-gallon drums of waste each week.

(5) The weight of materials sent to landfill is not known. However, this company reports that during 1974 approximately 650 capacitors were rejected. The rejected units were drained and then sent to a landfill.

NWMAR115781

Process water used at various plants consists of water used in detergent washing, in ultrasonic washing, condensate from the steam jet ejectors, seal water from the vacuum pumps, water used in phosphatizing and in fluoride baths and rinses, and water used in caustic treatment and painting operations. Additionally, water is used for sanitary purposes and in some plants it is also used as boiler feed.

The quantities and types of water used at these plants are given below:

	Plants					
	100	101	102	104	105	106
Intake gallons/day	740,000	12,500	1,000,000[1]	1,260,000	480,000	336,500
Water Usage in gallons/day						
Non-contact cooling	655,000	3,000[2]	388,000[3]	1,195,000	387,000	326,500
Process water						
Rinse water from hot solder dip	200	-	-	-	-	-
Detergent washing & rinsing	-	8,000	-	25,000[4]	200	-
Phosphatizing baths	-	-	-	-	400	5,000
Water used in tin plating	-	-	-	-	12,000	-
Fluoride bath & rinse	-	-	-	-	50	-
Water used in painting					50	-
Pump seal water & steam condensate					44,000	-
Sanitary	44,900	1,500	52,000	10,000	65,000	5,000
Boiler feed make-up	40,000	-	-	30,000	15,000	-

Notes: (1) 560,000 gallons/day of this water is used as process rinse water in non PCB associated, electrolytic capacitor operation
(2) Make-up water
(3) It has been estimated that only 150,000 gallons of this water is associated with the plants PCB operation. The balance is used in the manufacture of Mica capacitors
(4) It includes water used in paint stripping and welding operations.

NWMAR115782

3.1.1.5 Wastewater Treatment

The major in-plant PCB wastes which reach water streams originate in the impregnation areas. Due to the nature of water requirements in this industry, at some plants it is possible to significantly reduce the quantities of wastes entering the water systems by adoption of proper housekeeping measures. Since there is no demonstrated technology available for the terminal treatment of PCBs in wastewaters, there are no PCB wastewater treatment techniques currently in use at any facility. Details on wastewater treatment techniques used at various facilities for purposes of oil recovery or neutralization and on-going containment programs undertaken by some plants to prevent the entry of PCBs into the environment are given in Task II report, "Assessment of Wastewater Management, Treatment Technology, and Associated Cost for Abatement of PCBs Concentrations in Industrial Effluent", February 3, 1976, pages 46 through 52.

3.1.1.6 Effluent Composition

Effluent from plants in this category range from 2500 to 1,260,000 gallons per day. As indicated in the waste treatment section, these effluents are sent either into receiving waterways or into municipal sewers without any PCB treatment. Available information on effluent flow rates and their PCB contents, for most plants in this category, are given in Table 3.1.1.6-1. More detailed effluent information were obtained on four plants and Table 3.1.1.6-2 compares the discharges from these plants. Table 3.1.1.6-3 lists PCB concentration of the plant intake water from various sources.

It is of interest to note that one plant (plant 100) reported large variations in the PCB content of the receiving waters even at the time when the plant was not in operation. They attributed the variations to storm conditions, stirring-up the sediments from the bottom of the river and greatly increasing the PCB concentration in the water phase.

NWMAR115783

TABLE 3.1.1.6-1 RANGE OF FLOW RATES & PCB CONCENTRATION IN EFFLUENTS FROM CAPACITOR MANUFACTURING PLANTS

Plant No.	Outfalls	Effluent Flow Rate gal/day	Effluent PCB Content ppb avg/max	Effluent PCB Content lbs/day avg/max	Disposition of effluent
100	001	800,000	17/55	0.1134/0.3670	River
101	None	9,000	161/161	0.0121/0.0121	Sewer
102	001	807,000	9	0.0605	River
	002	165,000	3.2	0.0044	River
	003	36,000	3.4	0.0010	River
104	Major outfall	1,060,000	21	0.1856	River
	Cooling water & roof drains	100,000	7.8	0.0065	River
	Lab & roof drains	32,000	4.4	0.0011	River
	Compressor cooling water	72,000	3.7	0.0022	River
	Paint strip rinse	50	4800	0.0002	River
105	Major outfall	650,000	370	2.0058	River
	From spray paint booths	1,500[1]	13,300	0.1664	River
106	None	336,500	26.6	0.075	Sewer
107	None	150,000	1900/4000	2.3769/5.7546	Sewers
108	Cooling water & boiler blowdown	48,000	45/108	0.0180/0.0432	River
	Cooling water	129,000[2]	338/705	0.3636/0.7585	Sewer
	Roof runoff	2,900	1360/2370	0.3290/0.0573	River
	Storm runoff	unknown	3/11	- -	River
109	001	100,000	57/83	0.0475/0.0692	River
110	None	2,570	821	0.0176	Sewer
111[3]	None	18,000	8.7	0.0013	Sewer
112[3]	None	10,224	130	0.0110	Sewer
113	001	12,000	14.3	0.0014	River
126	None	580	6200[3]	0.03	Sewer

Notes: (1) Discharged once every 4-5 weeks.
(2) Contains 10,000 gpd sanitary sewage and 8000 gpd of surface water infiltration
(3) These facilities recycle most of the non-contact cooling water used at the plant. These effluents consist of a small fraction of the cooling water plus their sanitary discharge.

NWMAR115784

TABLE 3.1.1.6-2

Comparison of Discharges

Plant	100	102			104				105
Outfall	001	001	002	003	002	003A	003B	006	004
pH	7.3	7.4	7.3	7.2	6.5-12.0	5.5-9.8	4.0-9.1	6.8-11.6	5.5-8.6
TSS, mg/l	3	16.6	1.54	2.8	5.2	4.7	4.0	3.1	9.5
PCB, ppb	17	9	3.2	3.4	21	7.8	4.4	3.7	370
Oil & Grease, mg/l	UK	3.10	3.38	2.18	7.20	14.40	30.70	2.66	12.8
Aluminum, mg/l	UK	ND	ND	ND	0.15	0.06	0.11	2.0	
Lead, mg/l	<.05	UK	UK	UK	UK	UK	UK	UK	UK
Copper, mg/l	<.003	UK	UK	UK	0.03	0.02	0.04	0.03	UK
Chromium, mg/l	<.005	UK	UK	UK	0.003	ND	ND	ND	0.03
Phenols, mg/l	<.001	UK	UK	UK	UK	UK	UK	UK	UK
Iron, mg/l	<.19	UK	UK	UK	0.29	0.30	0.34	1.66	0.52
BOD, mg/l		4.37	2.45	1.7	UK	UK	UK	UK	UK

ND - Non detectable
UK - Unknown

NWMAR115785

Table 3.1.1.6-3

Intake Water PCB Concentration

Plant	100	101	104	105	106	111	112
Source	Municipal	Municipal	River	Well Water	Municipal	Municipal	Municipal
PCB, ppb	0.09-2.5	4-7	57.0	40.0	0.25	1.0	1.0

NWMAR115786

3.2 Askarel Transformer Manufacturing Industry

All plants in this category manufacture transformers using mineral oil as the dielectric fluid. This dielectric fluid is the principal impregnant used at these facilities. PCB transformer oils (blends of 60 to 70 percent Aroclor 1254 or 1242 and 40 to 30 percent trichlorobenzene) are used in only 5-10 percent of these plants' manufacturing volume.

In general, a transformer consists of a core and coil immersed in a dielectric fluid. There are two broad classifications of transformers: distribution transformers, which are used to step down voltages, and power transformers, which are used primarily to step up voltages. The precipitation power supply units can be actually classified as a third class of askarel transformer. However, the larger plants in this category have only two manufacturing departments — distribution and power; and they manufacture the precipitator transformers in their distribution transformer department. The following types of askarel transformers are manufactured at these plants:

A. Askarel Distribution Transformers

1. Network (Receive up to 14,400 volts and deliver 120, 240 and 480 volts)
2. Pad - mounted (Receive up to 14,400 volts and deliver 120, 240 and 480 volts)
3. Pole - mounted (Receive up to 14,400 volts and deliver 120, 240 and 480 volts) The application of these transformers in power distribution systems places a great premium upon their reliability and high overload capability.
4. Precipitator power supply (Receive 480 AC volts and deliver 50-60 kilovolts low amperage DC) These units are generally installed close to hot gas stacks in an atmosphere that would be a fire hazard to oil-insulated transformers and a corrosive hazard to open dry-type transformers. Sealed dry-type transformers are impractical for high-voltage DC.

NWMAR115787

Voltages listed cover the majority of askarel distribution transformers. Product scope includes up to 34,500 primary volts and virtually any secondary voltage, 34,500 and below.

Quantities of askarel used in this class of transformers are in the range of 500 to 5,000 lbs. in each unit depending on the rating and the size of the transformer.

A great majority of distribution type transformers have provision for venting. Many of these units are equipped with spring loaded venting devices which vent upon a pressure excursion, and diaphragm rupture discs are offered as a customer option.

B. Askarel Power Transformers

1. Secondary substation
   (a) Load center units
   (b) Secondary substation generation units
   (c) Switchboard units
   (d) Internal units
   (e) Motor control units

   These 5 comprise the largest group of askarel-insulated transformers and they find widespread application in the automobile, paper, chemical, textile, steel, nonferrous metal, cement, mining and petroleum industries. They are used in commercial and public buildings, such as schools and hospitals; in defense and nuclear energy installations; and by private and public utilities.
2. Master unit substation
3. Primary unit substation
4. Limited ampere substation
5. Industrial furnace

NWMAR115788

Furnace transformers used in the hot, dirty atmosphere in proximity to glass melting and induction furnaces, which require high current, low voltage power supplies (receive up to 15,000 volts and contain 2000 to 4000 lbs. of askarel each). Existing technology does not permit construction of sealed dry-type transformers for these power ratings.

6. Rectifier

Rectifier transformers used for large rolling mills and DC industrial power supplies (receive up to 15,000 volts AC and deliver low voltage high amperage DC. Each unit contains about 19,000 lbs. of askarel). These units are covered by the same comments given for industrial furnace transformers.

7. Transportation

Railroad transformers used on-board in electric locomotives or multiple unit electric railroad cars (receive up to 25,000 volts and contain 700 to 2400 lbs. of askarel in each unit depending on the rating and size of the transformers).

(a) Third rail

These transformers are used for rapid transit systems, and are basically serving a rectifier function

(b) Locomotive

Prior to 1932, all on-board transformers were open dry type. Because of problems with them, railroads went to askarel-insulated transformers. The changes in locomotive design since the 1930's would not now accomodate open dry-type transformers as replacements for askarel units. A recent trend has been to replace askarel by oil units, and this will continue unless new Department of Transportation regulations require nonflammability.

NWMAR115789

However, since a tunnel fire in 1940 caused by an oil filled locomotive transformer, Penn Central will not allow any oil containing transformer equipped locomotive into New York City.

(c) Multiple-unit car (MU)

These transformers are mounted under the flat-bed of passenger cars. They ride along in this location, about 8 inches above the rail, at speeds up to 150 mph. The transformer must be ruggedly built to withstand the impact of flying debris and constant vibration. Power to the cars is brought in through an overhead catenary and is fed to the underside of the car where the transformer, controls, and propulsion equipment are located.

Space and weight are critical in this application. There are only about 33 inches above the rail. The width of the transformer is limited by the width of the car.

Only oil- or askarel-insulated units would provide the required performance levels in the space available. As with locomotive applications, present Department of Transportation regulations do not restrict the use of flammable liquids, and the use of askarel units has been dictated largely by the economic considerations of fire insurance rates, and by Penn-Central safety regulations.

8. Reactors

These units provide reactance (receive up to 15,000 volts under normal operating conditions. During normal operating conditions, they deliver volts and current as received. During power surges they choke the voltage and deliver the normal output).

9. Grounding,transformers (receive up to 15,000 volts).

NWMAR115790

3.2.1 Transformer Manufacturing Plants

There are thirteen companies in the U.S. which manufacture askarel transformers at eighteen plants. The name and location of these plants are given in Table 3.2.1-1. Some plants manufacture various types of transformers described above and others manufacture only one specific line of transformers.

All plants in this category were contacted to obtain information on their waste water. Detailed information was obtained on two plants which were visited. The largest U.S. transformer plant (based on quantity of PCB use) was not visited because of lack of cooperation. The data base represents approximately 20 percent of the 1974 PCB usage for transformer application. The PCB usage in this category was 12,000,000 lbs. in 1974 (equivalent to 15.0 to 17.0 million lbs. PCB transformer oil). The PCB usage in individual plants is considered by these companies to be confidential information. The range of plant PCB usage was 975 fold in 1974. Plant ages range from three to eighty-five years.

The amount of askarel used in individual transformers ranges from 40 to 1500 gals. (516 to 19,350 lbs.) with an average of about 232 gals. (3,000 lbs.). A sketch of a large substation transformer is shown in Figure 3.2.1-1. G.E. estimates that the total askarel-insulated units that have been put into service in the United States since 1932 is 135,000, and virtually all of these units are still in service. The lifetime-before-failure is often longer than 30 years, and almost all units that do fail are rebuilt and returned to service. The current production rate of askarel transformers is about 5,000 units per year.

3.2.1.1 Askarel Handling

Few plants in this category purchase PCBs and trichlorobenzene and do their own compounding. Most plants purchase pre-compounded askarel from Monsanto. Smaller plants purchase their askarel in 55 gallon drums, filter the askarel and pump directly into the transformer tanks. To large plants askarel is shipped via rail cars. Rail cars enter in a designated area at the plant site. Askarel is then pumped from the rail cars into the raw askarel storage tank. Any spillage in this area is cleaned by rags or floor dry. The raw askarel

NWMAR115791

Table 3.2.1-1

U.S. Transformer Manufacturing Industry Using PCBs

Company Name	Location of the Plant
Westinghouse Electric Corp.	South Boston, Va. Sharon, Pa.
General Electric Company	Rome, Ga. Pittsfield, Mass.
Research-Cottrell	Finderne, N.J.
Niagara Transformer Corp.	Buffalo, N.Y.
Standard Transformer Co.	Warren, Ohio Medford, Oregon
Helena Corp.	Helena, Alabama
Hevi-Duty Electric	Goldsboro, N.C.
Kuhlman Electric Co.	Crystal Springs, Miss.
Electro Engineering Works	San Leandro, Calif.
Envirotech Buell	Lebanon, Pa.
R.E. Uptegraff Mfg. Co.	Scottsdale, Pa.
H.K. Porter	Belmont, Calif. Lynchburg, Va.
Van Tran Electric Co.	Vandalia, Ill. Waco, Texas

NWMAR115792

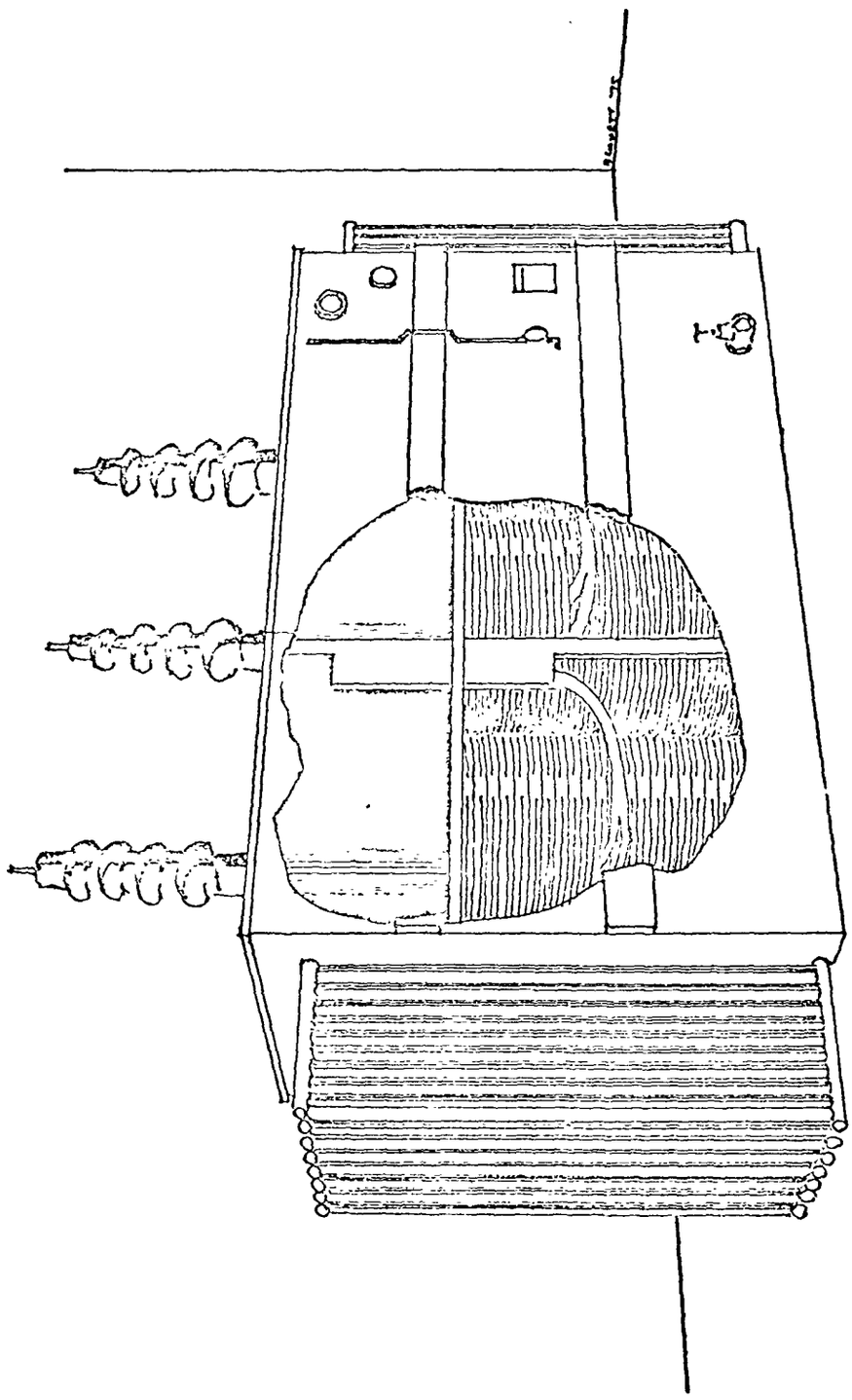


FIGURE 3.2.1-1. SUBSTATION TRANSFORMER

NWMAR115793

is next filtered through attapulgite clay or fuller's earth and is often passed through a plate and frame type filter for final cleaning and then stored in the finished product storage tanks. Spent clay or fuller's earth from this operation is drummed and stored on site or sent to a landfill.

In some plants, the entire storage area is located within dikes and curbs designed to contain at least the contents of the largest single tank plus sufficient free board to allow for precipitation.

At most plants the askarel is distributed from the tank farm area to the filling station, but at one plant (Plant 103) the finished askarel is next trucked from a covered/curbed storage area to an uncovered/bermed tank farm area. Here the truck enters a shelter area, and the askarel is then pumped from the truck into distribution storage tank.

Recycled askarel from the manufacturing operations is generally returned through pumps into a storage tank or into 55 gallon drums and from there it is either filtered for reuse or is sent to incineration if it is proved to be defective.

3.2.1.2 Process Description

Most plants manufacture all the hardware and components necessary for the transformer assembly. The transformer interiors and the containers are brought to the askarel filling stations where transformers are assembled, filled and sealed.

The filling operation is done in a designated station. At plants where small quantities of askarel are handled, spills and drips are cleaned via floor dry or rags. At plants where large quantities of askarel are handled, filling operation is conducted on gratings located on sumps. All drainage is directed into these sumps. The sumps are inspected and cleaned periodically. All scrap askarel from sumps is pumped into drums and sent to incineration.

Various transformer assembling and filling procedures are being practiced throughout this industry. In general, all transformer assembling and filling operations consist of a predrying step for removing moisture

NWMAR115794

from the transformer interiors, several stages of askarel filling and askarel topping, addition of electrical connections and bushings, electrical testing and sealing.

At plants where relatively small quantities of askarel are used, the assembly and filling procedure for distribution and power transformers are alike. Some plants manufacture only a given size of transformers (single tank size operations). At larger plants different assembling and askarel filling procedures are employed for various transformer subcategories. Some of the askarel transformer assembling and filling procedures practiced within this industry are described below.

3.2.1.2.1 Assembly and Askarel Filling Procedure for the Distribution and Power Transformers

A. Vapor Phase Drying Prior to Filling

This procedure is primarily used in the filling of network and pad-mounted transformers. The drying of the transformer internals is a vapor phase treatment with a kerosene-like petroleum distillate. A schematic flow diagram depicting this system is given in Figure 3.2.1.2.1-1. The assembling steps for these transformers include the following:

- First the transformer interiors are placed in large vacuum chambers heated with steam coils. The petroleum liquid is admitted, vacuum and heat are applied. The petroleum vapors rise to be condensed on the interiors, exchanging latent heat for sensible heat and raising the temperature of the interiors. After a specific time the liquid is pumped out; vacuum and heat are continued to dry the internals.
- The internals are next removed and placed in their own containers and flushed with askarel at atmospheric pressure. The askarel is kept in the tank until the liquid temperature is lowered to a preset level at which time it is pumped out of the tank. The purpose of askarel flushing is to chill the transformer interiors prior to final filling.

NWMAR115795

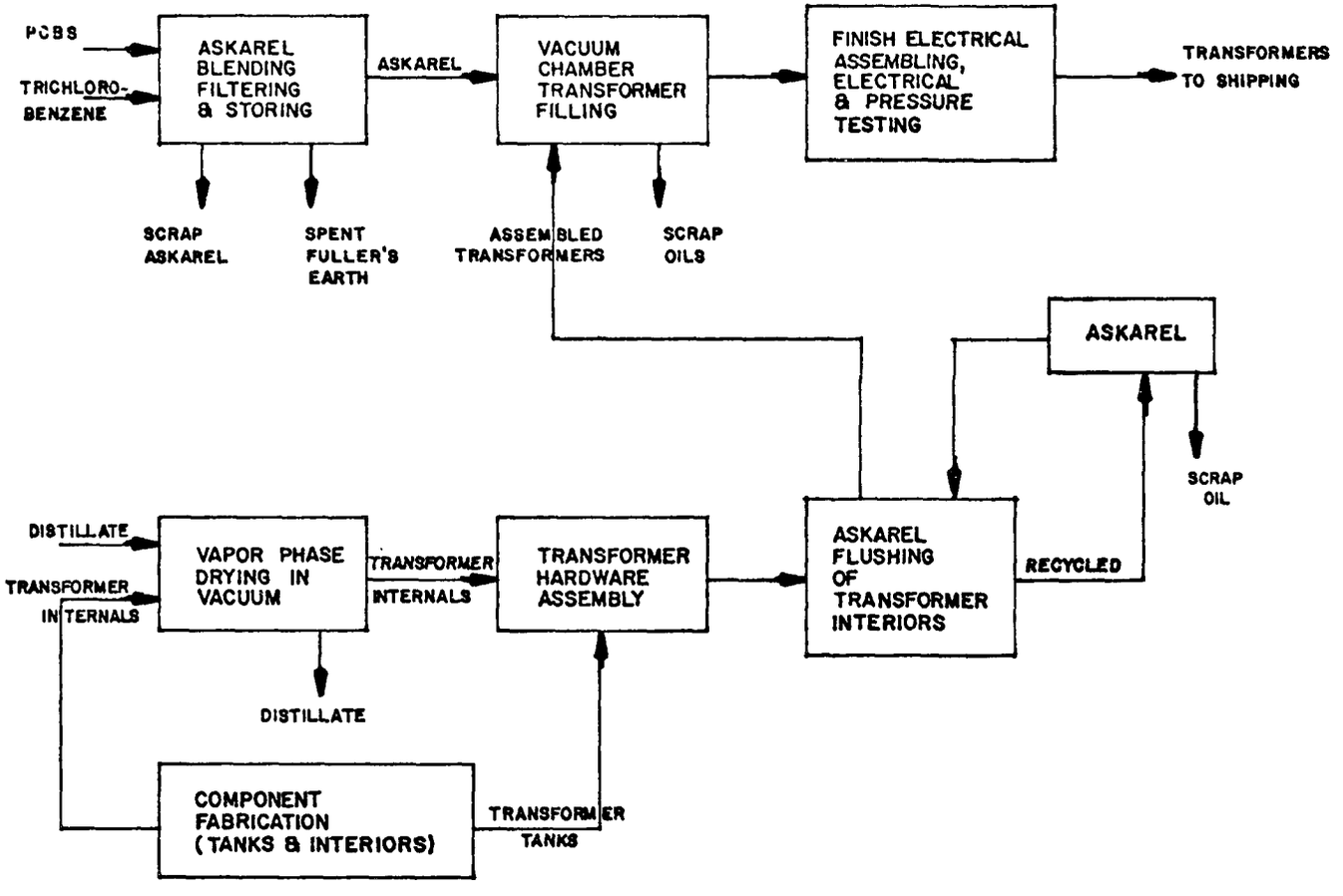


Figure 3.2.1.2.1-1
TRANSFORMER FILLING WITH VAPOR PHASE PREDRYING OF INTERIORS

NWMAR115796

- The tank is next placed in a designated vacuum chamber. Vacuum is drawn and then fresh askarel is metered in slowly to avoid foaming or flooding.
- The vacuum chamber is next opened, the electrical connections are made and the liquid level in the tank is then brought to the operating level at atmospheric pressure. The transformer tank is then crane lifted and lowered onto conveyors and sent to specified test stations for a series of electrical tests before the transformer is completely sealed.
- If a transformer fails the electrical tests, it is returned; the askarel is drained and reprocessed. Otherwise, the transformer is sent to cover welding operations.
- The tank is next lifted and sent back via conveyor belts to the filling station where it is topped with askarel through an access overhead pipe. The transformer is next pressure tested for leaks. The bottom drain valve is then sealed and the top opening is pipe fitted and sealed. Sealing is accomplished primarily by teflon tape. However, for some transformers, the sealing is done by an air cured sealant at customer's request.

B. Oven Drying of Transformer Internals Prior to Filling

This procedure is used primarily in the assembly of pole type or precipitator transformers. The drying of internals for this category of transformers is accomplished in a convection oven. The internals are then placed in their own casings and the bushings and electrical connections are next made. Vacuum is then applied via a mechanical pump and the tank is filled with askarel while the transformer internals are still at a predetermined elevated temperature. Exhausts from this operation are pulled through a venting system.

NWMAR115797

Most transformers in this subcategory have gasketed covers with barrel band type connections. Subsequent to the filling operation, the transformers are sealed and pressure tested for leaks. The large units are liquid pressure tested while the smaller ones are air pressure tested. A schematic flow diagram depicting this system is shown in Figure 3.2.1.2.1-2.

The contaminated oil from the vacuum pump is treated as waste askarel and is sent to incineration.

C. Oven Drying of Assembled Units Prior to the Filling

This procedure is used primarily in the assembly of the precipitator transformers. Here the transformer internals are placed in their own casings, the covers are welded on the casings and the assembled tank is placed in the convection oven all sealed. At an elevated temperature, vacuum is applied at predetermined intervals. The tank is then transferred to the filling station where askarel is added through an upper pipe opening under vacuum. Both the top piping and the drain valve are next sealed and the unit is then pressure tested. A schematic flow diagram depicting this system is shown in Figure 3.2.1.2.1-3.

D. Procedure for Assembling the Askarel Filled Power Transformers

The same procedure is used to assemble all types of askarel filled power transformers. The transformer internals are dried in sealed vacuum tanks, then they are placed in their own containers and the cover is welded and sealed. The unit is then pressurized and checked for leaks by a helium detector. The tank is next transferred to the filling station where low vacuum is drawn for a period of 24 hours. The askarel line is then connected and the tank is filled slowly while under vacuum up to the operating level. The unit is then sealed and sent to electrical testing. After the tests the transformer is returned back to the filling station where it is nitrogen pressure tested just prior to shipping. The schematic flow diagram depicting this system is shown in Figure 3.2.1.2.1-2.

NWMAR115798

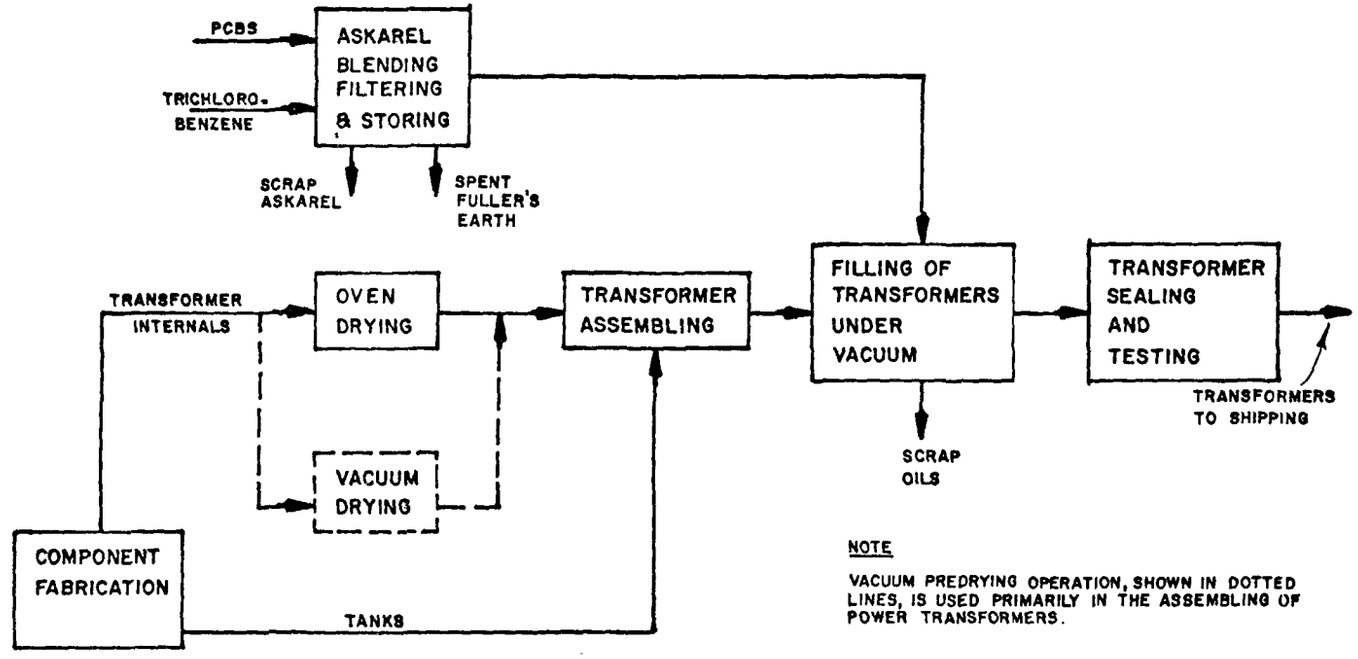


Figure 3.2.1.2.1-2
TRANSFORMER FILLING WITH OVEN OR VACUUM CHAMBER PREDRYING OF TRANSFORMER INTERNALS

NWMAR1157999

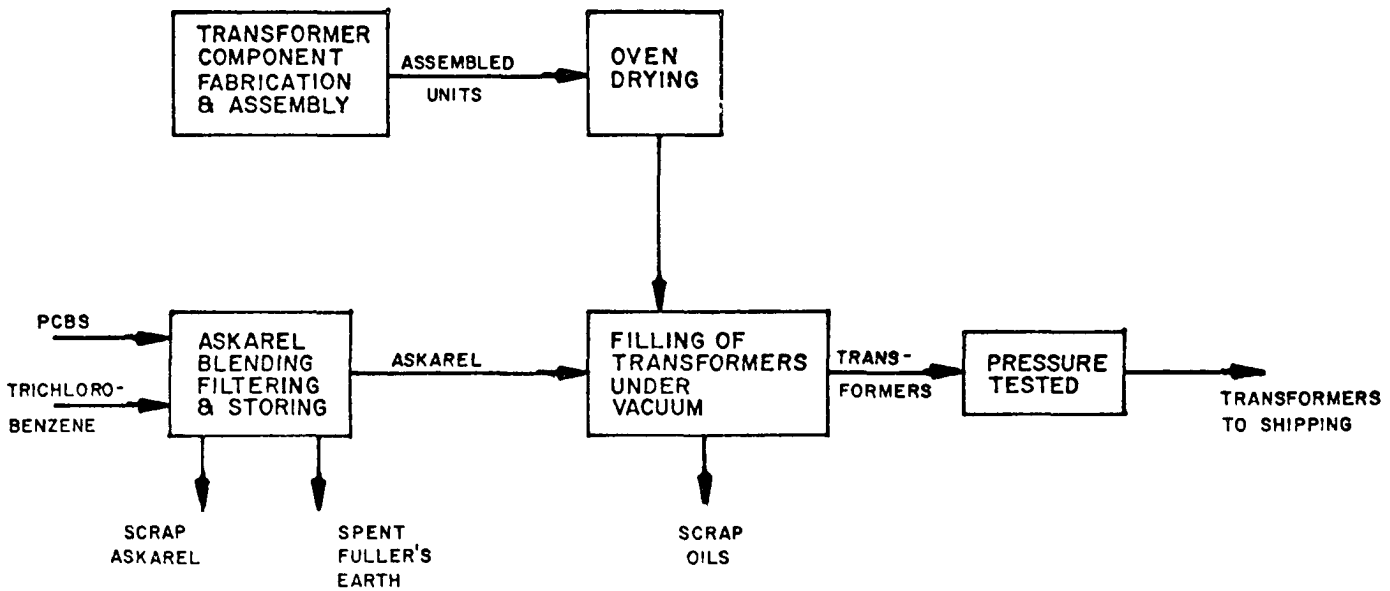


Figure 3.2.1.2.1-3
TRANSFORMER FILLING OPERATION WITH OVEN PREDRYING OF ASSEMBLED HARDWARE

NWMAR115800

All power transformers have air space on the top and are equipped with an air cooled circulation system. Additionally, each unit has a spring loaded relief valve as standard equipment. These transformers have a greater potential for environmental contamination through the vent system, via leaks on the pump and the valves.

3.2.1.3 Raw Wastes

In general, the process raw wastes from these plants consist of waste askarel collected in sumps or pans at the filling stations, contaminated vacuum pump seal oil, contaminated kerosene-like petroleum distillate (used in at least one plant in the vapor phase drying operation), contaminated askarel used for transformer interior flushing and contaminants in the plant effluent.

Additionally, plant 103 has a unique waste stream consisting of contaminated ground water which is being pumped from three caissons at the plant site. Plant 103 also has a bleedwater discharge from their incineration system.

Solid wastes from these plants consist of rags and floor dry used for miscellaneous cleaning purposes and spent clay used for Aroclor filtration. Additionally, at plant 103 it includes the sludge from oil/water separators.

Non-product PCB discharges are shown in Table 3.2.1.3-1. Estimates on the quantities of raw waste generated in two plants which were visited are given below.

	Plants	
Quantities of Waste Loads	103	114
Wastes to incineration, lbs/ton of PCB used	115	98.0
Solid waste material stored on site in 55 gallon drums	135 units	Unknown

3.2.1.4 Water Use

Water is not an essential component of the transformer manufacturing process. PCB wastes which reach water streams at these plants are due to inadvertent occasional loss during handling and residuals accumulated

NWMAR115801

TABLE 3.2.1.3-1

NON-PRODUCT PCB DISCHARGES

Source	103	114
Plant exhaust	Air	Air
Incinerator exhaust	Air	None
Personal hygiene and sanitary water	Sewer	Sewer
Ground water pumped through caissons	To oil separators then river	None
Water used at plant	To oil separators then river	Sewer/river
Contaminated oils and waste PCBs	incineration	Incineration
Floor sweepings and rags used for cleaning	decapsulator	Incineration
Rejected transformer interiors for copper recovery	decapsulator	Stored on site
Contaminated and defective empty drums	To steel furnace in steel mill	Shipped to the company which handles their contaminated oils
Sludge from the oil separator	Stored on site	None
Clay used for askarel filtration	Stored on site	None

NWMAR115802

around the drainage systems from past operations when no precautions were taken in handling and disposal of PCBs.

This category uses water primarily for non-contact cooling purposes in vacuum pumps, compressors and at some plants as contact cooling in their welding and plating operations and in phosphatizing of the steel surfaces prior to painting. All contact cooling operations listed above are primarily non-PCB related operations. Only plant 103 has a PCB related process water which consists of the water used in their waste incineration system for quenching the hot gases from the reaction section. Plant 103 is also the major water user in this category.

In most smaller plants all cooling is accomplished by air. At these plants water is primarily used for hygiene and sanitary purposes and for occasional compressor or pump cooling purposes. The only water that comes into contact with PCBs at these latter plants is that used for personal hygiene. The types and quantities of water used at two plants visited are given below.

	Plant No.	
Water Usage in Gallons/day	103	114*
Non-contact cooling	1,646,000	38,000
Process water		
. Contact cooling	183,000	None
. Detergent washing	2,000	None
. Incineration quench	122,000	None
Hygiene	Unknown	300
Boiler make-up	Unknown	200
Sanitary	Unknown	9,000
Non PCB related		
. Water used in a lab	Unknown	500
. Water used for external cleanups	None	4,000

*Breakdown of the water usage was estimated.

NWMAR115803

3.2.1.5 Wastewater Treatment

There are no effluent treatment techniques in practice at any plant in this category for the removal of PCBs. However, in 1972, a John Zink designed thermal oxidation incinerator was erected at plant 103 to safely dispose of PCBs. A schematic flow diagram of this unit is given in Figure 3.2.1.5-1. This unit consists of two steam atomized burners and a long cylindrical chamber to provide residence time for thermal degradation. Following the chamber is a water spray quench pot and a counter current packed scrubber column located at the base of the stack.

The waste oils are brought into the incinerator site in 55 gallon drums or by truck trailers. These waste oils are next pumped from the drums or from the trailers into the incinerator feed tanks. The steam atomizing burners inject the combustible liquid wastes into the combustion section with air, in such a manner to create a vortex type turbulence. This produces high heat release and effective combustion promoting the thermal degradation process. After combustion, the waste gases proceed through the oxidation chamber which provides 3 to 12 seconds of residence time at temperatures 1600 to 1800^{o}F for the degradation reactions to go to completion. The flue gases from the chamber pass through a quench pot which contains a series of water sprays to cool the gases. An induced draft fan then forces the cooled gases through the packed bed scrubber column. Here, acidic ions produced during the combustion process are absorbed in the scrubber liquor. The scrubber liquor is then neutralized and disposed into the sewer.

A high temperature decapsulator has been incorporated in the thermal oxidizer unit for solid incineration and copper recovery. The exhaust of this unit is routed to the upper end of the oxidizer chamber.

Details on wastewater treatment techniques utilized at one facility (plant 103) for purposes of oil recovery and on-going containment programs undertaken by two plants (plants 103 and 114) in order to prevent the entry of PCBs into the environment are covered in the Task II report, "Assessment of Wastewater Management Treatment Technology, and Associated Costs

NWMAR115804

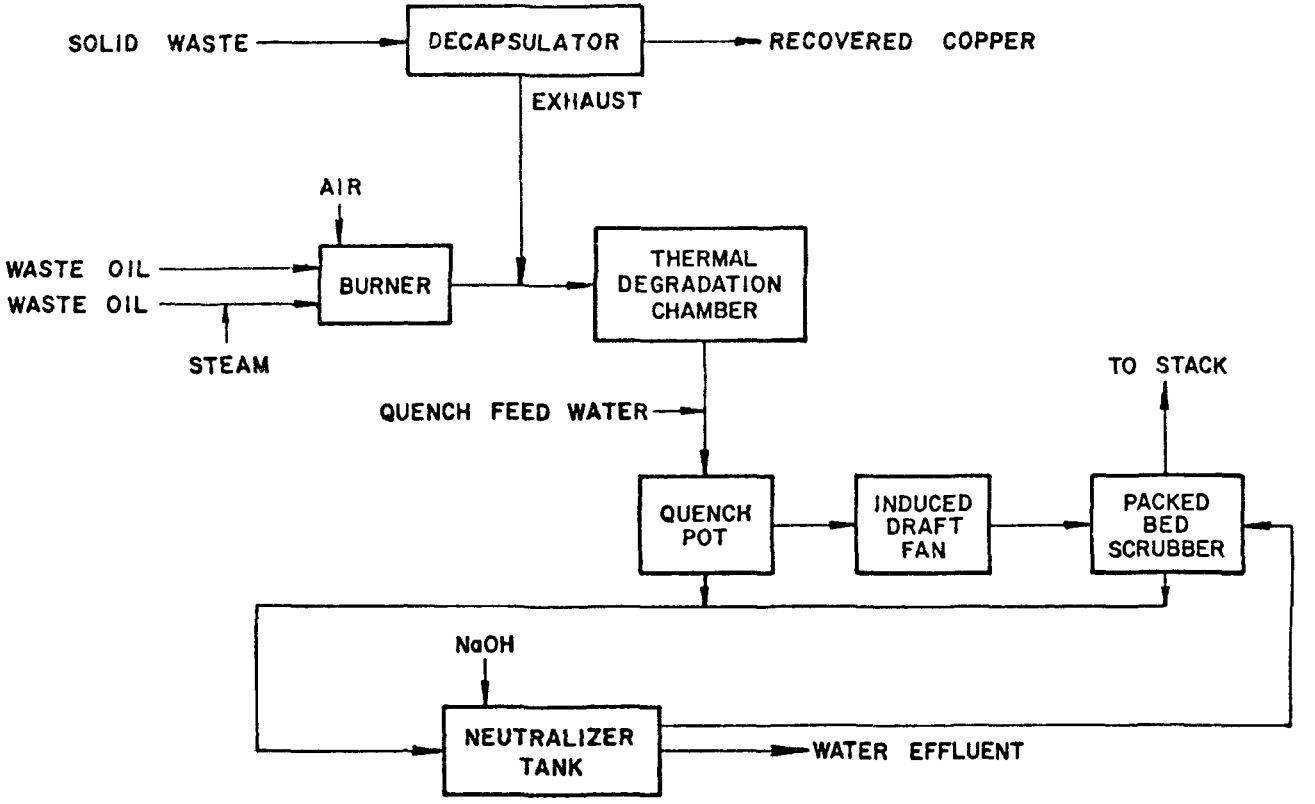


Figure 3.2.1.5-1. PROCESS FLOW DIAGRAM FOR THERMAL OXIDIZER INCINERATOR AT PLANT 103

NWMAR115805

for Abatement of PCBs Concentration in Industrial Effluents", February 3, 1976, pages 71 through 75.

3.2.1.6 Effluent Composition

Effluent flow rates and PCB contents are available from the three plants which discharge into the rivers and from two plants which discharge primarily into sanitary sewers. Detailed effluent composition is available only on Plant 103. This information is given in Tables 3.2.1.6-1 and 3.2.1.6-2, respectively.

The remaining plants in this category which discharge to sanitary sewers report that their water usage, for reasons other than for sanitary purposes, is minimal. However, they have no data available on the quantities and composition of water discharged.

3.2.2 Askarel Transformer Repair Industry

A total of 13 companies repair transformers containing PCBs at a total of 131 locations. The current industry structure has been identified, and several potential problems were noted. No estimates have been made of the pollution which occurs from this industry.

3.2.2.1 Transformer Inspection and Maintenance

Askarel transformers are very reliable and have lifetimes that range up to 40 years. The failure rate of askarel filled transformers has been estimated by the manufacturers to be 0.2 percent per year. Failure occurs primarily due to the degradation of the PCB fluid caused by electrical arcing within the transformer.

Nine electrical utilities were contacted to determine their inspection and repair procedures. All of these companies have some type of program, usually informal, for the checking of their transformers. In most cases this consists of a simple annual inspection which may include a general cleaning operation of the facilities adjacent to the hardware (e.g., the vaults may be cleaned and vacuumed). Inspection involves looking for evidence of leaks. One utility performs an annual power factor test on the windings, and if this test indicates a problem in the transformer, then its dielectric fluid

NWMAR115806

TABLE 3.2.1.6-1

PCB CONCENTRATION IN EFFLUENTS FROM TRANSFORMER MANUFACTURING PLANTS

Plant No.	Discharge Designation	Effluent Flow Rate Gal/Day	Effluent PCB Content ppb Avg/Max	Effluent PCB Content lb/day Avg/Max	Disposition of Effluent
103[1]	005	1,310,000	4.9/120	0.0535/1.311	River
	006	550,000	7/75	0.0321/0.344	River
114	None	50,000	Unknown	Unknown	Sewer
	None	2,000[2]	Unknown	Unknown	River
115	002	36,000	<1/2	<0.0003/0.0006	River
	003	24,000	2/113	0.0004/0.0226	River
	004	150,000	<1/3	0.0013/0.0039	River
116[3]	#1	252,000	3.4/11	0.0071/0.0231	River
	#2	378,720	2.1/3.8	0.0066/0.0120	River
	#3	504,000	8/19.1	0.0336/0.0803	River
117	Batch discharge	13,500	28.6/unknown	0.0032/unknown	Sewer

Notes: (1) This plant has other discharges out of their properties. Discharges listed above are those associated with PCB related operations.

(2) Estimated.

(3) Discharges designated as #1, #2, and #3 are the combined effluents from their power house, and one each from their two manufacturing areas, respectively. According to the plants' Corps of Engineers permit application form, filed in July 1971, this plant has 13 outfalls.

NWMAR115807

TABLE 3.2.1.6-2

INFLUENT AND EFFLUENT COMPOSITIONS OF PLANT 103

	Incoming Municipal Water	Outfall 005		Outfall 006	
Average flow rate million gpd	1.86	1.31		0.55	
pH yearly average	6.4	7.7		5.5	
pH min.-max.	—	6.4-8.0		3.1-7.1	
		Avg/Max Conc.	Avg lbs/day	Avg/Max Conc.	Avg lbs/day
Alkalinity, mg/l	14	25/25	273	15/20	69
BOD, 5-day, mg/l	2	3/3	28	27/30	124
Chemical oxygen, mg/l	9	23/34	251	75/92	344
TS, mg/l	69	70/70	765	364/497	1671
TDS, mg/l	68	67/67	735	341/483	1565
TSS, mg/l	1	3/9	31	23/30	106
TVS, mg/l	34	19/22	208	89/96	408
Ammonia, mg/l (AN)	0.05	<0.2/1.0	<2	2.8/3.0	13
Kjeldahl Nitrogen, mg/l	0.45	0.8/1.0	9	4.6/5.1	21
Nitrate AsN, mg/l	0.15	0.55/0.9	6	0.98/1.02	5
Phosphorus Total, mg/l	0.01	0.04/0.05	<1	54/124	248
Color (As P)	30	25/30	-	30/30	-
Turbidity, mg/l	<25	<25/<25	-	<25/<25	-
Total hardness, mg/l	44	31/44	340	33/44	152
Organic Nitrogen, mg/l	0.5	0.6/0.7	6.6	1.8/2.0	8
Sulfate, mg/l	9.0	14/18	153	9.0/9.0	41
Sulfide, mg/l	<0.1	<0.1/<0.1	<1.0	<0.1/<0.1	<0.5
Chloride, mg/l	6	6/8	61	11/13	50
Cyanide, µg/l	<0.00	0.00/<0.01	0.04	<0.00/<0.00	<0.02
Fluoride, mg/l	0.16	-	-	9.5/12.0	44
Aluminum - total, µg/l	100	500/550	5	200/200	0.9
Boron - total, µg/l	70	-	-	9/70	0.04
Calcium - total, mg/l	6.5	7.0/7.5	77	7.7/8.0	35
Chromium - total, µg/l	<10	30/30	0.3	310/350	1.4

NWMAR115808

TABLE 3.2.1.6-2 (CON'T)

	Incoming Municipal Water	Outfall 005		Outfall 006	
Cobalt, total, µg/l	<7	4/4	0.04	-	-
Copper - total, µg/l	500	20/500	0.2	30/500	0.13
Iron - total, µg/l	330	150/330	1.6	3200/3500	15
Lead - total, µg/l	<30	<10/30	<0.1	80/90	0.36
Magnesium - total, µg/l	7	3/7	36	3/7	16
Manganese - total, µg/l	200	50/200	0.5	120/200	0.55
Mercury - total, µg/l	<1	<1/<1	<0.004	2/2	0.01
Molybdenum - total, µg/l	<7	-	-	90/99	0.41
Nickel - total, µg/l	100	<10/100	<0.1	10/100	0.04
Potassium - total, mg/l	1.1	0.88/1.10	9.6	0.99/1.1	4.5
Silver - total, µ	<10.0	-	-	2.0/2.0	0.009
Sodium - total, mg/l	5	6/10	66	25/30	117
Tin - total, µg/l	<7	7/10	0.07	-	-
Titanium - total, µ	2	-	-	3/3	0.01
Zinc - total, µg/l	30	70/75	0.76	730/800	3.4
Oil & Grease, mg/l	1.0	2/10	21	3.0/9.0	13.7
Phenols, µg/l	3	101/110	1.1	168/180	0.77
Surfactants, mg/l	<0.02	0.11/0.15	1.2	0.22/0.30	1.0
Chlorinated hydrocarbons, mg/l (except pesticides)	<1.000	1.000/5.000	11	1.000/1.000	4.6
PCBs, µg/liter	-	4.9/120	0.05	7/75	0.03

NWMAR115809

is tested - at least this is the theoretical method of operation since the company has only two PCB-type transformers in use and neither has ever failed the power factor test. Another company measures the operating temperature of the units and makes a visual inspection for leaks; this company also claims that transformers located in the generating facility are inspected daily (visual inspection) and that units located in vaults are checked at least weekly. While most major inspections are carried out annually, the range of time intervals between inspections is 6 months to 18 months, with one company saying that they inspect at least once every 2 or 3 years, and another saying that substation transformers are inspected weekly.

These companies perform no sampling and analysis work on their askarel transformers. One company has annual inspection of all transformers, but only the mineral oil-type units have samples withdrawn for analysis to see if there is deterioration or contamination. A company which used to perform power-factor tests until about 8 years ago has since abandoned such tests and does not withdraw askarels for analysis.

Servicing of transformers is only rarely performed in-house. The response of most companies was that servicing of askarel-type transformers had yet to be required. One company did its own servicing up until 8 or 10 years ago, but since then, because of the special handling problems associated with askarels, such work has been farmed out to G.E. and Westinghouse service centers. The general trend seems to be that major servicing is more likely to be done at special facilities outside the utility companies while minor servicing, such as the repair of small leaks is taken care of at the transformer site by the utility.

More than half of the companies have not scrapped transformers in the past five years, and most have not scrapped any in the past 10 years. One utility company has had no transformer failures in 20 years (except for a minor leak of less than 1 gallon ten years ago). These companies have no specific disposal methods for such instances. One company said that scrap transformers are handled through a local junk company and that askarel disposal is the junk company's problem. A company which says it has scrapped no transformers says that when the PCB capacitors fail they are shipped back to

NWMAR115810

the manufacturer; presumably, though it was not stated directly, failed transformers would also be returned to their manufacturers. One company which is proud of its disposal practices has disposed of 200 to 400 gallons of askarel per year since 1970 (most of it comes from failed capacitors); until this year it was all sent to Monsanto for incineration, but starting this year they have been sending it to Sheffield, Ill., where it is dumped in a landfill that has been approved by EPA for the disposal of radioactive wastes. This company stated that many utility companies dump their PCB-related wastes in local landfills.

There has been little PCB lost to the environment through the safety release valve on the transformers. The consensus response was that if the valve released there would be askarels "all over the place". The spokesman for one utility did not know whether the transformers they used had safety valves. One company said that a transformer vented several years ago when a fuse that was supposed to protect the transformer did not protect it.

Very seldom is a failed transformer scrapped. However, sometimes the repair work needed in a failed unit could be rather extensive and very costly. The owner of the unit may request to scrap his unit. If the repair shops scrap a transformer, they follow the procedure recommended by NEMA. However, if the owner of the transformer decides to handle the disposal of the unit himself, the unit is shipped back to the owner. Disposal is then usually made through a local junk dealer.

3.2.2.2 Repair of Failed Transformers

In talking with a major transformer manufacturing company which specializes in the servicing of transformers, it was learned that PCBs used by service shops are primarily for refilling the units which have failed and have to be repaired. Apparently, very few facilities handle their own servicing. Major service work is almost always handled by repair shops while minor service work, such as changing a gasket, to prevent a minor leak, may be taken care of by the owner of the transformer. Additionally, the repair

NWMAR115811

shops often handle askarel conditioning services. In such a case, the serviceman carries the filter press to the costomer's site and performs this service on site. Several gallons of PCBs are used in this service for topping the unit and adjusting the level. The procedure for the repair or disposal of failed transformers and the handling of the PCB liquid in those transformers is summarized in Figures 3.2.2.2-1 and 3.2.2.2-2.

A number of potential sources of environmental contamination have been identified, and are discussed in detail in the following notes to the figures.

1) Testing and analysis of PCB transformer fluid has been largely discontinued due to the strict requirements imposed on the disposal of the samples. This change in procedure may be expected to increase the probability of major failures of transformers containing PCBs.

2) Accidental spills of PCBs from transformers can occur due to leaks, venting caused by short circuits, or mechanical damage to the transformer case. In most cases, the transformer is contained in a vault or is surrounded by dikes which will limit the spill to a controlled area. Only in the case of railroad transformers would the leakage resulting from an accident be expected to be uncontrolled.

3) Transformers which are scrapped by the owner/user may be a serious potential source of pollution. Those transformers built during the past several years are well marked with the hazards of the PCBs which they contain. Disposal of junked transformers by electrical repair shops is governed by a detailed specification of the National Electrical

NWMAR115812

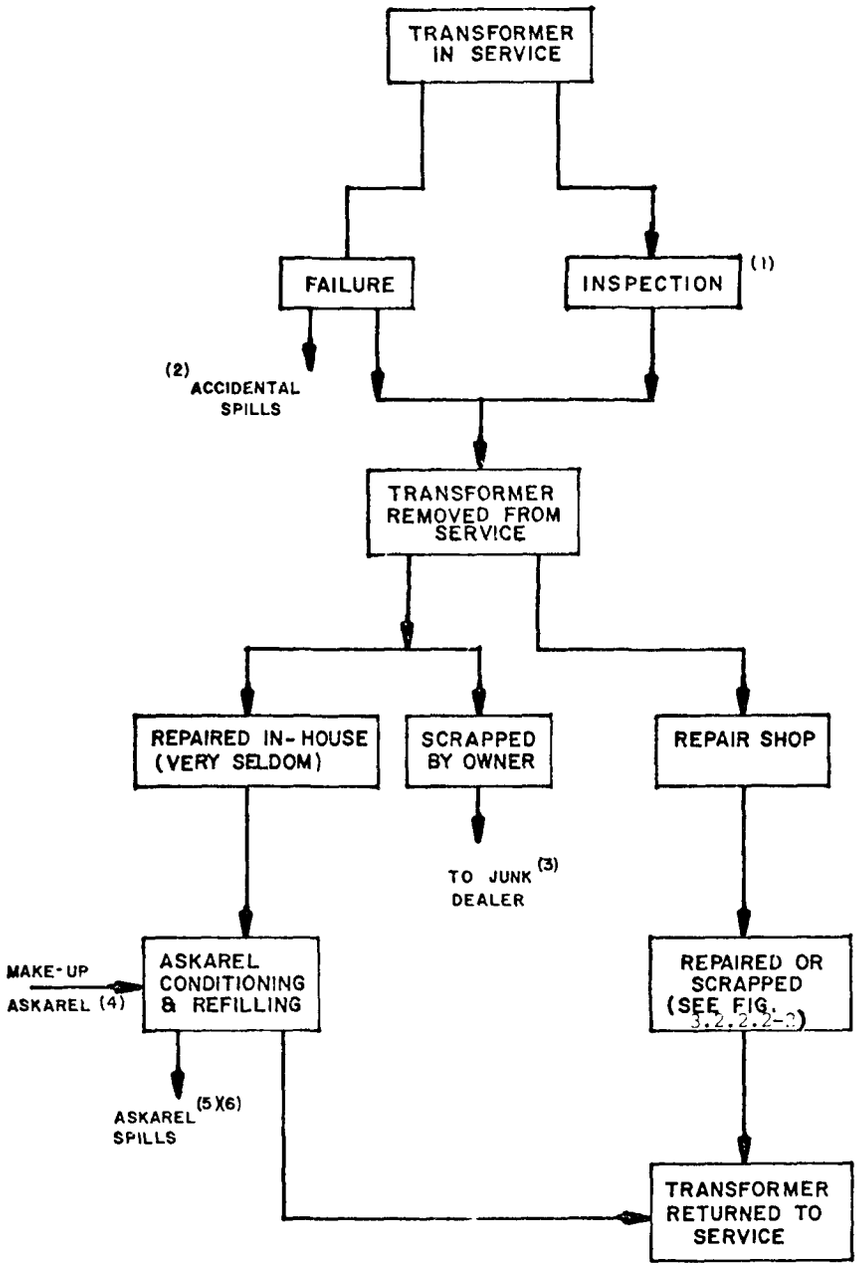


FIGURE 3.2.2.2-1. TRANSFORMER MAINTENANCE & SERVICING

NWMAR115813

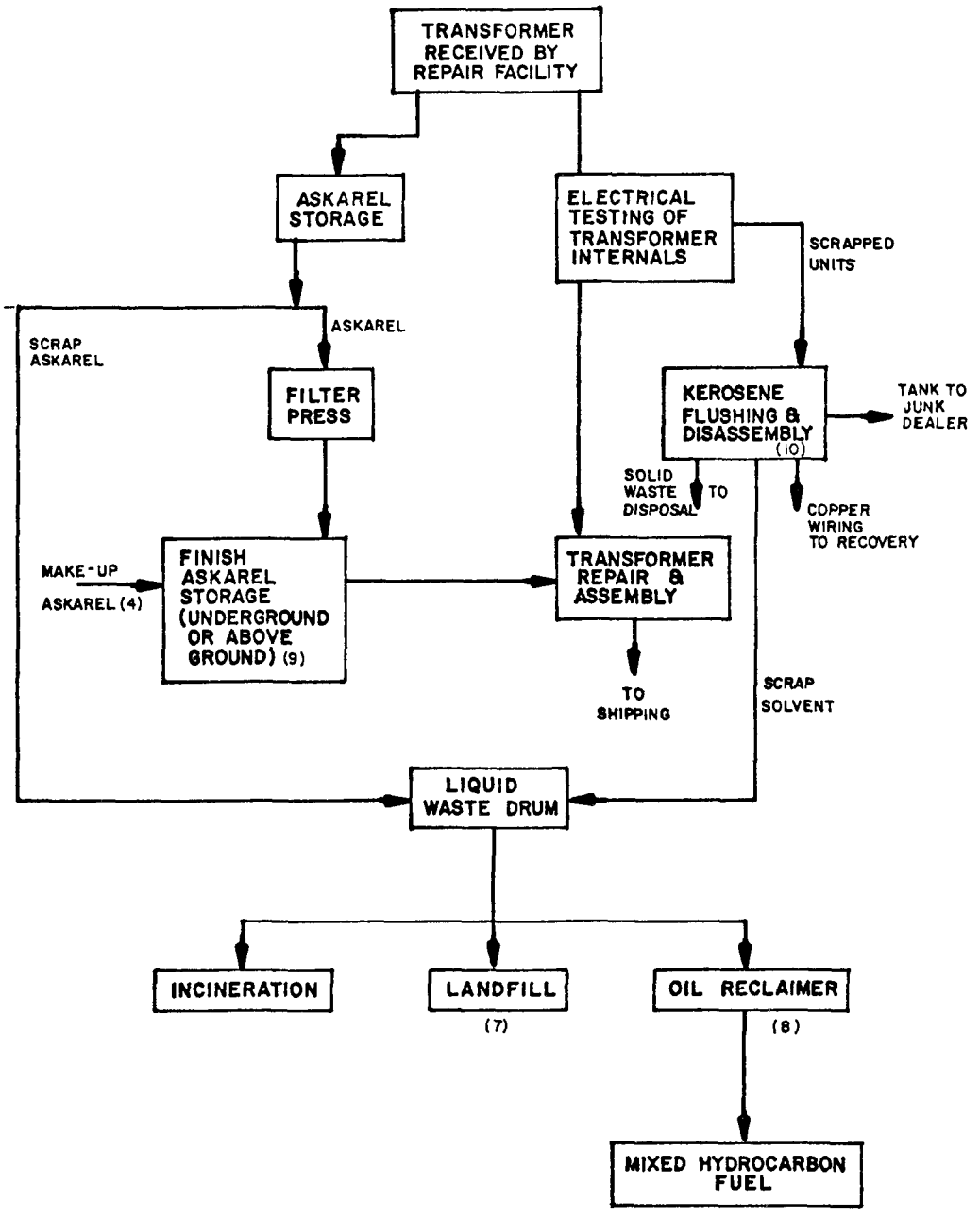


FIGURE 3.2.2.2-2. TRANSFORMER REPAIR

NWMAR115814

Manufacturers Association (NEMA). However, the disposal of transformers through small local junk yards may result in significant pollution because:

a) The junk yards are not familiar with PCB handling procedures.

b) The older transformers are not marked with special instructions.

c) 90 to 95 percent of the transformers seen by the junk yards would contain mineral oil, and the occasional transformer containing PCB would be noted only as containing non-flammable transformer oil. This would not result in any special handling of the PCBs.

d) Disposal of PCBs by open burning in a trash incinerator will not completely destroy the PCBs, but will vaporize this material and disperse it into the atmosphere.

This is only a potential problem at this time, as uncontrolled scrapping of transformers has not been documented. However, several responses to the questionnaire claimed that uncontrolled handling of PCB filled transformers by junk yards was thought to have occurred in the past.

4) Considerable PCB is shipped in 55 gallon drums to repair shops and users. The residue in each drum after it is emptied may contain up to a pound of PCB. Empty drums which are recycled to drum reclaiming facilities or scrap yards would introduce this relatively small, but significant, amount of PCB into an uncontrolled environment. All drums presently in use have detailed handling instructions painted on the drum, and this information

NWMAR115815

should minimize any potential problems from this source.

5) Filter residues and losses are in general treated as any other waste containing PCBs and are being placed in drums and held for controlled disposal.

6) Scrap PCB is packaged in 55 gallon drums. The NEMA instructions are very specific as to the required disposal procedures for this material. Small repair shops which do not have access to controlled disposal sites or services have been known to mishandle the scrap PCB by disposing into uncontrolled landfills (note 7) or through oil recovery services (note 8).

7) Landfills are a satisfactory disposal method for scrap PCB transformer oil if the leach water is monitored. In a few cases scrap PCB and PCB contaminated material is sent to a municipal dump.

8) At least one case is suspected where PCB transformer oil may have been sent to an oil reclaiming company which mixed it with other hydrocarbon wastes and sold it to a power company as fuel. It should be noted that the mineral oil used in 90 to 95 percent of the transformers presently in service. Problems may result when PCB transformer oils are mixed with mineral oils and handled in this manner.

9) New and conditioned PCB transformer oil is normally stored in large surface or underground tanks at the repair shop. Leakage may occur from

NWMAR115816

these tanks into ground waters. No standards have been established for checking for such losses.

10) The scrapping of unrepairable transformers is covered by the NEMA standard (ANSI C107.1-1974). This standard requires that the transformer be drained and then flushed with solvent to remove PCB residues before the metal values are reclaimed. Possible sources of contamination would be incomplete flushing and the mixture of used solvent with hydrocarbon rather than with PCB residues. This is considered unlikely in the major transformer repair shops.

3.2.2.3 PCB Usage in the Transformer Repair Industry

The PCB usage figures for the transformer manufacturing and repair industries are summarized below.

	PCBs Use, lbs				
	1971	1972	1973	1974	1st half-1975
New PCBs used to repair transformers	590,000	580,000	440,000	780,000	480,000
PCB reclaimed and reused in repair of transformers	2,000	64,000	160,000	110,000	78,000
PCB shipped to user to replace transformer losses	3,000	3,000	4,000	2,000	2,000
PCB disposed in transformer repair				570,000*	
PCB used in transformer manufacturing				11,000,000	
Total PCB in service in transformers				270,000,000	

* This figure may include PCBs contaminated wastes as well as PCB.

NWMAR115817

3.2.2.4 Transformer Service Life

There have been relatively few failures of PCB filled transformers, and statistically significant data is not available to support service life estimates. General estimates by transformer manufacturers indicate the following expected service life of this equipment:

Service life of substation transformers	40+ years
Service life of power transformers, including those on railroad locomotives	30 years

Transformers exhibit a small but significant infant mortality rate (failure within the first year of service). Overall transformer failure rate estimates are in the range of 0.2 percent per year.

3.2.2.5 Usage rate of PCBs in Transformer Repair

The total PCB used in 1974 in the repair of transformers was approximately 0.3 percent of the estimated total PCBs in service in transformers. This figure is consistent with the estimated failure rate of 0.2 percent per year for in-service transformers.

The usage of PCB in the transformer repair industry is approximately 7 percent of that of the transformer manufacturing industry.

3.3 Investment Casting

The investment casting industry produces precision-cast metal parts and shapes for the aircraft and other machinery manufacturing industries. Approximately 25 of the 135 investment casting foundries in the United States currently use PCB filled waxes in the manufacture of metal castings. The PCB incorporated in the waxes is decachlorobiphenyl (deka). The remaining foundries use either polychlorinated terphenyl (PCT) filled waxes or unfilled waxes. This section presents a review of the usage of deka filled waxes in the industry, including available information on use history, process technology, and potential

NWMAR115818

PCB-bearing waste streams. Currently available information on PCTs usage in the industry is also included.

3.3.1 Background

There are currently 135 investment casting (IC) foundries and five investment casting wax manufacturing plants in the United States. The IC industry had its start in the United States during World War II when urgent demands for arms and aircraft parts required more efficient methods of producing finished, precision parts than standard machining techniques offered. During the war the waxes used by IC foundries consisted of a blend of carnauba wax, beeswax, paraffin, and rosins. However, over the last decade wax formulations have evolved which consist of a variety of polymeric compounds and other fillers such as decachlorobiphenyl and PCTs. By reducing the wax content through low-shrinkage fillers (such as PCBs and PCTs) volumetric shrinkage of the ceramic mold is controlled. This allows the production of metal castings with smaller dimensional tolerances than were available with the original unfilled waxes.

The major wax manufacturing companies are:

1. Yates Manufacturing Company, Inc.
2. M. Argueso and Company, Inc.
3. Freeman Manufacturing Company
4. J. F. McCoughlin Company

The Yates Manufacturing Company, Chicago, Ill., is the sole known U.S. supplier of deka waxes. The decachlorobiphenyl content is 30 percent of the total wax by weight (Solomon, P., Yates Manufacturing). Yates currently imports deka from Caffaro S.P.A., Italy, at a rate of 300,000 to 500,000 lbs. per year, which corresponds to the manufacture of between 1 and 1.5 million pounds of deka wax, annually. At a cost of $0.70 per pound, (Lewis, W.H., Signicast Corp.) the annual volume of sales of deka wax should be in the range of $700,000 to $1 million per year.

All the wax manufacturers listed previously are believed to use imported PCTs as pattern wax fillers. Since the general properties of the deka and PCTs are similar, it is believed that the wax production and use

NWMAR115819

processes are similar also. Contacts with industry indicate that the volume of PCTs in wax is probably about the same as or greater than that of deka PCBs. Monsanto was the leading (and probably only) U.S. producer of PCTs prior to their voluntary cessation of production in 1972. Domestic production of PCTs by Monsanto through 1972 was as follows:

Year	Million of Pounds Aroclor 5460
1968	8.87
1969	11.60
1970	17.77
1971	20.21
1972	8.13

It is believed that a relatively small fraction of this production was used in casting waxes, probably on the order of a million or so pounds per year. Aroclor 5460 (Monsanto's trade name for their 60-percent-chlorine PCTs) was used primarily in adhesives, lubricants and paper coatings.

The current source of imported PCTs is believed to be Prodelec (France), which markets the material as Electrophenyl T-60 (60 percent chlorine), which, it should also be noted, may contain PCB contaminants.

In summary, the investment casting process, which is described more thoroughly in Sections 3.3.2.1 and 3.3.2.2, is a lost-wax casting process in which the shape to be cast is molded from wax and then invested or surrounded by a slurry of refractory ceramic. After the ceramic mold has hardened to an appropriate strength, the wax is melted or burned out leaving a molded cavity. Molten metal is then poured into the cavity, and cooled to form the casting.

The major losses of the virgin and used waxes occur during the dewaxing of the ceramic mold. As the ceramic mold is heated to remove the wax, a small portion of the wax diffuses into pores of the mold. Later, the mold with the trapped waxes is fired in a furnace to set the mold and remove the wax. Depending on furnace conditions, the decachlorobiphenyl in the wax may be burned or released to the atmosphere. At least several percent of that used is believed to be emitted via this route.

NWMAR115820

It is a normal practice by many foundries to recover the drained pattern wax and reuse it several times in sprues and gates. Purchased wax is apparently used an average of 2.5 times. During the dewaxing process the virgin wax (used to form the pattern) and the old wax (used to form the gates and sprues) are collected as one mixture. Little of the wax is destroyed in the process; therefore, it is considered probable that the investment casting foundries store or dispose of relatively large amounts of used PCB-containing wax.

3.3.2 Investment Casting Technologies

3.3.2.1 Principles of Investment Casting

The principles of investment casting are the same for both the solid mold and shell processes, but the method of forming the ceramic mold differs somewhat between the two. Both require a pattern, gating to a central sprue, removal of the pattern by melting, pouring metal into the cavity left by the melted pattern, removal of mold material from the cast cluster, and cutting of castings from the sprue.

The investment shell process is depicted in Figure 3.3.2.1-1.

The Pattern: The process begins with production of a one piece heat-disposable pattern. This pattern is usually made by injecting wax or plastic into a metal die. Dies range from simple, hand-operated single-cavity tools to fully automated multi-cavity devices, depending on production quantities and complexity of the parts to be cast.

A heat-disposable pattern is required for each unit being cast. Each pattern has the exact geometry of the required finished part, but they are made slightly larger in order to compensate for volumetric shrinkage during the pattern production stage and during solidification of the metal in the mold.

The pattern carries one or more gates which are usually located at the heaviest casting section. The gate has three functions:

NWMAR115821

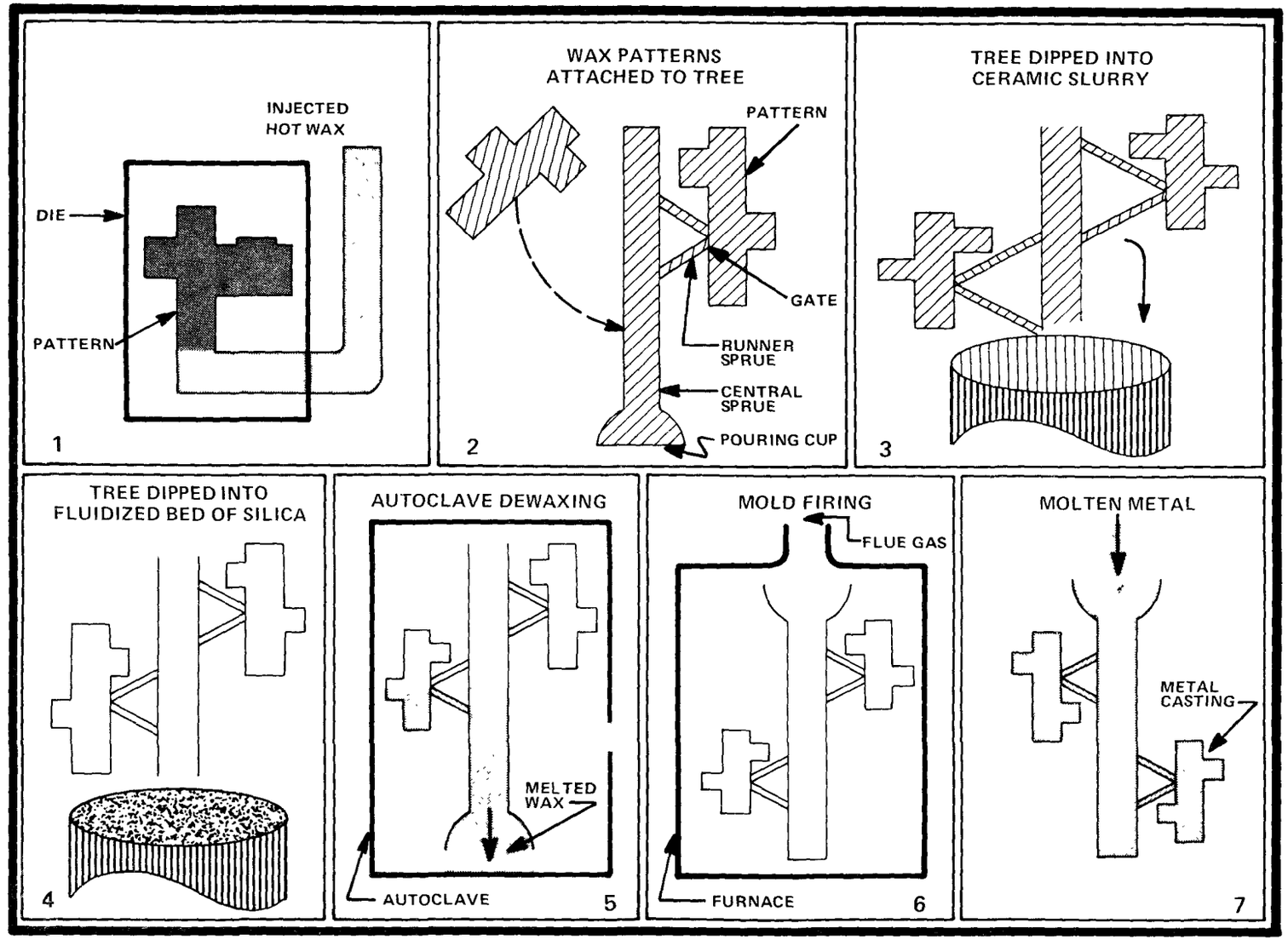


Figure 3.3.2.1-1. INVESTMENT SHELL PROCESS

NWMAR115822

(1) To attach patterns to the centrally-located sprue or runner, thus forming a tree-shaped cluster;

(2) To provide a passage for the draining of pattern wax once the mold is sufficiently hardened and has been heated; and

(3) To guide molten metal entering the mold cavity in the pouring operation.

Clustering: Patterns are fastened by the gate to one or more runners. The runners are attached to a pouring cup. All of these parts are usually made of wax. Patterns, runners and pouring cup comprise the cluster or tree upon which the ceramic mold is formed. The number of runners and their arrangement on the pouring cup may vary considerably, depending on alloy type and the size and configuration of the casting.

Molding: Up to the point of forming the ceramic mold, all foundries operate in essentially the same manner. After assembling the pattern to a tree, however, they may form the mold by either the investment flask process or the investment shall process.

Solid Mold or Investment Flask Process: There are two investment flask techniques, depending on the type of alloy to be poured. Ferrous alloys require highly refractory materials and binders. The entire cluster is dipped into a ceramic slurry, drained and stuccoed with fine ceramic sand. This step is usually repeated after the first coating has dried. This coated cluster is then placed in an open-end metal can (the flask) which is filled with a coarse slurry of ceramic backup material (investment). The investment hardens to comprise a green mold. When the flask with its contents are placed into an autoclave, the whole cluster (consisting of wax patterns, runners and sprues) melts and runs out through the pouring cup. The resulting monolithic mold contains cavities of the desired casting shape, with passages leading to them.

Nonferrous alloys are cast in ceramic molds bonded with plaster of paris. The entire tree (heat-disposable patterns, gates, runners, and pouring cup) is placed in an open-end metal flask without a first

NWMAR115823

ceramic coating. Investment slurry is poured into the flask, completely surrounding the cluster. Before the binder sets up, the flask is placed under vacuum to remove all air entrapped during mixing of the investment. When the investment becomes hard, patterns are melted out exactly as in ferrous casting.

The Investment Shell Process: This technique, as described in Figure 3.3.2.1-1, involves dipping the entire cluster into a ceramic slurry, draining it, then coating it with fine ceramic sand. After drying, the process is repeated several times, using progressively coarser grades of ceramic material, until a self-supporting shell has been formed. The thickness of the shell is usually between 3/16 and 5/8 inch.

The coated cluster is then placed in a steam autoclave where the wax melts and runs out through the gates, runners, and pouring cup. The resulting ceramic shell contains cavities of the desired casting shape, with passages leading to them.

Casting: Monolithic shell molds and solid molds must be fired to burn out the last traces of pattern material and to attain a degree of permeability before the molds can be filled with metal. In the case of solid molds, this heating has to proceed slowly, in a controlled cycle which stretches over 12 to 18 hours, to avoid cracking of the mold. The shell molds, made of ceramic material with an extremely low coefficient of expansion, can be placed immediately into a hot furnace. Because the shell molds have relatively thin walls, they can be fired and ready to pour after only a few hours in the furnaces.

The hot molds may rely on gravity alone to carry the molten metal into the intricacies of the mold, as is common in sand casting, or the process may use vacuum, pressure and/or centrifugal force in order to faithfully reproduce intricate details of the wax patterns.

Melting equipment employed depends on the alloy. For nonferrous alloys, gas fired or electric crucible furnaces are usually used. For ferrous alloys, high frequency induction furnaces and indirect arc furnaces are common.

NWMAR115824

Cleaning: After cooling, mold materials are removed from the casting cluster with vibrating equipment. Individual castings are usually removed from the cluster by means of cut-off wheels, and any remaining protrusions left by gates or runners are removed by belt-grinding. Generally, castings are sand blasted for smooth finish, then they are ready for such secondary operations as heat treating, straightening and machining.

Reclaiming of Pattern Waxes: The present cost of virgin pattern wax is approximately $.79/lb. In the future, it may be more economical to reclaim wax for use as pattern waxes, in addition to its present use in gates and runners. Furthermore, through a precipitation method, it is possible to remove fillers, including PCBs, from used wax in order to prepare unfilled wax.

Improvement of Investment Casting Processes: Several improvements in the investment casting techniques and procedures have been suggested by TRW Metals in Minerva, Ohio, which developed them through a two-year Air Force contract (AFML-TR-74-237). The areas of improvement were in wax pattern formation, mold production processes and metal pouring.

Wax pattern formation techniques were improved through simultaneous multiple injections of the gates and runners. The usual procedure requires separate steps.

Two suggestions for improvements were made for the mold production process: (1) elimination of the drying cycle between slurry dipping and sand coating, and (2) the use of microwave ovens to melt pattern wax out of the ceramic mold or shell.

The use of microwave dewaxers would have the advantage of reducing wax emissions in flue gas and drain condensates of autoclave ovens. However, microwave dewaxing may not eliminate wax losses occurring during mold firing as a result of wax trapped in the pores and cavities of the ceramic mold.

3.3.2.2 Foundry Process - Use of PCT and PCB Filled Waxes

A flow chart which typifies the use of PCBs and PCTs in investment casting is presented in Figure 3.3.2.2-1. PCB filled waxes are

NWMAR115825

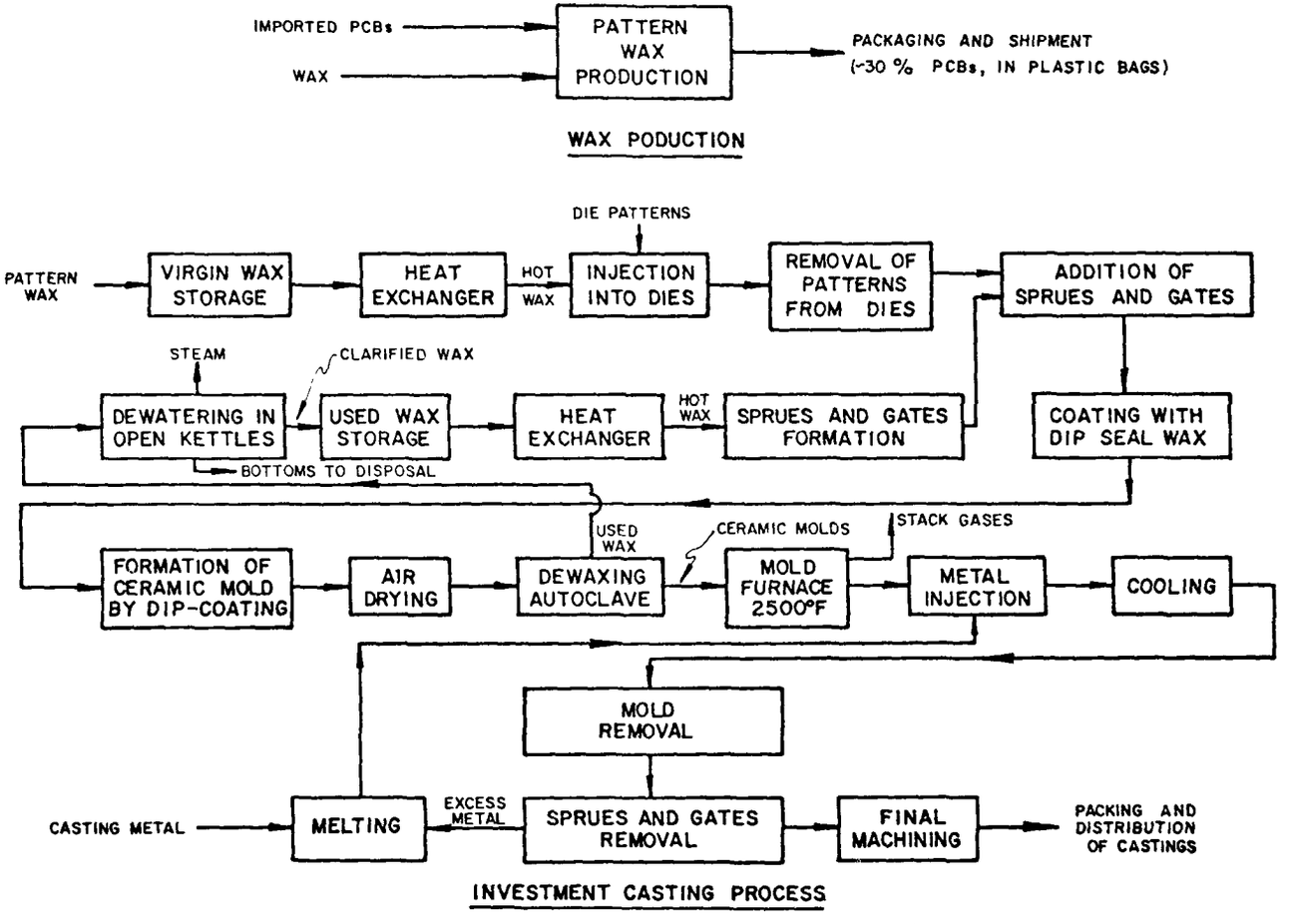


FIGURE 3.3.2.2-1

FLOW CHART OF PCBs USAGE IN INVESTMENT CASTING

NWMAR115826

purchased from wax manufacturers in bulk quantities of 10,000 or more pounds, sealed in plastic bags and contained in boxes for shipment. The received pattern wax is stored in a stockroom at the foundry until melted for the production of wax patterns. Once melted, the wax is injected into a pattern die where the wax is allowed to solidify. The pattern die is then disassembled and the wax pattern removed. Several wax patterns are produced before forming the tree. The formation of the tree entails attaching the individual wax patterns to the sprues and gates, and after the trees are assembled, the sprues are coated with a dip-seal wax to fill the voids on the rough sprue surfaces.

The next step in the process is the formation of the ceramic mold. This is accomplished by dip-coating the wax trees in a ceramic slurry and a fluidized bed of silica, and air drying of the coated tree. This process is repeated several times before the wax is melted out of the mold.

Dewaxing is accomplished by one of three techniques: steam autoclave, microwave oven, or flash firing in a mold furnace. Most foundries apparently use the autoclave technique, which involves subjecting the ceramic coated trees to steam until the wax within the mold is melted out, leaving the ceramic shell. The melted wax is either disposed of or reclaimed for use as sprues and gate wax. The new microwave technique involves heating the molds with microwave energy. Microwave units of 5- and 10-kilowatt output are commercially available for this application. The third technique of flash firing combines dewaxing and mold firing in one step. The ceramic coated wax trees are placed in a furnace where all the wax is removed from the tree by flash firing. Most of the wax is vaporized and leaves the furnace with the stack gases. It is not known how many facilities use flash firing.

If the foundry dewaxes the trees using autoclave or microwave techniques, the dewaxed ceramic molds must be fired in the mold furnace to strengthen the ceramic and to remove wax residues. The ceramic molds are raised to temperatures of between 1900 and 2000^{o}F for approximately two hours. The vaporized wax residues leave the furnace with the stack gases. The foundries claim that only 1 to 2 percent of the wax remains in the molds before mold firing. This estimate of trapped or wall absorbed wax appears to be low for two reasons:

NWMAR115827

(1) The porosity of the ceramic mold can be as high as 30 percent, and

(2) Trapped waxes in the cavities of the pattern vary in amount, depending on the pattern's geometric configuration.

After firing, the ceramics are ready for metal pouring. The steps involved in pouring, and the subsequent recovery of the castings are evident in Figure 3.3.2.2-1, starting with metal pouring.

The high cost of pattern wax has stimulated foundries to reclaim used wax. For example, the PCB filled waxes sell for approximately 70 cents per pound. The average weight ratio between pattern wax and wax in sprues and gates is about 40:60. Therefore, reclaiming of used wax, especially for use in sprues and gates, ahs become a very important part of the foundry process.

Reclaiming involves placing the used wax in open kettles or tanks and heating it above the boiling point of water until all the water (from the steam autoclave) is eliminated. After dewatering, the reclaimed wax is reconstituted by adding paraffin and other additives until certain melting-point specifications are met. It is claimed that wax fillers are not added to adjust the filler content (Wurster, W., Consolidated Casting Corp.).

For those foundries which practice wax reclamation on their used wax, it is estimated that 5 to 10 percent of the wax is deliberately disposed of. The major source of the discarded wax is probably the dregs from the dewatering kettles.

3.3.2.3 Waste Streams

Idealized waste streams (containing PCBs and PCTs) leaving an investment casting foundry are shown in Figure 3.3.2.3-1. The broken lines within the process box in Figure 3.3.2.3-1 indicate potential PCB and PCT escape routes via air emissions from the foundry unit processes. The solid lines between the processes indicate the production routes of the waxes.

NWMAR115828

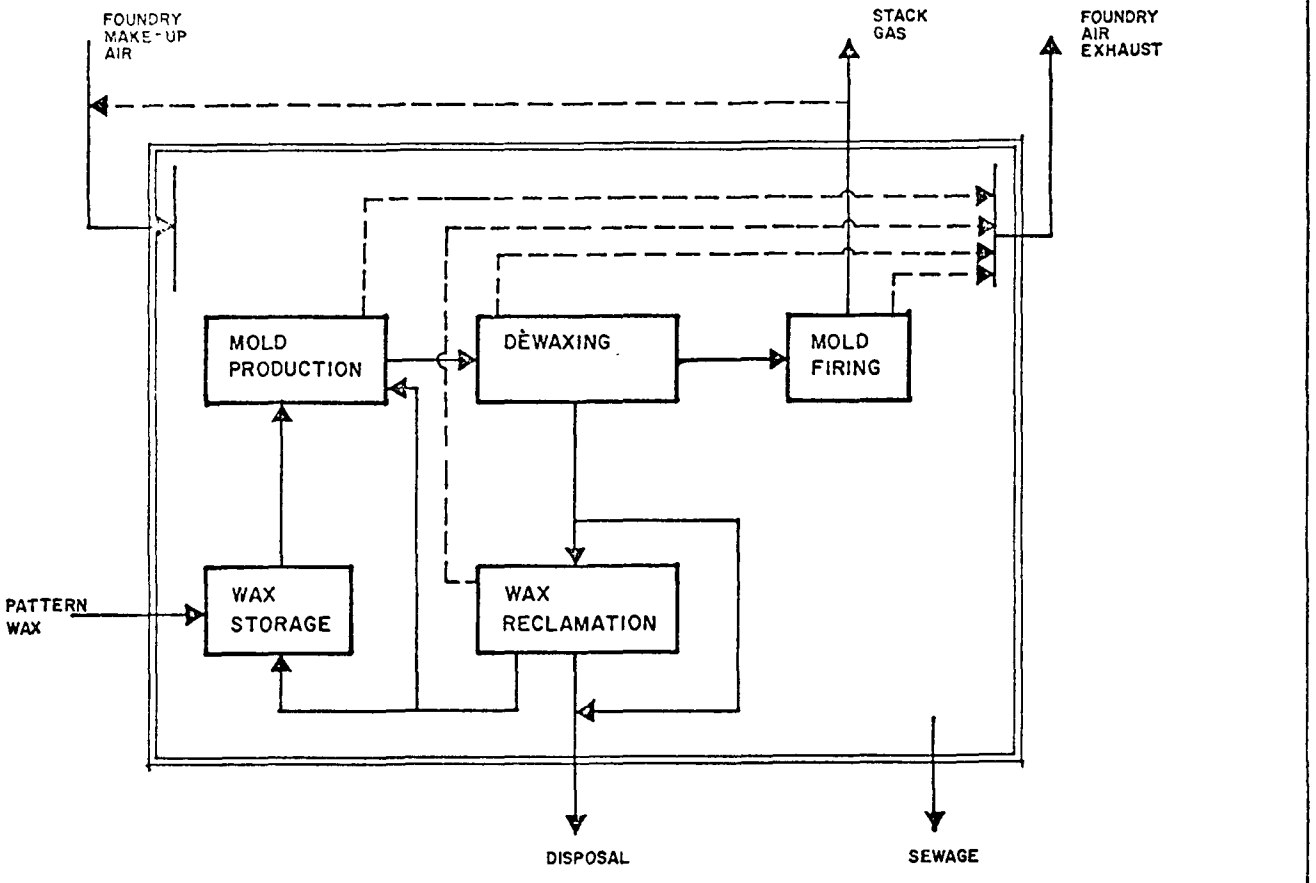


FIGURE 3.3.2.3-1

IDEALIZED FLOW CHART FOR AN INVESTMENT CASTING FOUNDRY, SHOWING WASTE STREAMS

NWMAR115829

The solid lines at the top of the figure indicate the two general ambient air escape routes, namely the stack gas from the mold firing furnace and the foundry exhaust air system. The two solid lines leaving the foundry (at the bottom of the figure) represent PCB and PCT escape routes: solid waste, which is usually sent to landfills, and raw sewage, which goes to municipal sewage treatment in most cases. The broken line outside the facility (at the top of the figure) indicates the possibility for inadvertent recycling of escaped PCBs or PCTs in stack gas or foundry air exhaust back into the foundry facility.

PCB-PCT-containing waxes enter the foundry as pattern wax packaged in plastic lined boxes which are stored until needed in the casting process. During mold production, when the wax is melted and injected into metal dies, wax fumes may escape. The type of dewaxing method employed by the foundries has a direct effect on the amount and mode of PCB or PCT loss to the environment, not only during dewaxing but also during process steps that follow. For example, the use of a steam autoclave, in addition to its own potential emission of PCBs or OCTs, also imparts moisture to the wax, and this water must be removed before the wax can be reused. Dewatering by evaporation at high temperature also likely contributes to air emissions. Flash firing, which combines mold firing and dewaxing into one step, probably emits high levels of PCBs or PCTs, and so far as is known, emission controls are not used.

Solid wastes can include unreclaimed used wax, excess reclaimed wax, bottoms from reclamations, and wastes from spills, equipment cleanout, etc. Although process water does not appear to be used, some plants may use cooling water. The steam autoclave appears to be a source of water vapor only.

3.3.3 Wax Manufacturing

To date, very little is known about the wax manufacturing process. However, it is known that in the process PCB or PCT compounds are added in powdered form to the wax base. Reduction of PCB or PCT particle size prior to mixing may be desired. Losses of dust to the environment by air routes from both size reduction and mixing operations would be expected.

NWMAR115830

3.3.4 Recommendations

The information presented herein represents the current knowledge of decachlorobiphenyl and polychlorinated terphenyls usage as wax fillers in the investment casting industry. This knowledge should be used as a basis for the development of an accurate assessment of the importance of PCB and PCT waste from the industry, and of the adequacy of available substitutes. Significant information gathering efforts would be required to establish a complete picture of the practices, processes and product of the investment casting foundries and wax manufacturers. Definition of the waste streams and emissions from the processes used would require sampling and analysis efforts in addition to the gathering of available process data and other information from the industry. The objectives of such a plan would necessarily include the following:

(1) Verification of the magnitude of PCB and PCT wax filler production and use;

(2) Development of detailed process descriptions, including waste streams, leading to a complete mass balance for the production and use processes (including significant variations);

(3) Definition of quantities and concentrations of waste streams, including waste form, abatement techniques, and ultimate disposal methods; and

(4) Evaluation of all reasonable alternatives to the use of PCBs and PCTs in casting.

A study plan to accomplish the above objectives was developed for OTS under Task III of this program (Contract 68-01-3259).

3.4 Secondary Fiber Recovery (Paper Recycling)

The secondary fiber recovery industry converts wastepaper from industrial, commercial, and municipal sources into reusable pulp, which is subsequently used to produce paper products, either as is or blended with virgin pulp. In the United States, there are approximately 230 paper mills

NWMAR115831

TABLE 3.4-1

PCB CONCENTRATIONS IN WISCONSIN PAPER PLANT EFFLUENTS

Plant	No. of Determinations	Average PCB Concentration (ppb)	PCB Discharged lbs./day	Aroclor Type
Badger Paper Mills	1	<.1	-	
Scott Paper				
Marinette	1	<.1	-	
Oconto Falls	1	<.1	-	
Shawano Paper	1	<.1	-	
John Strange Paper	1	4.00	.037	1242
Bergstrom Paper	4	28.40	1.25	1242
Kimberly Clark	1	0.28	.010	1242
Thilmany Paper	2	<.1	-	
Fort Howard Paper				
Mill Effluent	1	2.60	0.158	1242
Deinking	1	6.40	0.586	1242
Deinking & Mill Effluent	3	7.07	1.060	1242
American Can				
Sulfite Sewer	1	0.10	0.002	1242
Paper Mill Lagoon	1	0.14	.012	1242
Charmin Paper	1	0.14	.019	1242
Green Bay Packaging	1	0.45	0.006	1242

Note: Effluent flow data for these companies was determined at time of PCB sampling.

NWMAR115832

which produce pulp completely derived from wastepaper and 550 mills whose generated pulp contains secondary fiber (typically 10 to 15 percent).

Wastepaper stands third behind pulpwood and wastes from other forest products as a source of paper pulp in the United States. In 1974, fiber recovery mills removed almost 13 million tons of wastepaper from the nation's solid waste streams.

The effluent discharges from some of the secondary fiber mills has been documented by Kleinert to contain Aroclor 1242,[1] an apparent incidental PCB contaminant occurring in the pulp production process. Table 3.4-1 shows the PCB (as Aroclor 1242) concentrations and discharge rates for some paper recovery within the State of Wisconsin. These data were collected in 1975 by the Wisconsin Department of Natural Resources in an effort to survey PCB discharges.

The following subsections present a review of the historical usage of Aroclor 1242 in carbonless copy paper production and a brief description of a secondary fiber recovery process.

3.4.1 Historical Use of PCBs in the Paper Industry

Aroclor 1242 (which appears to be the predominant PCB found in mill effluents)[1] was used in the manufacture of carbonless copy paper sold by the Appleton Paper Division of the NCR Corporation during the period 1957 to 1971. Tables 3.4.1-1 through 3.4.1-3 provide data indicating: (1) The magnitude of Aroclor 1242 consumption in the manufacture of NCR carbonless paper; (2) Production quantities of NCR carbonless paper; and (3) The weight percent of Aroclor 1242 in carbonless paper.

From these tables, several significant facts are derived concerning the magnitude of PCB use in the manufacture of carbonless paper products. Some of these facts are:

(1) Approximately 44 million pounds of Aroclor 1242 were purchased (from Monsanto) for the manufacture of NCR carbonless paper;

NWMAR115833

TABLE 3.4.1-1

HISTORY OF AROCLOR 1242 CONSUMPTION
IN THE MANUFACTURE OF NCR CARBONLESS PAPER
FOR THE YEARS 1957 THROUGH 1971[1]

YEAR	(THOUSANDS OF POUNDS)
1957	587
1958	779
1959	1019
1960	1149
1961	1643
1962	1953
1963	2281
1964	2705
1965	3489
1966	4246
1967	4355
1968	5801
1969	6278
1970	6611
1971	1266
TOTAL - 1957 through 1971	44162

Note: [1] From data compiled and reported by Appleton Papers Division, *NCR Corporation.*

NWMAR115834

TABLE 3.4.1-2

HISTORY OF NCR CARBONLESS PAPER PRODUCTION
FOR THE YEARS 1957 THROUGH 1971

YEAR	ESTIMATED NCR CARBONLESS PAPER PRODUCTION - TONS
1957	10010
1958	13264
1959	17434
1960	20703
1961	25504
1962	29708
1963	34583
1964	41762
1965	51855
1966	60594
1967	69512
1968	83250
1969	87336
1970	91576
1971	88977
TOTAL,[1] 1957 through 1970	726068

Note: [1] Total excludes 1971 because use of Aroclor 1242 was discontinued in May, 1971 but estimated production of NCR carbonless paper is for full year.

NWMAR115835

TABLE 3.4.1-3

RATIO OF AROCLOR 1242 CONSUMPTION FOR CARBONLESS
TO NCR CARBONLESS ESTIMATED PRODUCTION

Year	(A) Aroclor 1242 Consumption Thousands of Pounds[1]	(B) NCR Carbonless Estimated Production Thousands of Pounds	PCB Content $\frac{(A)}{(B)} \times 100$
1957	587	20020	2.9
1958	779	26528	2.9
1959	1019	34868	2.9
1960	1149	41406	2.8
1961	1643	51008	3.2
1962	1953	59416	3.3
1963	2281	69166	3.3
1964	2705	83524	3.2
1965	3489	103710	3.4
1966	4246	121188	3.5
1967	4355	139024	3.1
1968	5801	166500	3.5
1969	6278	174672	3.6
1970	6611	183152	3.6
1971	1266	177954	-
TOTAL[2] 1957 thru 1970	42896	1274182	Avg. 3.4%

Notes: (1) From data compiled and reported by Appleton Papers Division, NCR Corporation.

(2) Total excludes 1971 because use of Aroclor 1242 was discontinued in May, 1971 but estimated production of NCR carbonless paper is for full year.

NWMAR115836

(2) The average weight percent of Aroclor 1242 in carbonless paper was 3.4 percent;

(3) Of the total PCBs sold in the United States during 1957-1971, 6.3 percent were sold for the NCR carbonless paper application; and

(4) 28 percent of the total Aroclor 1242 sold by Monsanto for plasticizer applications was purchased for the manufacture of NCR carbonless paper.

Although NCR developed and sold the product, the actual manufacturing step whereby Aroclor 1242 was incorporated into the paper was performed by the Mead Corporation of Dayton, Ohio, who exclusively supplied carbonless paper to NCR. NCR, in turn, either used the supplied paper to manufacture ledger (business) forms or sold and distributed the carbonless paper to other form manufacturers. Aroclor 1242 is reported to be the only Aroclor type used in the production of carbonless paper. Specifically, Aroclor 1242 was used as a solvent for certain color reactants which were encapsulated into microspheres 10-20 microns in diameter and applied to one side of the paper during the coating process. The walls of the microspheres consisted of a gelatin-gum arobic formulation which was hardened by treatment with an aldehyde (such as formaldehyde). Since 1971, alkyl biphenyl compounds have been used in place of Aroclor 1242 as the dye carrier.

Very little is known about other uses of PCBs in the paper industry. Past usage of PCBs in paper coatings and adhesives appears likely, although the quantities used could not have been near the magnitude of PCB usage in the carbonless copy paper. Almost certainly PCBs were used in some of the inks, and possibly paper colorants, which can also be expected to occur in wastepaper. According to Monsanto, the favored Aroclor type used in inks was 1254, which contains most of the same isomers as 1242 but at different relative concentrations.

NWMAR115837

In addition, PCBs can enter the pulping process through contamination of intake water and in virgin pulp. Little is known about the magnitude of any of these sources, or even how much carbonless copy paper containing PCBs remains in files, etc. to enter the paper recycling processes in the future.

3.4.2 Fiber Recovery Mill Process

The following is a generalized description of the mill process for recovering paper fiber. Portions of this description was provided by the Bergstrom Paper Company in Neenah, Wisconsin. Figure 3.4.2-1 depicts the general process, up to the paper making section, in block form.

The fiber recovery process is a purification process wherein fibrous materials are deinked and separated from non-fibrous materials through controlled cleaning and mechanical treatment, followed by washing and cleaning. The color is next removed from the pulp by a multi-stage bleaching system accompanied by intermittent washing and centrifugal dewatering.

Pulping and Deinking: The fiber regeneration process starts with feeder crews loading the sorted paper onto a belt conveyor. The conveyor feeds a hydropulper, where wastepaper is pulped and deinked through the action of hot water, steam, caustic soda, and deinking chemicals. The breaking down of the paper stock is accomplished through a combination of mechanical and chemical treatment. At this point, larger metallic objects and other non-paper materials mixed with the wastepaper are collected into traps at the bottom of the pulper. The pulped stock leaves the hydropulper via extrusion through perforated plates, and goes to blending chests for additional retention time and agitation. From the blending chests the stock passes over a vacuum filter which is used for heat and chemical recovery. Much of the filtrate is recycled to the hydropulper; excess filtrate goes to treatment. The stock is then diluted and sent to centrifflers where small metallic particles such as pins and staples are removed.

NWMAR115838

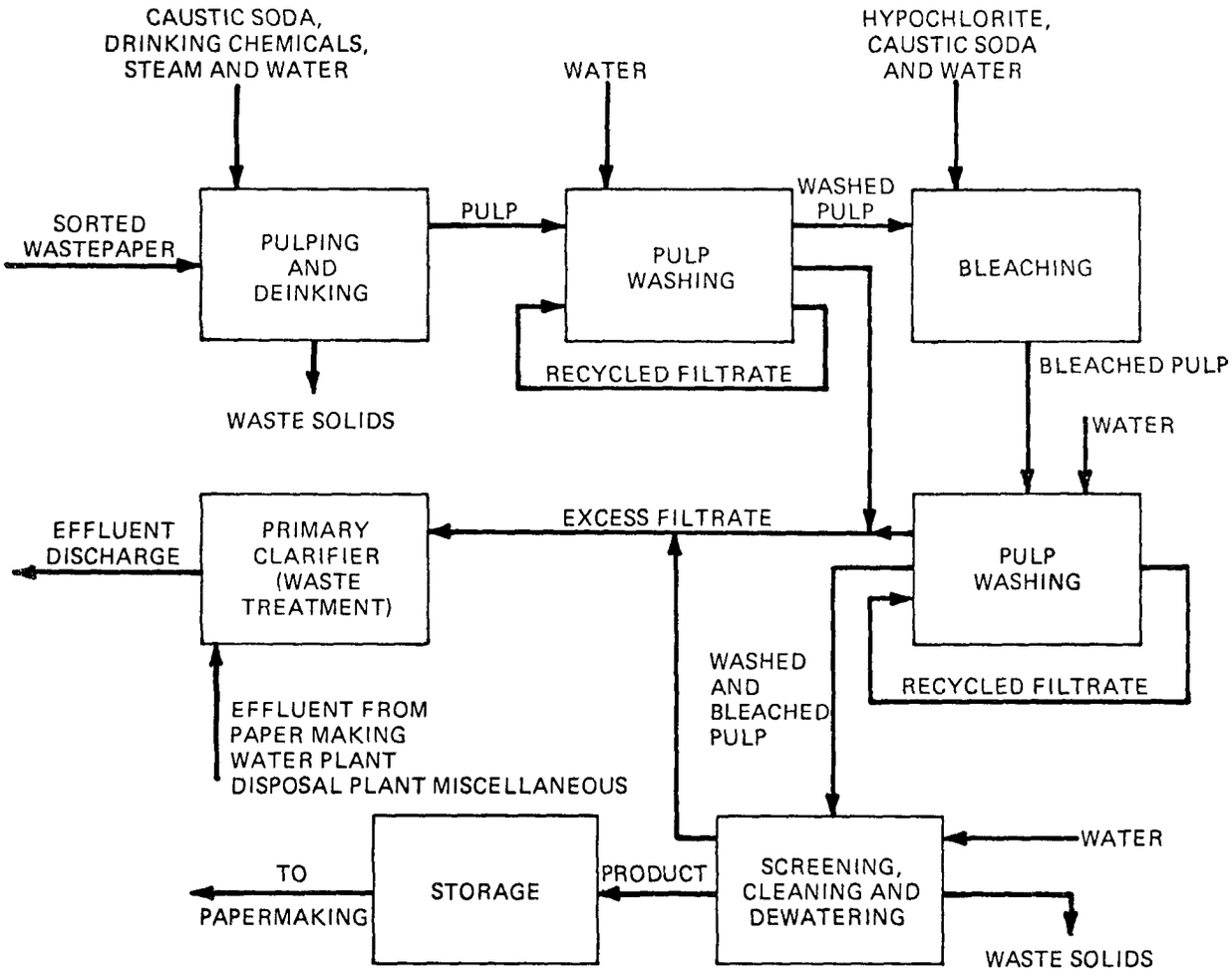


Figure 3.4.2-1. MILL FIBER RECOVERY PROCESS AND WATER EFFLUENTS

NWMAR115839

Pulpwashing: Accepted stock from the centrifflers goes on to the washing stage. Stock washing is accomplished in a four-stage counter-flow washing system. The first stage consists of cylinder washing, the second and third stages consist of sidehill washers, and the fourth stage is another cylinder washer. The cleanest water is used for dilution at the fourth stage, and the filtrate is fed to the preceding stage, finally reaching the first stage from which the filtrate is discharged for waste treatment.

Bleaching: Following washing, the stock goes to a three-stage bleachery. At the first stage the stock is chlorinated by sodium hypochlorite solution in a tower. After chlorination, the stock is washed on a vacuum filter. In the next stage the stock is treated with caustic soda and sodium hypochlorite. After retention in a second tower the stock is diluted and again washed on a vacuum filter. It is then treated again with sodium hypochlorite in a third tower.

Screening and Cleaning: After retention in the third tower, the bleached stock is diluted for the next cleaning process, which is a three-stage pressure screen system. Accepted stock from the first stage pressure screen goes to a five-stage centrifugal cleaner system for removal of small-sized heavy contaminants. Following this, the pulp is sent to a four-stage system of centrifugal cleaners for removal of lightweight contaminants.

After the cleaning, the stock goes to a final washing stage and is then dewatered (thickened) and stored in high density towers for paper making.

Flow Rates and Composition of Discharges: At Bergstrom the separate waterborne discharges from the paper and the paper making process are combined with other facility waste streams and directed to a central waste treatment system. Only the effluent from the primary clarifier of the waste treatment system is discharged to the environment. The average effluent flow rate for Bergstrom during 1975 was 3.9 million gallons per day. This volume rate is broken down as follows:

NWMAR115840

Process	Volume Rate to Waste Treatment Million Gallons/Day
Deinking	2.5
Paper Making	.9
Water Plant	.3
Disposal Plant and Miscellaneous	.2

Table 3.4.2-1 is a tabulation supplied by Bergstrom of the 1974 averages for various parameters in their raw water source and waste clarifier effluent. The average Aroclor 1242 concentration in the effluent was reported to be less than 8 ppb.

Recommendation (Paper Recycling): The information presented herein with regard to PCBs in paper recycling processes is based on a very limited study effort on the secondary fiber recovery industry. It is recommended that a more detailed study be performed of PCBs involvement in this industry. Important aspects which should be addressed include:

(1) Definition of paper recycling processes and the PCBs material balance therein (PCBs input versus PCBs content in effluent and product);

(2) Definition of past PCBs usage in paper and routes into recycled paper;

(3) Development of present distribution of PCBs originally used in paper;

(4) Determination of applicable effluent treatment methodology and associated cost estimates; and

(5) Projecting future contribution of PCBs to the environment from this industry.

NWMAR115841

TABLE 3.4.2-1

COMPOSITION OF RAW WATER AND CLARIFIER EFFLUENT (1974 DATA)
(Bergstrom Paper Co.)

	Raw Water	Clarifier Effluent
Aldrin, µg/l	<0.1	<0.4
Ammonia Nitrogen, mg/l	0.32	1.72
Arsenic, µg/l	<8	<8
Barium, µg/l	14	140
Beryllium, µg/l	<0.3	<5
Boron, µg/l	33	235
Cadmium, µg/l	<16	<16
Chloride, mg/l	10	482
Chlorine, mg/l	<0.5	<0.5
Chromium, µg/l	<4	26
Cobalt, µg/l	<14	14
Copper, µg/l	<5	78
Cyanide, mg/l	<0.005	0.12
Dieldrin, µg/l	<0.03	<0.03
Fecal Coliform Count/100 ml	4	<10
Fluoride, mg/l	0.46	0.48
Heptachlor, µg/l	<0.07	<0.5
Lead, µg/l	<42	85
Manganese, µg/l	10	50
Mercury, µg/l	0.7	0.5
Nickel, µg/l	<33	<33
Nitrate Nitrogen, mg/l	0.29	1.32
Nitrite Nitrogen, mg/l	<0.005	0.43
Kjeldahl Nitrogen, mg/l	0.82	19.0
Oils, Fats, Grease, mg/l	<1	26.4
Phenol, µg/l	4	26
Phosphorus, mg/l	0.11	0.57
PCBs, µg/l	<0.5	8.0 (1242)
Selenium, µg/l	<8	<8
Sulfate, mg/l	45	74
Sulfide, mg/l	<0.05	<0.05
Sulfite, mg/l	<2	<2
Suspended Solids, mg/l	<1	465
Thallium, µg/l	<1	<25
Zinc, µg/l	67	420
BOD_5, mg/l	1.1	665

NWMAR115842

3.5 Industrial Use of PCBs as Hydraulic and Heat Transfer Fluids

3.5.1 General

The use of PCBs in hydraulic and heat transfer systems increased rapidly during the 1950s and 1960s until, in 1970, the maximum sales by Monsanto for these uses, plus lubricants, were about 11.3 million pounds, or over 15 percent of the total 1970 reported domestic sales. Since 1971, Monsanto has not marketed PCBs for these uses, and although it should be noted that such usage of PCBs in deep mining equipment is expressly allowed by the OECD agreement to which the U.S. is party.

When PCBs sales for heat transfer and hydraulic uses were eliminated by Monsanto in 1971, the affected industries turned to substitutes or, in a very few cases, imported PCBs. Phosphate esters have found acceptance in many types of hydraulic systems where PCBs were formerly used. Glycols and other alcohols have replaced PCBs in some heat transfer systems, and there are a number of other substitutes used for this purpose (including other chlorinated hydrocarbons).

It is surmised that there are industrial concerns still using PCBs in these semi-closed systems. Hesse reported at the National Conference on PCBs in November, 1975 that a number of such users had been found in Michigan. Later contacts with these same firms indicated that all had voluntarily replaced the PCBs in their systems with substitute fluids. Very little work has been done to ascertain the magnitude of current PCBs usage for hydraulic and heat transfer purposes. Of the total reported Monsanto domestic sales of PCBs over the period 1957-71 for heat transfer fluids, hydraulic fluids, and lubricants, 81 million pounds, it seems reasonable that at least 95 percent have been replaced by substitutes or were in systems now obsolete. On this basis the maximum amount still in use would be on the order of four million pounds. A figure of two million pounds still in use is probably more accurate.

NWMAR115843

3.5.2 Use of Imported PCBs by Joy Manufacturing

Until recently, Joy Manufacturing Co. (Pittsburgh, Pa.) manufactured mining equipment which utilized a PCB motor coolant. Joy imports PCBs, as a mixture similar to Aroclor 1242, from France (Prodelec). Presently, the PCB type motors are no longer manufactured and have been replaced on new units by an air-cooled motor. However, PCB coolant fluids purchased from France are being used for servicing the old liquid coolant motors. Currently, there are approximately 1100 of the old motors in the field, each of which contains an estimated 3 - 4 gallons of PCB type coolant fluid. The operating time of these motors before complete overhaul is between 1 and 2 years. The major benefit derived from using the PCB type coolant was its fire retardant characteristics.

From the information received by representatives of Joy Manufacturing Company, and from available physical properties, it is estimated that between 40,000 and 60,000 pounds of the imported PCB type coolant fluid would be necessary to replace and "top off" the fluids in the old motors each year.

3.6 Recent Use of PCBs in Product Development Activities

Since the voluntary limitation on the sale of PCB compounds in the United States by Monsanto, small quantities of PCB compounds have been imported for new product development by at least one U.S. company. Such a use application, by E. I. duPont de Nemours and Co., Wilmington, Del., was for development work on a new polymer which is derived from the reaction of decachlorobiphenyl (deka) and Bisphenol A.

According to duPont representatives, they have imported small quantities of deka from Caffaro (Italy) for experimental purposes with the intent to develop a new product called NR-140 polymer. Approximately 2000 pounds of deka were imported in 1974; however, duPont did not import any deka in 1975. A decision was made not to commercialize the new product because of the uncertainties associated with the regulation of PCBs.

It is estimated by duPont that, if the new product had been commercialized, the annual purchase of deka would be in the range of 5-10 million pounds.

NWMAR115844

BIBLIOGRAPHY

1. Adduci, V.J., Letter to Mr. Russell Train with attachment entitled, "Statement of Electronic Industries Association to Environmental Protection Agency Concerning Proposed Toxic Pollutant Effluent Standards for Polychlorinated Biphenyls (PCB)", June 25, 1975.

2. Air-conditioning and Refrigeration Institute, Letter to Dr. C.H. Thompson, EPA, March 27, 1974.

3. AFML-TR-74-237, "Mfg. Methods for Production of Quality Superalloy Engine Parts", DDC Acquisition No. AD B0074 DCL.

4. Blatz, Philip S.D.,(E.I. duPont de Nemours and Company, Wilmington, Delaware), Personal communication, August 14, 1975.

5. Bolin, A.E., (Van Train Electric Corp.), Telephone communication, October 31, 1975.

6. Butner, J., (Sangamo Electric Co.), Personal communication, October 2, 1975.

7. Clark, R., (Universal Manufacturing Corp.), Telephone communication, November 24, 1975.

8. Colder, A.W., (Joy Manufacturing Co., Pittsburgh, Pa.), Personal communication, September 8, 1975.

9. Dornbush, W., (McGraw-Edison's Power System Div.), Personal communication, September 23, 1975.

10. Falk, Bernard H., (National Electrical Manufacturers Association), Letter to Dr. C. Hugh Thompson, EPA, March 25, 1974.

11. Farnsworth, George B., presented General Electric Testimony, FWPCA(307) Docket No. 1.

12. Gabel, H.E., Jr., (Niagara Transformer Corp.), Telephone communication, November 3, 1975.

13. Gunn, R., (H.K. Porter Co., Inc.), Telephone communication, November 3, 1975.

14. Hart, L.P., Jr.; Wright, Gary; Marquis, R.; and McKenzie, W.R., (General Electric Co.), Personal communication, October 22, 23, and November 11, 25, 1975.

15. Hesse, J., (Michigan Department of Natural Resources), paper presented in Chicago, EPA sponsored symposium on PCBs, November 19, 1975.

NWMAR115845

16. Hubbard, H.L., Encyclopedia of Chemical Technology, 1965, Vol. 5, pp 289-297.

17. Jard Company, Inc., Letter to the Consumer Products Safety Commission, May 2, 1974.

18. Johnsen, L.A., (Research-Cottrell Manufacturing Division), Personal communication, October 28, 1975.

19. Kleiner, S., Survey of Effluents in the State of Wisconsin in 1974 and 1975 by the Wisconsin Department of Natural Resources, Data presented in Chicago, EPA sponsored symposium on PCBs, November 19, 1975.

20. Kingsolver, W.S.,(McGraw-Edison Co.), Personal communication, December 15 & 26, 1975.

21. Leighton, I.W., "Demonstration Test Burn of DDT in General Electric's Liquid Injection Incinerator", U.S. EPA Region I, 1974.

22. Leisy, A.E. & Smull, Warren, (Monsanto Industrial Chemicals Co.) Personal communication, October 8, 1975.

23. Leisy, A.E., (Monsanto Industrial Chemicals Co.), Personal communication, November 6, 1975.

24. Lewis, W.H., (President, Signicast Corp., 9000 North 55th Street, Milwaukee, Wisc.), Statements made during lecture of Investment Casting Institute meeting, October 4, 1975.

25. Monsanto Industrial Co., Testimony, FWPCO(307) Docket No. 1, Presented by Mr. W.B. Papageorge.

26. National Industrial Pollution Control Council's Report, "The Use and Disposal of Electrical Insulating Liquids", June, 1971, p. 10.

27. Nelson, J.S., (General Electric), Letter to Dr. Martha Sager, with attachment entitled The Impact of a "Ban" on the Use of PCB in Capacitors, November 21, 1973.

28. Nelson, J.C., and Simon, E.L. (General Electric Company), Personal communication, September 4, 1975.

29. Oliver, O.M., (Standard Transformer Co.), Telephone communication, October 30, 1975.

30. Ortman, J., (Sprague Electric Co.), Telephone communication, November 20, 1975.

31. Papageorge, W.P., (Monsanto Industrial Chemicals Co.), Personal communication, August 27, 1975.

NWMAR115846

32. Pierle, A. Michael, (Monsanto Industrial Chemicals Co.), Polychlorinated Biphenyl Study, Personal communication, November 17, 1975.

33. Report on Power Transformer Troubles, 1969, Edison Electric Institute Publication No. 71-20 (1971).

34. Rollends, D., (Jard Corporation), Personal communication, October 2, 6, 1975 & January 15, 1976.

35. Rountree, William C., (Assistant General Counsel for Legislation, U.S. Dept. of Commerce), Letter to Dr. C. Hugh Thompson, EPA, March 26, 1974. (See discussion of PCB beginning on fourth page of attachment).

36. Salazer, A., (National Electrical Manufacturers Association (NEMA)), Personal communication, August 19, 1975.

37. Solomon, P., (Yates Manufacturing Co., Chicago, Illinois), Personal communication, September 9, 1975.

38. Stenger, R.A., "Monitoring of the General Electric Company", U.S. EPA Region II, Surveillance Analysis Div., Edison, N.J. September 26, 1975.

39. Thallner, K.A., (Helena Corporation), Telephone communication, October 31, 1975.

40. Thayer, J.H., (General Electric Co.), Personal communication, October 15, 1975.

41. Tuttle, C.; Teeple, P.L.; Hutzler, J.R.; & Butterworth, N., (Aerovox Industries, Inc.), Personal communication, September 25, 26, 1975.

42. Uptegraff, R.E., (R.E. Uptegraff Mfg. Co.), Telephone communication, November 3, 1975.

43. Vollmar, John R., (Louis T. Klauder and Associates), Letter to Dr. C. Hugh Thompson, EPA, March 22, 1974.

44. Wolsky, S.P., (P.R. Mallory & Co., Inc.), Telephone communication, November 21, 1975.

45. Wurster, W., (General Manager, Consolidated Casting Corp, 2425 Carolina St., Dallas, Texas), November 5, 1975.

NWMAR115847

SECTION VI

WASTE TREATMENT TECHNOLOGIES

1.0 INTRODUCTION

This section includes descriptions and discussions of existing and proposed technologies for the treatment of various types of wastes generated at PCB-producing and PCB-using plants. Also included are discussions of the presently available control technologies and technologies to be available within three years, plus technologies that will not be available for five or more years. The treatment and control costs included here have been developed and presented in the Task II report "Assessment of Wastewater Management, Treatment Technology, and Associated Costs for Abatement of PCBs Concentrations in Industrial Effluents", EPA Contract No. 68-01-3259, issued February 3, 1976.

1.1 Summary of Waste Management Problem Areas

Based upon detailed plant inspections and examinations of the processes in the production of PCBs and their use in capacitors and transformers, it has been determined that there are four major categories of wastes to be considered: waste liquid PCBs, PCBs in wastewater, PCB contaminated solid wastes, and airborne PCB emissions. It has also been determined that the characteristics of wastes in PCBs producing and using operations are similar enough that the same kinds of control and treatment technologies can be used.

1.1.1 Waste Liquid PCBs and Contaminated Scrap Oil

The users of dielectric materials have strict requirements for purity. Typical requirements are:

Inorganic chlorides	100 ppb maximum
Acidity, mg KOH/g	0.01 maximum
Water content	30 to 35 ppm maximum
Resistivity, 100°C, 500 V, 0.1 inch gap	100 to 500 x 10^9 ohm-cm, minimum
Dielectric strength, 25°C	35 kv minimum

NWMAR115848

When these or other properties cannot be met at the producer's facility, or by the user during transformer and capacitor filling operations, and it is found that the properties cannot be restored to askarel specifications by filtering and drying, disposal is required. The types of PCB contaminated liquids requiring disposal are:

1. PCBs contaminated with mineral oil
2. Mineral oil contaminated with PCBs
3. Nonreclaimable contaminated transformer askarels - arced askarels, askarels from manufacturing spills and sump accumulations, and askarels from holding basins, drip and drain pans, washings, sample jars and containers

1.1.2 PCBs in Wastewaters

The most likely pathways by which PCBs enter wastewater streams are operator wash-up after PCB handling and groundspills that mix into rainwater runoff. The significance of the first pathway can be illustrated by the realization that sixteen operators (or 4 operators 4 times a day) washing 1 ounce per day of PCB from their hands, account for one pound per day of PCB discharge.

Other wastewater categories discussed in the industrial characterization section of this report are:

1. Incinerator scrubber and quench water
2. Steam jet ejectors in vacuum distillation
3. Capacitor detergent wash solutions

1.1.3 PCB-Contaminated Solid Wastes

Solid wastes can be divided into two categories, burnable and non-burnable.

1.1.3.1 Burnable Solid Waste Materials Containing PCBs

Burnable wastes can be disposed of by high-temperature incineration. Such wastes consist of cellulosic materials, rags, pressboard, wood, sawdust, fuller's earth in bulk or in cloth bags, blotter papers, nitrile or cork gaskets, and similar materials.

NWMAR115849

1.1.3.2 Nonburnable Solid Waste Materials Containing, or Contaminated with PCBs

Nonburnable wastes may consist of capacitor and transformer internal components; steel, copper and aluminum components; filter units of the steel mesh construction type; and askarel drums and cans. Wastes of this type should be drained, with the liquid collected in drip pans, before disposal.

1.1.4 Air Emissions of PCBs

Although PCBs have very low vapor pressures they can be emitted to the atmosphere from the following operations and practices:

1. Aroclor scrubbing of air in PCBs manufacture
2. Vapor exhaust from steam jet ejectors
3. Evaporation from accidental spills
4. Evaporation from hot surfaces as part of flood-filling, inspection or holding operations
5. Vacuum pump exhausts
6. Evaporation from plant wastewater

1.2 Summary of Current PCBs Waste Control Practices

1.2.1 Control of Waste Liquid PCBs and Contaminated Scrap Oils

Plant visits have shown the major control methods to be incineration and disposal in sealed drums sent to sanitary landfills. Both incineration and landfilling may be carried out by the facility generating the waste, or the facility may engage a contractor.

Monsanto, the only U.S. producer of PCBs, has an incinerator (designed by John Zinc, Inc.) that vaporizes PCB liquids and sustains them in a turbulent burning gas at more than 2200°F for 2 seconds. One transformer manufacturer uses a John Zink designed incinerator that vaporizes PCBs and burns them at 1600 to 1800°F for 3 seconds or longer; this facility can also destroy PCBs soaked into transformer internal parts, but cannot routinely handle spent fuller's earth.

NWMAR115850

A number of PCB users send their solid wastes to the Rollins Environmental Services facility at Logan Township, N.J. Rollins uses a specially designed complex having a rotary kiln and a liquid turbulent burning chamber, both of which exhaust into an afterburner. Liquids can be burned in either the liquid chamber or the kiln; in the kiln liquid wastes can help to incinerate solids. The afterburner is 40 feet long, providing good residence time, and it is followed by a hot duct of about equal length that allows further combustion. Rollins claims a residence time of 3 to 4 seconds at a minimum temperature of about 2400°F at the aft end of the hot duct. The gases then go to a venturi scrubber and a tower scrubber for cooling and neutralization. For non-PCB incineration, Rollins sometimes lowers combustion temperature to 2200°F and residence time to 2 to 3 seconds. These residence times and temperatures were chosen experimentally to get 99.999-percent PCB destruction. This facility also handles all kinds of solids, as will be explained later, and it operates with EPA approval.

Another facility that incinerates liquid PCBs, with New York State EPA approval, is the Chemtrol Corp.'s facility at Model City, New York.

Liquids going to landfill are sealed in drums and added to landfills that have deep clay bases and impervious bulkheads to prevent leaching and seepage. However, incineration is the preferred disposal method for liquids.

1.2.2 Control of PCBs in Wastewaters

Our plant investigations have revealed that there are no methods being practiced whereby dissolved or otherwise bound PCBs in water streams are being either extracted from those streams or destroyed in them.

In the separation of PCBs from wastewaters, PCBs and sludges are removed from the bottom of water bodies, while oily phases are removed from the surfaces. However, nothing as yet is being done to treat the water layer itself; this is the area of PCB wastes control and treatment most needing development.

In general, waste streams contain between 1 ppb and 500 ppb of PCBs; most levels range between 10 and 50 ppb. PCB concentration of less than 1 ppb are undetectable.

NWMAR115851

Several plants use methods to keep the quantity of PCB contaminated wastewaters as small as possible. A few plants planned adsorption tests with carbons and other adsorbents, but there were no full-scale operations.

1.2.3 Control of Solid Wastes Contaminated with PCBs

The two current methods of disposal of solid or semi-solid PCBs wastes are incineration and landfill. Since we found only one PCB-using manufacturing facility with partial incineration capability, and Monsanto's incinerator cannot handle solids, all facilities except one must ship their solid wastes away from the plant site for either treatment. The one plant with partial capability can incinerate transformer internals to recover copper, and also can incinerate paper, rags, cardboard and the like. However, they do not as yet, incinerate fuller's earth, contaminated dirt, and similar materials. These are drummed and stored for later disposition.

Although there are a number of experimental facilities throughout the U.S. that could undboutedly incinerate all types of solid materials, one commercial venture has received the bulk of the work. Rollins Environmental Services can handle liquids incineration. For solids incineration of almost all types, the tumble burner or rotary kiln is used. When PCB contaminated materials are to be destroyed, the kiln temperature is brought up to 2200°F. All kinds of solids, packed in 47-gallon lined fiber drums and not posing unusual safety hazards are accepted. The current (late 1975) fee is about 7-1/2¢/pound. Additional charges of $3/fiber-drum handling, plus transportation charges, and possibly other charges for unusual problems, might be made.

Rollins will not accept impact sensitive, radioactive materials, or heavy metals concentrations of more than 25 ppm in the PCBs wastes. For wastes packed in steel drums, Rollins charges a $10/drum handling charge. As a general rule, anything packed according to the latest ICC tariff for hazardous materials will be accepted.

As with the liquids incineration, the gases from the kiln at 2200°F pass to the afterburner at a temperature of about 2500°F. Gases exit

NWMAR115852

the afterburner to a long hot duct that completes combustion and maintains the temperature at 2400°F until the gases enter the venturi scrubber, and thence to the lower scrubber and then the stack. Rollins has experimented with lower temperatures of 2000 to 2200°F and has not found destruction of PCBs to be at the 99.999 percent level desired. The residence time for gases at the 2400°F must be 3 to 4 seconds in a turbulent regime.

With regard to landfilling, one commercial venture has handled a large quantity of the PCB solid wastes under supervised conditions. The Chemtrol Pollution Services Co. of Model City, N.Y., operates a landfill located on the shore of Lake Ontario, under New York State EPA supervision, in a geologic setting claimed to be ideal for complete containment.

This "scientific landfill" is located entirely above ground on a bed of 40-feet-thick clay. Constructed on this foundation are cells for receipt of drummed solid wastes. The cells are lined with 30-mil chlorinated polyethylene film, and when loaded, are sealed, or covered with 5-feet of clay. At the bottom of each cell there is a sump, so that all leachate is collected and removed. That leachate is pH controlled, settled, filtered, and treated by flow through a carbon bed. The ground and surface waters are checked monthly for chemical content by an outside analytical laboratory. The facility has been approved for usage as a PCB disposal site by the New York State EPA, and thousands of drums have been landfilled over the last five years. An inventory is kept of the contents of each cell.

Chemtrol has the capability of converting semisolids and sludges to solids by using silicate cement powders and proprietary gelling agents.

Our review and analysis of the industrial situation for PCBs solid wastes control shows there are adequate options, at higher prices, for safe disposal and destruction. There is no longer a justification for open dumping to the ground or in lagoons.

1.2.4 Control of Air Emissions of PCBs

Most air emissions from ambient temperature PCBs are not controlled or collected for treatment in any way. PCB emissions generally are

NWMAR115853

collected as part of the overall plant air exhaust, which frequently is ducted to roof exhausts without treatment. Several plants used exhaust chilling and/or fibrous or granular filtration of air; these methods offer the potential for PCB emission reduction.

The hot flood-filling of capacitors is followed by a cool down period before the filling tank is opened to the plant atmosphere. However, the temperature is still between 100 and 150°F; the area of the opening is several square meters, through which tank gases can reach the plant atmosphere. The tanks have individual exhaust ducts, but they lead directly to a roof exhaust system. The PCB-covered capacitors are held in an oven at 100 to 150°F to prevent any moisture condensation before sealing. Vapors from this storage are ducted to the roof and vented also.

In some cases, waste scrap oils containing PCBs are burned together with fuel oil in standard boiler systems. In these instances much of the PCB content is probably vaporized and exhausted to the air, rather than incinerated.

2.0 CANDIDATE PCBs WASTE TREATMENT TECHNOLOGIES CONSIDERED

As part of the examination phase of this study of alternative methods, we have contacted a number of equipment suppliers, developers, and researchers, in both the U.S. and elsewhere.

Key information was obtained on potential methods of PCBs removal from, and destruction in, wastewaters, by cooperative testing between Versar, Inc., and several materials suppliers and process developers. Their assistance is gratefully acknowledged.

We visited the U.S. producer, Monsanto, and several transformer and capacitor manufacturers to ascertain the nature, characteristics and quantities of plant effluents that now contain measureable amounts of PCBs, or might contain PCBs following a spill or other incident. This has provided the background for weighing the advantages and disadvantages of all available technology for potential application to PCBs wastewater treatment. We discussed and evaluated the control methods now used, possible shortcomings, and ideas for more optimized systems.

NWMAR115854

In order to find the new technology and approaches that might be forthcoming, we made a computer search of Chemical Abstracts from 1972 to the present, and focused on degradation, decomposition and waste treatment data. Searches were also made of the Lockheed Engineering Index, National Technical Information Service, and Predicasts for information on new developments.

The text reference used as a source of summarized data prior to 1972 was: The Chemistry of PCBs, by Hutzinger, Safe and Zitko, published in 1974 by CRC Press.

Candidate treatment technologies have been divided into the same four categories listed in Section 1.1. Also, as we evaluated technologies, they were placed into categories, as follows, indicating their level of development:

1. Demonstrated Full-Scale Treatments
2. Pilot-Scale Methods
3. Research Approaches to PCBs Removal or Destruction

Some treatment methods were designed for disposal of compounds similar to the PCBs, e.g., chlorinated hydrocarbons and other refractory organics.

The full-scale plant treatments are ready for application to PCB waste problems now. The pilot-scale methods are expected to take one to five years to be developed to the point where they will be determined suitable, or unsuitable, for plant-scale PCBs applications.

Methods currently under development are expected to take three years or more before being ready for plant-scale applications.

Section 2.5 contains a discussion of the applicability of various treatments to the zero discharge objective.

2.1 Treatment of Waste Liquid PCBs and Contaminated Scrap Oils

Only two kinds of treatment or disposal methods are considered suitable for waste liquid PCBs and contaminated scrap oils, and they are now being used. However, there are improvements and design features needed to prevent PCB transfer into the water, air or land.

NWMAR115855

2.1.1 Incineration

The standard configuration, long cylindrical steel combustion chamber, having a length to diameter ratio of between 4/1 and 8/1 and well insulated with high alumina refractory brick, is suitable as a primary chamber. Two injectors should be provided: one for a high-BTU gas or fuel oil, and one for the PCB waste liquid. Primary air or steam is provided to vaporize oils, and secondary air is added to complete combustion and provide excess air. These feeds should be made tangentially, or with adequate baffling to assure turbulent flow throughout, and to prevent hot or cold spots in the chamber. It is obvious that almost any residence time may be allowed for a gas flowing through a cylindrical chamber. However, there is a maximum residence time above which turbulence is assured throughout the chamber. Turbulence throughout is assured when wall temperatures are uniform in all parts of the chamber. Most fuel flames provide adiabatic combustion temperatures of about 3000°F. When the more endothermic PCBs are being destroyed, the flame can be rapidly cooled to 2200 to 2500°F; for the very high destruction efficiences desired, 99.999 percent or higher, this is the minimum temperature range required, for a residence time of 3 to 4 seconds. After combustion there should be allowance for afterburning, which may be accommodated in insulated ducts. These can be of sufficient length to assure total residence time of 3 to 4 seconds. Following the combustion phase there must be rapid cooling of the gases, usually by the injection of cold water from a peripheral ring of sprays or jets. Also, the cooling water should be neutralized so that hot hydrochloric acid contact with further components is obviated.

In some systems a high energy venturi scrubber is used to control particulates, if they are expected in the gas stream. In all systems the gas stream is then washed counter currently with water, or water plus neutralizing agent, in some form of a packed tower. Usually a demister is the last element contacted by the gas before it is exhausted through the stack.

The stack gas emissions and the scrubber effluent liquid should be monitored periodically for PCBs levels, and the incinerator should

NWMAR115856

have adequate automatic controls to prevent PCBs from being emitted undestroyed. The chief fail-safe control is a pyrometer that causes burner shutdown if the combustion chamber or duct temperature drops below about 2150°F. There are other controls that can warn if such an occurrence might take place. These flow rate controls on the primary and secondary feeds can be monitored so that low fuel flow, or high PCBs-to-fuel flow ratio can indicate a temperature drop. Inadequate air flow can also cause temperature decreases. All such parameters should be monitored, and adequate operator warnings provided. And, of course, to prevent destruction of the venturi scrubber sections, shutdown should automatically take place if cold water flow is ever insufficient.

2.1.2 Sanitary or Scientific Landfill

Sanitary landfilling is an alternative to incineration for PCB users who cannot justify incineration facilities just for PCBs, and who have no waste pickup service organization within reasonable distance. Landfills that will adequately contain PCBs should have all the features described in Section 1.3.3 above, plus there must be assurance that the liquid containers will be sealed and leak proof, and have long life in the landfill.

2.2 Treatment of Wastewaters Containing PCBs

Treatment of wastewaters containing PCBs has received very little attention in practice thus far. Our survey has found a variety of methods for reduction, and even for achieving "zero discharge", of PCBs in wastewaters.

2.2.1 Carbon Adsorption

Carbon adsorption is a well-known water purification and industrial product purification technique. The use of carbon adsorption is well-suited to removing PCBs from wastewater since it is most effective in removing high molecular weight, non-polar, relatively insoluble compounds from water. All these requirements are met by the PBCs.

As will be discussed later, Versar has conducted tests, in cooperation with carbon suppliers, demonstrating the relative effectiveness of

NWMAR115857

various activated carbon products. PCB concentrations on the order of 1 ppb were taken as a reasonable effluent objective.

The disadvantage of carbon adsorption is that once used, the carbon may have to undergo destruction by high temperature incineration rather than be regenerated, as is the usual practice. The great advantage of carbon treatment is that a wide spectrum of other toxic organics can simultaneously be effectively removed from water.

Carbon adsorption is currently being used in large-scale municipal water purification systems. Thus capital costs, operating costs and reliability factors are well-known. At the 68th Annual AIChE Meeting in November 1975, G. Strudgeon of Zurn Industries described design features for a 30-million-gallon-per-day carbon system to be built for municipal wastewater treatment at Garland, Texas. This system will cost $5 million, including carbon regeneration. Operating costs are expected to be $6,000 per day.

Although carbon adsorption is the only mechanism thus far proven effective in removing PCBs, three other carbon-based treatment techniques are under study: biodegradation, whereby bacteria-coated carbon particles break down pollutants in wastewater; catalytic action, wherein a very active surface holds pollutant molecules while other degradation or oxidation reactions take place; and chemical reaction, in which carbon is actually depleted as part of a chemical reaction that removes pollutants. The techniques were also discussed at the 68th Annual AIChE Meeting.

As an adjunct to this evaluation study, Versar conducted cooperative laboratory adsorption isotherm tests with Carborundum Company and ICI-US. These tests have extended the ranges of carbon adsorption data published by Calgon Corp. into higher and lower concentrations. Laboratory adsorption isotherm testing is a reliable technique for determining the feasibility of adsorption treatment for PCBs removal from wastewaters and specifically indicates:

1. The effluent levels of PCBs concentration obtainable by adsorption treatment
2. The weight of PCBs adsorbed at the concentrations being studied

NWMAR115858

On the other hand, the laboratory test does not determine the necessary contact time for granular carbon beds to effect the desired reduction. This determination is usually performed in small pilot carbon beds under hydraulic flow conditions.

Laboratory and pilot plant tests involving PCBs must be designed to prevent losses of PCBs. The root of the problem is the very low, parts per billion, solubility of PCBs in water. Examples of pathways of experimental loss are:

1. Evaporation to the air
2. Adsorption on a variety of solid surfaces and sediments

2.2.1.1 PCBs Adsorption Testing by Carborundum Company

Versar, Inc., together with Carborundum Co., conducted a preliminary study to determine the ability of an experimental, coal-based activated carbon in removing PCBs from water. This study also provided an analytical check in that both companies made electron-capture gas chromatograph analyses on the same samples, and there was close agreement on results.

The coal-based activated carbon had a surface area of 950 to 1050 square meters per gram. The iodine number was approximately the same as the surface area, indicating that almost all of the pores had a diameter greater than 10 to 15 Angstroms.

The control and test samples were filtered before extraction and gas chromatographic analysis. The removal of PCBs by solids, surfaces, filter media, and the like, was known and expected prior to these tests, thus a high PCB concentration in the filtered control and test samples was the target.

The PCB mixture used was Aroclor 1254. It was solubilized by methanol to give a 1000 ppm stock solution. This was diluted with distilled water to prepare 1000-ppb test solutions.

Table 2.2.1.1-1 presents the data. The filtered control level is considered the actual level the carbon was adsorbing, rather

NWMAR115859

TABLE 2.2.1.1-1

CARBORUNDUM CO. TESTS OF PCBs (AROCLOR 1254)
REMOVAL FROM WATER BY AN EXPERIMENTAL ACTIVATED CARBON

Prepared PCBs Concentration (ppb)		Carbon Dosage[1] (mg/l)	PCBs Conc. Before Treatment [Control Conc. After Filtering] (ppb)	Effluent PCB Conc. After Carbon Treatment (ppb)	Percent PCBs Removal
Control -	1000	--	160	--	--
Test	1000	1.0	160	59	63.1
Test	1000	2.0	160	20.6[2]	87.1
				22.0[3]	86.2
Test	1000	10.0	160	2.6[2]	98.4
				2.4[3]	98.5

NOTES: [1] Experimental material, coal-based, 950-1050 square meters/gram.
[2] Versar Inc.'s analysis.
[3] Carborundum Co.'s analysis.

NWMAR115860

than the prepared level. The filter removed 84 percent of PCBs in these test runs.

As shown in Table 2.2.1.1-1, the percent PCBs removed from a concentrated water solution (160 ppb) at low carbon dosages was quite good. During plant surveys we found PCBs concentrations in wastewater destined for river discharge to range from 50 to 500 ppb, so the 160-ppb concentration treated in this study was an intermediate value; it was, however, also the highest value treated in the cooperative studies under this program.

Carborundum Co. plans to continue this effort to determine the effects of other carbon dosage levels on various feed PCBs concentrations. The data given here are only considered preliminary.

2.2.1.2 PCBs Adsorption Testing by ICI-US

In a cooperative program with Versar, ICI-US performed preliminary adsorption tests to determine the ability of powdered carbon in removing Aroclor 1254 from water. Versar conducted all analytical tests for this program.

The Aroclor was solubilized with methanol so that a 1000-ppm concentration of Aroclor 1254 in water was achieved. Two types of granular activated carbon were tested: lignite base, and coal base. Both types were ground to a fine powder (90 percent through 325 mesh) before adsorption testing. Prior to grinding, the lignite-base and coal-base carbons had a surface area of about 650 square meters per gram and 1000 square meters per gram, respectively.

The test solutions were made up from distilled, deionized water to a volume of 1 liter. Four levels of Aroclor concentrations were treated: 10 ppb, 100 ppb, 500 ppb and 1000 ppb. Both the control and treated solutions were filtered before analysis. The great affinity of PCBs for all solid surfaces was not fully anticipated, during these tests. The filtration was uniform for all samples through 2.4-cm Reeve Angel fiberglass discs (Grade 934AH). As can be seen in Table 2.2.1.2-1, most of the PCBs were

NWMAR115861

TABLE 2.2.1.2-1

ICI-US TESTS OF PCBs (AROCLOR 1254) REMOVAL
FROM WATER BY TWO TYPES OF COMMERCIAL CARBONS

Prepared PCBs Concentration (ppb)	Carbon		PCBs Conc. Before Treatment (Control Conc. After Filtering) (ppb)	Effluent PCBs Conc. (After Carbon Treatment) (ppb)	Percent PCBs Removal
	Type	Dosage (mg/l)			
Control, 10	--	--	1.07	--	--
Test, 10	Lignite[1]	4	1.07	0.177	83.5
Test, 10	Coal[2]	4	1.07	0.190	82.2
Control, 100	--	--	11.15	--	--
Test, 100	Lignite	30	11.15	0.213	98.1
Test, 100	Coal	30	11.15	0.111	99.0
Control, 500	--	--	5.32	--	--
Test, 500	Lignite	100	5.32	0.09	98.3
Test, 500	Coal	100	5.32	0.114	97.9
Control, 1000	--	--	37.5	--	--
Test, 1000	Lignite	100	37.5	0.32	99.2
Test, 1000	Coal	100	37.5	0.24	99.4

NOTES: [1] Larger pore, 650 square meters per gram.

[2] Smaller pore, 1000 square meters per gram.

NWMAR115862

removed in filtration. However, by using the filtered "control sample" as an approximation of the amount the filter removes from all feed samples, we can get a good preliminary estimate of the PCBs removal ability of the two kinds of commercial carbons at various wastewater pollutant levels, and at various carbon dosages.

The results of these laboratory tests indicated that powdered carbon was highly effective in removing PCBs from water at four levels from 1 to 40 ppb. There was not a great deal of difference between the effectiveness of the two carbons. The lignite carbon has relatively large pores and smaller surface area than the coal-based carbon. The lignite-based carbon simulates the activity of the coal-based carbon after the latter has a number of thermal regenerations. Thermal regeneration tends to increase the pore size, and lower the surface area of any given carbon. These kinds of activated carbons, however, tend to stabilize at about 550 square meters per gram, even after many regenerations.

The conclusion from these results is that carbon-adsorption can be effective in removing PCBs from wastewaters, even after many thermal regenerations. It is quite significant that in all these tests, the treated effluent PCBs levels ranged from 90 to 320 parts per trillion, which are well below the target maximum PCB level of 1 ppb.

Further testing is needed to get confirmatory isotherm data and column test data. In column tests, the granular form of carbon was used, and, therefore, some of the interior portions of the carbon were not as accessible as they would have been in the powdered form. Thus the tests with powdered carbon, given on a weight fraction basis (i.e., pounds PCBs removed per pound of carbon), yield the maximum weight fraction of PCBs that that can be removed in a scaled-up commercial system.

2.2.1.3 PCBs Adsorption Testing by Calgon Corp.

Adsorption isotherms were run on Aroclor 1242 and 1254. Stock solutions of each compound were prepared in acetone at 100 mg/l.

NWMAR115863

Filtrasorb(R) 300 (FS-300) activated carbon was used throughout. Carbon was added from a stock suspension of 1 g or 2 g of pulverized FS-300 per liter of distilled water.

Isotherms of Aroclor 1242 and 1254 were prepared by the following method. Exactly 1 ml of PCB solution was added to seven flasks, each containing slightly less than 1 liter of distilled water. Measured volumes of the 2 g/l carbon stock solution was added to each flask to give carbon concentrations of 0,2,5,10,25,50 and 100 mg/l. The total volume of each flask was 1000 ml. After four hours agitation on a wrist shaker, each solution was filtered through 0.45 micron millipore pads and stored prior to analysis in a refrigerator in quart amber glass bottles having Teflon-lines caps.

A nickel-63 electron capture gas chromatograph was used for analysis; all samples were extracted and concentrated approximately 100 times before analysis. The method is described in the 1971 EPA report, "Methods for Organic Pesticide Analysis in Water and Wastewater."

Table 2.2.1.3-1 shows the PCBs removal data, and gives comparative data for Aldrin. It appears that the Aroclors are removed as effectively as pesticides. Removal from the 50-ppb level to the 1-ppb level seems possible.

Figure 2.2.1.3-1 shows the Calgon data plotted to give the weight percent of PCBs that Filtrasorb-300 carbon can adsorb, at levels down to 1 ppb. As can be seen, the curves take a downward break at about 2 to 3 ppb, indicating that the weight of activated carbon required to remove a unit weight of PCBs is rising rapidly. If this kind of data is confirmed with larger-scale column testing, it would mean that removal of PCBs from water in the parts per trillion range is far more difficult than removal in the parts per billion range.

Also from the figure it can be seen that the initial concentrations (C_o) of the Aroclors were about 100 ppb. However, filtration before testing removed PCBs so that the starting concentrations for the tests were 45 and 49 ppb.

NWMAR115864

TABLE 2.2.1.3-1

RESULTS OF CALGON CORP. LABORATORY ISOTHERM TESTS FOR CARBON REMOVAL OF PCBs

Carbon Dosage (mg/l)	Residual (ppb)		
	Aroclor 1242	Aroclor 1254	Aldrin
Control	45	49	48
1.0	--	--	—
2.0	7.3	37	26
2.5	--	--	--
5.0	1.6	17	15
10.0	1.1	4.2	12
12.5	--	--	--
25.0	--	1.6	6.3
50.0	--	1.2	4.4

NWMAR115865

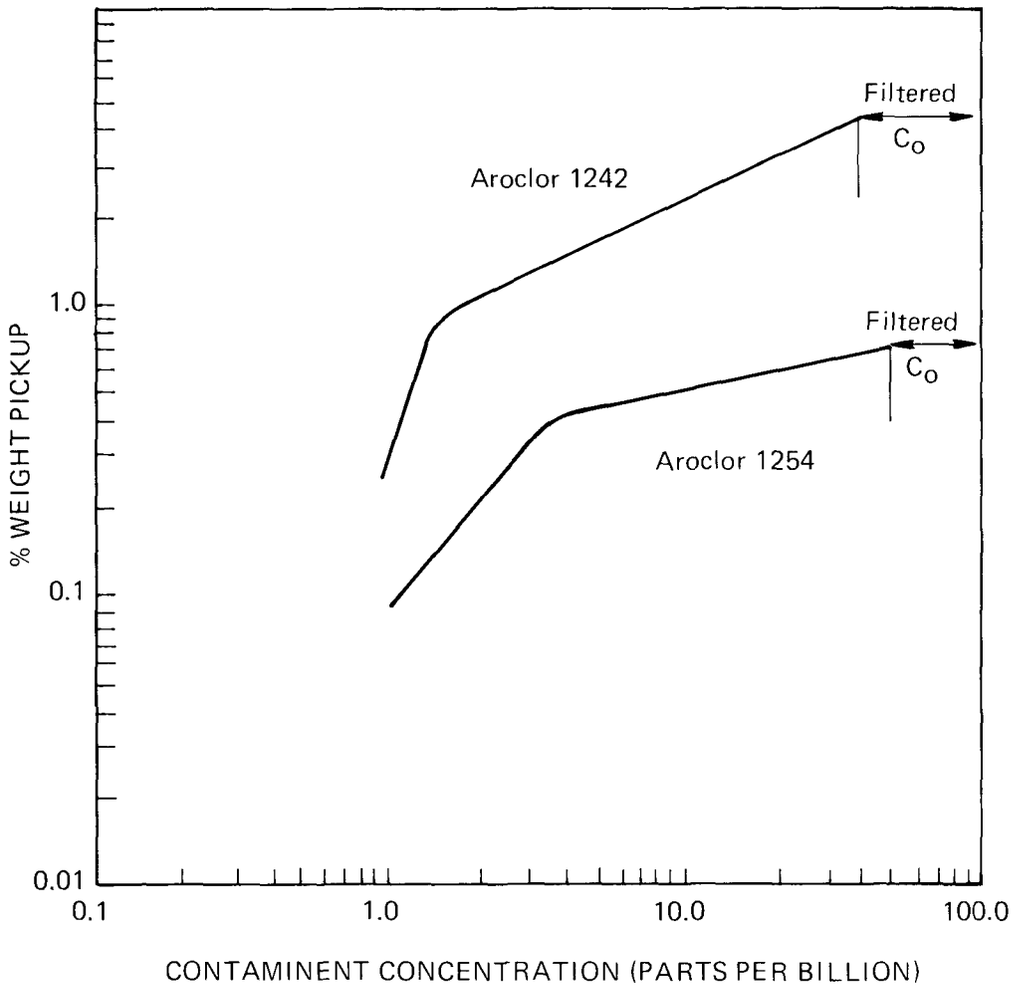


Figure 2.2.1.3-1. EQUILIBRIUM CARBON ADSORPTION OF PCB'S FROM WATER AT LOW CONCENTRATIONS (CALGON DATA)

NWMAR115866

Hager and Rizzo of Calgon Corp. have described the essential elements of full-scale adsorption systems in a paper presented to the EPA Technology Transfer Session on Treatment of Toxic Chemicals held in Atlanta on March 19, 1974. Each system is comprised of three basic functional components:

1. The adsorption treatment of the wastewater
2. The carbon reactivation equipment
3. The carbon/water transport arrangement

For PCBs, the practicality of reactivation must be determined.

2.2.1.3.1 Adsorption Treatment of Wastewater

The adsorbers hold the granular activated carbon beds through which the wastewater flows. They can be designed for pressure or gravity flow to achieve the desired contact time of the water with the carbon. Suspended solids and space limitations also must be considered in the adsorber configuration. Flow rates usually fall under 10 gpm per square foot of carbon bed surface area. Contact times for industrial wastewater mixtures usually are in excess of 60 minutes, which is about twice the time employed for purification of domestic sewage. When suspended solids are present, they can be filtered out by the carbon bed; this dual purpose of carbon beds can be usefully employed as long as the adsorbers are designed to accommodate periodic backwashing and bed-cleaning procedures such as air scour and surface wash. For PCBs service, minimum backwashing would be desirable since backwashing would create large quantities of concentrated wastewater needing incineration or treatment. Some settling and prefiltering would be required for optimum system performance.

A well designed water distribution system or underdrain system would insure good backwashing performances, as well as even distribution of water flow. Well established filtration design practices can be effectively employed in carbon bed systems. Carbon beds must be periodically removed via water slurry and obstructions to the flow of carbon from the adsorber should be avoided in adsorber design.

NWMAR115867

Carbon beds are normally in excess of 10 feet deep and usually fall into one of four basic configurations:

1. moving beds
2. beds in series
3. beds in parallel
4. expanded beds

The type of configuration selected depends on a number of variables; principal among them are total water flow, suspended solids, and degree of contaminant reduction desired.

2.2.1.3.2 Reactivation of the Granular Carbon

Thermal oxidation, using either multiple hearth furnaces or rotary kilns, is generally employed to reactivate the exhausted carbon. The size of the thermal reactivation equipment is based on the carbon exhaustion rate, i.e., pounds of carbon exhausted per thousand gallons of wastewater treated, and the weight of contaminant on the carbon. Excess capacity is designed into the thermal reactivation unit to allow for variances in carbon use rate due to changes in the wastewater flow and organic loading.

The exhausted granular activated carbon is heated to 1600 to 1800°F to effect volatilization and oxidation of the dissolved organic contaminants. Oxygen in the furnace is normally controlled at less than 1 percent to effect selective oxidation of contaminants over activated carbon. A 5 percent loss of activated carbon per reactivation cycle is an acceptable bench mark upon which to base granular carbon system economics. Particularly for the PCBs, which require an incineration temperature in excess of about 2200°F plus several seconds residence time, the reactivation equipment must include an afterburner. An air scrubber with HCl neutralization would be the last element of the reactivation train. Thus far, the regeneration of carbon used for PCBs adsorption has not been proved.

NWMAR115868

2.2.1.3.3 Carbon Transport

Granular spent carbon is usually transported between the adsorbers and the reactivation equipment by water slurry. Various pumping designs can be employed including centrifugal and diaphragm pumps as well as hydraulic or pneumatic pressure. The transport piping should include flush ports and wide radius bends. Typical loading is between 1 and 3 pounds of carbon per gallon of water, depending upon distance and elevation considerations.

2.2.1.3.4 Materials of Construction

Special consideration should be given to the selection of materials of construction with regard to corrosion and erosion.

1. Galvanic Corrosion - Any tendency toward galvanic corrosion due to water characteristics, such as conductivity and pH, will be enhanced in granular carbon beds. Mild steel tanks or adsorbers holding granular carbon under water should be lined. Tanks can also be constructed of cement or reinforced synthetic resins or plastics.

Carbon-in-water slurry piping, which experiences only periodic exposure, is usually exempted from special corrosion considerations.

2. Erosion - Periodic replacement of the carbon beds can cause lining failures at exit ports in carbon tanks and adsorbers. Special grades of stainless steel are usually employed for such wear points.

2.2.1.4 Carbon Regeneration Alternatives - Wet Catalytic Oxidation

For small installations, it might prove feasible to dispose of spent carbon by incineration. Carbon supply companies also offer spent carbon removal services and off-site regeneration.

However, there is a new wastewater treatment technique which might be applicable to carbon regeneration, namely wet catalytic

NWMAR115869

oxidation. Several laboratory studies in wet catalytic oxidation are described in Appendix C. Lockheed Missiles and Space Co. (Waste Treatment Systems Section) of Sunnyvale, California, announced in January, 1976, that they have a process ready for pilot plant evaluation and commercial scale-up.

In a preliminary look at the PCBs destruction potential of wet catalytic oxidation, a wastewater sample from an unnamed user of PCBs was subjected to treatment. The PCB mixture approximated Aroclor 1221 most closely, and was very concentrated to 5 ppm in the wastewater sample. Since 5 ppm is much higher than that Aroclor's solubility in pure water, it is believed that solubilizing agents or particulates were carrying most of the PCBs. Within 20 minutes of treatment time, however, about 90 percent of the PCBs had been destroyed, and no large quantities of reaction products were detected. However, this is just one data point and confirmation is needed. The test reactor was a continuously stirred batch system, with air continuously sparged in. The test conditions used were: reactor pressure, 1500 psig; temperature, 550°F; catalyst concentration, 0.5 gram; and reactor volume, 1.5 liters.

The proposed use of wet catalytic oxidation is for carbon regeneration while in spent water slurry form.

Since the capital and operating costs of the catalytic system are tied to the hydraulic load, it might be practical to trap PCBs with carbon in wastewater, and then treat the carbon slurry by catalytic oxidation to destroy the PCBs. In this way, PCBs would be removed from the wastewater by the highly efficient carbon adsorption method, while the volume handled by the catalytic system would be greatly reduced.

Feasibility testing for regeneration of activated carbon by catalytic oxidation is needed. The activated carbon industry has long sought alternatives to thermal regeneration of carbon, because of the loss of carbon by oxidation. With solvent regeneration, or acid or base treatment, the first regeneration only produces about 40 percent of the active surface, which then usually decreases to 30 percent after several more treatments.

NWMAR115870

Such degradation is unacceptable. Thus the questions to be answered are: a) Can catalytic oxidation destroy adsorbed PCBs on carbon, converting them to CO_2, H_2O and HCl? b) Will the regenerated carbon have, say, 90 to 95 percent of its original activity? c) Can the process be operated economically? The last question must take into account the necessary operation pressures (500 to 2000 psi), operating temperatures (300 to 650°F), source of oxygen (air, O_2 or ozone), type and lifetime of catalyst, residence time, and materials of construction, among other variables.

2.2.1.5 Further Applications Data

ICI-US provides an excellent booklet entitled "A Symposium on Activated Carbon", providing considerable detail on applications. ICI also provides information on special graphical procedures helpful in the scale-up from isotherm to column testing.

2.2.2 Ultraviolet-Assisted Ozonation

Both UV radiation, and ozone, separately, have been used in water purification for some time. But only in the last five years or so has the synergism of the combination been appreciated in the destruction of organics in water.

Two commercial organizations, Houston Research, Inc., of Houston, Texas, and Westgate Research Corp. of Marina Del Rey, California, are engaged in development of UV-assisted (or catalyzed) ozone oxidation of refractory organics. Both organizations have cooperated in preliminary tests of PCBs destruction, and the method has shown great promise as a large-scale, economic water treatment method. The companies are working mostly with 253.7 nanometer, near-UV, radiation, but they plan to investigate far-UV mercury radiation at 184.5 nm.

It is of particular significance that these methods promise destruction of hydrocarbon organics completely to CO_2 and water. Thus they are likely candidates for zero discharge and total recycle systems.

Related to this is the work of Lawrence at Environment Canada (Burlington, Ontario), who is studying the use of near-UV radiation (about

NWMAR115871

365 nm), available from sunlight, in conjunction with titania or alumina photocatalysts rather than the combination of UV and ozone. The ultraviolet region extends to 380 nm, and then blends into visible violet. Studies using visible light are described further below.

UV radiation is generally provided by commercially available tubes, which when operated at low power (and low pressure in the emitting tube) are quite efficient in transferring UV radiation to water. The range of effectiveness is quite short, probably of the order of a few inches maximum, because UV transmissibility in water is poor, and is degraded further by even small amounts of particulate matter.

Ozone is sparged into the reactor, and vigorous stirring is provided until increasing turbulence or mixing power input does not further increase reaction rate.

Various kinds of efficiency values are given to rate different systems, flows, arrangements, etc. For overall efficiency, the units of measure are total organic carbon removed per watt-second of UV input, or per gram of ozone introduced.

Since ozone generation is expensive, work is directed toward optimum use of the ozone introduced. The cost is almost completely that of the electric power used in the silent discharge tube method of making ozone from air. And, of course, UV generation is also an electric power cost factor.

The following subsections discuss UV radiation and its molecular interactions, the photodegradation of PCBs, and UV-assisted ozonation experiments with PCBs.

2.2.2.1 Molecular Responses to Ultraviolet Energy

Energy absorbed in the ultraviolet region (10 to 380 nm) causes electronic transitions within molecules. The principal characteristics of an absorption band are its wavelength and intensity. The wavelength of maximum absorption (λ max) corresponds to the wavelength of radiation having energy equal to that required for an electronic transition. A molar

NWMAR115872

absorptivity at maximum absorption (E max) of 10,000 calories per mole or greater is regarded as high intensity absorption. Low intensity absorption is considered an E max of less than 1,000 calories per mole; biphenyl in alcohol at 250 nm has an E max of 18,000, and in hexane at 246 nm, an E max of 20,000.

This would seem to indicate that the basic structure of the PCBs would be readily activated by a mercury lamp generating 253.7-nm radiation. However, this absorption will be modified by the number of chlorine atoms attached to the biphenyl groups. If at any point in the destruction of PCBs, saturated hydrocarbons are formed, they will be unresponsive to 253.7-nm radiation. Saturated hydrocarbons contain sigma electrons exclusively. Since the energy required to bring about ionization of the sigma bonds is of the order of 185 kcal per mole it is only available in the far ultraviolet, below 200 nm. Single carbon-carbon and carbon-chlorine bonds have about the same high bond energy, and are similarly resistant to rupture; however, there is a mercury emission at about 185 nm, which should be capable of activating those bonds, thus making them highly reactive in the presence of oxidizers such as ozone.

Thus it appears possible to produce the excited states in PCB molecules necessary to make them highly receptive to oxidation. Since ozone is a powerful oxidizing agent, and it too is excited in the same regions making it even more effective, the possibilities for a wide range of oxidations are present. This would seem to make complete destruction of PCBs to CO_2, water and HCl feasible.

2.2.2.2 Photodegradation of PCBs

Because of the strength of the C-Cl bond, it has heretofore been assumed that little photochemical cleavage occurs. Further, in the photochemical breakdown of DDT and related compounds, cleavage of the aromatic C-Cl bond is usually not involved. However, Safe and Hutzinger reported in Nature in 1971, that hexachlorobiphenyl photolyzed readily in organic solvents when irradiated at 310 nm. The resultant products are formed by stepwise loss

NWMAR115873

of chlorine, rearrangement, and condensation. Other researchers have found that certain pure chlorobiphenyls and PCB mixtures can be decomposed by laboratory UV sources and by sunlight, over long time periods.

The wavelength of the UV radiation appears critical to photochemical decomposition. Low-pressure mercury lamps emitting 254 nm seem to be several times as effective as the UV from sunlight, which is greater than 295 nm. Studies have been carried out in organic solvents and water, and in both liquid and vapor states.

Much of the past work has been on organic solvent solutions of PCBs in order to have high working concentrations. Vapor phase studies have been run to simulate treatment of atmospheric emissions in environmental studies.

Reductive dechlorination, the main photoreaction of chlorobiphenyls, is faster in hydroxylic solvents such as methanol and isopropanol. Even chlorobenzene loses chlorine rapidly on irradiation in isopropanol. Complete dechlorination of a PCB mixture has been observed in 15 minutes in an alkaline isopropanol solution, using a mercury lamp (Anon., Chemical Marketing Reporter, Nov. 6, 1972, page 22). Biphenyl and sodium chloride were identified in the reaction mixture.

Photosensitizers can increase the decomposition rates. Tryptophan, diethylaniline, benzophenone and triphenylene sensitized the photoreaction of dichlorobiphenyl. The reaction was quenched by n-hexyl mercaptan and di-n-butyl sulfide. Experiments in water solution have been hampered by adsorption of the PCBs on the walls of reaction containers, particularly ones made of glass.

Attempts have been made to use surfactants to keep the PCBs in suspension. Adsorption on such solids as calcium carbonate, silica, and soils, in water suspension, has been tested as an aid to photolysis. However, UV radiation will not penetrate deeply into solids, so adsorbed PCB must be kept close to the surface.

NWMAR115874

2.2.2.3 Experimental Factors in UV-Assisted Ozone Oxidation of PCBs

For several decades the advantages of ultraviolet radiation in the sterilization of aqueous and dry media have been known. Likewise, the powerful sterilizing, oxidizing effects of ozone have been known. Only with the relatively recent advent of requirements for removing refractory organics from water, and the ability to detect these organics in parts per trillion and even lower concentrations, has the need for powerful oxidizing capability been felt. It was quite natural to combine the two effects into a single treatment or staged treatments, with the result being a strong synergism in many cases.

Enough data has now accumulated to show that UV/ozone wastewater treatment is a powerful method for removal of refractory organics. It has the potential of removing organics to an effective zero discharge level. However, as the decrease in very small concentrations becomes exponential with time, the residence time required in UV/ozone treatment equipment becomes a critical factor. The following variables have been identified as affecting residence time:

1. Molecular structure of the organic
2. Concentration
3. UV transmissivity of the wastewater
4. UV intensity
5. UV wavelength
6. Ozone concentration
7. Liquid turbulence and gas-liquid contact (transfer coefficients)
8. pH
9. Temperature

The following subsections present experimental findings about the relative significance of these variables.

NWMAR115875

2.2.2.4 Destruction of PCBs and Refractory Organics at Houston Research, Inc.

2.2.2.4.1 PCB Destruction Data

In preliminary experimentation on the feasibility of PCBs destruction, a high pressure 650-watt mercury tube generating 253.7-nm radiation was used in a 21-liter reactor. Figure 2.2.2.4.1-1 shows the arrangement for a smaller reactor. Oxygen, with an ozone concentration of 2 percent, was sparged in at 3 liters per minute. This was felt to be excess ozone usage, but a good starting point for tests. A 1000-ppm solution of Aroclor 1254 in methanol was used to get a 514-ppb solution of Aroclor 1254 in water. Otherwise the solubility of Aroclor 1254, which is about 50 percent pentachlorobiphenyl, is only 12 ppb in water. It was theorized that significant destruction of this compound would forecast even greater destruction of the other Aroclors now produced, which are all less chlorinated and more soluble in water.

Figure 2.2.2.4.1-2 is a plot of the normalized residual concentration of Aroclor versus time of UV-assisted ozonation. It can be seen that in 1 hour about 2/3 of the PCBs had been decomposed; and in 3 hours, only about 7 percent of the original PCBs remained.

2.2.2.4.2 Operating Data Obtained from Refractory Organics Tests

Houston Research has been studying ozonation for water purification for more than four years. Comparison tests have shown that the addition of UV radiation enhances the reaction rate by 10 to 100 fold. Further it was found that, for the most refractory compound they had tested prior to the PCBs, acetic acid, there was essentially no reaction without UV assistance. However, with UV radiation, the oxidation proceeds rapidly at room temperature.

Figure 2.2.2.4.2-1 shows the effects of UV and temperature on acetic acid destruction. The ordinate is the fraction of total organic carbon remaining, showing that for the 30°C or 50°C tests, with

NWMAR115876

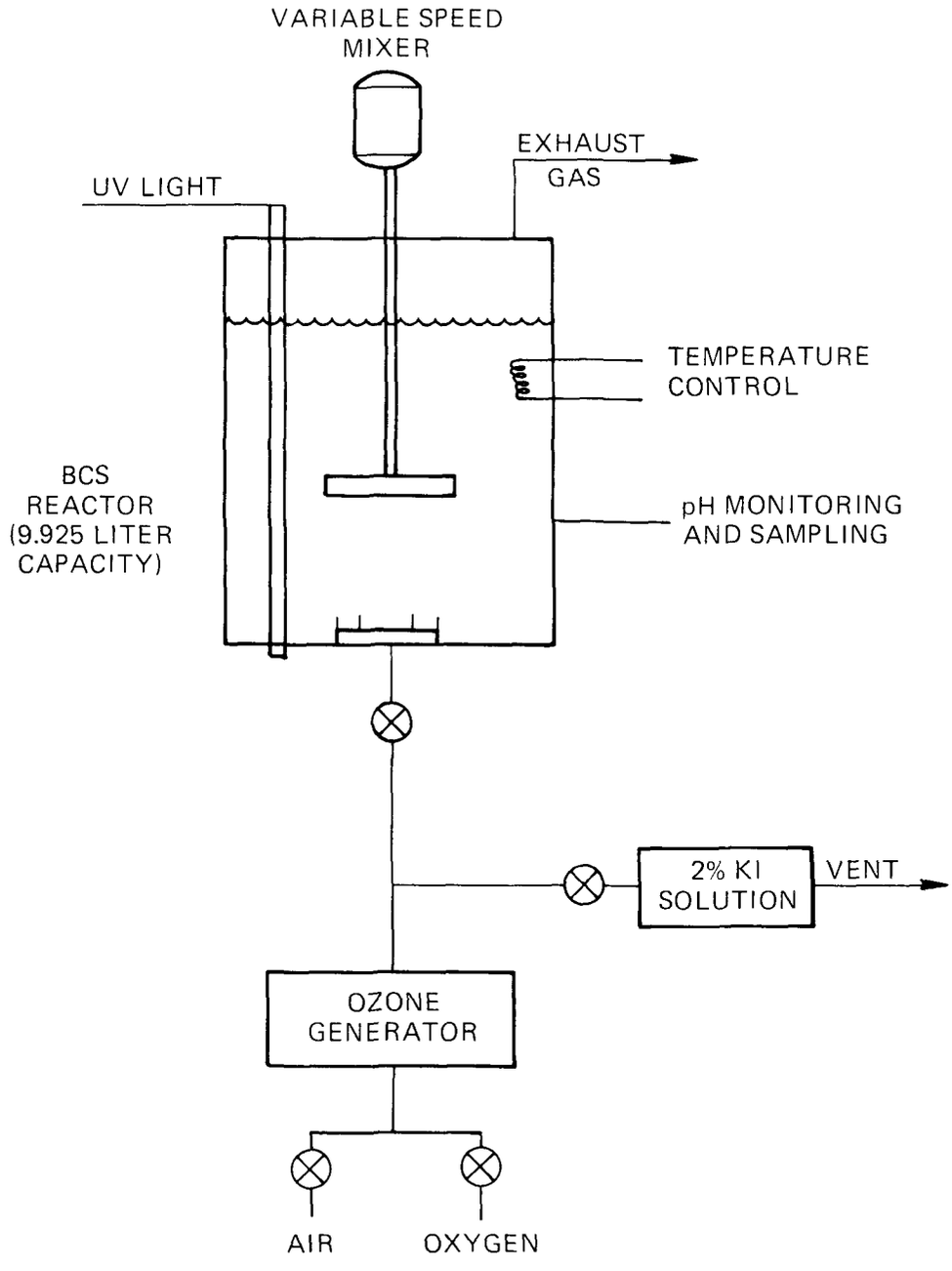


Figure 2.2.2.4.1-1. LAB SCALE APPARATUS FOR REACTION AND MASS TRANSFER STUDIES AT HOUSTON RESEARCH, INC.

NWMAR115877

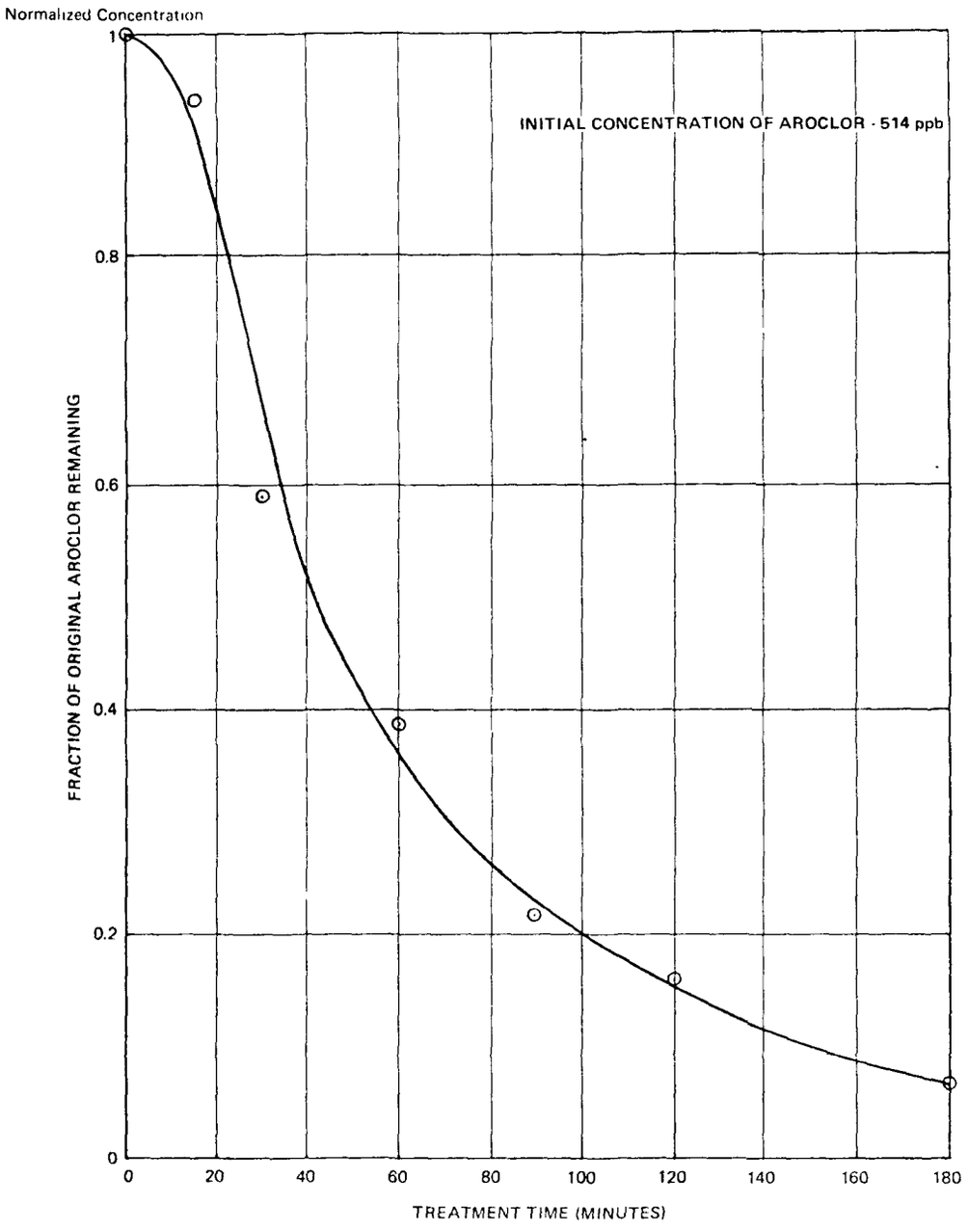


Figure 2.2.2.4.1-2 AROCLOR 1254 DESTRUCTION BY UV-ASSISTED OZONATION

NWMAR115878

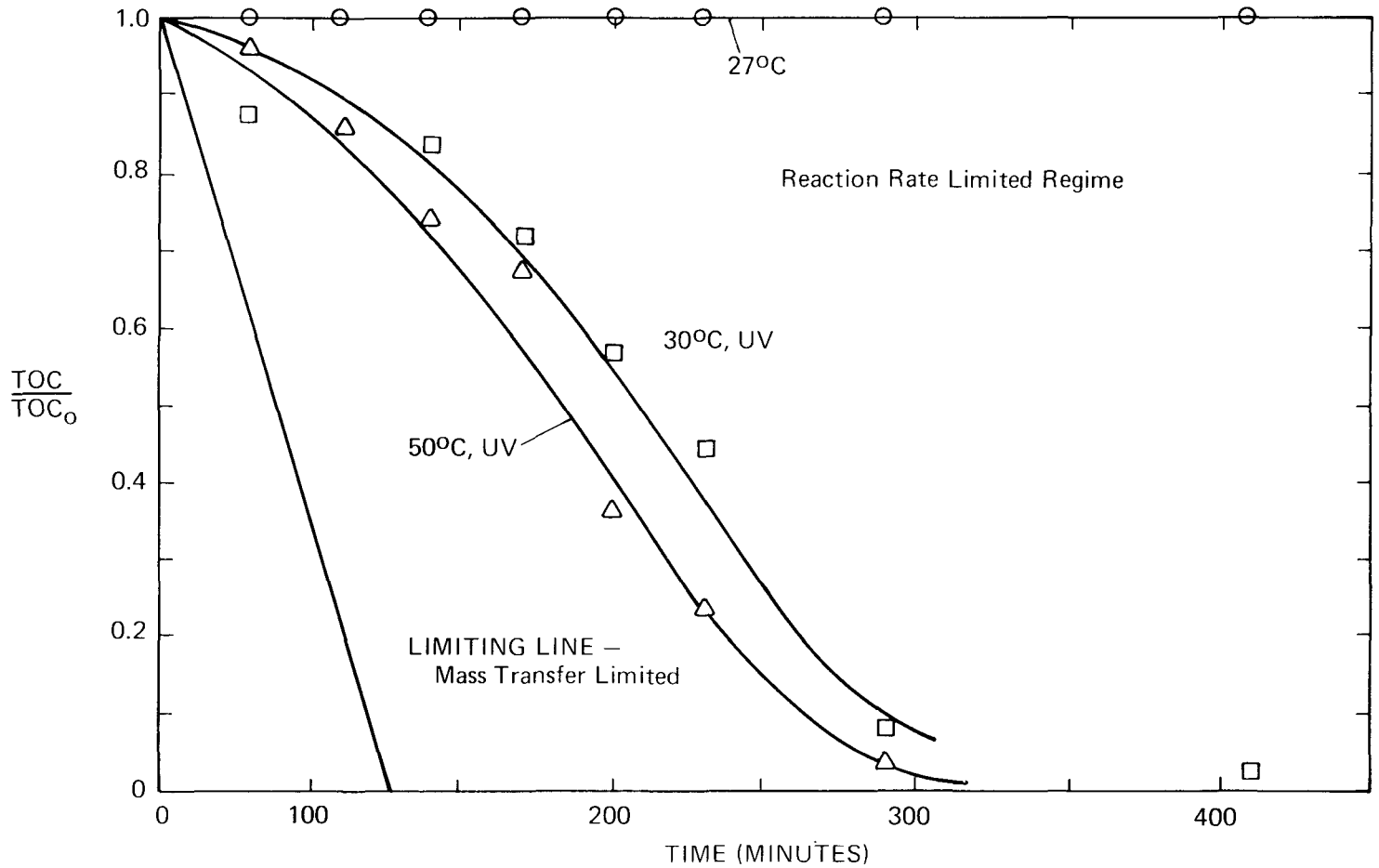


Figure 2.2.2.4.2-1. OZONE OXIDATION OF ACETIC ACID, EFFECT OF UV AND TEMPERATURE (INITIAL CH_3COOH - 105 mg/1, O_3(I) = 3.5 mg/1)

NWMAR115879

UV, there is nearly complete destruction to CO_2 and water within 4 to 5 hours The fact that the curves are displaced to the right of the mass transfer limiting line shows that some chemical reaction rate improvement can be sought.

Figure 2.2.2.4.2-2 shows the oxidation improvement achieved by doubling the UV power input, with near constant temperature. Further description may be found in: "Ozone/UV Process Effective Wastewater Treatment", by Prengle, Mauk, Legan and Hewes, in Hydrocarbon Processing, October, 1975.

These are a sampling of the kinds of optimization experiments that must be run with the PCB oxidation system to obtain good economy of design and efficiency of operation.

2.2.2.5 Destruction of PCBs and Refractory Organics at Westgate Research Corp.

2.2.2.5.1 PCBs Destruction Data

Cooperative testing and research between Versar, Inc., and Westgate Research, Inc., determined the effectiveness of Westgate's UV-assisted ozonation process in destroying PCBs. The following experimental conditions were used in the treatment of synthetic wastewaters containing Aroclors 1254 and 1016:

Reactor volume = 3 liters

Reaction time = 4 hours (excess time used to give best chance of destruction)

UV Source = one 43-watt, low-pressure Hg lamp operating at 253.7 nm

Reactor type = vertical, cylindrical, 18 inch long, 3 inch diameter (UV path length = 2 inches)

Pressure = atmospheric

Temperature = 23°C

pH = 6.2

NWMAR115880

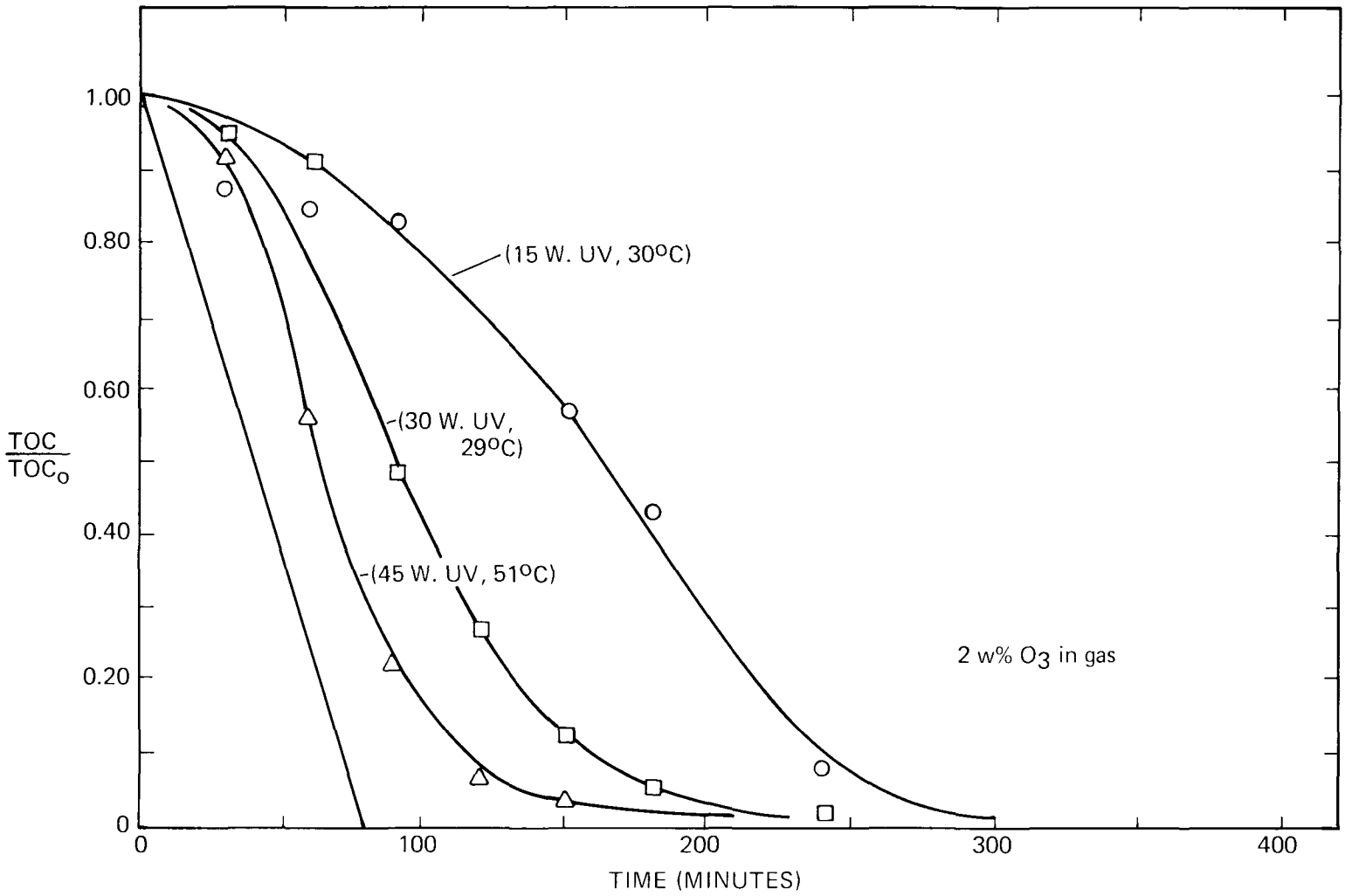


Figure 2.2.2.4.2-2. OZONE/UV OXIDATION OF ACETIC ACID; EFFECT OF INCREASED RADIATION INPUT

NWMAR115881

Ozone feed = 70 milligrams ozone/minute in 3.4 liters per minute of oxygen; or about 1.4 percent by weight ozone in oxygen

Reactant preparation = Pure Aroclor 1254 was mixed with an equal portion of methanol, which was then mixed with distilled water to get an apparent true solution. A Hamilton syringe, with vernier calibration giving microliter increments was used to prepare an estimated 200-ppb concentration in a beaker. This solution was added to the reactor (3 liters). Then a 200-ml sample was withdrawn to get the "before" sample.

When preparing the Aroclor 1016 solution, a more concentrated PCBs solution of about 800 ppb was achieved. The before and after treatment concentrations of PCBs are shown in Table 2.2.2.5.1-1.

The data show that the destruction was highly effective in these pioneering tests; more than 99 percent of the original PCBs were destroyed. In addition, the final concentration was at the desired level of about 1 ppb. Such an effluent would be expected to be a reasonable stream for recycle operations and intermediate term zero discharge potential.

Of course the contact time and ozone expenditure were overly large, but the goal of this preliminary testing was to demonstrate destruction of two key Aroclors in use today.

A more comprehensive study of the UV-ozonolysis of Aroclor 1016 was run, with samples removed from the reactor every 15 or 30 minutes for up to 4 hours. As shown in Table 2.2.2.5.1-2, the initial PCB concentration was 237 ppb. Within 45 minutes the PCB level had been degraded to 1 to 2 ppb, a 99^{+}-percent decomposition. After 2 hours the PCB concentration was less than 100 ppt. The last column in the Table labeled

NWMAR115882

Table 2.2.2.5.1-1

UV Ozonolysis Destruction of Typical Capacitor and Transformer PCBs at Westgate Research

	Aroclor 1016	Aroclor 1254
Initial (influent) Concentration (ppb)	790	200
Final (effluent) Concentration (ppb)	0.5	1.5

Table 2.2.2.5.1-2

Destruction of Aroclor 1016 by UV-Ozonation at Westgate Research

UV-Ozonation Time (minutes)	Aroclor 1016 Conc. (ppb)	Chlorinated Products Conc. (ppb)
0	237.0	0.00
15	14.7	33.8
30	7.76	25.86
45	1.73	21.80
60	1.73	18.47
75	0.52	17.63
90	5.2	21.43
120	< 0.1	12.64
150	< 0.1	16.91
180	< 0.1	9.12
210	< 0.1	23.07
240	< 0.1	12.58

NWMAR115883

"Chlorinated Products Concentration" is of particular interest. This is the first time quantitative data on the residual compounds in the reaction mixture have been compiled. These residual compounds reach a 33.8-ppb level within 15 minutes from the start of the test and then erratically and slowly drop to about 10 to 20 ppb over the 4 hour period.

The only statements that can be made about these residual compounds is that they are non-PCBs, but chlorinated materials. Possibly a different UV wavelength, or ozone concentration, or the use of a catalyst or other agent could degrade these other products to the non-detectable level.

2.2.2.5.2 Pilot-Scale Tests of Refractory Organics Decomposition

Zeff has described pilot-scale tests of UV-assisted ozonation using 253.7-nm radiation ("UV-OX (TM) Process for the Effective Removal of Organics in Waste Waters", presented at the 68th Annual Meeting of the AIChE, November 20, 1975). This work has grown from a patented invention for a household appliance used to purify tap water. The effectiveness of the method is demonstrated by the reduction in total organic carbon (TOC) of 500 ml of tap water from 5 mg/l to 1 mg/l in 1 minute, using 0.07 mg of ozone and 0.1 watts of 253.7-nm UV. The bacteria plate count was also reduced by a significant amount.

In these studies, batch reaction conditions were optimized to get closest to complete TOC destruction with least O_3 and UV energy input. Then continuous and two-stage operations were investigated. As shown in Figure 2.2.2.5.2-1, a 6-inch-path length of UV was compared with a 3-inch path. In a batch test, the longer path condition took 3 to 4 times as long as the shorter path to achieve the same TOC reduction, in approximate accord with the inverse square law.

The laboratory-scale equipment arrangement is shown in Figure 2.2.2.5.2-2. Table 2.2.2.5.2-1 presents TOC reductions for a 5-part organic mixture under two experimental conditions, showing ozone usage

NWMAR115884

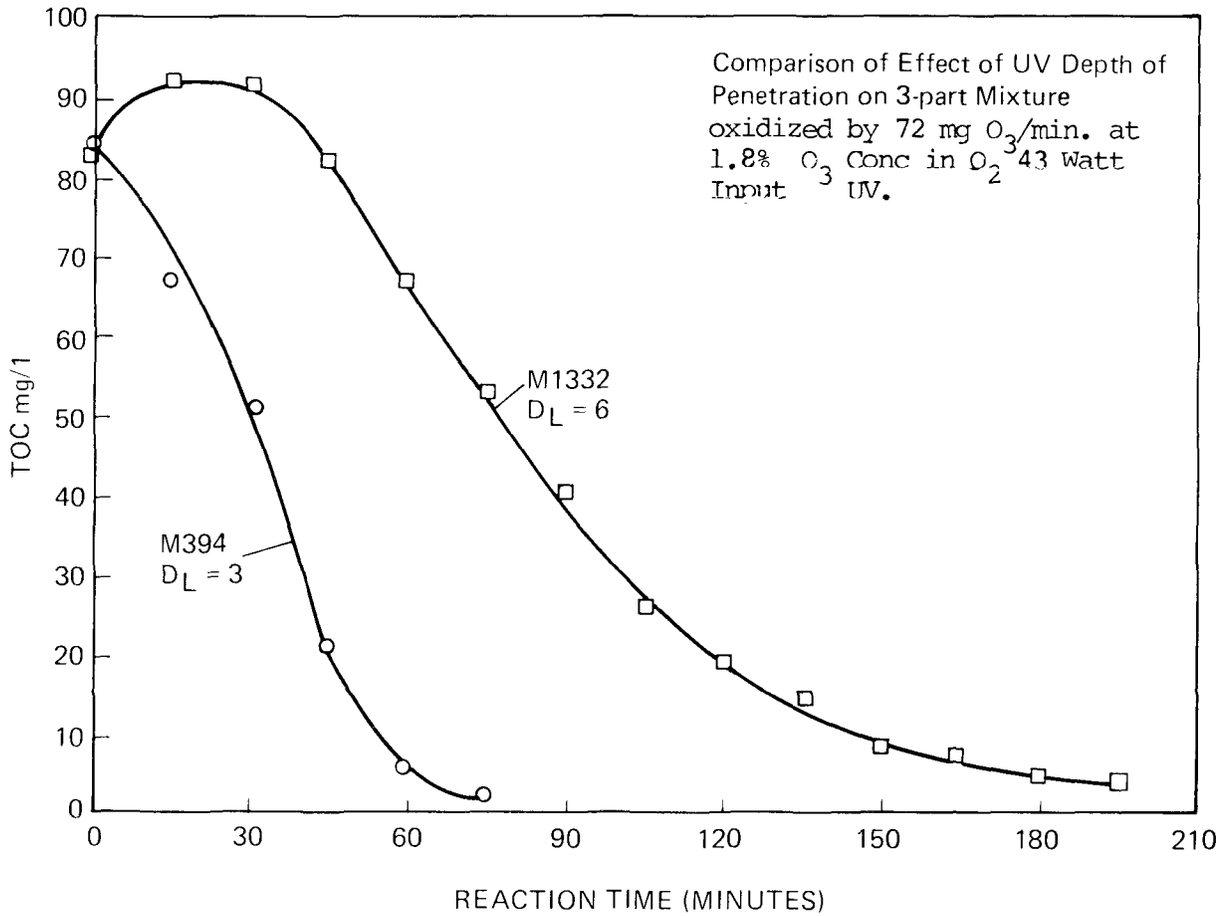


Figure 2.2.2.5.2-1. THE EFFECT OF UV PATH LENGTH ON TOC DESTRUCTION

NWMAR115885

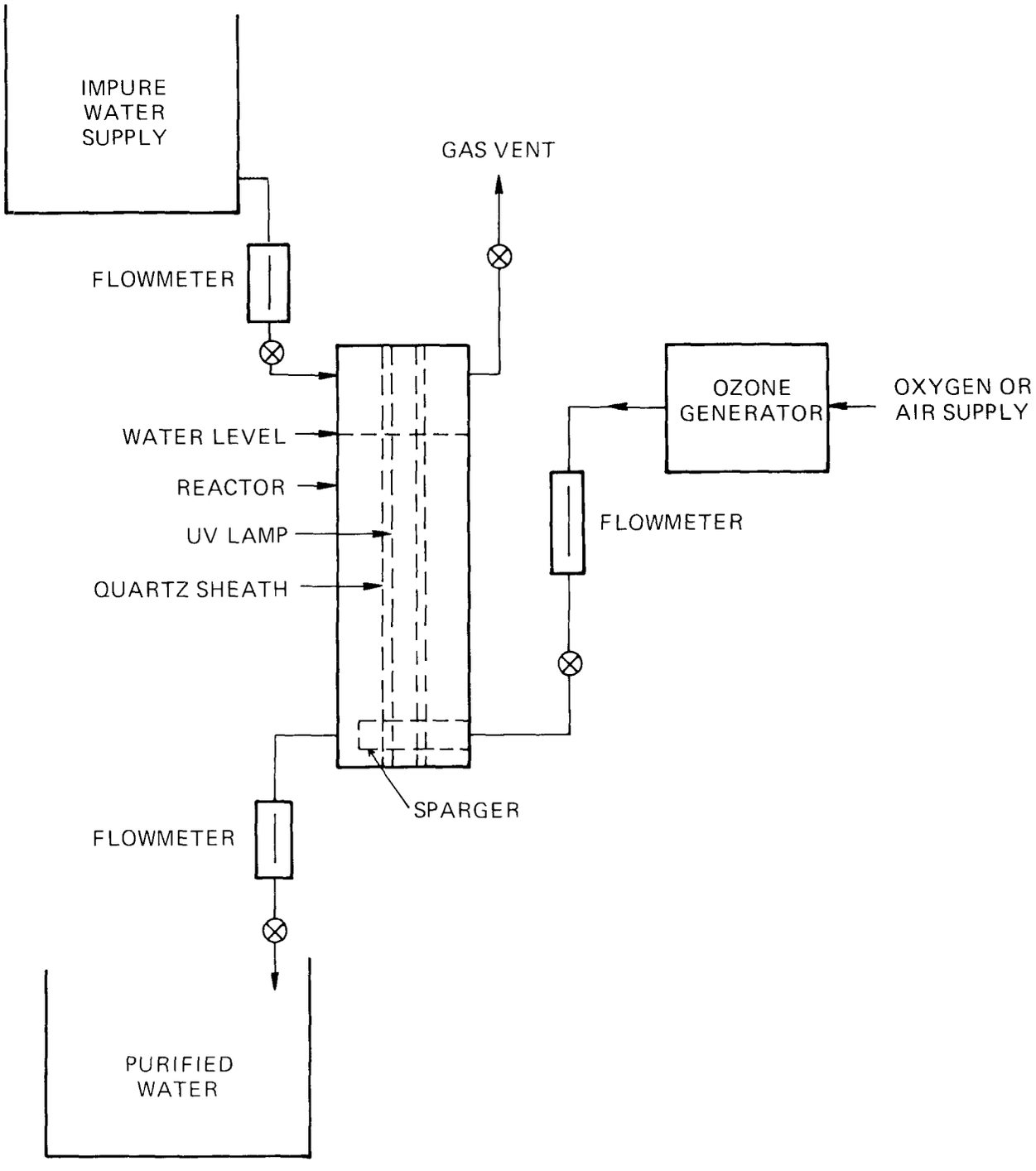


Figure 2.2.2.5.2-2. SCHEMATIC OF BENCH REACTION SYSTEM AT WESTGATE RESEARCH CORP.

NWMAR115886

TABLE 2.2.2.5.2-1

Simulated Two-Stage, Continuous UV-Ozonation of a 5 Component Mix at Westgate Research Corp.

(43 watt UV Input Reactor 1)
(28 watt UV Input Reactor 2)

	Experiment Number	S341	S342
REACTOR 1	Influent Conc TOC mg/l	39.0	75.5
	Res Time/Real min	80	48
	Input O_3 Conc % by wt	2.5	2.7
	Input O_3 Mass Flow mg/min	124	171
	Output O_3 Conc % by wt	1.3	1.8
	Output O_3 Mass Flow mg/min	65	113
	Effluent TOC Conc mg/l	9.0	21.0
	Ave Rate of TOC Removal mg/min	4.5	13.6
	UV Index w-m/mgC	9.6	3.2
	Supplied TOC/O_3 Effic %	29.0	63.7
REACTOR 2	Input O_3 Conc % by wt	2.5	2.7
	Input O_3 Mass Flow mg/min	124	171
	Output O_3 Conc % by wt	1.5	1.9
	Output O_3 Mass Flow mg/min	74	120
	Effluent TOC Conc mg/l	5.0	6.0
	Ave Rate of TOC Removal mg/min	0.6	3.7
	UV Index w-m/mgC	46.7	7.5
	Supplied TOC/O_3 Effic %	3.9	17.5
OVERALL	Ave Rate of TOC Removal mg/min	2.5	8.7
	UV Index w-m/mgC	13.9	4.1
	Supplied TOC/O_3 Effic %	16.4	40.6

NWMAR115887

efficiencies, and energy usage efficiencies, with a simulated two-stage continuous operation. Zeff has calculated the prime energy costs for UV-assisted ozonation based on a scale-up of a pilot reactor. The pilot reactor handled 20 gph, so that 210 of these units in parallel would handle 100,000 gpd. The plant area needed for this equipment would be only 18 feet square, with a height of 3 feet.

Based on pilot tests of this reactor, it might be assumed that it could convert wastewater of 40 mg/l TOC to less than 5 mg/l, using six 43-watt UV lamps. It is assumed that a UV energy requirement of 5 watt-minutes per millgram of carbon oxidized will suffice. Also, the ozone requirement will be 2 moles per gram-atom of carbon oxidized, but at a 75-percent efficiency, or 2/.75 = 2.67 moles ozone per gram-atom of carbon. Assuming a power cost of 1.5¢/KWH; the ozone generating power cost would be $53.40 and the UV power would be $18.93; or a total of $72.33 per 100,000 gal. of water treated.

Zeff points out that the 210 reactor modules would require 1260 43-watt lamps (six per reactor). This appears to be a large number of lamps, but it is actually very practical. Such arrays of lamps are regularly used for room illumination in factories and large offices, and the low-pressure mercury lamps used here are nothing but fluorescent lamps without the phosphor coating. An extended array such as this is much more energy-efficient than fewer high-power high-pressure industrial UV irradiators; and maintenance and replacement of lamps is much simpler. The life of the low-power lamps is 7500 hours as compared to 1000 hours for the high-power lamps.

2.2.2.6 Laboratory Test Results from AiResearch Corporation

In the laboratory tests of the AiResearch Corporation, high-pressure 450-watt mercury lamps were used. The test solutions were very dilute mixtures of methanol, ethanol, isopropanol, and acetone in water. The ozone was introduced into the 4-liter organic mixture in an oxygen stream bubbled in at 2 liters per minute; ozone concentration in the oxygen was 33 mg/liter. With the expenditure of 7.9 grams of ozone, the mixture of alcohols and acetone was reduced from 115 mg/l COD to 10 mg/l in 2 hours.

NWMAR115888

2.2.2.7 Comments on UV/Ozone Tests

These highly encouraging tests by three different companies in the destruction of some of the most refractory organics encountered in wastewater treatment, give confidence that scaled-up systems can adequately destroy PCBs in industrial wastewaters. The next step required is detailed cost effectiveness testing in pilot-scale equipment.

2.2.3 Non-Carbon Adsorbents for PCBs

A variety of non-carbon materials, some well-known for treating water and some that seem to be quite specific for PCBs removal, have been found. Limited cooperative laboratory testing of PCBs removal has been conducted in order to gain insight into potential effectiveness.

Materials considered or examined were:

1) Rohm and Haas Amberlite XAD series resins - These were laboratory-tested for PCBs removal
2) Polyvinyl chloride - Tested by Canadian investigators for PCBs removal
3) Clays and Humus - Tested by Monsanto for PCB removal
4) Polyurethane - Tested by Canadian, Swedish and other investigators for PCBs removal
5) Sphagnum Peat - Used in commercial water purification, but has not been tried with PCBs
6) Polyelectrolytes as floccing agent - Not really adsorbents, but could be aids to removing finely divided adsorbents from treated wastewaters; have not been tested
7) Coal - Not tested with PCBs, but being experimentally used for water treatment
8) Molecular Sieves - Not tried with PCBs, since they were judged to be of improper character; they would be expected to preferentially remove water from PCBs, rather than PCBs from water
9) Miscellaneous Sorbents - A number of proprietary Oil Sorbents, such as the "3M Brand" series, that were not tested with PCBs, might have some application

NWMAR115889

2.2.3.1 The Amberlite XAD Series of Macroreticular Resins

2.2.3.1.1 PCBs Adsorption Testing

Cooperative preliminary experimental work was carried out between Versar and Rohm and Haas to test the PCB-adsorption capacity of XAD-4 resins. The tests confirmed the effectiveness of this resin (see Appendix D).

Since carbon adsorption is the more established technology for removal of organics, it was felt that a side-by-side comparison of a carbon and an Amberlite resin would be useful.

These tests showed that resin and carbon are comparable in PCBs removal effectiveness. The resin method includes on-site regeneration, with the concentrated waste PCBs treated by incineration. Details on the apparatus and materials used by Rohm and Haas and the results of their experiments are given in Appendix A.

2.2.3.1.2 Process Concept for Resin Adsorption of PCBs

Based upon the experiments described in Appendix A, the Rohm and Haas experience has led them to envision the following plant-scale process, subject to further experimentation.

The wastewater to be treated is passed through one or more columns, each containing polymeric adsorbent. Once the resin is loaded to capacity with PCB, it is taken off line for regeneration. A water miscible solvent is usually used for regeneration, and is in turn displaced from the adsorbent by water. The stream resulting from this operation is carefully fractionated to optimize solvent recovery. The final rinse usually contains a very low level of solvent in water and this must be collected as a PCBs wastewater.

The distillation column permits solvent recovery at high purity, leaving water and PCB in the bottoms. To minimize

NWMAR115890

distillation costs, a patented variation of the process, called "superloading", is used to maintain a high PCB concentration in the final toxic material to be disposed. Part of this process includes a separator from which the organic phase is PCB while the aqueous phase is recycled to "superload" the adsorbent. A completely enclosed system can readily be designed to insure minimum operator exposure to PCB. A process concept flow sheet of such a PCBs removal system is shown in Figure 2.2.3.1.2-1.

The experimental work necessary to plant-scale design is as follows:

1. More extensive leakage data should be gathered for XAD-4 and other Amberlite polymeric adsorbents, encompassing several influent concentrations of PCBs; other Aroclors should also be tested.
2. The ability of the Amberlite polymeric adsorbents to be solvent regenerated should be demonstrated and the optimum solvent determined
3. The capacity of the Amberlite polymeric adsorbents should be determined over a number of loading/regeneration cycles to see the effect, if any, of long-term operation on capacity.

The description of XAD-4 resin and its comparison with other Rohm and Haas resins that might also have application to PCBs removal are given in Appendix B.

Further descriptions of non-carbon adsorbents are presented in the Appendix C. They contain relevant experimental work on PCBs and refractory organics, and are included to give a more complete picture of the options assessed under this program. Also included in Appendix C are summaries of catalytic reduction, catalytic oxidation, microorganism studies, ultrafiltration, and reverse osmosis. For the removal of PCBs from wastewater, all are considered to be in the research stages. Several have potential for contributing to zero discharge technology.

NWMAR115891

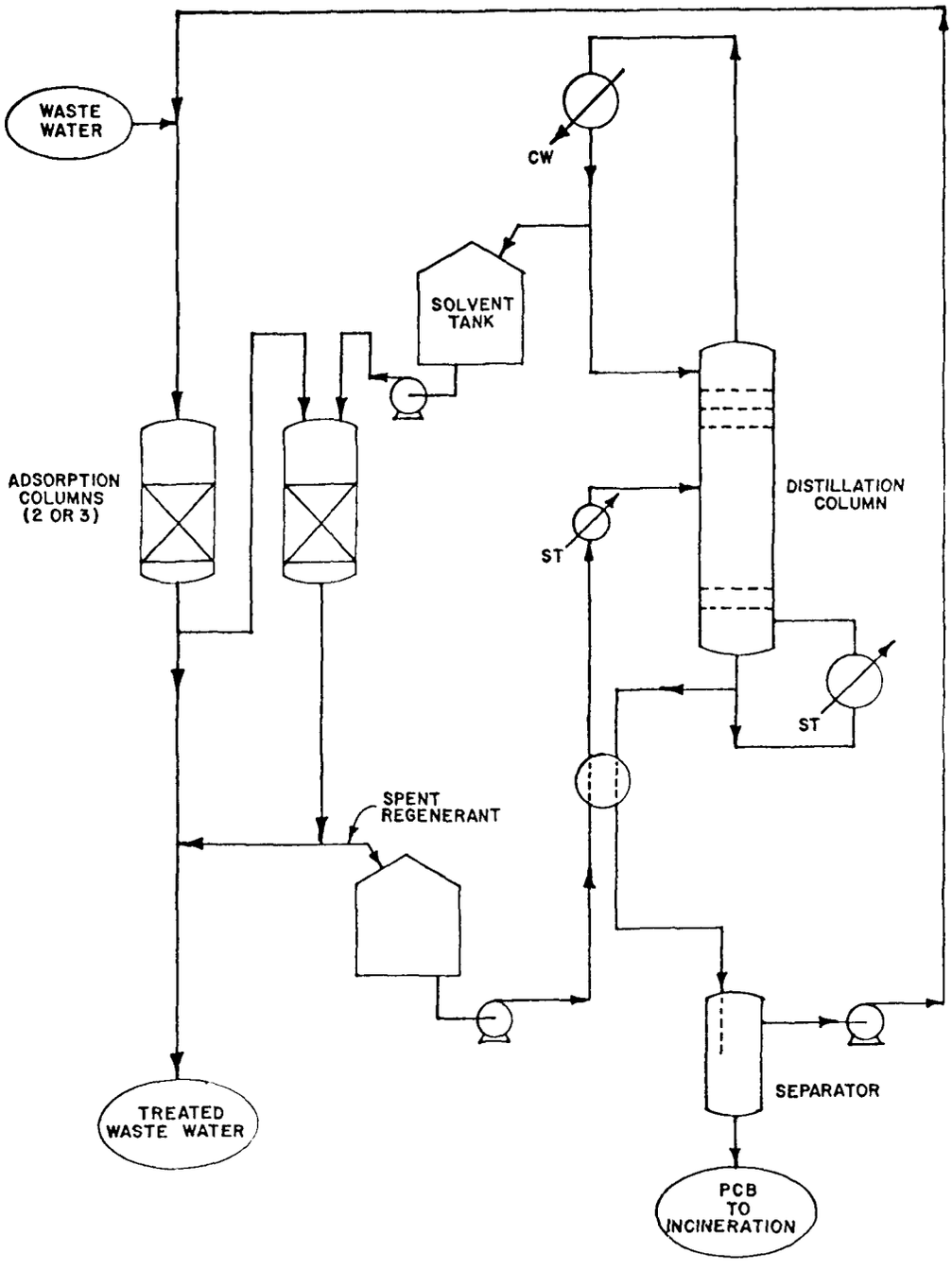


Figure 2.2.3.1.2-1
PCBs REMOVAL PROCESS CONCEPT FLOW SHEET
BY ROHM AND HAAS COMPANY

NWMAR115892

2.3 Treatment of PCBs - Contaminated Solid Wastes

2.3.1 Incineration

Incineration has been described in Section 1.3.3. For the variety of solids ranging from granular particulate, such as fuller's earth, to large chunks of solids, such as transformer internals, the best destruction method is rotary kiln incinerator, followed with adequate afterburning to prevent PCB vaporization.

2.3.2 Sanitary Landfill

The best technology for segregation of the PCBs solid wastes so that spillage, leakage to waterways, or emissions to the atmosphere will not occur, is described under Section 1.3.3.

2.4 Treatment of Air Emissions

2.4.1 Condensation Methods

Our survey found one plant that was practicing chilling of exhaust gases from PCBs processing areas. With the low vapor pressure of PCBs even at room temperature, it might be expected that they could be effectively swept out of chilled air with the condensing water. Undoubtedly this does occur to some extent; however, the high activity coefficients of PCBs tend to keep them vaporized at levels near their pure liquid vapor pressure at that low temperature. Previous work by Versar has shown that PCBs in stack emissions from sludge incineration are not removed by water scrubbing (EPA Contract 68-01-1587).

2.4.2 Granular Adsorption Methods

Although no information was uncovered on the collection of PCBs from air streams by any form of granular filter, it would be expected that such treatment should be effective. In fact, it would be expected that the same adsorbents discussed under Sections 2.2.1 and 2.2.3 above would be the most effective. Activated carbon removal of organic vapors has been practiced in such widely divergent circumstances and devices as gas masks, kitchen range hood systems, and submarine air recycle systems.

NWMAR115893

2.4.3 Catalytic Oxidation of Organics in Evaporated Effluents

Studies of vapor phase oxidation show the potential for PCBs destruction in air exhausts at lower than incineration temperatures. Catalysts would have to be resistant to HCl vapors, but fuel savings and insulation savings would be large. This procedure should be amenable to all proportions of water and organics in such air streams.

Borkowski passed PCB vapors over a catalyst at elevated temperatures ("The Catalytic Oxidation of Phenols and other Impurities in Evaporated Effluents," Water Research (1); 367 (1967)). Copper oxide was the most active of a large number of catalysts tested and oxidation to carbon dioxide and water appeared to be complete at temperatures over 300°C and at residence times of about 0.08 seconds. Without the catalyst, 1000 to 1200°C was required to achieve the same degree of removal.

Walsh and Katzer studied contaminated air-water vapor streams over supported copper oxide and showed that the rate was first order in phenol and relatively rapid between 150 and 270°C ("Catalytic Oxidation of Phenol in Dilute Concentration in Air", Ind. Eng. Chem. Process Design Develop, (12); 477 (1973)). At 150°C and a space velocity of 4100 hr^{-1} the phenol conversion was 99.6 percent, and there was little evidence of any intermediate organics in the condensate.

These methods of air purification are in the research stages, and actual testing of PCBs in air is required.

2.5 The Potential for Zero Discharge

The best method of achieving zero discharge, in the face of the practical problem of defining what a zero concentration is, is to establish total recycle. This appears feasible for wastewater, but not for solids or air emissions. Fortunately, for solids, incineration technology promises very high efficiency of destruction simply by setting the temperature and residence times high enough.

NWMAR115894

For air emissions, although vapor pressures are low for PCBs, large surfaces have the potential for giving off significant quantities of PCBs. Versar research has found powerful adsorption and destruction methods for organics in air. If destruction equivalent to that achieved by incineration can be achieved at lower temperatures through catalyzed reactions, near zero emissions are possible.

For wastewater recycle, methods of adsorption and catalytic destruction promise PCBs reduction to levels low enough such that reuse is practical. Our survey has shown some municipal and fresh waters contain PCB concentrations of 1 ppb or greater, and many river waters can contain many times that. Thus the recycled water at 1 ppb of PCB would be very suitable for reuse.

3.0 RATIONALE AND SELECTIONS OF CURRENTLY RECOMMENDED WASTE TREATMENT METHODS

Based upon our plant surveys of the PCB-using capacitor and transformer manufacturers, the single U.S. PCB manufacturer, and waste treatment equipment suppliers, and upon the analysis and evaluation of all available technologies whether in commercial use, pilot plant, or research stages, Versar has developed recommendations for the most practical treatment methods available now. We have also made predictions of methods applicable over the short- and long-term future. Our current recommendations are based on technology that is either currently in use and doing an excellent job of PCB destruction or removal, or holds great promise of doing that job based upon success in similar but non-PCB, applications.

3.1 Incineration Recommended for Liquid PCBs and Scrap Oils

For liquid PCBs and contaminated scrap oils, we determined only two candidate methods: incineration and sanitary landfill. It is possible that some chemical degradation methods discussed under wastewater treatment might later become applicable to concentrated PCB liquids, but the prospect is not clear at this time.

Sanitary landfill is not recommended for liquids when incineration is available. The potential for liquids escaping in large quantities from ruptured

NWMAR115895

containers, caused by any of a number of circumstances, and then causing massive leaching and liquid control problems at the landfill, is felt to be too great.

Incineration, on the other hand, offers a straight-forward and physically simple method of final destruction. Incineration facilities that have successfully handled PCB liquids are available in Massachusetts, New York, Delaware, Illinois, Texas and Louisiana. Pilot or experimental facilities are available in other parts of the country. With the increase in requirements for disposing of many other liquid organics, it is expected that new facilities suitable for PCBs destruction will be added.

Versar therefore recommends incineration, particularly if there is a choice of the kind of disposal facility to be constructed.

3.2 Carbon Adsorption and UV-Assisted Ozonation Recommended for PCBs in Wastewater

Our survey of wastewater treatment technology was extensive and excellent potential for current, near- and long-term methods was found. The longer term pilot- or research-scale methods hold great promise for achieving zero discharge.

For wastewater treatment, Versar's recommendation is carbon adsorption. This technology has been well proved in a wide variety of industrial adsorption problems. It is constantly being successfully applied to the removal of new organics from water. Our cooperative laboratory work with several suppliers has confirmed preliminary reports of success in removing PCBs. All of the aspects of commercial carbon adsorption, from favorable capital and operating economics to reasonable operating methods, materials of construction, and lack of transport of pollution to air or land, have been proven for PCB-like materials. There is every reason to expect commercial success with PCB removal from wastewater.

Potential problems with carbon adsorption includes the collection of backwash water and spent carbon for incineration or other treatment. With these limitations in mind, we studied the various alternatives and have determined

NWMAR115896

that the UV/ozone method is the best. However, it must be appreciated that this technology is still somewhere in the pilot-plant and research stage, but our cooperative testing with two equipment suppliers shows the method to be effective in destroying PCBs. It offers the potential of degrading breakdown products all the way to CO_2, water and HCl. Any kind of process that generates no solids or liquids for later disposal must be considered for application where no wastewater treatment facilities now exist, and where facilities for incineration of carbon system wastes are not convenient.

The major factors yet to be determined for the UV/ozone systems are costs and operating practicality. Separately, UV and ozone systems are being used in commercial applications, and it is therefore anticipated that the combination will be practical. Choices of the proper UV-radiation wavelength and power levels still need to be made, as well as methods of improving ozone-use efficiency. It appears that commercial UV and ozone generators are suitable.

3.3 Incineration and Landfill Recommended for Contaminated Solids

Although incineration is recommended for PCB contaminated solids, because of its final destruction capability and prevention of any long-term problems, sanitary or scientifically-controlled landfilling must be considered a close second choice. At present, the only incineration facilities for handling the full spectrum of PCB-contaminated solids are those of Rollins Environmental Services in Delaware, Texas and Louisiana. This limitation on locations for treatment requires that the alternate, landfill, be considered.

Landfill, as practiced by Chemtrol Corp., appears perfectly suitable for containment of PCB-contaminated solids, at least over a medium term. Our reservation with this method is that it might be relegating a problem to the future. Our concern is that some decades in the future, when a landfill might be closed, no agency will be prepared to handle the sump emptying and maintenance necessary to prevent leaching. We anticipate that some time in the future, many landfills will have to be mined, and final destruction or recovery carried out for land use or hazard reasons.

NWMAR115897

3.4 Dry Carbon Filter Adsorption Recommended for Control of Air Emissions

For much the same reasons listed in Section 3.2, we recommend that current emissions of PCBs in plant air be trapped in carbon-containing filters. It is recognized that other and better adsorbents may emerge from research, as described in Section 2.2.3, but it is felt that such advances will be readily applicable to any kind of filter pack, screen or cartridge system already in use.

The long record of proven capability of carbon adsorption is the main factor in its choice. However, since contaminated carbon must be either incinerated or regenerated, over the longer term we see the use of low-temperature catalytic oxidation methods as described in Section 2.4.3. Catalytic oxidation methods hold promise for near zero discharge, with the generation of no solid wastes.

NWMAR115898

BIBLIOGRAPHY

1. Hutzinger, O., Safe, S. and Zitko, V., The Chemistry of PCBs; CRC Press, 1974.

2. Carn, B., "Upflow - Downflow Carbon Adsorption", Paper #85C; Nov. 19, 1975.

3. "Methods for Organic Pesticide Analysis in Water and Wastewater", Federal Register, Volume 38, #75, Part II, 1971.

4. Hager, D.G.; and Rizzo, J.L., "Removal of Toxic Organics from Wastewater by Adsorption by Granular Activated Carbon", presented to EPA Technology Transfer Session on Treatment of Toxic Chemicals; Atlanta, Ga., April 19, 1974.

5. "A Symposium on Activated Carbon", ICI-United States, Willmington, Delaware, Booklet #19897; 1968.

6. Hutzinger, O., and Safe, S., Nature, 1971.

7. Prengle, H.W., Jr., Mauck, C.E., Legan, R.W., and Hewes, C.G., III., "Ozone/UV Process Effective Wastewater Treatment" in Hydrocarbon Processing, October, 1975, p. 82-87.

8. Zeff, J.D., "UV-OX(TM) Process for the Effective Removal of Organics in Wastewater", Paper #101C, presented at the 68th Annual Meeting of the AICHE, November 20, 1975.

9. Brice, C.A., et al., "Final Report on MUST Wastewater Treatment System", under Contract DADA 17-71-C-1090; July 15, 1973.

10. Borkowski, B., "The Catalytic Oxidation of Phenols and Other Impurities in Evaporated Effluents", in Water Research 1 367 (1967).

11. Walsh, N.A., and Katzer, J.R., "Catalytic Oxidation of Phenol in Dilute Concentration in Air", in Ind. Eng. Chem. Process Design Develop. 12 477 (1973).

12. Musty, P., and Nickles, G., J. Chromat., 89:185 (1974).

13. Lawrence, J. and Tosine, M.M., "The Adsorption of PCBs from Aqueous Solutions and Sewage", Progress Report (undated), 1975; Water Chemistry Section of Canada Center for Inland Wastes, Burlington, Ontario, L7R4A6.

14. Gesser, H.D.; in Analytical Letters, 12:883 (1971).

15. Tucker, E.S., et al. (Monsanto), in Bulletin of Environmental Contamination and Toxicology 13(1):86 (1975).

NWMAR115899

16. Hague, R., et al., Environmental Science Technology, 8:139 (1974).

17. Berg, et al., Bulletin of Environmental Contamination Toxicology, 7:338 (1972).

18. Sawai, T., Genshiryohu Kogyo, 18(12):43-7 (1972).

19. Stuart, J.D., et al. (University of Connecticut, Dept. of Chemistry), preprint paper. Nat. Meet. Div. Air, Water Waste Chemistry, ACS 1972, 12(2, 804).

20. Smith, G., and Chen, J.W. (Southern Illinois University), presented paper #101E at 68th Annual AIChE Meething, November, 1975.

NWMAR115900

SECTION VII

PRODUCTION AND DISTRIBUTION

1.0 PRODUCTION AND CURRENT USE

1.1 Domestic Production of PCBs and PCTs

Currently there is only one known commercial scale PCB production installation in the U.S., the William G. Krummrich plant of the Monsanto Chemical Company in Sauget, Illinois. This facility is specifically designed for chlorobiphenyls production and has a design capacity of 48 million pounds per year.

Until 1971 PCBs were also manufactured at Monsanto's Anniston, Alabama plant which had a design capacity approximately equal to the Sauget plant. The Alabama operation was discontinued and the plant dismantled in 1971.

PCBs manufactured by Monsanto are marketed under trade name "Aroclor". Tables 1.1-1 and 1.1-2 present data from Monsanto related to production and sales of PCBs from 1957-1974 and production of polychlorinated terphenyls (PCTs) from 1959-1972. The production of PCTs were terminated in 1972. Until then in addition to PCBs (Aroclor series 12) Monsanto manufactured Aroclors 2565, 4465, 5442 and 5460. Aroclors 2565 and 4465 were blends of PCBs and PCTs and Aroclors 5442 and 5460 were two different grades of PCTs. Also given in these Tables are breakdowns of domestic sales per use category and by PCB grade. Detailed information and breakdown on PCB/PCT blends and PCT grades is not available. However, Monsanto reports that the predominant material produced was Aroclor 5460. When produced and marketed these materials were used in plasticizer applications. Figures 1.1-1 through 1.1-3 are graphical representations of these data.

As can be seen from Figure 1.1-1, the majority of the PCBs produced in the United States was marketed domestically. Production and sales of PCBs in 1974 were less than half of those for 1970, where production and sales of PCBs were at their maximum. The difference between production and sales on

NWMAR115901

TABLE 1.1-1

PCB & PCT MANUFACTURE AND PCB SALES

MONSANTO INDUSTRIAL CHEMICALS COMPANY

1957 thru 1964
(Thousands of Pounds)

	1957	1958	1959	1960	1961	1962	1963	1964
U.S. PRODUCTION OF PCBs	(1)	(1)	(1)	37919	36515	38353	44734	50833
DOMESTIC SALES OF PCBs	32299	26061	31310	35214	37538	38043	38132	44869
U.S. EXPORT SALES OF PCBs	(2)	(2)	(2)	(2)	(2)	(2)	3647	4096
U.S. PRODUCTION OF PCTs	-	-	2996	3850	2322	4468	4920	5288
DOMESTIC SALES OF PCBs BY CATEGORY								
Heat Transfer	-	-	-	-	-	157	582	929
Hydraulics/Lubricants	1612	1549	2685	2523	4110	3915	3945	4374
Misc. Industrial	704	755	1569	1559	2114	1681	1528	1692
Transformer	12955	5719	5984	7921	6281	7984	7290	7997
Capacitor	17028	14099	16499	16967	15935	15382	15606	19540
Plasticizer Applications	(1)	3939	4573	6244	9098	8924	9181	10337
Petroleum Additives	-	-	-	-	-	-	-	-
DOMESTIC SALES BY PCB GRADE								
Aroclor 1221	23	16	254	103	94	140	361	596
Aroclor 1232	196	113	240	155	241	224	13	13
Aroclor 1242	18222	10444	13598	18196	19827	20654	18510	23571
Aroclor 1248	1779	2559	3384	2827	4023	3463	5013	5238
Aroclor 1254	4461	6691	6754	6088	6294	6325	5911	6280
Aroclor 1260	7587	5982	6619	7330	6540	6595	7626	8535
Aroclor 1262	31	184	359	326	361	432	414	446
Aroclor 1268	-	72	102	189	158	210	284	190
Aroclor 1016	-	-	-	-	-	-	-	-

(1) Production figures and Plasticizer Applications figures unavailable during year indicated.
(2) U.S. Export Sales figures unavailable during year indicated.

NWMAR115902

TABLE 1.1-2

PCB & PCT MANUFACTURE AND PCB SALES

MONSANTO INDUSTRIAL CHEMICALS COMPANY

1965 thru 1974
(Thousands of Pounds)

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
U.S. PRODUCTION OF PCBs	60480	65849	75309	82854	76389	85054	34994	38600	42178	40466
DOMESTIC SALES OF PCBs	51796	59078	62466	65116	67194	73061	34301	26408	37742	34406
U.S. EXPORT SALES OF PCBs	4234	6852	8124	11231	10624	13651	-	6388	8346	5395
U.S. PRODUCTION OF PCTs	6470	8190	9450	8870	11600	17768	20212	8134	-	-
DOMESTIC SALES OF PCBs BY CATEGORY										
Heat Transfer	1237	1766	2262	2529	3050	3958	3060	752		
Hydraulics/Lubricants	4616	4258	4643	5765	8039	7403	1552	0		
Misc. Industrial	1841	1779	1426	1283	1079	1627	1155	0		
Transformer	8657	8910	11071	11585	12105	13828	11134	25656	37742	34406
Capacitor	23749	28884	29703	29550	25022	26708	14141			
Plasticizer Applications	11696	13481	13361	14404	16460	19537	3259	0		
Petroleum Additives	-	-	-	-	1439	-	-	0		
DOMESTIC SALES BY PCB GRADE										
Aroclor 1221	369	528	442	136	507	1476	2215	171	35	57
Aroclor 1232	7	16	25	90	273	260	171	0	0	0
Aroclor 1242	31533	39557	43055	44853	45491	48588	21981	728	6200	6207
Aroclor 1248	5565	5015	4704	4894	5650	4073	213	807	0	0
Aroclor 1254	7737	7035	6696	8891	9822	12421	4661	3495	7976	6185
Aroclor 1260	5831	5875	6417	5252	4439	4890	1725	305	0	0
Aroclor 1262	558	768	840	720	712	1023	1	0	0	0
Aroclor 1268	196	284	287	280	300	330	0	0	0	0
Aroclor 1016	0	0	0	0	0	0	3334	20902	23531	21955

NWMAR115903

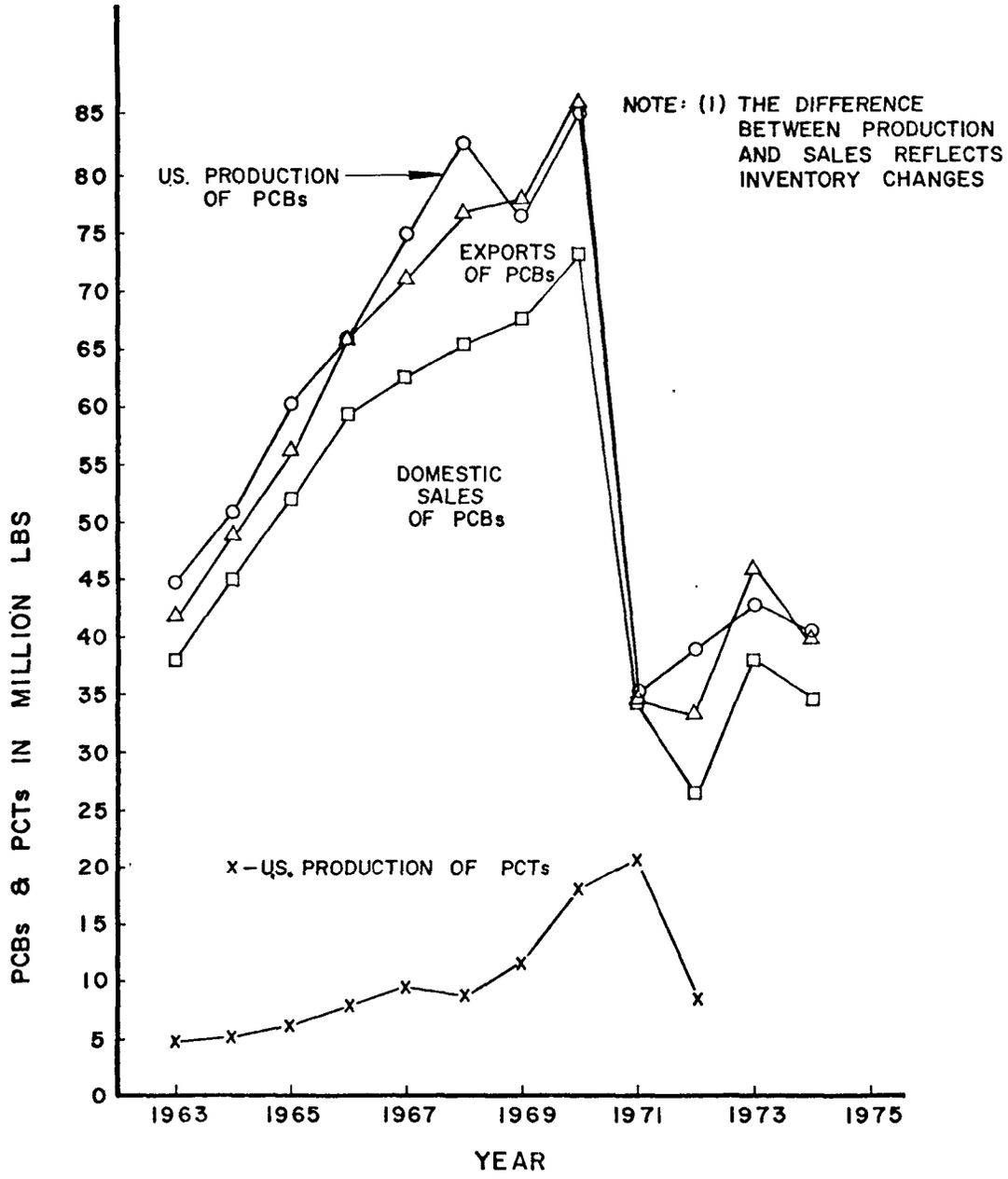


Figure 1.1-1 - U.S. Production of PCBs and PCTs and Domestic Sales and Exports of PCBs

NWMAR115904

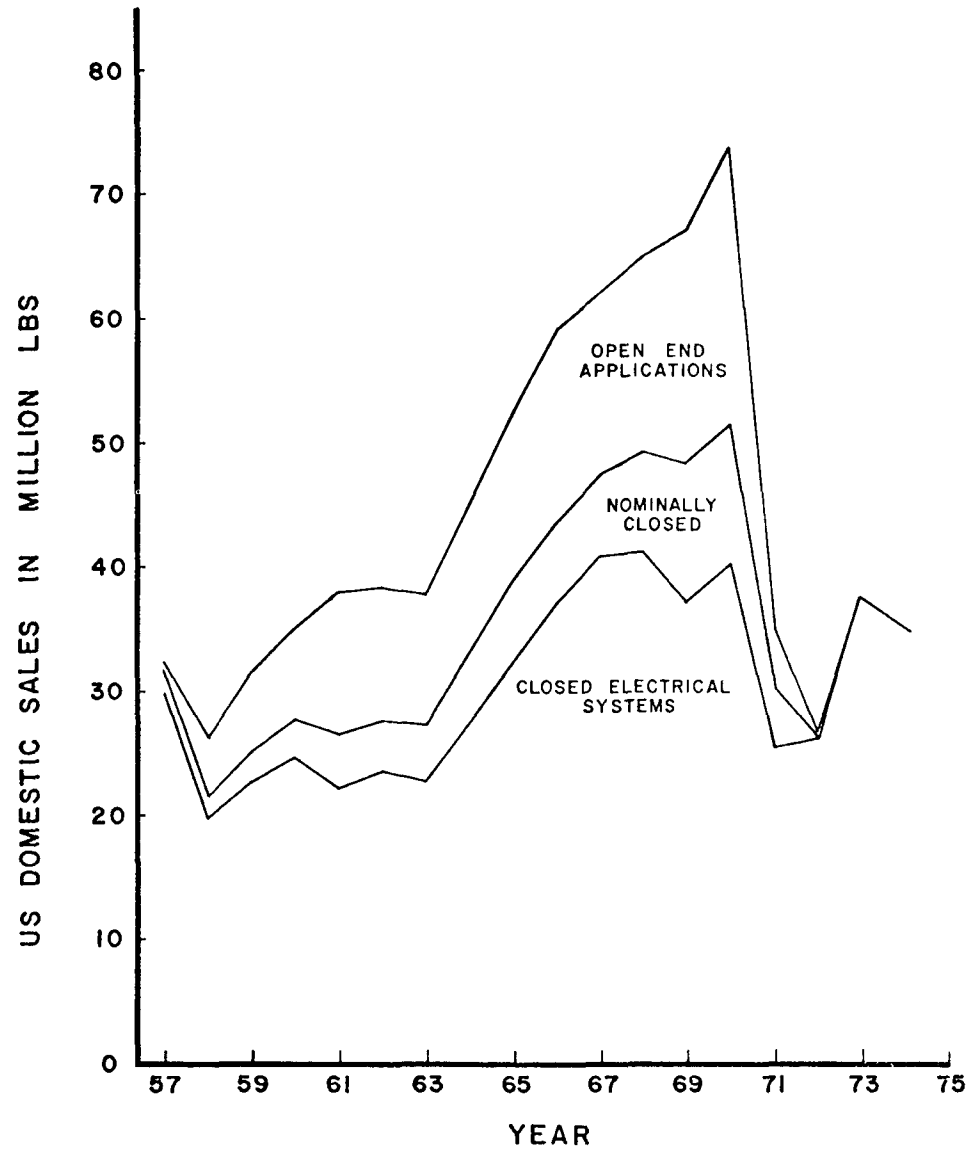


Figure 1.1-2 - U.S. Domestic Sales of PCBs by End Use Applications

NWMAR115905

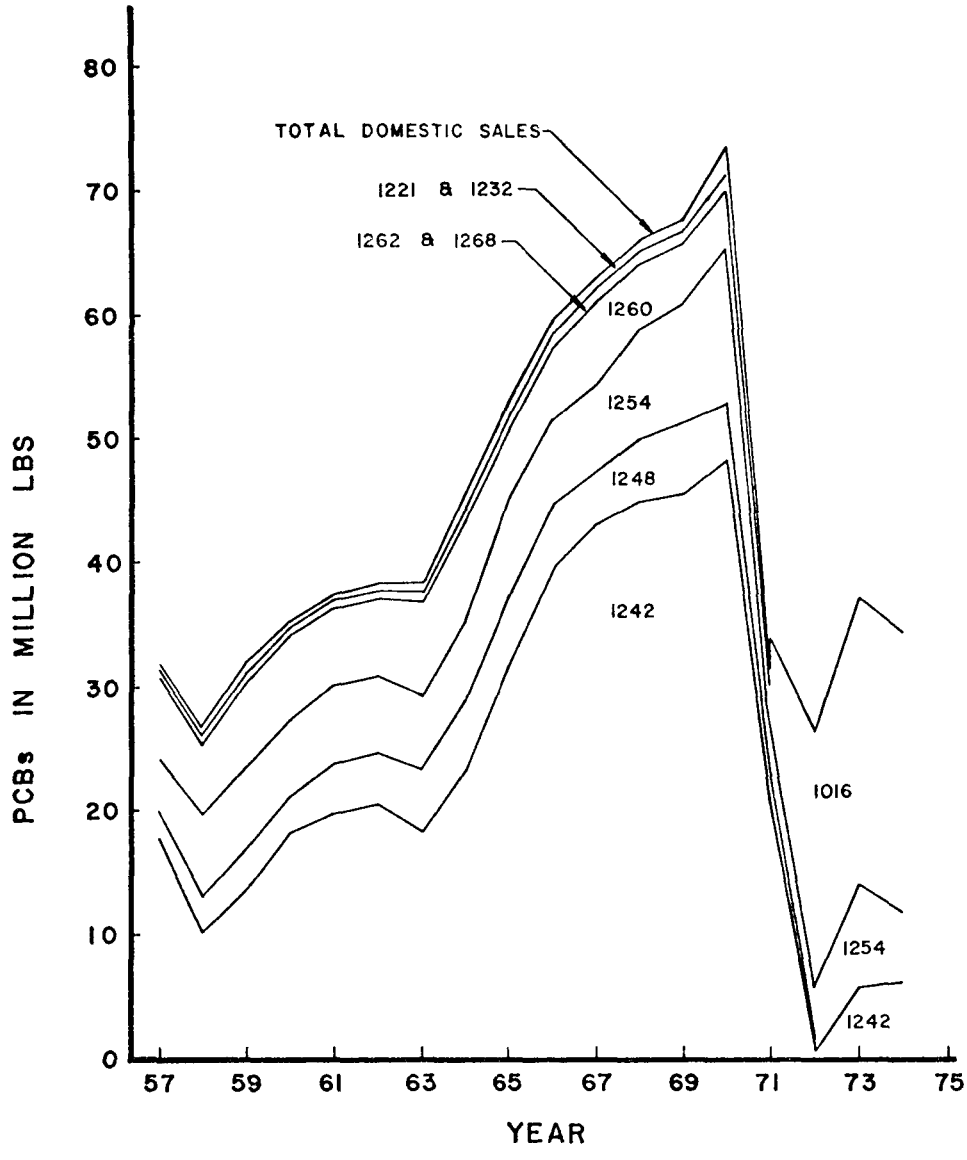


Figure 1.1-3 - U.S. Domestic Sales of PCBs by Type

NWMAR115906

this graph reflects inventory changes of PCBs. Figure 1.1-1 also indicates that the production of PCTs increased steadily through 1971 when their production was at the maximum. The production of PCTs was terminated in 1972.

Table 1.1-3 shows production, sales and export of PCBs for the first quarter of 1975. Monsanto reports that sales for Aroclor are expected to increase at an average annual rate of 6-7 percent over the next few years. Additionally, exports of Aroclor are expected to maintain the same ratio to the U.S. production as in the past.

Figure 1.1-2 indicates that prior to Monsanto's voluntary restriction of sales to all applications with the exception of "closed electric systems", approximately 13 percent of the PCBs in the U.S. was used in "nominally closed" applications (heat transfer, hydraulic fluids and lubricants) and 26 percent was used in "Open End" applications (plasticizers, surface coating, ink, adhesives, pesticide extenders, and microencapsulation of dyes for carbonless duplicating paper) where entries of PCBs to the environment are more probable and PCB emissions are uncontrollable. At present, almost all domestic production is being used in "closed electric systems" (transformer and capacitor applications) where PCB emissions are more controllable.

Between 1957 and 1971 there were twelve different types of Aroclor manufactured by Monsanto with chlorine contents ranging from 21 to 68 percent. Aroclor 1242 and grades lower than 42 percent chlorine made about 48 percent of the total production consumed. U.S. Sale of Aroclor 1242 has dropped drastically since 1971 and has been replaced by Aroclor 1016. Sales of Aroclor 1254 remained about the same for the period 1957 - 1974. Currently, there are four different types of Aroclor manufactured by the Monsanto Company-Aroclors 1221 and 1016 for capacitor applications and Aroclors 1242 and 1254 for transformer applications.

Past and current end-use of PCBs by types are presented in Table 1.1-4. In the years prior to 1971 the largest "open-end" use of PCBs and PCTs has been in plasticizer applications. According to Monsanto, a large percentage of the production of Aroclor 1242 and lower chlorine content grades and the entire PCT production were used for this application. Following Monsanto's

NWMAR115907

TABLE 1.1-3

PCB MANUFACTURE AND SALES

MONSANTO INDUSTRIAL CHEMICALS COMPANY

First Quarter - 1975

	(Thousands of Pounds)
U.S. PRODUCTION	8532
DOMESTIC SALES	7986
U.S. EXPORT SALES	1538
DOMESTIC SALES	
Transformer and Capacitor	7986
DOMESTIC SALES BY PCB GRADE	
Aroclor 1221	10
Aroclor 1242	2201
Aroclor 1254	2115
Aroclor 1016	3660
PREDOMINANT UTILIZATION OF AROCLORS	
Aroclor 1221)	Capacitors
Aroclor 1016)	
Aroclor 1242)	Transformers
Aroclor 1254)	

NWMAR115908

TABLE 1.1-4

END-USES OF PCTs AND PCBs BY TYPE

End-Use	1016	1221	1232	1242	1248	1254	1260	1262	1268	PCTs
Existing Sales										
Capacitors	XX	X		XX through 1971		X				
Transformers				X		XX	X through 1971			
Sales Phased-Out										
Heat transfer				X						
Hydraulics/ lubricants										
. hydraulic fluids			X	X	X	X	X			
. vacuum pumps					X	X				
. gas-transmission turbines		X		X						
Plasticizers										
. rubbers		X	X	XX	X	X			X	
. synthetic resins					X	X	X	X	X	XX
. carbonless paper				XX						
Miscellaneous Industrial										
. adhesives		X	X	XX	X	X				XX
. wax extenders				XX		X			X	XX
. dedusting agents						X	X			
. inks						X				XX
. cutting oils						X				
. pesticide extenders						X				
. sealants & caulking compounds										XX

Notes: (1) X denotes use of a given Aroclor in a specific end-use, while XX denotes principal use
(2) PCTs denote series 25,44 & 54 Aroclors

Source: Monsanto Industrial Chemical Co.

NWMAR115909

voluntary restrictions in 1972, Aroclor sales for plasticizer applications dropped to small percentage to that of the previous years. Historically, capacitors have always been the single largest PCB use category except for the years 1969-1971 when Aroclor usage for plasticizer applications was higher. The major uses of PCBs prior to 1969 in order of volume of material used is listed below:

- Capacitors
- Plasticizers
- Transformers
- Hydraulic fluids and lubricants
- Heat transfer fluids

1.2 Foreign Production and Distribution of PCBs

Known current foreign producers of PCBs are the United Kingdom, Czechoslovakia, France, Germany, Italy, Spain and the U.S.S.R. Detailed information on total production of PCBs outside the U.S. is not available. However, total foreign production of PCBs was roughly estimated by the Interdepartmental Task Force to be 80-85 million pounds annually prior to 1971. This value included 26 million pounds produced by Japan. Foreign production of PCBs has, however, decreased primarily due to Japanese action on banning the domestic production of PCBs. In 1973 foreign production of PCBs was estimated to be 43 million pounds, accounting for a 50% reduction. Production, trade and use of PCBs by OECD member countries for the year 1973 is given in Table 1.2-1. The combined PCB output of three major European producers, France, Italy and United Kingdom was about 36 million pounds in 1973. World commerce in PCBs is expected to decrease further, due to OECD member countries' activities, and to be essentially confined to capacitor and transformer applications.

1.3 Summary of Recent PCBs and PCTs Imports

A summary of estimated imports of PCBs since 1971 is presented in Table 1.3-1. Importation of PCBs appears to be steady or increasing, and currently is in the range of one percent of the domestic sales reported by Monsanto.

NWMAR115910

Table I.2-1 - Production, Trade and Use of PCBs
OECD Member Countries (1973)

Country	Total Production of PCBs	Total Import of PCBs	Total Export of PCBs	End of Use by Category								
				Transformer Application	Capacitors (large)	Capacitors (small)	Heat Transfer System	Hydraulic Equipment	Vacuum Pump	Lubricating & Cutting Oil	Plasticizers	Others
Australia												
Austria[2]	*											
Belgium	0	?	?	1.16	0.40	-	?	?	?	?	?	0
Canada	0	2.38	0	1.98[3]	0.44[4]	0.41[4]	0	0	0	0	?	0
Denmark												
Finland	0	0.53	0	0.09[3]	0.44[4]	0	0	0	0	?	0	0
France	21.33	0.66	10.12	6.48	2.87		0.16	0.17	0.01	0.49	1.45	0.25
Germany[2]	*											
Greece												
Iceland												
Ireland												
Italy	5.55	3.53	2.44	2.70	3.14[3,4]	0	0	0	0	0	0.64[4,5]	0.16[6,8]
Japan	0	(2)	(2)									
Luxembourg												
Netherlands	0	?	0	?	?	?	?	?	?	0	0	0
New Zealand	0	0.04[9]	0	0.075	0	0	0	0	0.005	0	0.02	0
Norway[10]	0	0.04	0	0	0.05[4]	0.005	0	0	0	0	0	0
Portugal												
Spain	*											
Sweden[10]	0	0.70	0	0	0.72	0	0	0	0	0	0	0
Switzerland												
Turkey	0	0	0									
United Kingdom	8.97	0.01	6.53	0.71[3] ←	1.82[9] →							
United States	42.18	0.57	8.35	←	37.87[13] →		?	0.04	?	?	0.04[12]	?

Notes:

(1) All quantities are in million pounds

(2) Information is not available

(3) PCB containing 54 wt % chlorine

(4) PCB containing 42 wt % chlorine

(5) PCB containing 64 wt % chlorine

(6) PCB containing 70 wt % chlorine

* indicates PCB producer country

(7) "Others" refers to PCBs were used to reseller and in research

(8) "Others" refers to PCBs used as a fire-retardant in plastics

(9) This figure includes about 6 percent from previously imported material

(10) Amount reported as import and quantities quoted in usage do not agree

(11) With regards to the use of PCBs in transformers and capacitors, definitive figures are not available

(12) Used in investment casting

(13) This figure includes 0.13 million pounds of imported material

NWMAR115911

Table 1.3-1

Preliminary Summary of PCBs Import Data for
1971-75 Versus Monsanto Production and Sales Data

	Year or Portion of Year				
	1971	1972	1973	1974	1975
Estimated Imports (lb)	550,000	700,000	480,000	450,000	450,000 (6 mos)
Monsanto Domestic Sales (lb)	34,301,000	26,408,000	37,742,000	34,406,000	7,986,000 (3 mos)
Imports as Percentage of Domestic Sales	1.6	2.7	1.3	1.3	-
Monsanto Exports (lb)	-	6,388,000	8,346,000	5,395,000	1,538,000 (3 mos)
Ratio of Exports to Imports	-	9.1	17.3	13.5	-

NWMAR115912

During 1971 and 1972 most of the PCBs imported into the United States originated in Japan, ostensibly corresponding to sales of stocks unsalable in Japan due to pending or established regulatory action. There apparently has been little or no U.S. importation of PCBs from Japan since 1972. The major importer was Marubeni America Corp., West Caldwell, N.J.

Since 1972, most of the imported PCBs originated in Italy, with a small amount imported from France (manufactured by Prodelec). This French material is similar to Aroclor 1242 and is used (40,000-60,000 lb. per year) as a coolant in mining machinery by Joy Mfg. Co., Franklin, Pa. Decachlorobiphenyl (Fenclor DK) is imported from Italy by Yates Mfg. Co., Chicago, Ill., for use in the manufacture of investment casting waxes. Estimated current usage is about 400,000 lb/year.

Polychlorotriphenyls, also used in pattern wax formulations, appear to be imported at an increasing rate. Estimated amounts are:

1973	1974	1975 (6 mos.)
160,000 lb.	330,000 lb.	200,000 lb.

Major importers of PCTs are Progil, Inc. (formerly Prochimie) and Intsel Co., both located in the New York City area. Most of the imported PCTs originate in France (Prodelec).

Use of PCBs and PCTs in casting waxes appears to be generally stable or increasing slowly, and under conditions of lack of regulatory control in the future, such use would be expected to continue at least at the current rate. On the other hand, Joy Mfg. Co. no longer manufactures mining equipment using PCBs as coolant; the amounts imported by Joy are used to service existing equipment. However, since Joy imports only 10 to 20 percent of the total, the overall imports will not be affected greatly by future decreases in imports by Joy.

2.0 FIFTEEN YEAR EXTRAPOLATIONS FOR PCB PRODUCTION AND USE IN ELECTRICAL EQUIPMENT

The subject data base was assembled from domestic sales figures for Aroclors reported by Monsanto – capacitor and transformer sales being summed

NWMAR115913

to obtain totals. For certain years (1972-1973), sales data were reported in aggregate, and in such cases, the reported figures were taken as totals, and usage breakdown was accomplished by assigning total amounts of Aroclor 1221 and 1016 to capacitors and total amounts of Aroclor 1242, 1248, 1254, and 1260 to transformers. All 1975 totals were obtained by quadrupling the reported first-quarter sales figures - a process which very likely yields an approximate lower-bound to the actual yearly totals - and, ultimately, Table 2-1 was constructed.

Manifestly, the available data base is far too limited to form the basis for any rational statistical analysis. The strong pertubational decrement in the 1971-1972 interval precludes the application of incremental regression -- even if a fifteen-year extrapolation were not required. In short, then, trend analysis becomes a generally risky proposition, and the optimum analytical approach seems to be limited to unbiased extrapolations of least-square linear fits to grouped subsets of the available data points.

Given this, three data base subsets appear promising:

(i.) the full base -- using all reported and 1975-estimated data, unweighted and unbiased;

(ii.) a singly-deleted base -- using all reported data, but eliminating the 1975 estimates. This tends to weight the extrapolations (however weakly) with regard to recent (last-decade) performance only, but the resulting curves can then be inspected without the bias of the estimated 1975 totals; and

(iii.) triply-deleted base -- formed by extracting the depressed 1971 and 1972 totals from the singly-deleted base. This construction eliminated the bias of the 1975 estimates, and discounts the effects of the interval decrements caused by regulatory effects. (A perhaps more realistic picture might be obtained by placing a decremental weight on 1975 totals -- under the assumption that some of the roll-back is reactively

NWMAR115914

Table 2-1

Total PCB Breakdown by Use
1966 - 1975

Year	Total (10^6 lbs.)	Capacitors (10^6 lbs.)	Transformers (10^6 lbs.)
1966	37.794	28.884	8.910
1967	40.774	29.703	11.071
1968	41.135	29.550	11.585
1969	37.127	25.022	12.105
1970	40.536	26.708	13.828
1971	25.275	14.141	11.134
1972	25.656	20.321	5.335
1973	37.742	23.566	14.176
1974	34.406	22.000	12.000
1975 (est.)	31.944	20.644	11.300

NWMAR115915

induced by the strong depression in the 1971-1972 totals. This would result, however, in externally biased extrapolations, and justifying a long-term lag of such effects with the available data appears difficult.)

These data bases, and the unbiased, least-square linear extrapolations derived from them, are graphed in Figure 2-1. Inspection of the curves shows that the 1975 estimate has little effect on the aggregate total; an event readily accounted for by noting that the singly-deleted base has the effect of depressing the capacitor total only slightly more than it elevates the transformer total. The triply-deleted base, however, provides almost no perturbation to the transformer total derived from the full base. Inspection of the curves for the aggregate total and the capacitor total indicate that this arises from the fact that the ratio of their time-derivatives (slopes) for the triply-deleted base is almost equal to its value with the full base.

Generally, the developed extrapolations disagree with mid-1975 industry estimates for the near-term future. Apparently, Monsanto and capacitor manufacturers tend to expect 1975 totals to resemble 1974 totals, followed by a five to ten percent increase in 1976, and a general four to five percent increase over the preceding year for 1977 on. Obviously, increases by a fixed percentage over preceding years yields exponentially increasing totals – an event undoubtedly strongly desired, but probably wholly utopian. Transformer manufacturers appear to tend toward a more conservative view; General Electric for example, expecting the demand for power transformers to rise and the demand for distribution transformers to fall – probably yielding a general saturation of the sales figures when integrated over all types.

Taking the available information into consideration, the impression remains that the triply-deleted data bases probably provide the most likely picture of what might be expected over a 25-year term. Naturally, such scenarios assume the external *status quo* as constant; technological, economic, and regulatory factors being capable of producing strong (and unassessable) variations in usage patterns. As a matter of fact, very recently, Monsanto has publicly announced that they would support a cessation of the PCB production when suitable alternative materials become available.

NWMAR115916

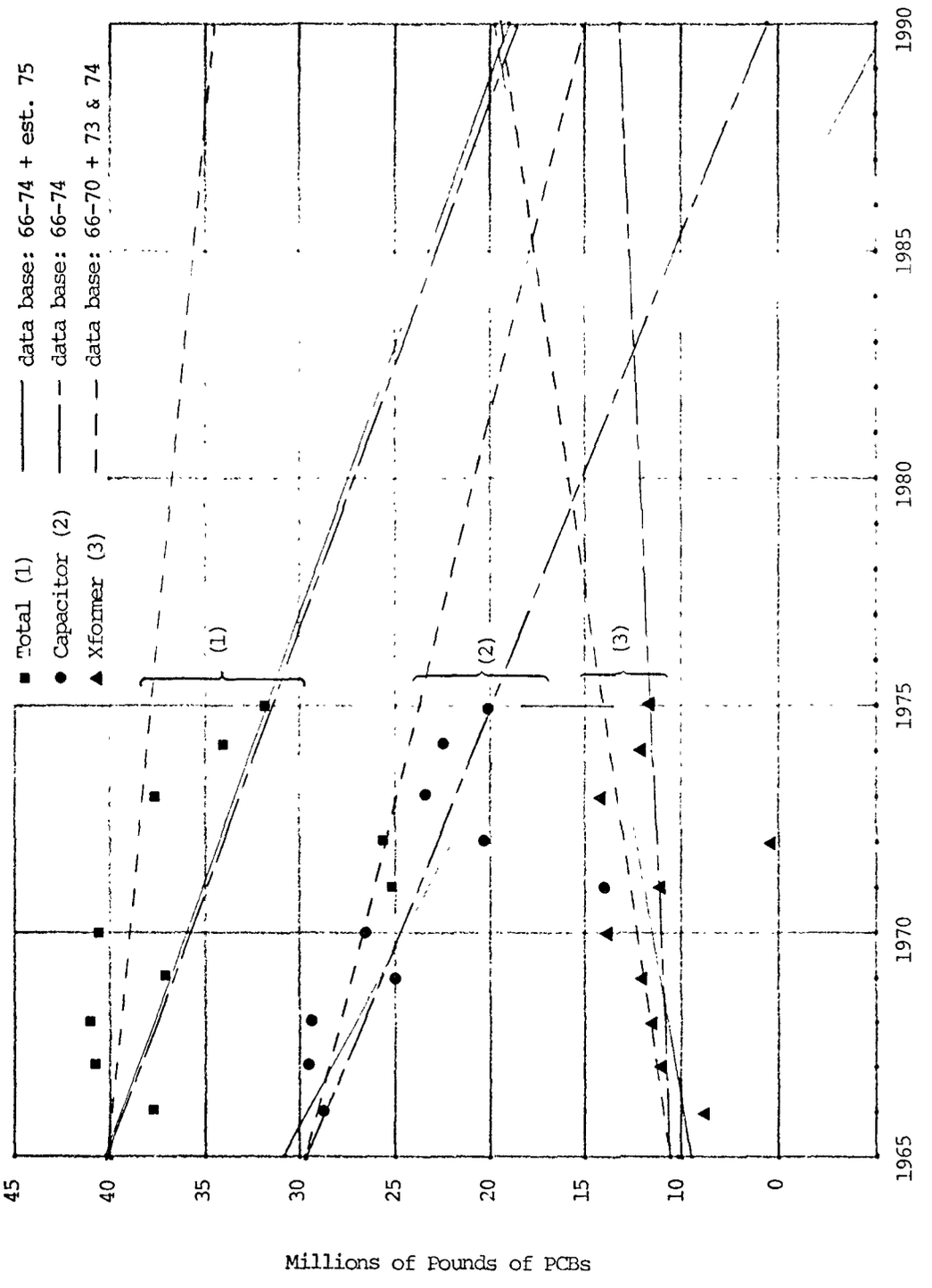


Figure 2-1. Unbiased Extrapolations of Least-Square Linear Curves for PCB Production and Use in Electrical Equipment

NWMAR115917

3.0 OVERALL MATERIAL BALANCE

Three separate approaches have been taken to obtaining overall data on total PCBs production, historical usage, and current distribution in the environment. Most of the uncertainty lies in the period 1930-1960, for which Monsanto data are lacking. Use of PCBs in transformers, particularly in electrical distribution systems, apparently began almost simultaneously with commercial production. Extensive use in capacitors can be traced to the intensive development and use of electrical home appliances, starting in the mid to late 1940's. Use in adhesives, paper, lubricants, etc., probably began in the early 1950's, and use of PCBs as a heat transfer fluid began early but increased rapidly between 1950 and 1970.

Using the Monsanto production data for 1960 to 1975, and assuming a linear increase in total PCBs production between 1930 and 1960, we obtain:

Production 1960 - 75	850×10^6 lb
Production 1930 - 60 (30 yr $\times$ 19 $\times$ 10^6 lb/yr ave)	570×10^6 lb
Total	$1{,}420 \times 10^6$ lb

Estimates of total PCBs usage by U.S. industries for the period 1930 - 1975 are given below:

PCBs by use category	
Capacitor & transformers	965×10^6 lb
Heat transfer	20×10^6 lb
Hydraulics/lubricants	80×10^6 lb
Misc. industrial	27×10^6 lb
Carbonless copying paper	45×10^6 lb
Other plasticizer uses	115×10^6 lb
Petroleum additives	1×10^6 lb
Total from Monsanto	$1{,}253 \times 10^6$ lb
Estimated total U.S. imports of PCBs	3×10^6 lb
Grant total PCBs usage	$1{,}256 \times 10^6$ lb

NWMAR115918

Alternatively, we have fitted least square correlations to each of the sets of Monsanto sales data for various uses, and to the domestic sales data set from 1957 to 1974, projected each plot back to 1930, and integrated. These operations, plus the addition of several other well established data points, produce the following results:

Total Domestic Sales, 1930 - 1970	767×10^6 lb
Domestic Sales, 1971 - 1975	168×10^6 lb
Total Exports, 1963 - 1974	82×10^6 lb
Estimated Exports, 1930 - 1963; 1975	70×10^6 lb
Monsanto In-House Use (unreported as sales)	25×10^6 lb
Total	$1{,}112 \times 10^6$ lb

As a comparison with the above, the 1973 Foster D. Snell study of PCBs concluded that the upper bound of U.S. usage of PCBs over 1934-72 was 1.175×10^9 lb. Adding usage figures for 1973-75 (about 105×10^6 lb), plus 150×10^6 estimated total exports, one obtains:

Estimated Total U.S. Production to Date	1.43×10^9 lb
Estimated Total U.S. Usage to Date	1.28×10^9 lb

Thus, it appears that the approaches taken to obtaining overall production and use quantities from various types of estimates yields:

U.S. Production

Maximum	1.4×10^9 lb
Minimum	1.1×10^9 lb

U.S. Usage

Maximum	1.25×10^9 lb
Minimum	1.0×10^9 lb

NWMAR115919

Sufficient data have been generated to allow an approach to the usage quantity through estimated quantities now in use or in the environment:

Transformers - 135,000 in service x 2,250 lb/unit average content	300×10^6 lb
Power Capacitors - 5×10^6 in service x 36 lb/unit average content	180×10^6 lb
Industrial Capacitors - 790×10^6 in service x 0.35 lb/unit average content	270×10^6 lb
Total in Electrical Service	750×10^6 lb
Total Other Than Electrical	8×10^6 lb
Grand Total	758×10^6 lb
Estimated "free" PCBs in the environment (see Section IX)	150×10^6 to 175×10^6 lb
Estimated amount degraded or incinerated (20×10^6 lb. by contract incineration; 5×10^6 lb incinerated with sewage sludge and other solid wastes; and 30×10^6 lb degraded mono and dichloro homologs) -	55×10^6 lb

Estimated amounts to landfill or dump:

Ten percent of capacitor and transformer usage as production wastes - $1.06 \times 10^9 \times 0.10 =$	110×10^6 lb
Obsolete electrical equipment (capacitors mainly) -	80×10^6 lb
Other sources (paper, plastics, etc.) -	100×10^6 lb
Estimated total	290×10^6 lb

In summary:

Amount in use	758×10^6 lb
Amount in landfills	290×10^6 lb
Amount "free" in soil, water, air, sediment	150×10^6 lb
Amount degraded or incinerated	55×10^6 lb
Total	$1,253 \times 10^6$ lb

NWMAR115920

Thus, using estimates, we can account for the maximum usage of 1.25×10^9 lb. calculated previously. We believe that the ranges of production and usage are well-defined by the maximum and minimum values presented above, and that the accuracy of the maximum values are sufficient for use in gross calculations pertaining to the PCBs problem.

NWMAR115921

BIBLIOGRAPHY

1. Colder, A.W., (Joy Manufacturing Co., Pittsburgh, Pa.), Personal Communication, September 8, 1975.

2. Environmental, Directorate, Organization for Economic Cooperative and Development, General Information on PCB Monitoring and Control, Paris, September 11, 1974.

3. Foster D. Snell, Inc., Market Input/Output Profile, Process Technology Assessment and Entry Into the Environment of Polychlorinated Biphenyls, EPA Contract 68-01-2106, December, 1973.

4. Leisy, A.E. and Smull, W. (Monsanto Industrial Chemical Co.), Personal Communication, October 8, 1975.

5. Papageorge, W.P. (Monsanto Industrial Chemical Co.), Personal Communication, August 22, 1975.

6. Polychlorinated Biphenyls and the Environment, Interdepartment Task Force on PCBs, Washington, D. C., May, 1972.

7. Solomon, P. (Yates Manufacturing Co., Chicago, Illinois), Personal Communication, August 8, 1975.

NWMAR115922

SECTION VIII

SUBSTITUTES FOR PCBs

1.0 INTRODUCTION

In 1970, the Monsanto Company announced a voluntary restriction on sales of PCBs for all but closed electrical applications. As a result of this action, since 1972 the use of domestically produced PCBs has been limited to the manufacture of electrical capacitors and the manufacture and maintenance of electrical transformers.

Satisfactory substitutes have been developed for all of the other previous uses of PCBs except in the manufacture of investment casting wax. Imported PCBs have been the sole source of material for this application. There are no complete data available on imports; however current aggregate information indicates that PCB imports are about one percent of domestic production.

A number of materials are currently being developed as substitutes for PCBs. The replacement of PCBs by any of these materials will depend on the specific technological, economic, and institutional requirements which govern each specific application. The evaluation of the substitutes must be based on careful consideration of all of these factors as they apply to each specific application where PCBs are currently being used.

2.0 ELECTRICAL CAPACITORS

An electrical capacitor is a device which stores electrical energy when a voltage differential is applied across the device. This stored energy reappears in the circuit as the voltage is decreased. The capacitor therefore performs an electrical function equivalent to that of a spring in a mechanical system. The amount of electric charge (q) which a specific capacitor can store

NWMAR115923

is a function of its size, or capacitance (c), and the voltage (v)

$$q = cv \tag{1}$$

and the energy stored in the capacitor (w) is a function of the capacitance and the square of the voltage:

$$w = \tfrac{1}{2}cv^2 \tag{2}$$

This energy is stored in the capacitor in the form of an electric field and in the dielectric material which is exposed to that field.

2.1 Function of the Dielectric Material

When a material is placed within an electric field there is a tendency for the charges associated with the constituent molecules of the material to move in the direction of the field (the positive charges move in the direction of the applied field, the negative charges in the opposite direction). If the material is a conductor, the mobile charges, usually electrons, will move freely under the influence of the field and a current is said to flow. However, if the material is a non-conductor, the applied electric field will cause a spatial displacement of the charge centers of the constituent molecules, with the result that surface charges will be induced on the material. The charge on opposite faces of the material will be opposite in sign and will generate an electric field within the material opposing the applied field. Such a material is known as a dielectric and is characterized by a parameter defined as the ratio of the electric field that would exist in that space if the medium were replaced by vacuum to that actually found within the dielectric - this parameter is referred to as the dielectric constant. The dielectric constant of most materials, at least at low frequencies, is greater than unity.

Since the effect of an applied electric field on a dielectric medium is the generation of a surface charge, it is clear that work must be done in the separation of these charges. Clearly, the larger the applied electric field, the larger the surface charge, and conversely, when the electric field is removed, the surface charge is zero. The energy that is required to establish the necessary surface charge is stored within the dielectric and can in most cases be recovered without loss by removing the external electric field.

NWMAR115924

In practice, the external electric field is established by applying electrical charges to a pair of metal plates placed on the opposite surfaces of the dielectric. Although the geometry of the conductor-dielectric sandwich can take a wide variety of forms, the specific geometry that is of most interest is that in which conductors are parallel plates separated by the dielectric. In this case the capacitance of the device is given as

$$C \propto \frac{eA}{d} \tag{3}$$

where e is the dielectric constant, A the area of each plate and d the spacing (the thickness of the dielectric).

As is stated above, the magnitude of the surface charges that are formed on the dielectric increases as the applied electric field increases. Eventually, the external electric field may become sufficiently strong to rupture the bonds that hold together the charges on the individual constituent molecules with the result that the dielectric breaks down; i.e., conducts current. The critical voltage (V_c) for a specific capacitor is

$$V_c = E_c d \tag{4}$$

where E_c is the dielectric strength, i.e. the maximum potential gradient (voltage) that the dielectric can sustain without rupture. Clearly, the dielectric constant and the critical voltage, or dielectric strength, are essentially unrelated.

The critical voltage of the dielectric material can impose severe limitations on the maximum voltage at which a capacitor can operate. The electric field strength in a capacitor is strongest at sharp edges and points caused by surface roughness and the edges of the conductive plates. If the electric field at these points exceeds the critical voltage of the dielectric, a corona discharge can occur which results in current leakage and heating of the capacitor and causes chemical degradation of the dielectric material. This critical voltage for corona discharge depends on both the geometry of the capacitor and the properties of the dielectric, and is known as the corona inception voltage. Air has a rather low dielectric strength; the presence of air bubbles in the dielectric will result in corona discharges if the capacitor is operated at applied voltages above about 270 volts.

NWMAR115925

When several capacitors, say C_1 and C_2, are connected in parallel, then the voltage across each is the same, V, while the charge on the capacitors is $Q_1 = C_1V$ and $Q_2 = C_2V$; hence the capacitance of the parallel combination is given as

$$C_t = C_1 + C_2 \tag{5}$$

On the other hand, if the two capacitors were connected in series, then the charge, Q, would be the same for each. In this case, the respective potentials would be given as $V_1 = Q/C_1$ and $V_2 = Q/C_2$, with the result that the total capacitance is given as

$$1/C_t = 1/C_1 + 1/C_2 \tag{6}$$

From the above considerations it can be seen that the effect of a small hole through the dielectric will be to produce a very small reduction in the overall capacitance, since the resulting structure may be considered as two capacitors, one with the normal dielectric, the other with air dielectric, in parallel. On the other hand, the breakdown strength of air is considerably less than that of most practical dielectric materials, so that the effect of such a discontinuity in the dielectric will primarily be in reducing the critical voltage of the resulting structure.

On the other hand, the effect of a gap between the dielectric and the plates is more serious since the resulting structure will act as if it were made up of several capacitors in series. From Eq. (6), it can be seen that the smallest capacitor in a series circuit will determine the total capacitance of the structure. Thus, a gap between the plates and the dielectric will have the effect of reducing the capacitance without a reduction in the dielectric strength.

In most practical devices, the assumption that the sole effect of the dielectric is the reduction of the internal electric field by the induction of surface charges is not entirely correct. In all such practical cases, there is a leakage current that flows through the dielectric. This leakage current produces heat within the dielectric. This leakage is very small in useful dielectrics, but the heating effect is not always

NWMAR115926

negligible. An additional dissipative process results when the dipole moment induced within the molecules of the dielectric is not exactly in phase with the inducing electric field. In those cases where in the constituent molecules have a permanent dipole moment, i.e. water, the inability of the orientation processes to follow the changes in the applied field becomes the dominant energy dissipation process; this is the basis of dielectric heating.

The combination of the mechanism by which energy is dissipated within the dielectric is called the loss-tangent; the smaller the loss-tangent, the smaller the energy loss within the dielectric and hence the better the capacitor.

2.2 Practical Capacitors

In its simplest form, a capacitor is a pair of metal plates separated by a dielectric material. Depending on the application, a great variety of structures have been used ranging from parallel plate mica or glass dielectrics for very small capacitors, through tantalum-tantalum oxide-tantalum structures which have very large capacitances with very low operating voltage ratings. The capacitors which use PCBs as the dielectric material have capacitance values in the range of a few tenths to tens of microfarads and are usually spiral wound of two thin aluminum foils and two paper spacers. To illustrate the utility of spiral winding, a 0.5 mfd capacitor made of two layers of aluminum foil 2.5 inches wide by 0.0005 inches thick and alternate layers of paper (dielectric constant = 2) 0.001 inches thick, would have a diameter of only 0.9 inches, whereas, in the plane parallel configuration, the structure would be 2.5 inches by 220 inches. Incidentally, taking the dielectric strength of the paper to be of the order of 500 kv/cm, the voltage rating of the above example capacitor would be about 1250 volts.

The manufacturer of spiral would metal/paper capacitors must avoid the presence of small imperfections in the paper dielectric and must insure complete and reliable matching of the metal foils to the surfaces of the paper. As an alternative to the requirement of very high quality control of the paper and of the forming process, it has been found to be cost effective to evacuate the spaces within the wound capacitor and to subsequently fill

NWMAR115927

the voids with a suitable liquid dielectric material prior to sealing the completed unit. This liquid displaces any air which may be left in the capacitor, thereby raising both the dielectric constant and the critical corona inception voltage.

2.3 Required Properties of Dielectric Liquid

The properties that are essential for the liquid dielectric can be described in terms of the functions that the liquid must fulfill:

- Electrical Properties - Should have a dielectric constant at least as large as that of the solid dielectric spacer, and a dielectric strength at least as high as that of the solid dielectric. The liquid must have a low loss factor to assure electrical efficiency and a high resistance to the formation of corona discharges.
- Physical Properties - Must be liquid at a suitable temperature to allow processing of the capacitor. Further, it should be liquid over the operating temperature range of the resulting capacitor with a sufficiently small coefficient of thermal expansion so as to fulfill its function over the entire temperature range. Must have a boiling point sufficiently elevated to ensure that the vapor pressure at the maximum operating temperature of the capacitor does not cause rupture of the container.
- Chemical Properties - Must be chemically compatible with the solid dielectric material and with the metal plates. Specifically, the dielectric liquid must wet both the plates and the solid dielectric without altering either material chemically or physically over the entire operating temperature range. The dielectric liquid must also be chemically stable at elevated temperatures and in the presence of intense electric fields so that its properties do not change over time.

NWMAR115928

- Flammability - Should be non-flammable and produce no flammable breakdown products if electrical arcing occurs within the capacitor.
- Cost and Availability - Should be inexpensive and readily available with well defined and standardized properties.
- Toxicity - Should be non-toxic and its possible breakdown products should be non-toxic.
- Environmental Persistence - Should be environmentally degradable and non-bioaccumulating.
- Legislative Acceptability - Must be acceptable under the laws of the U.S. and of all other countries to which capacitors are exported. Should be acceptable under the relevant electrical codes which govern the use of capacitors.

2.4 The Use of PCBs in Capacitors

PCBs have been the standard dielectric liquid used in almost all liquid-filled capacitors since 1929. Prior to 1952 the liquid used in capacitors was Aroclor 1254 (54 percent chlorine); it was then replaced by Aroclor 1242 (42 percent chlorine), which has better electrical properties. In September 1971, Monsanto introduced a new capacitor liquid, Aroclor MCS-1016, which is a modified Aroclor 1242. This material is the standard against which the properties of any other proposed capacitor dielectric fluid must be compared.

2.4.1 Properties of PCB Capacitor Dielectric Liquid[1]

The relevant properties of Aroclor 1016 are as follows:

. Electrical Properties

dielectric constant (ASTM D-150-47T)	5.85 ($25^{o}C$)
dielectric strength (ASTM D-149-44)	>35 KV
resistivity (ASTM D-257-46)	$>500 \times 10^{9}$
loss-tangent (Dissipation factor-ASTM D-150-47T)	0.0025

NWMAR115929

- Physical Properties

melting point (pour point)	$-19^{\circ}C$
viscosity at $100^{\circ}F$	71-81 SUS
boiling point	$325-366^{\circ}C$
specific gravity ($25^{\circ}C$)	1.362
coefficient of thermal expansion	.00068 $cc/cc^{\circ}C$

- Chemical Properties

corrosiveness: liquid - noncorrosive
breakdown products - corrosive

solvency: high, but satisfactory materials have been developed

stability (max. service temp.) $95^{\circ}C$

- Flammability

liquid (Cleveland open cup flash point): $141^{\circ}C$

breakdown products: nonflammable (primarily HCl and carbon)

- Cost and Availability

cost $5.14/gallon

availability - no problem

NWMAR115930

- Persistance

  environmental - very persistent

  % biodegradation (48 hour activated sludge) $33 \pm 15\%$ [2]

  bioaccumulating - very

- Legislative Acceptability

  banned in Japan, essentially banned in Sweden

2.4.2 Advantages and Disadvantages of PCBs in Capacitors

Aroclor 1016 has a relatively high dielectric constant of 5.85 which is well matched to the dielectric constant of 6.10 of the paper used in capacitors. This mixture of PCBs is chemically very stable, even in the presence of high temperatures and intense electrical fields. It is probable that some slight dechlorination of the PCB occurs during the long term operation of capacitors. The resulting HCl would lower the dielectric strength of the PCB. However, the Aroclor 1016 used in capacitors usually contains a few tenths of one percent of a chemical scavenger (usually an organic epoxide) which reacts with any HCl which is formed, and thereby extends the life of the capacitor.

The only major problems associated with the use of PCBs are their extreme environmental persistence and chronic toxic properties which are made more severe by the high degree of bioaccumulation which occurs in the environment. The recent restrictions imposed by the governments of Japan and Sweden on the use of PCBs in those countries will require that a suitable substance be developed for use in electrical equipment which will be exported.

2.4.3 Usage of PCBs in Capacitors

The General Electric Co. reports that approximately 100 million PCB type capacitors are produced annually in the U.S. with a value of 140 million dollars, most of them for first-time use.[3] Total annual PCB requirement for capacitor manufacturing is 21 million pounds, about 50 percent of which is used in large power factor correction capacitors.

NWMAR115931

Capacitors used in lighting and air conditioning applications contain 0.005 to 0.09 gals. (0.05 to 1.0 lbs.) of PCBs. The largest power capacitors contain about 6.7 gals. (77 lbs.) of PCBs. The most popular size contains about 3.1 (36 lbs.). The National Electrical Code requires that any installation of capacitors in which any single unit contains more than 3 gallons of combustible liquid shall be in a vault like that required for transformers.(4)

The life expectancy of capacitors exceeds 10 years for lighting applications and more than 20 years in electric utility power transmission application. Although capacitors are considered long-lived products, they could fail due to poor process control, materials quality and misapplication. According to G.E., existing PCB capacitors have been developed to the point that failures are considered essentially negligible. In each application, the first-year failure rates are less than 0.2 percent. This level of life and reliability had not been achieved prior to the introduction of PCBs. Furthermore, the relative non-flammability of askarels significantly reduces the fire hazard that might otherwise accompany those failures that result in rupture of the case. Capacitors are not rebuilt and returned to service after failure. They are disposed of and replaced by new capacitors.

2.5 Alternatives to the Use of PCBs in Capacitors

There are two main approaches that might be adopted in the development of substitutes for the PCBs in capacitor applications, (a) a straightforward replacement of PCBs that would require minimal alternation of the present production techniques; and (b) the introduction of new production techniques designed to eliminate the need for a liquid dielectric. In either case, the alternative solution must be significantly less environmentally distressing than the currently used PCBs.

2.5.1 Substitutes for PCBs

So long as the present method of construction of capacitors is used, the dielectric liquid is required and must necessarily satisfy the physical, chemical, and toxicity requirements at least as well as do PCBs. These requirements can be relaxed only in conjunction with a more or less severe restriction on the maximum operating temperature of the capacitor. On the other hand, some sacrifice in the dielectric constant and dielectric

NWMAR115932

strength would be possible by increasing the dimensions of the capacitors. In many applications this increased size would be troublesome, but not so serious as to be impractical. Further, there are some applications in which the non-flammability of the dielectric liquid and of its possible breakdown products could be somewhat sacrificed. Finally, the cost factor could be considerably relaxed.

A number of compounds are being developed as replacements for PCBs in capacitors. The following list of compounds must all be considered as possible substitutes for PCBs in at least limited applications.

2.5.1.1 Phthalate Esters:

2.5.1.1.1 Dioctyl Phthalate: (DOP)

Current status:
Used in capacitors in Japan. Used by General Electric Co. under the trade name "Econol" in capacitors manufactured for export to Japan.

Advantages:
Price: one-half that of PCB.
Availability: Widely used as a plasticizer for PVC.
Dielectric Constant: 5.3; similar to PCB.

Disadvantages:
Chemical stability: capacitors are limited to 85°C max. vs 95°C max. for PCB.
Corona inception voltage: lower than PCB.(5)
Flammability: Flash point is relatively high (220°C) but more flammable than PCBs.
Toxicity: Suspected carcinogen. Extensive additional testing is required.(5)

2.5.1.1.2 Diisononyl Phthlate:

Current status:
Currently being tested by Exxon Chemical under the trade name "Enjay 2065".(6)

NWMAR115933

2.5.1.4 Silicones

Current status: Developmental work is being done in the U.S. by Dow Corning Co. No information is currently available, but Dow Corning has indicated that a formal announcement will be made late in 1976.[10]

2.5.1.5 Diaryl Sulfone

Current status: The Monsanto Company has been conducting extensive tests with a proprietary dielectric liquid trade named "MCS-1238".[2] Detailed chemical information is not currently available on this material; however, an example cited in German and U.S. patent disclosures is a mixture of tolylxylyl sulfone, isopropyl biphenyl, and minor ingredients which may be antioxidants. Complete information has been promised by Monsanto for the late first quarter of 1976.

Advantages: (MCS-1238)
Dielectric constant: 6.0
Corona inception voltage: similar to PCB.
Biodegradation (48 hour activated sludge): 70% ± 10%.
Bioaccumulation: does not concentrate in food chain.
Toxicity: Rat oral LD_{50} = 3.8 g/kg. Rabbit dermal LD_{50} - 5 to 8 g/kg.

Disadvantages: (MCS-1238)
Flammability: more flammable than PCBs.
Chronic toxicity: lack of data.

2.5.2 Elimination of Dielectric Liquids in Capacitors

Because of the complex and strongly interacting requirements on a liquid dielectric material, there is considerable interest in the development of capacitor designs which do not require a liquid dielectric. The rather advanced technology involved in the production of very thin plastic films of very high physical integrity, such as is required in many food packaging applications, has opened the way for the production of plastic

NWMAR115934

films of suitable dielectric constant and dielectric strength for capacitor applications. The parallel development of methods for the deposition of thin, carefully controlled metallic films on non-conducting surfaces, such as is widely practiced in the semiconductor industry, suggests that the use of a liquid dielectric material could be circumvented by metallic films deposited onto suitable plastic substrates. The resulting metallized film can be spirally wound into useful capacitors. The essential problems associated with this approach, aside from the development of suitable high speed processing equipment, lie in the selection of a plastic substrate that is tractable but also stable at sufficiently high operating temperatures, and in the complete elimination of air from the capacitor. An additional problem with this approach lies in the nature of the polymers that have been studied; nearly all of the suitable materials are themselves flammable and so are their probable breakdown products.

A number of different plastic films are used in low voltage DC capacitors. Most of these materials exhibit a relatively high loss-tangent (dissipation factor) which results in over-heating when subjected to an alternating electric field. Only polypropylene has a loss-tangent sufficiently low so that it can be used in AC capacitors, and the dielectric constant of this material is about 2.2 (vs 5.85 for PCB).

The polypropylene film that is used in capacitors is considerably thinner than that used for packaging and decorative applications. There is no current source of satisfactory capacitor grade polypropylene film in the U.S. The technology for metallized polypropylene film capacitors comes from Pye TMC of England which is partially owned by Philips. Representatives of this company have approached most major U.S. manufacturers. Currently, this technology has been purchased by one U.S. manufacturer at a cost of four percent of their capacitor sales for the life of the technology usage. The failure rate of the dry film capacitors is reported to be 20 times that of PCB filled capacitors, primarily due to corona discharges into air that is trapped in the dielectric layers. Present efforts on dry film type capacitors are directed toward the development of a suitable capacitor design. Polypropylene capacitors are widely used in Europe at voltages up to 250 volts. Capacitors suitable for U.S. applications are not expected for 3 to 5 years.

NWMAR115935

2.6 The Use of PCB Capacitors in Electrical Equipment

Each of the specific uses of PCB capacitors imposes special requirements on the performance of the capacitor and on the properties of the dielectric liquid. The evaluation of the various substitute liquid dielectrics and of the dry capacitor designs must be based on the suitability of the resulting capacitors for each of these uses.

2.6.1 Power Factor Correction

The largest use of PCB filled capacitors is to increase the efficiency of electrical power distribution by correcting for the power factor of inductive machinery such as industrial motors, induction furnaces, and fluorescent light transformers. In general, the load imposed on a power line by these electrical devices is not purely resistive, but is also partly inductive. The voltage drop (V_L) across such an inductor is proportional to the rate of change of current through the device; hence

$$V_L = -L \frac{di}{dt} \tag{7}$$

where the negative sign expresses the reaction of the inductance (L) to a change in current (i) through the inductance. If the current is expressed in the form

$$i = i_o e^{j\omega t} \tag{8}$$

where $j \equiv \sqrt{-1}$, $e^{j\omega t} = (\cos \omega t - j \sin \omega t)$, $\omega = 2\pi f$, $f \equiv$ frequency.

Then

$$V_L = j\omega L \, i = Z_L \, i \tag{9}$$

where Z_L is the inductive reactance given by

$$Z_L = j\omega L \, . \tag{10}$$

NWMAR115936

On the other hand, for a capacitance (c), the potential difference

$$V_c = \frac{Q}{c} = \frac{\int i\, dt}{c} = -\frac{1}{j\omega c}\, i \qquad (11)$$

where Q is the electric charge on the plates of the capacitor. Hence, the capacitive reactance Z_c is given by

$$Z_c \equiv -\frac{1}{j\omega c} \ . \qquad (12)$$

If a series circuit containing inductive (L), capacitive (c), and resistive (R) elements has a potential difference $v = v_o e^{j\omega t}$ across it, the relation between current and applied potential difference is given by

$$Ri + L\frac{di}{dt} + \frac{1}{c}\int i\, dt = V_o e^{j\omega t} \qquad (13)$$

A solution of this equation is in the form

$$i = i_o e^{j(\omega t + \theta)} \qquad (14)$$

where θ is the phase difference between the applied potential difference and the resulting series circuit current. On substitution of the assumed solution into the differential equation (13), one finds

$$(j\omega L + R - \frac{j}{\omega c})\, i = V \qquad (15)$$

which is, in the general (Ohm's Law) form,

$$Z\, i = V \qquad (16)$$

where

$$Z \equiv R + j(\omega L - \frac{1}{\omega c}) = |Z|\ e^{j\phi} \qquad (16')$$

where

$$|Z| \equiv \sqrt{R^2 + (\omega L - \frac{1}{\omega c})^2} \qquad (16'')$$

NWMAR115937

and

$$\phi = \tan^{-1} \left(\frac{\omega L - \frac{1}{\omega C}}{R} \right) \qquad (16''')$$

and, in order to satisfy Eq. (16)

$$\theta = -\phi \ . \qquad (17)$$

The power dissipated in a series R, L, c circuit is given by

$$P = \frac{1}{T} \int_{o}^{T} VI \, dt \qquad (18)$$

where T is the period $\equiv \frac{1}{f}$

which, on integration, yields

$$P = I_o V_o \cos \phi \qquad (19)$$

where ϕ is the phase angle given by Eq. (16'''').

The importance of the phase angle is best described by noting that electrical power is generated in such a manner that the voltage and current are in phase, i.e. $(\cos \phi)_{generation} \equiv 0$.

Hence

Power generated - power consumed = Power losses in transmission

$$V_o I_o - V_o I_o \cos \theta = V_o I_o (1 - \cos \theta) = \text{power loss due to unfavorable phase angle} \qquad (20)$$

Since the voltage is fixed and $\cos \theta \leq 1$, the transmission line current must be increased in order to supply the load when there is a lagging phase angle. However, the resistive losses in the transmission lines are proportional to the square of the current transmitted. Therefore,

NWMAR115938

efficient transmission of electrical energy requires that the net phase angle, or power factor, of the load be as close to unity as possible. This power factor correction is achieved by the introduction of a capacitor in series with the inductive load at the load end of the line.

The function of a capacitor in such a circuit can perhaps be better understood by examining the interchange of electrical energy among the various components of the circuit. In an inductive device, such as a motor or a fluorescent light, which is subjected to an alternating current, a considerable amount of energy is stored in the form of a magnetic field and then returned to the circuit in the form of current when the voltage decreases. In a purely inductive circuit, this current is transmitted back to the generator and is lost in the form of heat in the transmission lines. The energy required to form the magnetic field during the next cycle must then be supplied by the generator. If a capacitor is placed in the circuit near the inductive load, the energy from the collapse of the magnetic field is stored in the capacitor in the form of an electric field when the voltage decreases, and then is transferred back from the capacitor to the inductive device to reform the magnetic field during the next cycle. Since the energy to form the magnetic field is transferred between the capacitor and the inductive device, it does not appear in the transmission lines. This decreases both the heat losses in the transmission lines and the amount of energy required from the generator.

The capacitor used for power factor correction functions as a temporary storage device for electrical energy. It is important that the energy losses be minimized, implying a low loss-tangent for the capacitor and a minimum distance between the capacitor and the inductive device. The other physical and electrical properties of the capacitor are a function of the particular application. There are three general types of power factor correction capacitors: high voltage power, low voltage power, and lighting ballast capacitors.

NWMAR115939

2.6.1.1 High Voltage Power Factor Capacitors

Power factor correction can be furnished by the electric utility by installing capacitors at substation locations. These capacitors are designed to operate at high voltages of 4800 to 13800 volts, and are manufactured in a size range from 15 kvar to 200 kvar. Each capacitor contains about 2 to 2½ gallons of PCBs, most of which is trapped in the porosity of the paper dielectric. These capacitors are generally installed in banks in a substation or mounted in groups on utility poles.

The failure rate of high voltage power factor capacitors is approximately .3% per year. These capacitors are usually protected by fuses so that the failure of one capacitor in a bank will not cause failure of other capacitors. Rupturing of these capacitors on failure is relatively unusual, and even when the case does rupture, loss of PCB is generally less than ½-gallon as most of the liquid is absorbed by the paper in the capacitor.

The high voltage power factor capacitors are usually installed outdoors in non-hazardous locations. Fire resistance is therefore of minor importance. The dielectric must have a high dielectric constant and a high resistance to corona formation in order to operate successfully at high voltages.

2.6.1.2 Low Voltage Power Factor Capacitors:

Electrical utilities structure their rates so that there is an economic advantage to the industrial user to supply the power factor correction for major inductive loads such as motors, induction furnaces, and welding machines. The capacitors for these applications are designed to operate at 250 to 575 volts.

The PCB/paper combination used as the dielectric in spiral wound capacitors operates most efficiently at a voltage of 400 volts per mil. Technological limits on paper manufacturing limit this dielectric combination to a minimum thickness of about one mil, so the full efficiency of these capacitors is not achieved at voltages below 400 volts. However,

NWMAR115940

capacitors of this type are used for power factor correction for voltage applications down to 220 volts with the motors in heavy duty whole-house air conditioners.

Low voltage capacitors are usually built into the equipment or located close to the inductive machinery in manufacturing plants. Important requirements of the dielectric and low flammability, low toxicity of the liquid and its degradation products, are chemical stability to achieve long service life of the capacitors. Dry film capacitors could find considerable use in 220 volt applications where space is not a severe limiting factor, as in air conditioners.

2.6.1.3 Lighting Ballast Capacitors

Normal fluorescent light fixtures are designed to operate on 110 volt power circuits. The fluorescent bulbs, however, require about 300 volts to operate. This high voltage is supplied by a transformer which is built into the fixture. A small percentage of fluorescent lights are built with a coil-and-core transformer and no power factor correction. These units are sold for household use on the basis of low initial price. The power factor of these lights is about 0.7.

The fluorescent lights which are manufactured for commercial and industrial applications all have the high voltage supplied by a ballast. This ballast consists of an auto transformer connected in series with a 4μf capacitor. The capacitor is of foil-PCB-paper construction and is sealed into an aluminum can. The transformer and capacitor are packaged in a steel can which is filled with a mixture of asphalt and sand as a potting compound. This finished ballast is about 1" x 2½" x 12", and has a life expectancy of 10 to 15 years in normal service. The lighting fixtures using this arrangement have a power factor of about 0.9. The capacitor in a fluorescent light ballast is usually installed very close to the bulbs, and depending on the design of the fixtures, the ballast operates at temperatures of 85 to 90°C.

NWMAR115941

High efficiency mercury arc and sodium arc lights are widely used for highway lighting and other high-intensity applications. The ballast units which supply the high voltage for these lights are similar to those used in fluorescent lighting, except they supply more power at a higher voltage.

It should be remembered that the amount of energy that can be stored in a capacitor is proportional to the square of the voltage, so that a 110 volt capacitor would require 8 times the plate area of a capacitor operating at 300 volts.

The major requirements for ballast capacitors are:

small size, implying a high dielectric constant;

ability to operate at 300 volts, which implies a complete exclusion of air so as to avoid corona discharge problems;

chemical stability when exposed to 90°C for long periods of time; and

non-flammability because of the use of the ballasts in houses and other flammable, hazardous locations.

Aerovox reports that they are developing a dry type metallized polypropylene capacitor which could be used in fluorescent ballast applications and that this design would be good for industrial applications up to 370 volts.[11] Application of these units up to 440 volts is considered a possibility. This substitute, when available, would be suitable for 50 percent of the current capacitor applications. It would increase the cost of low voltage power factor capacitors by 20 percent as compared to a PCB unit but would double the cost of ballasts (separate units would be required for purposes of start and storage). The film and metallizing equipment used in these capacitors are manufactured in Europe and currently must be imported. The use of this technology will require major redesign of the parent products, particularly when used in fluorescent light ballasts and room size air conditioners. Because of space and temperature limitations, the dry film capacitors could not generally be used to replace failed capacitors in existing electrical equipment.

NWMAR115942

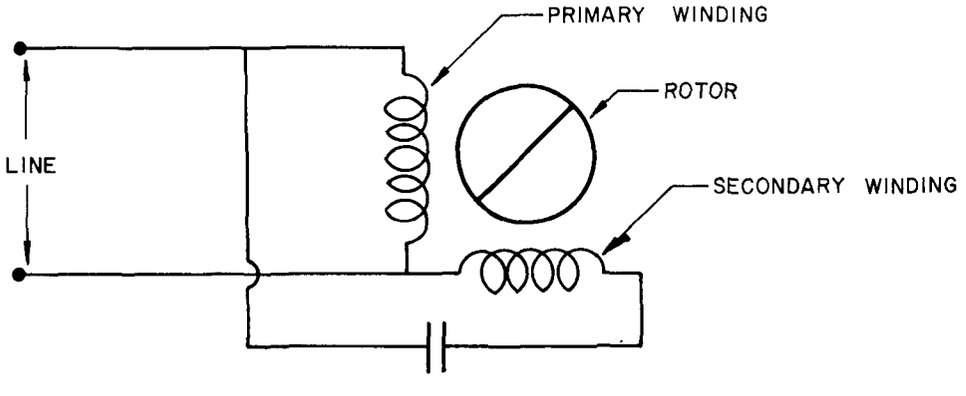
It should be noted that the general use of dry film capacitors in European fluorescent lights is not comparable with U.S. practice. The European line voltage is normally 250 volts, which is below the corona discharge voltage into air, but which allows a decrease in size of the capacitor by a factor of 6 compared to 110 volt applications. In addition, the European fixtures are usually single bulb, rather than the dual bulb fixtures used in the U.S., and the auto transformer is much less reactive as it needs only to increase the voltage from 250 to 300 volts. As a result, much less capacitance is required for power factor correction in European fixtures, and the capacitor, can operate efficiently at normal line voltages. Finally, the capacitors in European fluorescent fixtures are installed as discrete components to allow for their replacement; this is necessary because of the higher failure rate of dry film capacitors compared to U.S. capacitors.

In spite of the relative severity of the technical requirements for U.S. ballast capacitors, industry sources indicate that there is probably a 50 percent chance that a usable dry film capacitor will be available in the U.S. by the end of 1976.

2.6.2 Motor Starting Circuits

Electric motors for residential use are designed to operate on single phase current. A number of different methods are used to develop the rotating magnetic field that is required to start the motor, and these methods differ in the amount of torque that is developed at low speeds. Certain applications, particularly compressors in air conditioning units, require a very high starting torque. This is achieved in a single phase motor through the use of a capacitive starting circuit.

In a capacitor run motor, stator windings are connected as shown below:



NWMAR115943

The starting field is connected to the power supply through a capacitor; the result is a starting winding current which leads the applied voltage. Hence, at standstill, the rotor sees fields nearly 90^{o} apart in time as well as 90^{o} apart in space. The resulting, effectively rotating, field results in high starting torque and a high power factor (important during the period when the back emf due to rotor motion is low so that the starting current is significantly higher than the running current). Because of the inductive effect of the starting winding, the capacitor is subjected to a voltage substantially higher than the line voltage. Most 110 volt appliance motors are designed so that the capacitor operates at an effective voltage of 370 volts, thus making optimum use of the characteristics of foil-PCB-paper capacitors.

The capacitor not only performs the necessary function of generating the starting field, but also provides significant power factor correction. In larger motors – primarily 220 volt air conditioner motors – the PCB motor run capacitor is sized for optimum power factor correction and additional capacitance is provided during the first few seconds of start-up by an electrolytic capacitor in parallel with the PCB capacitor. The electrolytic capacitors provide very high capacitance in a small package, but they have a dissipation factor of about 7 percent which causes rapid temperature increases. The electrolytic capacitor is disconnected by a centrifugal switch when the motor reaches running speed. This prevents failure from overheating and results in a configuration with good operating characteristics and satisfactory power factor.

The motor run capacitor is normally built into the motor. This results in a requirement for small size, long life, and fire safety for the capacitor. It is possible that dry film capacitors could be used in this application. However, the high voltages suggest that a liquid dielectric capacitor would be more suitable if a satisfactory substitute were developed for PCBs.

NWMAR115944

In some applications, DC motors can be used in place of single phase AC motors. Such DC motors are used in some European electrical appliances where the electronic speed control that can be achieved with the DC motor results in a savings compared to the more complex speed control mechanisms required with an AC motor. In these European appliances, the DC power is supplied by a silicon rectifier. However, the output from the rectifier must be filtered to eliminate the AC components, and this filter circuit normally uses a liquid filled capacitor. In addition, the DC speed control circuit requires an additional capacitor. While these circuits could be redesigned to eliminate the use of capacitors, the resulting DC motor would not appear to be economically competitive with the capacitor run motor except in a limited number of special applications.

2.6.3 Electronic Filter Capacitors

Rectifier circuits are used to supply DC current to electronic components. For instance, the circuitry of most U.S. television sets operates at 300 volts DC. The output of the rectifier must be filtered to achieve a stable DC current. Most television sets use a PCB capacitor operating at 300 volts to pass the AC components of the current. This achieves the required 300 volt DC power required by the other components.

Requirements for this capacitor are long life at 300 volts, small size, and good fire resistance. Either a dry film capacitor or a suitable liquid dielectric capacitor could be substituted for the PCB capacitor in this application, although the larger size of the dry film capacitor may limit its use in repairing existing television sets.

2.7 Institutional Barriers to Substitutes for PCBs in Capacitors

The final choice of an acceptable substitute for PCBs will be made by the capacitor manufacturers based on the performance characteristics and fire safety of alternate dielectric materials. This choice will be affected by performance waranties that are common in this industry and by evaluations of safety as reflected in the codes and regulations which govern the use of capacitors. The traditional industry practices and the formal regulations both impose institutional barriers to the acceptance of a substitute for PCBs.

NWMAR115945

These barriers are a major factor in the rapid replacement of PCBs, and should be carefully considered in the formulation of government regulations and in the industrial marketing of alternate dielectric materials.

2.7.1 Performance Acdeptability

Capacitors are sold with stringent performance warantees which cover both the capacitance and the expected life or maximum failure rate of the capacitors. These warantees are based on various capacitor standards which are established by industry groups. The wide usage of a particular type of capacitor will depend on the existence of relevant standards which allows the user to choose equivalent capacitors from different manufacturers.

Currently, no industry standard exists for dry film capacitors for AC applications. However, such a standard is being developed by a committee of the E.I.A. and should be formalized by the end of 1976. This standard will establish minimum performance criteria for any dry film AC capacitors which may be manufactured.

Sales of capacitors to performance specifications implies the acceptance of considerable liability by the capacitor manufacturer. Because of the expense of repairs to lighting fixtures and appliances which have been sold to consumers, the liability due to early failures could easily exceed the cost of the capacitors. A situation of this type occurred during the 1960's when many fluorescent light ballast capacitors failed prematurely. This group of failures occurred when the voltage stress on the PCBs was increased, resulting in a slightly increased rate of degradation by dechlorination caused by corona discharges. The increased failure rate was not apparent on short term tests; the replacement of the failed ballasts was very expensive to the capacitor manufacturer. This problem was solved by the addition of a chemical scavenger to the PCB.

Because of the occurrence of past performance failures and the high potential cost of future failures, the capacitor industry can be expected to be very conservative in the introduction of substitutes for PCBs. Substitutes will be accepted only after the accumulation of substantial long term (3 to 5 years) service testing data. Since the greater biodegradability of the

NWMAR115946

substitutes implies that they will exhibit lower chemical stability than PCBs, considerable testing at service conditions will be required to support the general use of any of these materials. This requirement of extensive service testing would be expected to delay the general acceptance of PCB substitutes by 3 to 5 years.

2.7.2 Fire Safety

The use of capacitors is governed by several industry standards which embody the general service experience and risk factors as perceived by industry representatives and fire insurance underwriters. These codes and regulations are specific for various applications of capacitors. The major applications must therefore be considered separately.

2.7.2.1 Utility Use of Power Factor Correction Capacitors

Most of these capacitors are installed in substations or are mounted on poles. In general, the locations of these capacitors are non-hazardous, and there is little risk that fire damage or personal injury will result from the failure of a utility capacitor.

The failure of existing utility capacitors may result in uncontrolled loss of PCBs into the environment. The frequency of capacitor rupture is reportedly quite low (estimated to be .02%/year) and the amount of PCB lost to the environment probably does not exceed 2 to 3 pounds per capacitor rupture. However, because of the large number of capacitors in service and the lack of means for containing any leakage, the total environmental load from this source may total several thousand pounds per year.

Current standards for the disposal of failed capacitors containing more than 2 pounds of PCB requires that they be buried in supervised dry land fills that meet state requirements.(1) In addition, the standards require that these capacitors be labeled with a warning as to their environmental hazards. This label must also contain detailed disposal procedures. The major apparent lack in these standards is in the area of control and disposal of leakage from failed capacitors. The necessity for such control may offset the economic penalties associated with the replacement of PCB capacitors by units which are environmentally less objectionable.

NWMAR115947

2.7.2.2 Industrial Use of Power Factor Correction Capacitor

The use of power factor capacitors in industrial plants is governed by state fire regulations and by the National Electrical Code (4) which has been formally incorporated into OSHA regulations.

The National Electrical Code requires that capacitors that contain more than three gallons of flammable liquid be enclosed in a vault or installed in a outdoors fenced enclosure. The definition of flammable liquid is not explicit, but the effect of the Code is to give large PCB capacitors a significant economic advantage compared to those containing other liquids. Proposals are currently being considered to define a class of transformer and capacitor liquids which are self extinguishing. This may eventually lead to a change in the code so that vaults will not be required for large capacitors in industrial applications. This code change is unlikely to be made prior to issuance of the 1981 code.

2.7.2.3 Lighting and Appliance Capacitors

These small capacitors are usually built into the ballast or appliance. Failure of the capacitor prior to the obsolescence of the light or appliance is infrequent, and the capacitor is scrapped as part of the entire assembly. Currently, most of this material ends in municipal landfills. With growing popularity of reclaiming metal values from municipal waste, there will be an increasing amount of PCB which appears as contaminants of scrap steel and is vaporized or burned off in the steel furnace.

The major drawback to the use of substitute materials is the fire safety of the appliance. Completed ballasts or appliances must meet minimum safety standards as specified by tests conducted by Underwriters Laboratories. Because the amount of liquid contained in these capacitors is small, there is probably little increase in fire hazard if a flammable liquid is used, especially if the capacitor is fused to prevent rupture of the case. However, acceptance of flammable liquids in capacitors will have to await action by Underwriters Laboratories, and recent conversations indicate that they have not yet established either specifications or test procedures for electrical equipment containing flammable liquid capacitors.[5]

NWMAR115948

3.0 ELECTRICAL TRANSFORMERS

Polychlorinated biphenyls are used as liquid coolants in electrical transformers which are located in enclosed or hazardous locations. PCBs have an advantage over the other major liquid transformer coolant (mineral oil) in that they are nonflammable. Gaseous coolants are also nonflammable, but gas cooled transformers have disadvantages which are considered below. Alternative liquid coolants are probably available, but to date none have been found which have all the advantages of PCBs. The following analysis includes a summary of the purposes of transformers in electrical circuits, heat generation in transformers, currently-used cooling techniques, materials being investigated as substitutes for PCBs, and institutional barriers to the use of substitute materials in place of PCBs.

3.1 Heat Generation in Electrical Circuits

In direct current electrical circuits, the power, P, delivered at a load consisting of pure resistance (e.g., a light bulb) is the product of the electrical current, i, moving through the load and the voltage, V, across the load,

$$P = (V)\ (i) \tag{21}$$

But since current is proportional to voltage for a given resistance,

$$V = (i)\ (R) \tag{22}$$

where R, the resistance, is the constant of proportionality. It follows that power delivered to the load resistance is the product of voltage, V, and the square of the current

$$P = i^2R \tag{23}$$

Since the wires that carry electrical power from the site of generation (be it a battery or an electrical generator) to the load resistance also offer resistance to the flow of electrical current, a portion of the power generated is lost through heating of the wires connecting the load to the electric power source. For a given wire diameter, electrical resistance is proportional to the length of the wire. In many circuits (e.g., an automobile electrical system), the power lost in the transmitting wires is small in

NWMAR115949

comparison to the power delivered at the load (such as the headlights). However, in transmitting electrical power over long distances, the resistance of the wires could cause the dissipation of a significant portion of the energy intended for the load.

In alternating current circuits, the power dissipated in a resistance (either in the load or in the wires carrying the power to the load) is also given by $P = i^2R$. (The relation, $P = (V)\ (i)$, always applies to power dissipated in DC circuits, but in AC circuits the expression only applies when the voltage and current are in phase with each other, which isn't always the case. In most practical instances involving purely resistive loads it is a fairly accurate means by which to calculate the power dissipated.)

The expression, $P = i^2R$, is not influenced by the phase relation between voltage and current and thus applies to both alternating and direct current circuits. It is apparent from this expression that the energy dissipated in a transmission wire having resistance R is proportional to the second power of the current; thus, if the current being delivered to the load were to be doubled, the energy losses in the transmission wire would be quadrupled.

Commercial electrical power is often generated many miles from where it is to be used. There are hundreds of thousands of miles of power transmission lines in this country, and it is not unusual for the electrical power generated in one place to be used hundreds of miles away, which means that a considerable amount of electrical resistance must be overcome in transmitting electrical energy to the user.

The method used to minimize energy losses in transmission lines is to reduce the current, i, and thus minimize the i^2R losses (also known as Joule heating losses) in the transmission wire. In order to deliver maximum power to the load, the transmission voltage, V, must be increased since the power delivered is (as with DC circuits) effectively given by $P = (V)(i)$. Thus, if the transmitted current, i, is reduced by a factor of 2 - which reduces the Joule heating losses of the transmission line by a factor of 4 - the voltage of the transmitted power must be increased by a factor of 2.

NWMAR115950

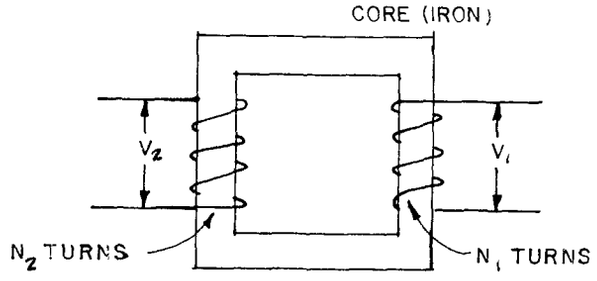
In practice, the electricity which is used in homes at 110 volts is transmitted at voltages ranging up to more than 700,000 volts - roughly 6500 times greater than common wall-socket voltage. As a result, the Joule heating losses are $(6500)^2$, or more than 40 million, times less than if the power were transmitted at 110 volts.

3.2 The Nature and Purpose of Transformers

The purpose of a transformer in an electrical circuit is to transform electrical power from its high-current low-voltage characteristics at the generating facility to the low-current high-voltage characteristics needed for efficient transmission; and then, at or near the site of use, transformers perform the opposite function, bringing the power back into its low-voltage (typically 110v or 220v) high-current form.

A transformer consists of two windings which are joined by a magnetic yoke. An alternating current applied to one winding (the primary winding) creates an alternating magnetic field in the yoke. This magnetic field induces an electric current in the other, or secondary, winding. In a simple transformer, as shown in the following sketch, the ratio of voltages in the primary and secondary windings is equal to the ratio of turns in the windings, or

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$



There are two types of transformers used in the electrical power industry: power transformers (used for "stepping up" the voltage at the plant) and distribution transformers (used for "stepping down" the voltage at or near the site of power use). Power and distribution transformers operate on the same principle - they differ only in whether the primary or secondary winding has the greater number of turns. If the transformer is being used for

NWMAR115951

stepping up voltage, then the primary side is the one having fewer turns; for stepping down, the primary side is the one having most turns.

The lengths of wire in the windings offer resistance to the flow of electricity, the result being the production of heat in the windings. Heat is also produced by electrical currents induced in the transformer core by same mechanism that induces currents in the secondary windings. Since the electrical resistance of most conducting materials increases with temperature, the efficiency of the transformer (i.e., the ratio of the output power to the input power) is maximized if the transformer is kept at a low operating temperature. Therefore, all transformers used in the electrical industry have provision for cooling, based on either gaseous or liquid coolant.

The coolants in common use today are:

- mineral oil, PCBs — liquid cooled transformers
- air, gas — dry type transformers

3.3 Desired Properties for Transformer Heat Transfer Fluids

The purpose of the heat transfer fluid in a transformer is to absorb the heat produced in the windings and core, to transfer the heat to cooling fins, and to provide electrical insulation within the transformer. The ideal fluid should have the following properties:

Heat transfer: Be a liquid with a low viscosity, high heat capacity, and high boiling point. (The use of low boiling point liquids or gases would require that the transformer be enclosed in a pressure vessel.)

Chemical stability: Not degraded by prolonged exposure to high temperatures. Non-flammable in the event of an electric arc within the transformer and subsequent case rupture. Non-corrosive, with non-corrosive products resulting from exposure to an electrical arc. Low solvency toward other materials used to construct the transformer.

NWMAR115952

Electrical properties: High dielectric strength. Low loss-tangent (minimized dielectric heating of the fluid). High resistance to corona formation.

Toxicity: Non-toxic and biodegradable. By-products from exposure to arc should also be non-toxic.

Cost: Low cost.

Availability: Readily available with reliable properties.

3.4 Use of PCBs in Electrical Transformers

PCB cooled transformers account for about 5 percent of all transformers in service.[3,12] The PCB coolant in these transformers is a mixture of 60 to 70 percent PCBs and 40 to 30 percent trichlorobenzene. The PCBs currently used in these mixtures are sold by Monsanto under the trade names of Aroclor 1242 and Aroclor 1254.

The mixtures of PCBs and trichlorobenzene are commonly known by the generic term Askarel. Askarel is defined by the National Electrical Code as "a generic term for a group of non-flammable synthetic chlorinated hydrocarbons used as electrical insulating media. Askarels of various compositional types are used. Under arcing conditions the gases produced, while consisting predominantly of non-combustible hydrogen chloride, can include varying amounts of combustible gases depending on the askarel type". The most commonly used askarel compositions are Inerteen (Westinghouse trade name for 60 percent PCB mixture) and Pyranol (General Electric trade name for 70 percent mixture). The exact composition of both Pyranol and Inerteen have been changed from time to time, but they have almost always been mixtures of PCBs and trichlorobenzene.

Prior to the mid-1950's, the insulating liquid used in many transformers (General Electric formulation) was a 50-50 mixture of Aroclor 1260 (60 percent chlorine) and trichlorobenzene. In the late fifties the benzene component was changed to a mixture of tri- and tetrachlorobenzenes. In September, 1971, at Monsanto's suggestion, the Aroclor component was changed to Aroclor 1254 (54 percent chlorine). The current Westinghouse formulation (Inerteen) utilizes Aroclor 1242.

NWMAR115953

The volume of askarel used in various transformers ranges from 40 to 1500 gallons (440 to 16,500 lbs), with an average of about 230 gallons (2500 lbs). One transformer manufacturer, General Electric, estimates the total number of askarel filled transformers put in service in the U.S. since 1932 to be 135,000; virtually all are still in service. Typical lifetime of a transformer is often greater than 30 years, and units that do fail are usually rebuilt and returned to service. The current production rate for askarel filled units is about 5,000 per year, requiring some 10-15 million pounds of PCBs.

Liquid coolants in transformers have better heat transfer and heat capacity characteristics than gaseous coolants. Askarel has the further advantage of being non-flammable. The other advantages of askarels are their high dielectric strength, their outstanding chemical stability, and their relatively low viscosity. Disadvantages , in addition to the environmental threat, are the highly corrosive HCl they produce when arcing takes place and their cost, which is about eight times as much as mineral oil on a volume basis.

Most askarel-filled distribution transformers are located inside public, commercial, or industrial buildings, or on the roof tops of such buildings. No special enclosures or vaults are required except as are necessary to prevent accidental electrical or mechanical contact of persons with the equipment. However, the National Electrical Code does specify vaults for the indoor installation of PCB-filled transformers rated more than 35,000 volts. Askarel-filled transformers are limited by the dielectric strength of the liquid to ratings below 69,000 volts.

Most power transformers are situated in remote locations where fire or explosions are not a threat to property. Mineral oils are commonly used in power transformers in these safe locations. However, some utilities use askarel-filled power transformers at generating stations.

Step up transformers used to supply the high voltage electricity to electrostatic precipitators are usually mounted on or very near the stack. This minimizes the problems associated with the in-plant distribution of high voltage power. These transformers are usually askarel filled units to minimize fire hazard in the usually crowded area of the stack.

NWMAR115954

Railroad locomotives which operate on high voltage AC power from overhead catenaries are used in the U.S. Northeast Corridor. Askarel-filled transformers are mounted in the engines or under the self-powered passenger cars, and reduce the catenary voltage to that required by the traction motors. These electric locomotives are mostly limited to passenger service on the Northeast AMTRAK routes and on the commuter lines around Philadelphia and New York. Large askarel-filled transformers are used in the old GG-I locomotives, under the Metroliner cars, in various commuter cars, and in the new E-60 locomotives. (Twenty-six E-60 locomotives are currently being delivered to AMTRAK by General Electric; each locomotive contains 710 gallons of askarel). Penn-Central Railroad operating rules require the use of askarels in all locomotives using the tunnels and stations in New York. This rule has been in force as a fire safety measure ever since an early GG-I locomotive containing a mineral oil-filled transformer was involved in a fire inside a tunnel early in the 1940's.

3.5 Present Alternates to the Use of PCBs in Transformers

Askarel-filled transformers are only used where considerations of fire safety, reliability, availability, and cost make such a unit preferable to an oil-filled transformer or to a dry type transformer. These alternative types of transformers are currently used in 95 percent of all applications, and could, with proper engineering design, be used to replace most of the remaining askarel-filled units. Consideration would have to be given to the specific limitations of these designs that presently make askarel-filled transformers preferable for certain applications.

3.5.1 Mineral Oil-Filled Transformers

If safety were not a consideration, there is no reason why oil-filled transformers could not be used in all applications. Askarel-filled transformers cost about 1.3 times as much as oil filled units of the same capacity, and thus most users prefer the oil-type where possible. The oil-filled transformers are the same size as the askarel units, and are considerably lighter in weight. In addition, mineral oil has somewhat better heat transfer characteristics than does askarel, and an electrical arc in mineral oil results in breakdown products that are non-corrosive.

NWMAR115955

The major disadvantage to mineral oil is its flammability. Transformer mineral oil has a flash point of 145°C, and if an arc occurs within the transformer, the breakdown products will be hydrogen and methane which are also flammable. Detailed records of such failures are maintained by the electrical industry.[13] Fire Underwriters do not approve of the use of oils and other flammable liquids for indoor applications; where oil-filled transformers are not specifically prohibited as on-site replacements for askarel-filled units, the National Electrical Code imposes certain restrictions upon their mode of installation.

Oil-filled transformers are used in almost all power transformer applications and for most substation distribution applications where the high voltage from the transmission lines is reduced to 12.8 kv for local distribution. Most rural pole mounted transformers which reduce the voltage to 220 volts are also oil-filled. The issue of flammability only becomes important where the distribution transformer must be buried, as in many urban applications, or located close to, within or on the roof of the building which it serves. Askarel-filled transformers are used for most of these hazardous areas.

Oil-filled transformers can be used in these applications only if they are suitably isolated from flammable structures or if these structures are suitably safeguarded against fires. When transformers are located outside of the building they service, however, the low-voltage power must be brought into the building via cables or insulated buses, incurring additional energy losses due to Joule heating in the additional low voltage transmission lines.

3.5.2 Open Air Cooled Transformers

Transformers can be built without the use of a liquid cooling medium. One type of dry transformer which is quite successful under limited conditions is the open air cooled transformer. In this design, the required cooling is provided by air which passes through the transformer due either to

NWMAR115956

thermal convection or forced fan circulation. In those sizes where air cooled transformers are available, they are about equal in price to askarel-filled transformers of the same kva rating. However, the following limitations govern the successful use of open air cooled transformers, and prevent them from being considered for many applications using askarel-filled transformers.

Heat capacity: The power drawn from a transformer usually varies over a fairly wide range. The rating of a transformer is basically governed by the power which it can handle continuously without overheating. If a liquid filled transformer is operated at overload conditions for a short period of time, the liquid will act as a heat sink, absorbing the excess heat produced in the transformer without a rapid increase in temperature. The result of this thermal inertia is that liquid-filled transformers can operate at outputs of up to 200 percent of rated capacity for a period of one to two hours without being damaged.

An air cooled dry type transformer does not have this heat sink available, and is limited to operating at a maximum service rating near its continuous rating. Where the current drawn on the transformer does not vary greatly during the day, this limitation is no problem. However, in most cases the variation in load would require that a dry transformer be sized 20 percent to 30 percent greater in capacity than a liquid-filled transformer for the same application.

Dielectric strength: The liquid coolant in a liquid-filled transformer also provides a significant level of electrical insulation between the various current carrying components within the transformer. Air has a much lower dielectric strength, and open air cooled transformers are limited to a maximum voltage of 25 to 40 kv.

The problem of electrical insulation is even more severe if the open air cooled transformer only operates intermittently. When the transformer is operating, the heat generated within the windings keeps their insulation dry, and maintains a high dielectric strength of this solid insulating material. However, when the transformer is not operating, the coils cool to ambient temperatures and the

NWMAR115957

insulation can absorb moisture from the air which reduces its dielectric strength. Therefore, an open air cooled transformer must be carefully dried before being put into service after each time it has been allowed to cool.

One final problem with dry air cooled transformers is due to the tendency of dust to be attracted from the air to the coils by electrostatic attraction. This dust can build up in the coils which blocks the flow of air and causes overheating, or the dust can form conductive paths which short circuit the transformer.

Dry open air cooled transformers are generally limited to dry, clean locations where the load requirements are fairly even and constant, and where the maximum voltage does not exceed 30 kv. This type of transformer is being successfully used in large office buildings, particularly tall buildings where the transformers are located every few floors. Even in this application, there are situations which are beyond the capabilities of the open air cooled transformer; for instance, in the Sears Building in Chicago, which is over 1400 feet tall, the electric power is brought into the building and up to the distribution transformers at 128 kv, which is beyond the voltage limitations of open air cooled transformers.

3.5.3 Closed Gas Filled Transformers

Transformers can be built which use a dry inert gas (usually at an elevated pressure) as a heat transfer medium. These transformers avoid the maintenance problems caused by moisture and dust in open air cooled transformers. However, they are similarly limited in overload capacity because of their reduced thermal inertia compared to liquid filled transformers.

Closed gas filled transformers must be installed in pressure tight containers due to the changes in gas pressure caused by changes in temperature. However, the maximum voltage ratings of these gas filled transformers can be equal to that of liquid-filled units.

NWMAR115958

A number of different gases have been successfully used as heat transfer media in closed gas filled transformers. The most common gas used in the U.S. in this application is the fluorocarbon hexafluoroethane (C_2F_6). Nitrogen and sulfur hexafluoride have also been used successfully in certain applications. Helium has not been found to be a satisfactory gas for this application because its low dielectric strength results in corona discharges within the transformer. Hydrogen gas is unsatisfactory as any leak in the transformer would result in a severe fire hazard.

Because of the necessity for the pressure vessel container, gas cooled transformers are 30 to 40 percent heavier than askarel-filled transformers, and cost two-thirds more than askarel transformers (and twice as much as oil-filled transformers). In addition, the gas filled transformers must often be specified in a larger size than the liquid-filled transformers to allow for the expected heavy load peaks of power consumption.

3.6 Current Alternatives to the Use of PCB Cooled Transformers

The National Electrical Code has detailed specifications for transformers which assure that transformer installations meet both fire and shock safety requirements. These safety requirements are achieved by the use of either non-flammable transformers (askarel or dry type) or vaults, or both. The final choice of the type of transformer to be used in each application will be a function of the code requirements and their economic consequences.

3.6.1 Vault Usage Requirements for Transformers

The National Electrical Code 1975[4] considers three types of transformers in connection with indoor vaults: dry type, askarel insulated, and oil insulated.

Askarel insulated transformers installed indoors and rated at more than 35,000 volts must be enclosed in vaults, according to Section 450-23. This same section specified that askarel transformers installed indoors and rated over 25 kva must have pressure-relief vents which must either be vented to the outside of the building, or some other provision must be made for "absorbing any gases generated by arcing inside the case".

NWMAR115959

The 35,000-volt criterion also applies to dry type transformers; they must be contained in vaults when in indoor installations. The Code also specifies that dry-type transformers rated at more than 112½ kva must "be installed in a transformer room of fire-resistant construction". Thus, if space is not a consideration, dry-type transformers - which generally occupy a larger volume than equivalent-capacity askarel insulated units - can directly replace askarel-insulated transformers.

In cases where space is not available for the larger-volumed dry-type transformers to replace the askarel-insulated units, or where the dry-type units might emit too much noise for a given location within a building, oil-insulated transformers would be required as replacements for askarel units. Section 450-24 specifies that oil-insulated units must be installed in vaults, but the following exceptions are made:

1. If the total capacity of the transformer does not exceed 112½ kva, vault walls need only be 4 inches thick instead of 6 inches as specified in Section 450-42.

2. Where voltage does not exceed 600, a vault shall not be required if suitable arrangements are made to prevent a transformer oil fire from igniting other materials.

3.6.2 Vault Construction Requirements for Transformers

Section 450-42 of the 1975 National Electrical Code specifies the construction requirements of vault walls, roof, and floor. "The walls and roofs of vaults shall be constructed of materials which have adequate structural strength for the conditions with a minimum fire resistance of 3 hours." (Six-inch thick reinforced concrete is stated in the Code as being typical 3-hour construction.) "The floors of vaults in contact with the earth shall be of concrete not less than 4 inches thick, but when the vault is constructed with a vacant space or other stories below it, the floor shall have adequate structural strength for the load imposed thereon and a minimum fire resistance of 3-hours."

NWMAR115960

Vault doors are specified in Section 450-43. "Each doorway leading into a vault from the building interior shall be provided with a tight-fitting door having a minimum fire rating of 3-hours" (as defined by the NFPA). "A door sill or curb of sufficient height to confine within the vault the oil from the largest transformer shall be provided, and in no case shall the height be less than 4 inches." Locks are required for vault doors, and "doors shall be kept locked, access being allowed only to qualified persons". The locks shall be arranged so that vault doors can be easily opened from inside the vault.

With regard to ventilation openings, Section 450-45 specifies the following:

Location: "Ventilation openings shall be located as far away as possible from doors, windows, fire escapes, and combustible materials."

Arrangement: "A vault ventilated by natural circulation of air shall be permitted to have roughly half of the total area of openings required for ventilation in one or more openings near the floor and the remainder in one or more openings in the roof or in the sidewalls near the roof; or all of the area required for ventilation shall be permitted in one or more openings in or near the roof."

Size: "For a vault ventilated by natural circulation of air to an outdoor area, the combined net area of all ventilating openings after deducting the area occupied by screens, gratings, or louvers shall not be less than 3 square inches per kva of transformer capacity in service, and in no case shall the net area be less than one square foot for any capacity under 50 kva."

Covering: "Ventilation openings shall be covered with durable gratings, screens, or louvers, according to the treatment required in order to avoid unsafe conditions."

Dampers: "All ventilation openings to the indoors shall be provided with automatic closing dampers of not less than No. 10 MSG steel that operate in response to a vault fire."

Ducts: "Ventilating ducts shall be constructed of fire-resistant material."

NWMAR115961

Section 450-46 specifies the drainage requirements for vaults: "Where practicable, vaults containing more than 100-kva transformer capacity shall be provided with a drain or other means that will carry off any accumulation of oil or water in the vault unless local conditions make this impracticable. The floor shall be pitched to the drain where provided."

Section 450-47 requires that pipes or duct systems "foreign to the electrical installation shall not enter or pass through a transformer vault". Piping or other facilities provided for fire protection or for water cooled transformers shall not be considered foreign to the electrical installation.

3.6.3 Transformer Vault Construction Costs

In an effort to determine the cost factors in the construction of transformer vaults, various construction comp-nies in the Washington, D. C. area were contacted. It was discovered that the incidence of vault construction in existing buildings is virtually zero; apparently all vaults existing in buildings built in the last twenty-five years were constructed as integral parts of the buildings the same as any other room or enclosure in the building. Thus the cost of constructing a vault cannot be easily broken out from the cost of the entire building structure, especially since the prime contractors in the construction industry often subcontract the various facets of the construction work (e.g., concrete forms, concrete pouring, plumbing, ventilation duct work) and the portion of the work required by the vault is included in the cost of construction of the entire building. The construction companies were reluctant to make cost estimates for installing vaults in existing buildings unless detailed drawings were submitted as a basis for estimation, and of the half dozen largest contractors contacted, none had any readily available data from previous such installations, and all claimed such installations were extremely rare.

The National Electrical Code allows the installation of oil-insulated transformers in outdoor locations adjacent to the site of power use. In the Washington area, as in many urban areas, "manholes" are used to house transformers in outdoor locations.

NWMAR115962

Useful cost information on manhole installations was obtained through the Potomac Electric Power Company of Washington, D. C. Manholes are precast concrete structures which are commonly installed in public space directly adjacent to the building receiving electric service. (The steel gratings seen in the sidewalks of downtown areas frequently cover manholes containing transformers.)

Manholes are supplied usually by precast concrete product manufacturers. Costs quoted by one manufacturer range from $875 for a 6' x 6' x 6' (inside dimensions) model to $1700 for an 8' x 10' x 7' model. These costs include delivery to the job site and installation into the excavation.

According to Pepco, manholes are usually installed flush against the property line of the building being served. In some cities, the local government pays for the manhole and its installation, but in Pepco's customer service area, the customer pays the cost. (Pepco customers also pay the cost for vault construction when transformers must be installed on private property.) Pepco used to install more than one transformer per manhole, but experience with fires has led them to put only one unit in each hole.

According to Pepco, there are no specific codes relating to manhole construction, but it is likely that local codes influence specific installations. Pepco provides the final 18 or so inches of each manhole installation in order to blend the entire installation into the surface grade; in such cases, and when Pepco has occasion to cast its own manholes, the local building code must be followed.

The average cost of installing a 5½' x 17' manhole is $10,000; no cost-range data were available from Pepco. The labor requirement is typically 600 to 700 man-hours, and total time is about one week. Cost factors include:

1. Working day restrictions - for example, rush hours in some parts of the city restrict work hours to 9:30 to 3:30, but the laborers must be paid for a full days work.

NWMAR115963

2. Rain time - the laborers do not work in the rain, but they must be paid.

3. Rocky soil - hand digging (i.e., with pneumatic drills and hammers) may be required in lieu of power shovels. In such cases labor costs - which account for 70 to 75 percent of installed cost - can more than double.

The only other cost for manhole installation is the "public space permit fee", a one-time fee to the local government which is about $20 in the Washington, D. C. area regardless of size of the manhole.

Because they are lighter and easier to handle, dry-type transformers are used very often by Pepco, especially in roof-top applications where noise is not a consideration and ventilation is not a problem. This lightness and ease of handling, in conjunction with the lack of vault requirements for dry-type transformers of less than 35,000 volts, might make roof-mounted dry-type transformers the most cost effective replacement for askarel-insulated units in areas where the air is relatively free of corrosive gases and dusts which could affect the transformer.

3.7 Substitutes for PCBs in Transformers

Because of the evidence that PCBs are damaging the environment, considerable work is being conducted to find a satisfactory substitute for PCBs in askarel-filled transformers. These efforts by various manufacturers are attracting considerable interest in the business and technical press.[14,15] The goals of these efforts is the development of a heat transfer liquid which will have satisfactory heat transfer properties, be environmentally acceptable, and be non-flammable. These requirements are basically contradictory; the chemical stablilty required for complete non-flammability implies that the liquid may be non-biodegradable and may accumulate in the environment. Therefore, each of the liquids that have been developed sacrifices a certain degree

NWMAR115964

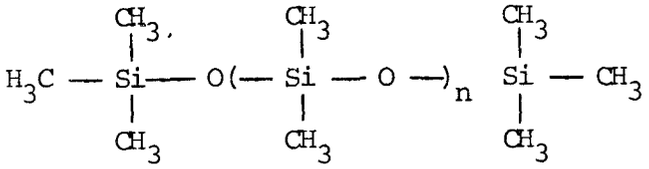
of fire resistance to achieve environmental acceptability. The following liquids have been proposed as substitutes for PCBs in transformers installed in hazardous locations.

3.7.1 Fluorocarbons

Certain fluorocarbon compounds have properties similar to the PCBs, and some study is being carried out in this area.[16] However, fluorocarbons are highly volatile in comparison to PCBs, and they are about six times as expensive at this time - though, of course, higher production volumes would lower their cost.

3.7.2 Silicones

Low viscosity silicone fluids (on the order of 50 centistokes) are also possible replacements for PCBs. Silicones are currently produced by four companies: General Electric, Dow Corning, Union Carbide and Stauffer. The silicone fluid recommended by one producer[17] is polydimethyl siloxane, which has this molecular structure:



Heat Transfer: Silicone fluids have the special advantage of a relatively temperature-independent viscosity. The silicone fluids have somewhat poorer heat transfer characteristics than askarel, but can be substituted directly for askarel in existing transformers, resulting in only a small decrease in the transformer rating.

Electrical Properties:[18]

Dielectric Constant	2.72
Dielectric Strength	400 volt/mil
Resistivity	7.1×10^{14} ohm-cm
Dissipation Factor	1.8×10^{-5} at 100 hz, 23°C

NWMAR115965

Flammability: Polydimethyl siloxane has a higher flash point than conventional, non-PCB transformer coolants: 280°C versus 146°C for mineral oil (PCBs have no true flash point). The heat of combustion of 50-centistoke polydimethyl siloxane is lower than that of mineral oil – 7.67 kcal/gm versus 11.0 kcal/gm – and since the silocones burn more slowly, they are considered poor fuel.[18]

On the Underwriters Laboratories fire-hazard classification (in which water is rated as 0 and ether as 100) polydimethyl siloxane is classified as 4 to 5, which is slightly higher than the 2 to 3 rating given to PCBs, but is considerably less than the mineral oil rating of 10 to 20.[19]

Ecological Persistence: These compounds do not biodegrade, as measured by sewage sludge breakdown to CO_2. However, there is evidence that they partly depolymerize to low molecular weight compounds upon contact with soil and water. Since ultra-violet light decomposes methyl silicones, sunlight exposure may be the mechanism for environmental degradation.

Bioaccumulation: No tendency for bioaccumulation or bio-concentration has occurred in experiments. In the mammals the compound is not adsorbed through the gastrointestinal tract or the skin.

Toxicity: The PCB substitute developed by Dow Corning for transformers is called 02-1090. This is a mixture of polydimethyl siloxanes of various chain lengths which have a viscosity of 50 CS. The literature on environmental and health characteristics of silicones[20] refers to at least six fluids, most of which are probably similar to the OZ-1090 but some of which could be other mixtures with certain additives. By necessity, the usefulness of published toxicological data depends on the validity of the assumption that all of these compounds have identical persistance, bio-accumulation, and toxicity properties.

NWMAR115966

A review of toxicological studies of silicones reported the following results:[20]

Dietary Toxicity:

LD_{50} (rats) >28 gm/kg

Extended Feeding Tests:

Guinea pigs - 47 gm/kg/day for extended period - no toxic effect.

Mallard ducklings and bobwhite quail - 5000 ppm for 5 days - no effect.

Rats - 20 gm/kg/day for 28 days - no effect.

Rats - 190 mg/kg/day for 90 days = no effect level.

Beagle dogs - 300 mg/kg/day for 120 days - no effect.

Mice - 3% in diet for 80 weeks - no effect.

Man - FDA allows silicones as food additives at up to 10 ppm.

The major deficiency in our knowledge of the silicones appears to be in their fate in the environment and the toxicity of their breakdown products.

Cost: The silicone transformer fluids currently cost up to twice as much as PCBs on a volume basis.

Availability: Dow Corning is currently completing evaluation of polydimethyl siloxane as a high voltage insulating fluid. They report, though, that a near term 100 percent replacement of PCBs in transformers by this fluid is not possible. If a transformer market were to develop for

NWMAR115967

polydimethyl siloxane, the present domestic capacity could only be adequate to supply new transformers. The time lag for a 100 percent replacement of PCBs in transformers by polydimethyl siloxane would be on the order of 5 to 10 years.

3.7.3 High Flash Point Mineral Oils

The flash point of mineral oil is a function of its molecular weight. Crude petroleum can be refined to have any required molecular weight over a wide range. This makes it possible to specify any particular flash point that is desired for the mineral oil transformer liquid. This approach has been taken by RTE Corporation in the development of their proprietary transformer liquid which has the trade name RTEMP.[21]

RTEMP is a highly refined paraffinic mineral oil which has a flash point of 296°C, approximately the same as the 50CS silicone liquid proposed by Dow Corning. To achieve this higher flash point, the oil is refined to have a higher molecular weight and consequently a higher viscosity which reduces its effectiveness in convective cooling. It may be possible to achieve a lower viscosity without sacrificing the fire resistance of the liquid, but this modification has not yet been demonstrated.

The major current advantage of the high flash point mineral oils is their low price relative to silicone and askarel, and their inherent biodegradability and low toxicity.

3.7.4 High Flash Point Synthetic Hydrocarbons

Certain mixtures of synthetic hydrocarbons may result in a liquid having the high flash point characteristics of RTEMP or silicone combined with a relatively low viscosity and satisfactory heat transfer characteristics. The Monsanto Co. is reportedly testing such a mixture

NWMAR115968

which has the trade name MCS-1866. No technical details are available on the liquid except that it is claimed to have flammability and heat transfer properties equivalent to silicone at a much lower cost, and to be environmentally acceptable. Monsanto has stated that the technical details will be made public early in 1976.

3.8 Institutional Barriers to the Use of Substitutes for PCBs

The National Electrical Code recognizes only three classes of transformers: askarel, mineral oil, and dry. The Code requirements for askarel and mineral oil transformers differ only in the vault requirements: for transformers located inside buildings or in hazardous locations, vaults are required for all mineral oil transformers, but only for those askarel transformers rated at over 35,000 volts. Askarel transformers are economically attractive for many applications because the savings in vault costs more than offset their higher price relative to mineral oil transformers, and their reliability is better than that of open air cooled transformers. In all cases, technically acceptable alternatives are available to replace askarel transformers; the only limitations are economic.

All of the substitute liquids that have been developed are more flammable than askarels, but less flammable than mineral oil. These liquids do not come within the definition of askarel in the National Electrical Code, and their use is governed by the rules that apply to oil filled transformers. Thus, there is no economic or technological incentive to use these alternate liquids under present Code regulations.

If the Code is to be changed to offer an economic incentive to the use of these liquids, the relative safety of each liquid must be assessed, and a decision must be made as to "how safe is safe enough". In particular, test

NWMAR115969

procedures must be developed which allow a realistic estimate to be made of the relative safety of each liquid under conditions which may be expected in service.

Limited testing of the relative fire safety of the various transformer liquids has been conducted by RTE Corporation. The properties of the four liquids that were tested are summarized in Table 3.8-1 which is reporduced from the test results report prepared by Mr. D.A. Duckett of RTE Corporation. (21)

The RTE test consisted of the following procedure for each liquid:

> Four gallons of liquid was heated to 150°C in a closed container. An electrical arc was then initiated below the surface of the liquid. Arc conditions were 4800 amperes at 4800 volts. The resulting explosion and fire was recorded photographically.

The results of this test were as follows: In all four cases, the lid was blown off the container and a fire ball was formed above the container. In the test of the transformer oil, the liquid remaining in the container continued to burn after the fire ball dissipated (as would be expected, as the liquid was heated to its flash point prior to the initiation of the arc). The other three liquids self extinguished within several seconds. Because the fire performance of the RTEMP and the silicone liquids were similar to that of askarel under these test conditions, both RTE Corporation and Dow Corning submitted proposals to the transformer committee of the National Electrical Code to allow the use of "self extinguishing" liquids where present Code regulations require the use of askarel. If these proposals were to be accepted, the use of these liquids would be allowed by the 1978 Code.

There are a number of questions which have not yet been satisfactorily answered concerning the use of the "self extinguishing" liquids. The most important question concerns the realism of the test conditions. It has been suggested that catastrophic arcing is a relatively unusual cause of transformer failure, and that a more frequent cause is prolonged minor arcing which creates

NWMAR115970

TABLE 3.8-1

PROPERTIES OF TRANSFORMER LIQUIDS
TESTED BY RTE CORPORATION*

FLUID PROPERTIES:	TRANSFORMER OIL	RTEMP	SILICONE DC-200	ASKAREL
DIELECTRIC				
Dielectric Strength (ASTM D-877) kV (25°C-fluids as received from vendor)	31	37	34	40
Dielectric Constant	2-2.5	2.2	2.74	4.5
Power Factor 50°C	<.01	0.6	0.6	--
100°C	1.0	2.2	0.9	--
150°C	2.5	10.5	1.5	--
Dissipation Factor (ASTM D-150)	.0004	<.05	.0002	.03
Volume Resistivity (ASTM D-1169) Ohm-cm	1.0×10^{12}	1.1×10^{13}	5.6×10^{14}	5.0×10^{12}
THERMAL				
Flash Point °C	150	296	304	--
Fire Point °C	162	321	360	--
Pour Point °C	<-57	-21	-55	-37
Thermal Conductivity 25°C cal/(sec-cm^2-°C)/cm	.000318	.000297	.000360	.000262
Specific Heat (cal/gm/°C) 25°C	.393	.450	.340	.264
Coefficient of Expansion(cc/cc-°C)	.00063	.0008	.00104	.00067
PHYSICAL				
Specific Gravity (ASTM D-1810) 25°C	.883	.883	.961	1.545
Interfacial Tension (dyne/cm)	49.4	25.5	20.8	50.0
Neutralization Number (mgKOH/gram)	<.02	.011	<.01	<.01
Viscosity (centistokes)				
25°C	16	800	50	18
50°C	8	150	30	10
100°C	3	24	16	4
150°C	--	8	12	<3

* Reproduced from report:

"Environmentally Acceptable Insulating Fluids May Replace Askarels", by D.A. Duckett, RTE Corporation; May 8, 1975.

NWMAR115971

a flammability problem due to the breakdown products of the transformer oil. If this were the case, neither silicone oil nor high flash point mineral oil would be significantly better than the present transformer oils.

Because of the limited test data that is available, it appears unlikely that the proposals will be approved for inclusion into the 1978 Code. Since the deadline for submission of proposals for this Code revision has passed, the most likely date for any Code revisions is the 1981 Code.

The general acceptance of alternate liquids in place of askarels will only occur after the performance of these liquids has been demonstrated by prolonged service tests under realistic conditions. The effect of the Code is to prevent the testing of alternate liquids in transformers which, under the rules, must be filled with askarels. The inclusion of the Code into the regulations of the Occupation Safety and Health Administration is an additional institutional barrier to the accumulation of adequate performance experience.

3.9 Relative Merits of Alternatives to New Askarel Transformers

The relative merits of the various alternatives that have been proposed are summarized in Table 3.9-1. Special consideration must be given to the suitability of each of the alternatives to the major types of transformers which currently use askarels.

3.9.1 Distribution Transformers

Very few distribution transformers presently use askarels. These transformers are generally installed at the site of major generating plants, and there would be little difficulty in designing these plants so that mineral oil cooled transformers could be used safely.

3.9.2 Power Transformers

Askarel cooled transformers are used in buildings and industrial plants without vaults where the maximum voltage is less than 35,000 volts. Currently available alternates in new construction are:

NWMAR115972

TABLE 3.9-1

Relative Merits of Alternatives to the
Use of Askarel Transformers in New Applications

	Toxicity	Fire Risk	Cost/ transformer relative to askarel transformer	Reliability vs PCB	Convertability of present transformers
Mineral oil transformer in vault	excel.	excel.	$5000 to $50,000 more	good	usually no
Mineral oil transformer installed in non-hazardous location	excel.	excel.	$5000 to $50,000 more	good	usually no
Dry transformer	excel.	excel.	1.5x	poor	usually no
Silicone heat* transfer oil	excel.	fair/good	1.3x	good	probably* yes
High flash point* hydrocarbon oil	excel.	fair/good	1x	good	probably* yes

* Use depends on Code regulations being changed to allow self extinguishing liquids as direct equivalents of askarels.

NWMAR115973

- Mineral oil transformer installed in a vault
- Open air cooled transformers - limited to clean dry environments with even power requirements. Satisfactory for most office buildings and shopping centers.
- Mineral oil transformers at a site away from the building. This will be satisfactory for most trailer parks and industrial plants except for those locations where space is extremely scarce.

A possible, future, alternative may be to use a "self extinguishing" transformer fluid in those applications where askarels are now required. This alternative requires that major changes be made to the National Electrical Code.

3.9.3 Precipitator Transformers

These are high voltage step-up transformers which are mounted on or near industrial stacks. It should be possible to use mineral oil cooled transformers in all such applications.

3.9.4 Railroad Transformers

These transformers use askarel due to Penn-Central Railroad regulations. However, foreign experience indicates that there is no significant fire risk from the use of more flammable liquids in these transformers: European practice has traditionally been to use mineral oil in locomotive transformers. About ten years ago an experimental transformer was built in France which used an enclosed gas cooled (sulfur hexafluoride coolant) transformer.[22] Although somewhat limited in peak power output (overload conditions) compared to oil-filled transformers, it performed satisfactorily during extensive tests. However, this type of transformer did not gain wide acceptance because it was more expensive than oil-filled transformers, and there was not felt to be any significant safety problem associated with the use of the oil-filled units.

General Motors Corporation recently supplied a demonstration electric freight locomotive to the Penn-Central Railroad for test. This

NWMAR115974

locomotive is designated a type GM-6. The transformers in this locomotive were supplied by a Swedish manufacturer, and are filled with mineral oil as Swedish regulations would not allow the use of PCBs even for test purposes. As a result of this material choice, this demonstrator locomotive is not allowed into the tunnels into New York.

Japanese practice over the past four years has been to use silicone oils in new railroad transformers. No service problems have been reported.

AMTRAK is presently negotiating the lease of several new electric locomotives from France. Preliminary specifications call for the transformers to be able to operate satisfactorily with mineral oil, askarel, or silicone oil as the coolant.

3.10 Replacement of Askarels in Existing Transformers

There are currently about 135,000 askarel-filled transformers in service in the United States. These transformers contain an average of 2000 to 2500 pounds of PCBs each, for a total in-service inventory of about 300 million pounds of PCBs. Accidental losses of askarel may occur due to failure of these transformers and accidental spills during servicing. It has been suggested that these losses may be a significant source of PCBs into the environment, and that this source of pollution could be minimized by refilling these transformers with an approved "self extinguishing" transformer liquid.

3.10.1 PCB Losses Due To Transformer Failures

The incidence of failure of askarel-filled transformers has been estimated to be 0.2 percent per year. No more than 1 percent of these failures result in a rupture of the transformer case and spillage of liquid. The usual failure involves only a venting of gases from the transformer safety valve, followed by immediate operation of the circuit breakers to remove the power from the transformer. Thus the expected incidence of spillage is probably on the order of 3 transformers per year containing perhaps 6000 lb of PCB. However, most askarel transformers are installed in buildings or in vaults where there is a provision for containing any leakage. It is probably

NWMAR115975

reasonable to assume that the cleanup activities following a transformer rupture are 90 to 99 percent effective in recovering the spilled askarel, which limits the total uncontrolled loss of askarels from transformer ruptures total of 60 to 600 lb per year. If it is assumed that the venting of vapors during a transformer failure results in the loss of an average of two lb of PCB due to evaporation, the total losses from this source will be about 540 lb per year. Thus, the total annual entry of PCB into the environment due to transformer losses is on the order of 4 lb per million lb of PCB in service.

3.10.2 Environmental Effects of An Askarel Replacement Program

The proposal to drain the existing askarel transformers and refill them with an environmentally acceptable heat transfer liquid presupposes the availability of sufficient quantities of a liquid having satisfactory fire resistant properties and heat transfer properties equal to askarel. No such material is currently available. The use of either silicone oil or a high flash point hydrocarbon material would require a change in the National Electrical Code regulations which govern the installation of transformers. In addition, all of these materials have poorer heat transfer characteristics than askarels, which may require the derating of all the transformers.

Assuming that a satisfactory substitute liquid were available, the retrofitting of the existing transformers still faces a number of practical problems. The most difficult problem is the achievement of thorough draining of askarels from the existing transformers. Much of the liquid is held in the insulation of the transformers by capillary action; simple draining of a transformer only removes 80 percent to 90 percent of the liquid. Therefore, it will be necessary to flush each transformer 2 or 3 times with a liquid which will dissolve the remaining askarel, and which is compatible with the liquid used to refill the transformer. This requirement of compatibility could be a major problem; for instance, askarels are immiscible in silicone foils.

It can reasonably be expected that the draining and flushing of each askarel-filled transformer will result in an average of 800 gallons of askarel and PCB contaminated liquid. This liquid must be shipped to an incinerator and burned under controlled conditions. Disposal of the liquid

NWMAR115976

could be expected to cost $700 plus the cost of the shipping containers and transportation.

The result of this draining, flushing, and refilling procedure will be a transformer which is filled with 300 gallons of an environmentally acceptable liquid that is contaminated with 10 to 20 lb of PCB. This reduction in the amount of PCBs in service will reduce the severity of potential transformer failures, but will not eliminate the need for careful handling or eventual disposal of the contaminated liquid.

A more serious concern would be the amount of accidental spillage which would occur when the scrap askarel and flushing liquid is shipped to the incinerator for disposal. The current lack of sufficient incineration facilities would require that much of this liquid be stored in drums or tanks for an extended period of time. In addition, the accidental leakage from broken drums and other accidents which can be expected to occur during transportation can be expected to release PCBs and flushing solvent to the environment.

3.10.3 Effect of Leaving Askarel Transformers in Service

The alternative of leaving the askarel in the transformers until they become obsolete or fail is probably to be preferred to retrofitting these transformers with a less toxic liquid. The existing askarel should last the life of the transformers; only infrequently is it necessary to filter the liquid to remove the degradation products of minor internal arcing, and askarel losses during this filter cycle should not exceed 1 percent of the total liquid in the transformer. Askarel for makeup of these losses will not be available once it is no longer used in new transformers; Monsanto has announced its intention of closing the only U.S. PCB manufacturing plant as soon as satisfactory substitutes are available for PCBs in electrical equipment. This should not prove to be a major problem in the maintenance of askarel transformers, as minor losses of liquid can be replaced with pure trichlorobenzene. The resulting mixture will be suitable as long as the concentration of the PCBs is above 50 percent; below this concentration of PCBs, solvent attack on

NWMAR115977

the solid insulation may occur. Complete replacement of the transformer required by lack of askarel should be infrequent and should not impose a significant economic burden on the electrical industry.

The decision to leave existing askarel transformers in service also gains time for the solution of the problem of scrapping failed or obsolete transformers. Current specifications require that transformers be drained and flushed before being scrapped. This, however, cannot be expected to remove more than 95 to 98 percent of the PCBs from the transformer internals.

It is currently very unusual for transformers to be scrapped, but when they are scrapped the value of the metal is sufficient to make recycling attractive. There is currently no acceptable facility for the recovery of metal from failed transformers. Special procedures would have to be used to prevent PCB residues from being carried through into the scrap furnaces. This will eventually be a significant problem. Better solutions to the problem can be expected if the problem is delayed by leaving existing transformers in service.

4.0 INVESTMENT CASTING

The investment casting process is a lost-wax casting process in which a pattern is molded from wax and then invested or surrounded by a slurry containing a refractory ceramic. After the ceramic mold is dried to an appropriate strength, the wax pattern is melted or burned out leaving a molded cavity. Molten metal is then poured into the cavity, and solidified by cooling to form a cluster of metal castings. Maintenance of close dimensional tolerances requires that the shrinkage of the wax be carefully controlled during the initial pattern step. This control requires either slow cooling of the pattern while the wax is solidifying or the use of a wax material which shrinks very little upon solidification.

4.1 Function of the Filler Material

One method of modifying the wax to achieve minimal shrinkage is to fill the wax with a finely powdered material that is insoluble in the wax and remains solid at the temperature at which the wax is cast into the molds.

NWMAR115978

Because this filler does not change state (from a liquid to a solid) on cooling, it exhibits very low shrinkage, and the resulting slurry of wax and filler will be much more dimensionally stable than will be the pure wax.

The second step in the casting process is to burn the wax residues out of the ceramic mold so that the mold will be completely empty when metal is cast into it. This requires that the filler be volatile at the temperatures used to fire the molds, and that the vapors be non-toxic.

4.2 Use of PCBs in Investment Casting

Some of the pattern waxes, especially those used in the casting of metal parts requiring tight dimensional tolerances, contain decachlorobiphenyl (deka) as the wax filler. Decachlorobiphenyl waxes contain approximately 30 percent (perhaps up to 40 percent) of the decachlorobiphenyl filler.[23] Pattern waxes are recovered and reused several times to form the sprues and gates of the patterns. Wax is apparently used an average of 2.5 times. During the dewaxing process the virgin wax (used to form the pattern) and the old wax (used to form the gates and sprues) are collected as one mixture. Little of the wax is destroyed in the process; therefore, it is probable that the investment casting foundries store or dispose of relatively large amounts of used PCB-containing wax.

It is estimated that approximately one to 1.5 million pounds of decachlorobiphenyl-filled wax is purchased yearly by U.S. investment casters. The cost of the PCB-filled wax is in the range of $0.70 per pound.[24] Imported polychlorinated terphenyls, which exhibit properties very similar to decachlorobiphenyl, is also used as a pattern wax filler. There is only one U.S. producer of deka-filled wax, and this company also produces PCT-filled pattern wax.

4.3 Advantages and Disadvantages of the Use of Deka PCBs in Investment Casting

The deka PCBs have nearly ideal properties for fillers in investment casting waxes. These materials are only slightly soluble in the wax, remain solid at the wax casting temperatures, and volitilize completely at the firing temperatures without charring or burning.

NWMAR115979

The only disadvantage to the use of deka PCB is its suspected possible environmental persistence and, by analogy to the other PCBs, its toxicity. No direct evidence of environmental damage from this compound has been found to date.

4.4 Alternatives to the Use of Deka PCBs

Potentially acceptable process alternatives for the deka PCBs could utilize either a replacement filler material or an unfilled wax.

4.4.1 Replacement Filler Materials

Properties required for a filler are: high melting point (over 300°C), high heat transfer coefficient, low thermal coefficient of linear expansion, and minimum ("zero") ash. The following materials have been suggested as possible replacements for deka PCB.

4.4.1.1 Isophthalic Acid

Isophthalic acid has been used as a filler material to a limited extent, but the grade of material that was previously available left an ash residue on firing.[25] A new grade of isophthalic acid, only recently commercialized by AMOCO Chemicals Corp., exhibits much lower ash and metal contents. The various grades of material available from AMOCO are as follows:[26]

Grade	Cost in Bulk	Comments
IPA 85	$0.24/lb	High ash
IPA 99	$0.27/lb	Previous use history
IPA 110	$0.31/lb	Being phased out
IPA 220	$0.35/lb	New - low ash

Although there is a considerable body of literature on phthalic acids and phthalate esters, their environmental fates are not known. Degradation routes properties of degradation products, etc., which are of great importance to an assessment of environmental acceptability have not been studied in depth. It can be surmised that this will be the case for most filler substitutes.

NWMAR115980

4.4.1.2 Polystyrene

Polystyrene plastic is available from a number of suppliers including Dow Chemical Co., Monsanto, and Foster-Grant. If this plastic were reduced to a sufficiently fine powder, it would have physical properties equivalent to deka PCB and should perform satisfactorily as a wax filler. The bulk cost of polystyrene pellets is $.40/lb, and the size reduction should cost an additional $.08/lb of filler.

Upon firing, the polystyrene could be expected to depolymerize to styrene which would be volitilized. Styrene vapor has known toxic properties. This potential problem may limit the serious consideration of polystyrene as a wax filler.

4.4.2 Unfilled Waxes

Prior to the use of PCBs or PCTs as fillers, unfilled waxes were used. Industry sources claim that reverting to the use of unfilled waxes would increase production costs by about 10 percent. However, new types of unfilled waxes have recently been introduced to the market, and it is claimed that their properties are equivalent to the filled wax and their cost is slightly lower ($0.60 to $0.65/lb).[27] Although the exact formulation of these waxes is not known, they reportedly contain no chlorinated additives.

4.5 Conclusions - Substitutes for PCB in Investment Casting

Technically adequate substitutes for decachlorobiphenyl filler in pattern waxes appear to be available. Maximum increases in costs would be about 10 percent. The only producer of wax containing PCBs could probably change to other types with very little technical difficulty or economic impact.

NWMAR115981

SUMMARY

SUBSTITUTES FOR PCBs

Capacitors

PCBs are used as the dielectric liquid in almost all AC capacitors used by the electrical utilities for power factor correction and in various industrial applications including appliance motors, fluorescent light ballasts, and power supply circuits in television receivers. PCBs are uniquely suited for capacitor applications because of their high dielectric constant, chemical stability, and non-flammability.

A number of different chemicals are being developed as replacements for PCB capacitor fluid. There is not yet sufficient data available on the electrical performance, chronic toxicity, or environmental effects of any of these liquids.

Dry film AC capacitors are also being developed. These capacitors are significantly larger than liquid-filled capacitors and are limited to a maximum of 280 volts. Satisfactory dry film capacitors will not be available until there are two separate technological breakthroughs: 1) the development of a plastic film that combines a high dielectric constant with a low loss-tangent; 2) the development of winding techniques that exclude all air from the winding of the capacitor.

Although it is probable that satisfactory substitutes for PCBs will be developed within the next 5 years, no such material is presently available and much additional research remains to be done.

Transformers:

PCBs are used as a major component of the non-flammable transformer liquid known as askarel. Only about 5 percent of all transformers are cooled with askarel. These are the transformers which are located in buildings and other hazardous locations where fire resistance is of great importance.

Most transformers are cooled with mineral oil. This liquid is flammable and the National Electrical Code requires that oil-filled transformers be

NWMAR115982

installed in fire proof vaults when they are used in buildings. Vaults are not required for askarel-filled transformers that are rated at less than 35,000 volts. Although the askarel-filled transformers are 20 percent to 30 percent more expensive than oil cooled units, the savings on vault construction costs more than offsets the difference.

Other currently available substitutes for askarel-filled transformers are open air cooled transformers, which are limited to lower voltage applications in clean, dry environments, and closed gas cooled transformers which are more expensive than askarel units. Both of these dry transformers have lower overload capacity than do askarel and oil-filled units.

Technically satisfactory alternatives are available to the use of transformers containing PCBs. The present choice of PCB units is based on the relative costs of the alternatives.

Several substitute liquids have been suggested which are less flammable than the currently used mineral oil, but which are more flammable than askarel. These liquids are characterized as being self extinguishing -- i.e., they do not continue to burn after being ignited by a momentary electrical arc. Proposals have been submitted to the National Electrical Code to allow the use of these self extinguishing materials under those conditions where askarels are presently specified. Because of the relative lack of service experience with these liquids, it is unlikely that these proposals will be accepted. The next Code revision (1978) will probably continue to recognize only askarel and "oil filled" transformers.

It is likely that the "self extinguishing" liquids will prove to be satisfactory alternatives to PCBs. Substantial experience on the performance of the liquids will be required before the Code requirements will be changed to allow their use. The restrictive Electrical Code, which has been incorporated into the OSHA Regulations, may act to inhibit the accumulation of this data and thereby act to postpone the general acceptance of these substitutes for PCBs.

It has also been suggested that PCBs be drained from existing transformers and replaced with a less toxic material. Analysis of this alternative suggests that it may have a worse effect on the environment than would the continued use of PCB in the transformers.

NWMAR115983

SUMMARY

INVESTMENT CASTING

Dekachlorobiphenyl is used by one manufacturer in the formulation of investment casting waxes. The deka PCB acts as an inert filler which reduces the shrinkage which occurs when the wax solidifies. Other manufacturers use polychlorinated terphenyls (PCTs) for the same purpose. All of the deka PCB and PCTs used in investment casting waxes are imported.

Several substitutes are available for deka PCB waxes. These include the replacement of the PCB with isophthalic acid, or the use of new low shrinkage non-filled waxes. Complete elimination of deka PCBs from this application should be possible without causing significant problems.

NWMAR115984

REFERENCES

1. Guidelines for Handling and Disposal of Capacitor-and Transformer-Grade Askarels Containing Polychlorinated Biphenyls, ANSI C107.1 - 1974, American National Standards Institute, Inc., N.Y., N.Y., January 9, 1974.

2. Wood, David, Chlorinated Biphenyl Dielectrics - Their Utility and Potential Substitutes, (Presented at the National Conference on Polychlorinated Biphenyls, Chicago, Il., November 19-21, 1975), Monsanto, 1975.

3. Nelson, J.D., (General Electric Company), "Effluent Limitations for Items on Toxic Substances List; Economic Impact of a Bar in PCB," Contained in Communication to Dr. Martha Sager, Chairman, Effluent Quality Information Advisory Committee, November 21, 1973.

4. National Electrical Code - 1975, National Fire Protection Association, Boston, MA, (NFPA No. 70-1975; NASI C1-1975), 1974.

5. Personal communications with knowledgable individuals in the electrical equipment industry.

6. Inchalik, E.J., (Exxon Chemical Co.), Verbal Presentation, National Conference on Polychlorinated Biphenyls, Chicago, Il., November, 1975.

7. Rey-Coquais, Bruno, (Prodelec, S.A.), Verbal Presentation, National Conference on Polychlorinated Biphenyls, Chicago, Il., November, 1975.

8. Branson, D.R., Health and Environmental Properties of Dow XFS-4169L Capacitor Fluid, (Oral Presentation to the U.S. E.P.A., Washington, D. C., October 16, 1975), Dow Chemical Co., October, 1975.

9. Branson, D.R., (Dow Chemical Co.), Verbal Presentation, National Conference on Polychlorinated Biphenyls, Chicago, Il., November, 1975.

10. Montgomery, Richard, (Dow Corning Corp.), Verbal Presentation, National Conference on Polychlorinated Biphenyls, Chicago, Il., November, 1975.

11. Tuttle, Cliffton, (Aerovox Co.), Personal Communication, September, 1975.

12. McAllister, John F., (General Electric Co.), "Benefits of PCB Use". Letter to Dr. Edward J. Burger, Jr., Executive Office of the President, Office of Science and Technology, December 30, 1971, 36 pp.

13. Report on Power Transformer Troubles, 1969, Edison Electric Institute, Publication No. 71-20, 1971.

14. "The Rush to Market for PCB Substitutes", Business Week, January 19, 1976, pp 30E-31E.

NWMAR115985

15. Bloomquist, W.C., "What is the Future for Askarel", Power, Vol. 120, No. 2, February, 1976, pp 68-70.

16. Interdepartmental Task Force on PCBs, Polychlorinated Biphenyls and the Environment, Washington, D. C., May, 1972.

17. Burrow, R.F. & Orbeck, T. (Dow Corning Corporation, Midland, Michigan) Silicone Fluid Filled Transformer - An Alternative to Askarel and Dry-Type Transformer?, (Presented at the Doble Engineering Client Conference, Boston, MA., Aprin 9-13, 1973), Dow Corning Corp., 1973.

18. Burrow, R.F., & Vincent, G.A., Silicone Fluids vs Hydrocarbon Oils:, a Comparison of Thermal and Electrical Performance Capabilities, (Presented at the 1974 Winter Meeting, IEEE Power Engineering Society, N.Y., N.Y., January 31, 1974), IEEE Paper No. C 74-258-0.

19. Report on Dielectric Medium Under the Classification Program - File MH9466, Underwriters Laboratories, Inc., May 26, 1972.

20. Rowe, V.K.; Spencer, H.C.; Bass, S.L; "Toxicological Studies on Certain Commercial Silicones", The Journal of Industrial Hygiene and Toxicology, Vol. 30, No. 6, pp 332-352.

21. Duckett, D.A., Environmentally Acceptable Insulating Fluids May Replace Askarel (Presented at the General Meeting, Edison Electric Institute Transmission and Distribution Committee, Minneapolis, Minn., May 8, 1975), RTE Corporation, May, 1975.

22. "Transformateur dans le gaz", Chemins de Fer, No.246, 1964-3, p 96.

23. Solomon, P. (Yates Manufacturing Co., Chicago, Illinois), Personal Communication, September 9, 1975.

24. Lewis, W.H. (President, Signicast Corp., 9000 North 55 St., Milwaukee, Wisc.), Statements during Lecture of Investment Casting Institute Meeting, October 4, 1975.

25. Edwards, Dan (Chicago Laboratory - Standard Oil Co., Amoco Chemical Corporation, Joliet, Ill.), Personal Communication, October, 1975.

26. Connelley, J. (New York Office, Standard Oil Co., Amoco Chemical Corporation, Joliet, Ill.), Personal Communication, October 1975.

27. Davidson, R. (Freeman Manufacturing Company, Inc., 1315 Maine Ave., Cleveland, Ohio), Personal Communication, November 1975.

NWMAR115986

SECTION IX

PCBs RELEASE AND CUMULATIVE ENVIRONMENTAL LOADS

1.0 ESTIMATES OF FREE PCBs IN THE ENVIRONMENT

1.1 PCBs Losses to the Environment Since 1930, by Use and by Chlorine Content of Molecule

This section includes an analysis of the estimated amounts of PCBs which have escaped to the environment, by molecular chlorine content. The approach and results are summarized below.

Loss factors, which include spillage losses during manufacture or use of the end products and losses due to inadequate disposal methods, are estimated on the following basis:

Use Category	% of Yearly PCB Use Lost to Environment
Closed electrical systems (transformers and capacitors)	5%
Hydraulic and heat exchange fluids	60%
Plasticizers	25%
Miscellaneous industrial applications	90%

Each of the assigned loss percentage factors can be the subject of considerable controversy. Suffice it to say that the choices made appear to be reasonable based on the widely varying information considered.

The following data have been computed on the basis of the production and sales data released by Monsanto on the PCBs. Since by far the largest production has been in the form of Aroclors 1242, 1248, 1254, and 1260, these data are based only on those four mixtures.

"Proportional Use Factors for PCBs" were computed from the Monsanto PCB manufacturing and sales data utilizing the domestic sales by category information. Since the detailed breakdown for the period 1930-1957 was not available, it was assumed that the pattern for this period followed the average

NWMAR115987

for the period 1957-1959. Estimates were then prepared of the actual production and use of the individual Aroclors listed above. Table 1.1-1 is a tabulation of the estimated amounts of Aroclors that have escaped into the environment, assuming that 5% of the PCBs used in capacitors and transformers escaped; 60% of that used for hydraulic media, and heat exchange media escaped; 25% of that used for plasticizers escaped; and, finally that 90% of that used in miscellaneous industrial uses has escaped.

These data may be expressed in terms of chlorine content, based on published Monsanto data on the isomers typically present, by chlorine content, in each Aroclor type. The results from such an exercise are presented in Table 1.1-2. The totals in the right-hand column represent the cumulative totals of all escaped PCBs by the year listed at the left.

The computed spectrum of chlorine contents based on the cumulative data on Table 1.1-2 is presented, for selected years, on Table 1.1-3.

The average chlorine content for the set termed "average values" is 4.38 chlorine atoms per molecule, compared to:

Aroclor	Chlorine Content (atoms/molecule)
1242	3.67
1248	4.22
1254	5.35

Thus, the distribution as is comes closest to Aroclor 1248. However, if it is assumed that all mono- and di-chloro biphenyl were biodegraded or otherwise destroyed, then the average chlorine content of the "wild" PCBs would be 4.67, intermediate between 1248 and 1254. If the trichloro isomers were also subtracted out, then the composite average chlorine content would be 5.0, which begins to compare favorably with 1254.

1.2 Total PCBs Accumulation and Current Rates

As a rough estimate of the total PCBs currently available to the biota (in active transport, in biological systems, etc.) in the United States, the total of 172,800,000 lb. from Table 1.1-1 may be reduced by a factor

NWMAR115988

TABLE 1.1-1

PCB ENVIRONMENTAL LOAD BY AROCLOR TYPE

[In Thousands of Pounds]

	Aroclor Type					
	1242	1248	1254	1260	1016	Total PCBs
1930-56	18709	5395	5003	3559	-	32466
1957	1991	704	676	932	-	4303
1958	1431	1065	917	783	-	4196
1959	2298	1597	1142	1118	-	6155
1960	2955	1226	989	1191	-	6361
1961	4082	1745	1295	1347	-	8469
1962	3992	1452	1222	1258	-	7924
1963	3648	2062	1166	1503	-	8379
1964	4597	2160	1224	1664	-	9645
1965	5928	2260	1456	1096	-	10740
1966	7010	1932	1247	1041	-	11230
1967	7442	1794	1158	1111	-	11505
1968	7789	1881	1615	954	-	12239
1969	9182	2190	2172	997	-	14541
1970	10072	1536	2575	1044	-	15227
1971	3232	112	717	266	167	4494
1972	48	-	229	20	1045	1342
1973	310	-	399	-	1177	1886
1974	310	-	309	-	1098	1717
					Grand Total -	172.8 × 10^6 lbs.

NWMAR115989

TABLE 1.1-2

CUMULATIVE ENVIRONMENTAL PCB LOAD
BY CHLORINE CONTENT

[In Thousands of Pounds]

	Cl_1	Cl_2	Cl_3	Cl_4	Cl_5	Cl_6	Cl_7	Cl_8	Cl_9	Total
1956	561	2540	6210	8221	8936	4017	1759	285	36	32,565
1957	621	2813	6894	9174	10070	4709	2182	360	45	36,868
1958	664	3020	7487	10130	11311	5419	2558	423	53	41,064
1959	733	3351	8417	11584	13086	6388	3085	512	64	47,219
1960	822	3760	9465	13070	14805	7344	3632	607	89	53,580
1961	944	4326	10922	15135	17128	8529	4162	715	89	62,049
1962	1064	4874	12301	17048	19279	9640	4751	816	102	69,973
1963	1173	5389	13693	19095	21575	10835	5437	936	117	78,352
1964	1311	6030	15369	21473	34160	12153	6192	1069	134	87,997
1965	1489	6846	17436	24315	27123	13391	6728	1157	145	98,735
1966	1699	7796	19747	27328	30097	14568	7230	1240	155	109,966
1967	1922	8799	22154	30406	33080	15754	7755	1329	166	121,471
1968	2156	9850	24674	33673	36376	17053	8243	1405	176	133,710
1969	2431	11088	27639	37543	40368	18625	8782	1485	186	148,251
1970	2733	12428	30735	41462	44523	20362	9365	1569	196	163,478
1971	2837	12880	31723	42624	45657	20840	9517	1590	199	167,972
1972	2881	13073	32131	43086	45782	20928	9539	1592	199	169,314
1973	2938	13324	32663	43700	46046	21076	9563	1592	199	171,204
1974	2992	13561	33165	44272	46265	21193	9582	1592	199	172,821

NWMAR115990

TABLE 1.1-3

COMPUTED SPECTRUM OF CHLORINE CONTENT FOR WILD PCBs

[In Percent]

	Weight Percentage of Isomers Containing Cl_x								
	Cl_1	Cl_2	Cl_3	Cl_4	Cl_5	Cl_6	Cl_7	Cl_8	Cl_9
1956	1.7	7.8	19.1	25.2	27.4	12.3	5.4	0.9	0.1
1960	1.5	7.0	17.7	24.4	27.6	13.7	6.8	1.1	0.1
1965	1.5	6.9	17.7	24.6	27.5	13.6	6.8	1.2	0.1
1970	1.7	7.6	18.8	25.4	27.2	12.5	5.7	1.0	0.1
1974	1.7	7.8	19.2	25.6	26.8	12.3	5.5	0.9	0.1
Average Values	1.6	7.4	18.5	25.0	27.3	12.9	6.0	1.0	0.1

NWMAR115991

accounting for environmental degradation of less chlorinated isomers and other destruction processes. Based on Table 1.1-2, this should be about 20 to 30 million pounds, resulting in a total of free PCBs of about 150 million pounds.

Estimates by Nisbet and Sarofim[1] in 1972 for total PCBs available through air and water dissipation amount to 180,000,000 lb. since 1932. This value is within four percent of the above estimate of about 173million pounds based on the loss factors specified.

Application of the five percent loss factor to the 1974 Monsanto domestic sales yields an estimate of 1,720,000 lb. lost to the environment during 1974, to which should be added a maximum of 50,000 lb. lost from imported materials. The 1974 total of 1,770,000 lb. entering the environment in available forms represents about 1.5 percent of the total amount estimated above to be available to the biota in the U.S.

The 1,770,000 lb. per year amount may be compared with estimates for 1974 by Peakall[2] as follows:

Industrial leaks and disposal	- 880,000 to 1,100,000 lb.
Disposal in dumps and landfills	- 15,000,000 lb.
Total	- 16,000,000 lb.

The figure of about 10 percent loss from the above required to match the 1,770,000 lb. per year loss rate does not appear unreasonable. However, it should be pointed out that the 16,000,000 lb. per year figure for leaks and disposal from Peakall represents almost half of Monsanto's reported 1974 domestic sales, and must be questioned.

1.3 Current PCBs Disposal in Landfills and Dumps

The most important current sources of land-disposed PCBs are:

(1) Solid wastes from the manufacture of PCBs and electrical equipment (including reject capacitors and transformer internals);

NWMAR115992

(2) Failed capacitors;

(3) Capacitors in obsolete equipment; and

(4) Municipal solid wastes other than electrical (obsolete equipment, sewage sludge, paper, plastics, etc.)

One relatively minor source is the transformer service industry. This industry handles about 2×10^6 lb. of PCBs annually (roughly half new PCBs). Assuming that 5 percent of the PCBs handled ends up as solid wastes (from filtration, etc.), results in 0.1×10^6 lb./yr. of solid material entering the landfills.

The major sources are treated below. Land-destined solid wastes from production of PCBs, capacitors, and transformers are estimated to contain about 1.2×10^6 lb./yr. of PCBs. Reject capacitors and transformer internals add about 0.7×10^6 lb./yr. to landfills. Since most PCBs used in investment casting are eventually land disposed, this adds 0.4×10^6 lb./yr. Adding in 0.1×10^6 lb./yr. for transport and other losses brings the total of land disposed PCBs from production and first tier use to 2.4×10^6 lb./yr.

The failure rate for PCB-impregnated capacitors is estimated at one percent per year. On this basis, and assuming that the failed equipment enters a landfill or dump, then about one percent of the approximately 450×10^6 lb. of PCBs estimated to be in service in capacitors, or 4.5×10^6 lb./yr., can be expected to be landfilled.

Capacitors which have not failed but are contained in obsolete equipment (TV sets, light fixtures, etc.) also end up in land disposal sites. This applies to small capacitors only, and it is estimated that one percent of the total are discarded in this manner each year. The amount of PCBs involved is $(0.01 \times 270 \times 10^6)$, or 2.7×10^6 lb./yr.

The amount of PCBs currently contained in land-disposed municipal and industrial wastes other than that assignable to transformers and capacitors

NWMAR115993

is difficult to estimate. Approximately 160 million pounds of PCBs have been used in plasticizer and other "open end" applications or in "semi-closed" applications such as hydraulic or heat transfer systems. Most of this usage occurred between 1960 and 1972, and it is likely that up to 80 percent of the total is either free in the environment or already in land disposal sites. The rest of this material, estimated to be on the order of 30 million pounds can be thought of as being literally "in service" or used and awaiting disposal. A prime example of the latter is used carbonless copy paper currently residing in files and awaiting disposal or recycling. It is estimated that about seven percent of this 30 million pound reservoir, or 2.1 million pounds, enters land disposal sites each year.

In addition, it is estimated that 0.3 million pounds of free PCBs in the environment are added to land disposal sites each year from a variety of sources (sewage sludge, dirt, garbage, etc.). This brings the total for municipal and non-electrical wastes to 2.4×10^6 lb./yr.

Source	PCBs Added to Landfills and Dumps, lb./yr.
Wastes from Production and First Tier Use	2.4×10^6
Failed or Obsolete Capacitors	4.5×10^6
Capacitors in Obsolete Electrical Equipment	2.7×10^6
Other Municipal and Industrial Wastes	2.4×10^6
Wastes from Transformer Service Industry	0.1×10^6
Total	12.1×10^6

Peakall's[2] estimate of 16×10^6 lb. of PCBs for leaks and disposal in 1974 is about 30 percent higher than the above total. Peakall[2] also estimated a total of 50×10^6 lb. for leaks and disposal during 1970, which is over two-thirds of Monsanto's 1970 reported domestic sales of about 73×10^6 lb. In the absence of no other comparable data, we estimate a current land disposal rate of between 10×10^6 and 15×10^6 lb./yr.

NWMAR115994

It should be noted that several large first-tier users of PCBs are not currently land-filling their solid wastes, but are storing the drummed wastes on-site in anticipation of potential regulations on disposal of such wastes. The wastes being stored are estimated to contain at least 0.5×10^6 lb. per year of PCBs; this is included in the above analysis as being finally disposed of in landfills.

1.4 Release of PCBs via Industrial Effluents (Waterborne)

Based on data obtained from industry, the following average PCBs waste loads for water effluents were estimated:

PCBs Production	1117 lb./yr.
Capacitors	2139 lb./yr.
Transformers	62 lb./yr.
Total	3318 lb./yr.

This number is very small in comparison to the estimated 10×10^6 to 15×10^6 lb. per year of PCBs going to landfills.

The above values for industrial discharges do not include PCBs discharged to municipal systems for those plants having discharges to rivers (ten plants). In the production category, all discharge is to a municipal system.

It should be noted that the above waste loads represent current industrial practice. It may be assumed that, prior to knowledge of the adverse environmental effects of PCBs, much of the types of material currently land-filled was not disposed of properly and thus entered the environment directly.

1.5 Spills of PCBs During Transport

The most complete set of transportation spill data for PCBs available to us are for the period 6/74 to 6/75. The spills during transport and the quantities involved are as follows:

NWMAR115995

Location	Gallons Spilled
Trion, Ga.	117
Lawrence, Ala.	600
Erie, Pa.	120
Unknown	~100*
Total	937 (10,213 lb.)

In addition, during this period, three railroad capacitors failed in the New York City area, spilling on the order of 50 lb. each, or a total of 150 lb. Since this occurred during transit, we chose to add this amount to the above total, for a grand total of 10,363 lb. spilled in the transportation-related incidents. This probably represents a minimum figure, since transport of defective product units (capacitors and transformers) and of PCBs containing wastes can be expected to release PCBs.

On the basis of the above, a tentative number of 10,000 lb. per year of transportation-related spills of PCBs is advanced.

*Capacitor shipment via truck overturned; leading units and soaked dirt removed from site for subsequent incineration.

NWMAR115996

REFERENCES

(1) Nisbet and Sarofim; Environ. Health Perspect., 1, 21, (1972).

(2) Peakall, D.B., "PCBs and Their Environmental Effects", CRC Review, 5, Issue 4, 1975.

NWMAR115997

SECTION X

INADVERTENT AMBIENT REACTIONS AS ROUTES OF ENTRY OF PCBs INTO THE ENVIRONMENT

1.0 INTRODUCTION

This is a report of a preliminary investigation into the ways that PCBs could enter the environment even if they were no longer manufactured, imported, used or disposed of in the U. S. The work focused on the reactions of aromatic compounds, particularly the biphenyls, and how the conditions found in ambient surroundings in the environment could lead to the inadvertent and undesirable synthesis of PCBs. Specifically the major question addressed was whether chlorination water treatments could convert biphenyl contamination into PCBs.

Beyond that, there are questions of the likelihood of the breakdown of compounds such as DDT, followed by recombination to produce a PCB; the breakdown and rearrangement of dyestuffs to form PCBs; and other potential routes to the inadvertent synthesis of PCBs.

When a candidate route is identified, one needs then to determine the probability of that reaction proceeding, and the reaction rate. Also, the determination of what relevant pollution loads and concentrations occur in wastewater or clean water systems is an obviously important factor. For this study, the objective was primarily the identification of PCB formation routes which could be significant. Studies to determine kinetics of these reactions have not, to our knowledge, been performed.

2.0 COMMERCIAL BACKGROUND, PRODUCTION AND PROPERTIES OF BIPHENYL

2.1 Origins and Commercial Usage Background

Biphenyl (previously known as diphenyl and phenyl-benzene) was first reported in 1862 by Fittig. In 1867 Berthelot identified it as the main product generated when benzene vapors were passed through a hot tube. During 1925-1926, Dr. Herbert H. Dow carried out experiments with diphenyloxide, using it as a heat transfer fluid in a steam power process. In 1927, Theodore Swann of the

NWMAR115998

Federal Phosphorus Co. was asked to supply biphenyl in commercial quantities for use as a heat transfer fluid in the refining of lube oils. He set up a pilot plant for this purpose.

Soon after, the Swann Corp. developed the "Aroclor" series of PCBs. Early in the 1930's, Monsanto took over this production. About that time Dow also entered into the field, developing "Dowtherm A", a eutectic of 73.5% diphenyloxide and 26.5% biphenyl. Dowtherm has been a popular heat transfer fluid since that time.

During the 1950's, the advantages of using biphenyl as a mild fungicide in individual fruit wrappers were appreciated. Later, biphenyl was used as a kraft paper and boxboard impregnant and as a coating in closed fruit packages. In the 1960's, the usage as a carrier for dispersed dyes began. All of these biphenyl applications have continued to be important up to the present. Hydroxybiphenyls are also used as preservatives, and aminobiphenyls are used as dye intermediates.

2.2 Production Methods and Rates for Biphenyl

The two principal producers in the U. S., Dow and Monsanto, both synthesize biphenyl by the thermal dehydrogenation of benzene.

At temperatures of 700-850°C, benzene reacts by a homogeneous gas-phase reaction (in which a benzene molecule joins with another benzene molecule or with a polyphenyl molecule, liberating hydrogen and forming diphenyl or higher polyphenyls), or by a heterogeneous gas-solid reaction giving carbon and hydrogen. Most process development work has been directed to repressing the second reaction, which is known to be catalyzed by metals, particularly nickel, iron, and copper.

In 1964 biphenyl appeared on the U. S. market as a by-product of phenol produced by the partial oxidation of benzene. Benzene can be oxidized to phenol and biphenyl with hydrogen peroxide as the oxidant. Other more recent sources of biphenyl are as a by-product of the hydrodealkylation production of naphthalene, and as a by-product of the dealkylation of toluene to benzene. The latter stream,

NWMAR115999

one of the bottoms from the benzene plant, has a fuel value of 1 to 2¢/pound. However, a 97 mol % pure biphenyl can sell for about 6¢ per pound. By-product streams of this type are rich in biphenyl (typically 15-20% by weight). It can be seen that wastewaters from a process like this could be the source of methyl biphenyls found in water supplies.

Coal tar amounts to about 3% by weight of coal processed. Biphenyl is part of the heavy oil fraction, along with substituted naphthalenes, accounting for about 10% of the tar. Thus biphenyl generation could amount to one pound for every ton of coal processed for liquid fuels. As more emphasis is placed on coal conversion, the potential contribution to the environmental load of biphenyl may increase.

One degradation route to biphenyl was found. It is possibly of importance since it indicates a pathway from chlorinated terphenyls to PCBs. When vapors of terphenyls are mixed with hydrogen and heated to 650-850°C., benzene and biphenyl are formed. Best results are obtained when 4 to 6 mols of hydrogen per mol of terphenyl are used (based on a Monsanto Patent). Typical terphenyls are Dow's "Tarophen" and Monsanto's "Santowax".

The above indicates that PCBs could be produced by the incomplete incineration of chlorinated terphenyls, or possibly from terphenyls themselves in the presence of decomposing PVC or other source of chlorine.

There is no recorded production data for biphenyl for any period of time. Data for biphenyl is included in the "other non-fuel" uses of benzene, which includes BHC, anthraquinone, and several other compounds, in addition to biphenyl. This whole category has amounted to between 50 and 100 million gallons of benzene equivalent per year over the last 30 years.

One industry source estimate for the early 1970's was 5 million gallons of benzene equivalent going to biphenyl. Allowing for the recent burgeoning interest in dye carriers by doubling that value, there could be as much as 80 million pounds of biphenyl sold annually in the U.S. This does not seem too unreasonable since one localized area of Georgia accounts for 22 million pounds per year.

NWMAR116000

On balance, a "best estimate" of 50 million pounds per year current biphenyl use would seem appropriate.

2.3 Properties and Characteristics of Biphenyl

Biphenyl is a rather stable organic compound, and it is resistant to thermal and radiation degradation. Some of its properties are given in Table 2.3-1.

TABLE 2.3-1 PHYSICAL CONSTANTS OF BIPHENYL

Solubility in water at 20°C., mg/l	7.5			
Melting point, °C	69.2			
Freezing or congealing point of commercial product, °C	68.5-69.4			
Boiling point at 700 mm, °C	255.2± 0.2			
Flash point, °C	113			
Fire point, °C	123			
Ignition temperature of dust cloud, °C	650			
	Temperature, °C			
	100	200	300	350
Vapor pressure, atm		0.251	2.436	5.509
Liquid density, g/cm^3	0.970	0.889	0.801	0.751
Heat capacity, cal/g	0.427	0.509	0.590	0.631
Heat of vaporization, cal/g	95	82	68	60

NWMAR116001

3.0 PROVEN BIPHENYL REACTIONS YIELDING PCBs

The two categories of biphenyl reactions examined in this section are the direct chlorination of biphenyl and the joining of two chlorinated phenyl groups into the biphenyl configuration.

3.1 Chlorination of Biphenyl

Although conflicting statements can be found in the literature, it is accepted that biphenyl is more easily chlorinated than benzene due to less resonance stability in the biphenyl. The behavior of biphenyl is complicated by the non-coplanarity of the two rings. Because of repulsion between the 2 and 2' hydrogen atoms, the rings of biphenyl itself have an angle of about 45° between their planes. This non-coplanarity greatly diminishes the resonance interaction between the rings, and is believed to make biphenyl more prone to reaction than benzene.

Since benzene can be brominated with bromine at 0 °C in the presence of iron, and also chlorinated with chlorine in the presence of iron at 50°C, we can expect significant reaction of biphenyl with chlorine in the presence of iron below 50°C. Also, solid biphenyl reacts with bromine vapor to give first 4-bromobiphenyl, and then 4, 4'-dibromobiphenyl. Biphenyl melts at about 70°C. The commercial production of PCBs by chlorination of biphenyl in the presence of an iron catalyst is conducted above 70°C in order to obtain and maintain the molten state for ease of transport and for better mixing with the added chlorine. The higher temperature conditions may also be important in the formation of the higher chlorinated homologs, but this is also dependent on contact time. The chlorination is exothermic.

The ease with which biphenyl may be chlorinated to two isomeric monochlorobiphenyls is best illustrated by an early description of a pilot plant synthesis by Jenkins, McCullough and Booth, of the Federal Phosphorus Company, in 1929.[1] They used a temperature just high enough to melt the biphenyl, and achieved iron catalysis by using iron filings. Schmidt and Schultz and Kramers had shown that antimony pentachloride was a catalyst for the reaction.[2, 3]

NWMAR116002

The method used by Jenkins and coworkers led to the formation of 2-chlorobiphenyl and 4-chlorobiphenyl. In this reaction some dichlorobiphenyl is always produced, with the amount depending on the temperature of chlorination and on the quantity of chlorine added. Higher temperatures during the chlorination produce higher percentages of dichlorobiphenyl. When the theoretical amount of chlorine for monochlorobiphenyl is added, considerable dichlorobiphenyl is formed.

The general conclusion derived from this synthesis evaluation is that it is quite reasonable to expect that chlorine contact with biphenyl at ambient temperatures will yield PCBs at a measurable rate. The effects of temperature, dilution by air or water, lack of iron catalyst, presence of other catalytic compounds, presence of UV radiation, and other reaction conditions present in the environment are not known.

3.2 Reactions Combining Phenyls to Produce Biphenyls

Two aromatic nuclei can be joined to form a biphenyl by interaction of a diazonium salt and a hydrocarbon (benzene) under the catalytic influence of metallic copper or zinc (Gatterman procedure). In the method developed by Ullmann, many biphenyl derivatives are made by the treatment of aryl halides with copper powder. The halogen atom must be reactive. NO_2 is an example of an activating group. These two procedures are of special interest because reactants similar to the above reactants, or their progenitors, have been found in public water supplies. Examples are mono-, di-, and trichlorobenzene and chlorinated nitrobenzene.

Hutzinger, Safe and Zitko synthesized twenty-three chlorobiphenyls using a number of different routes.[4] The compounds ranged from mono- to decachlorobiphenyl. The general procedure used involved the use of diazo compounds. The specific chloraniline, selected to give the desired PCB, is heated in concentrated hydrochloric acid to about 50°C, then cooled to -5°C and diazotized with a solution of sodium nitrite in water. The mixture is stored for 30 minutes at this low temperature, then filtered. The filtrate is added to cold, vigorously stirred benzene, and a solution of sodium acetate (or

NWMAR116003

sodium hydroxide) in water. The mixture is stirred for 12 hours at 25°C., and then the PCB is recovered from the benzene layer. As an example, by this method, starting with 2, 3, 4, 5 - tetrachloroaniline, they synthesized 2, 3, 4, 5 tetrachlorobiphenyl.

They also prepared decachlorobiphenyl by the exhaustive chlorination of Aroclor 1268. The Aroclor was mixed with twice its weight of antimony pentachloride, and heated for four hours at 150°C.

Wolf and Kharasch showed that irradiation of orthoiodophenol in benzene gave 2-hydroxybiphenyl with a 65% yield.[5]

The conclusion drawn from this review of the reactions of a number of aryls is that there are a number of low temperature reactions (0-50°C.) that are capable of yielding biphenyls. In addition, some of the reactants have already been identified as present in water supplies.

4.0 BIPHENYL USAGE IN HEAT TRANSFER FLUIDS, DYES AND PACKAGING

Although the prime usage for biphenyl is the production of PCBs, it also has important use in heat transfer fluids, as a dye carrier, and as a paper or paperboard impregnant.

4.1 Heat Transfer Fluids

In heat transfer fluids, for the temperature range 250-360°C, biphenyl is used alone, or in combination with other compounds. Dowtherm "A", or Diphyl in Europe, is the combination of biphenyl with diphenyloxide. A mixture of bi- and terphenyls was used as a coolant-moderator in the AEC prototype organic-liquid cooled nuclear reactor at Piqua, Ohio.

4.2 Dye Carriers for Polyesters and Polyolefins

Disperse dyes (dye and carrier combinations) are the most widely used dye type for unmodified polyesters. Dye uptake is rather slow, and frequently pressure-dyeing above 100°C is used. Also, carriers or accelerants like biphenyl are used to cause the fiber to swell and allow more rapid penetration of the dye into the fiber.

NWMAR116004

Polyolefin fibers are also difficult to dye. Their non-polar nature and impermeability are the problem properties. However, dye carriers such as biphenyl penetrate these fibers and leave the insoluble dye residue within the fiber. Of course, most of the carrier would be expected to leave the fabric in dye-setting and washing processes. Disperse-dyed polypropylene fibers generally lack the bright colors sought in apparel, but they are used in tufted carpets and upholstery fabrics.

4.3 Biphenyl as a Mold Preventative in Packaging

Biphenyl itself has been used for many years as a mild fungicide in citrus fruit wrappers and packaging. The 2-hydroxybiphenyl sodium salt has also been used as a preservative, germicide and fungicide.

The use of biphenyl as one ingredient in impregnated tissue for wrapping citrus fruit began in the Middle East, then grew in the U.S. An odor control agent was added since biphenyl has such a pronounced odor.

Practically all of the biphenyl containing coating is now applied to the inside of the corrugated cardboard cartons used for shipping citrus fruit; or the biphenyl is applied to a pad of sheets placed inside the carton.

It would be impossible to ship citrus fruit across the U.S. in cartons, without a blue mold preventative like biphenyl. Years ago, "orange crates" of open lattice wood were used to let air circulate through and reduce mold formation. However, this exposed the fruit to the drying effects of air, external molds, water, dirt, etc. The new sealed cartons prevent all these problems, but absolutely require a mold retardant. The coating on cardboard or in tissue consists of a petroleum jelly or similar base with about 15-20% of biphenyl.

During the mid-1950's, the FDA investigated the toxicity of biphenyl, and some of the results of this investigation emerged as a threat to the future of the $40 million/yr. segment of the kraft paper industry devoted to making the cardboard cartons, liners, wrappers etc. for citrus fruit shipping. The Institute of Paper Chemistry (IPC) was chosen to determine methods of analysis,

NWMAR116005

and to referee an investigation of the potential problem. As a result of the work by IPC, biphenyl was given a clean "bill-of-health" by the FDA and has continued in use.

4.4 General Biphenyl Occurrence in the Environment

The above descriptions of biphenyl usage indicate a potential for its widespread occurrence. Of particular interest here is the occurrence of biphenyl in industrial usages where water treatment by chlorination is practiced, as in paper recycling and dyeing operations.

5.0 PCBs GENERATION AND WASTEWATER EXPERIMENTS IN A MAJOR U.S. BIPHENYL USAGE LOCALITY

For the past three years, Dr. Peter Gaffney of the Biology Department of Georgia State University has been investigating the problems of biphenyl and PCBs contamination of a watershed in northwest Georgia. He has also conducted experiments on the conversion of biphenyl to PCBs. Support was provided by the Georgia Environmental Protection Division. He estimates that this locality uses about 22 million pounds per year of biphenyl as a dye carrier in carpet dyeing. This relatively small geographical area accommodates 250 to 300 mills representing 65% of the world's carpet and rug industry.

Also, W. C. Tincher of the Environmental Resources Center of Georgia Institute of Technology has been studying the problem of biphenyl effluents from polyester carpet manufacturing in Georgia. Other workers have been concerned with the residual odor of biphenyl in carpets.

In New England, R. A. Hites of MIT has been analyzing river water for biphenyl wastes from dyeing processes.

Dr. Gaffney originally became interested in the problems of biphenyl and PCBs in water when he was called to investigate a BOD problem at a municipal waste treatment plant. Two-thirds of the flow to that plant (4 million gpd out of a total of 6 million gpd) came from a carpet dyeing mill. When looking for agents that might affect the biomass in the activated sludge portion of the plant, two questions arose:

NWMAR116006

1. Could the biphenyl (used as a dye carrier) discharged from the mill be affecting the biota, since biphenyl is a known mold suppressant?

2. Could the biphenyl be converted to PCBs during waste treatment chlorination, and could the PCBs exert a harmful affect on the biota, as well as contribute toxic organics to downstream water supplies?

Although these studies are still underway, preliminary data indicate that PCBs can be formed in the suspected manner.

The original report of Gaffney's work told of finding 18 ppm of PCBs in the scrapings from the surfaces of trickling filter rocks in the municipal treatment plant.[6] At the time, no PCBs were detected in the influent.

This seemed a strong indication of PCBs formation within a municipal treatment plant. The plant was using about 350 pounds per day of chlorine for influent odor control and effluent disinfection.

When it was later discovered that there was an upstream transformer plant using PCBs, further testing indicated there were detectable PCBs in the intake water to the mill and the town.

Dr. Gaffney continued his previous work on chlorination of organics as they pass through municipal treatment plants.[7] The tests and data are considered preliminary at this time, and further reaction and analytical data are highly desirable.

In laboratory tests, detectable levels of PCBs were formed when 10 mg/l of biphenyl were added to deionized water, held at 20°C, and then 1 mg/l of chlorine was added and the reactants kept in contact for one hour. Fifteen peaks were formed in the electron capture chromatogram (a hexane in water control gave four peaks with the same treatment). When iron was included in the reaction mix, four more peaks were formed (total of 19). It is believed that these peaks are largely chlorobiphenyls. Addition of an Aroclor to the pure water resulted in the growth, by 50 fold, of the peak height for dichlorobiphenyl due to chlorination.

NWMAR116007

When municipal wastewater was analyzed before and after laboratory chlorination, as described above, the dichlorobiphenyl peaks increased in height by ten-fold.

Although the tentative conclusion from this work was that PCBs can be formed through chlorination of biphenyl in wastewater under laboratory conditions, extrapolation of the results to actual wastewaters from industrial sources is probably premature. Even more tenuous, but of equal interest, is the possibility of further chlorination of PCB molecules via chlorination.

However, it should be noted again that the use of biphenyl as a dye carrier leads less to its dissipation in products than to its eventual destruction or discharge as waste. Assuming that half of the biphenyl so used appears as waste, a biphenyl to PCB conversion of even 0.01 percent during chlorination treatment for the 22 million pounds per year of biphenyl in northeast Georgia corresponds to the generation of over 1,000 lb/year of chlorinated biphenyls in that area.

6.0 POTENTIAL DEGRADATION AND SUBSEQUENT REACTION OF DDT AND RELATED COMPOUNDS IN THE ENVIRONMENT TO FORM PCBs

It appears possible that there are a number of compounds in the environment that could be partially decomposed and then reacted with their own decomposition products, or with other reactants, to produce PCBs.

As early as 1969, Plimmer and Klingebiel reported that DDMU, dichlorobenzophenone, and dichlorobiphenyl, were all products of the photolysis of DDT or DDE in methanol at 260 nm ultraviolet radiation.[8] This conversion may be sensitive to reaction conditions. In the same year, Mosier, Guenzi and Miller did not observe formation of PCBs or DDMU when they subjected solid DDT or DDT in hexane to UV irradiation at 254 nm.[9]

Since that time, most researchers publishing on this topic have suggested the possibility of conversion of DDT to PCBs. Peakall and Lincer stated that the possibility that PCBs could be derived from DDT should be considered.[10] They did not believe this could occur in metabolic processes in tissues. However, they felt that UV catalyzed free radical reactions to form dichlorobiphenyl from DDT could be expected in the atmosphere.

NWMAR116008

Although they could envision tautomeric shifts leading to various isomers of dichlorobiphenyl, they could not theorize a route to more highly chlorinated biphenyls by these DDT reactions. They also pointed out that PCBs extracted from biological materials matched well with the PCBs found in Aroclors like 1254 (one-half pentachlorobiphenyl, and about one-quarter each of the tetrachloro and hexachloro homologs). Thus, if DDT degradation to dichlorobiphenyl were taking place, further chlorination would also have to take place, by some other reaction, to lead to the material found in biological specimens. Peakall and Lincer also point out that the ethane component between the two rings in DDT is the weakest part of the structure and is the site at which most transformations of DDT take place. The PCBs, not having that weak point between the two benzene rings, thus are expected to be more stable than DDT, which is the case. Maugh again reported on the DDT conversion potential, apparently unaware of the Plimmer and Klingebiel report, and showed the potential for vapor phase photolysis.(11)

Peakall, in his recent comprehensive review, "PCBs and Their Environmental Effects", does not cite other references for other mechanisms of DDT conversions.(12) However, Kothny, in a letter to the editor of Chemical and Engineering News, states a case for the formation of gaseous chlorine from particulate chlorides under the influences of ozone and solar radiation.(13) He states that the chloride loss from particulates, formed by the evaporation of water from sea spray, "has been known for some time". Kothny then goes on to attribute PCBs formation to the reaction between a wide range of aromatics that could be present in the atmosphere, and chlorine, formed as described above. He also suggests potential PCBs formation from all manner of waterborne aromatics by action of municipal and industrial chlorination of pure and wastewater.

7.0 COMPARISON OF POTENTIAL INADVERTENT AMBIENT REACTIONS

Of the types of reactions cited in this section as holding potential for inadvertent ambient production of PCBs, the possible chlorination of biphenyl during industrial and muncipal water and waste treatment appears to the authors to have the most significance. In general, the other reactions cited would

NWMAR116009

TABLE 8-1

PCBs Concentration in the Effluents of the Machinery & Mechanical Products Manufacturing

Subcategory No.	Manufacturing Operations	PCBs Concentration mg/l (1)		
		Min.	Max.	Avg.
1	Casting & Molding of Nonferrous Metals	0.2	5.1	2.1
2	Mechanical Material Removal	0.2	63.3	6.997
3	Material Forming - All Materials Except Plastics	0.2	63.3	9.867
4	Physical Property Modification	0.2	100.0	12.842
5	Assembly Operations	0.2	104.4	15.553
6	Chemical-Electrochemical Operations	0.5	2.8	1.65
7	Material Coating	0.2	224.8	18.241
8	Smelting and Refining of Non-ferrous Metals	0.2	18.0	9.1
9	Molding and Forming - Plastics	-	None	-
10	Film Sensitizing	0.3	123.9	28.136
11	Dockside Ship Building Activities (2)	-	None	-
12	Lead Acid Battery Manufacture	7.5	30.0	18.75

Note: (1) Information obtained from the Development Document for Effluent Limitations Guidelines for the Machinery & Mechanical Products Manufacturing EPA Contract No. 68-01-2914, Vol. 3, June 1975.

(2) No water effluent; all solid wastes.

NWMAR116010

effluents; however, evidence of the presence of chlorinated hydrocarbons was found. Effluent Guidelines study on Subcategory 10, Film Sensitizing Industry, is currently underway. According to the information presented in Table 8-1, this subcategory was demonstrated as having the highest levels of PCBs concentration in the outfalls. Verification sampling work to be conducted on these effluents will provide a further test of the validity of the data in Table 8-1.

It is considered quite likely that effluents from industries other than those directly involved with the production and process usage of PCBs may exhibit significant amounts of PCB contamination. Much of this contamination, if found, could be attributed to past usage of PCBs and products containing PCBs, although, as stated elsewhere in this report, current usage must also be considered a possibility. To our knowledge, no significant effort to determine the extent of PCBs contamination from such sources has been made.

NWMAR116011

require two steps (chlorination plus condensation of aryls or decomposition of DDT followed by recombination of selected fragments); they also would be expected to involve compounds present in relatively low concentrations compared with potential biphenyl concentrations in some industrial waste streams.

For all of these reactions, however, mono- and dichlorobiphenyls would be the expected products. Although these are believed by many researchers to be significant (especially in an aquatic environment), it is generally accepted that they are more easily biodegraded and less bioaccumulative in comparison to the more highly chlorinated PCB homologs. The possible formation of more highly chlorinated PCBs from mono- and dichlorobiphenyls is thus also of interest to the environmental PCBs problem.

8.0 PCBs FOUND IN THE EFFLUENTS OF THE MACHINERY AND MECHANICAL PRODUCTS MANUFACTURING INDUSTRY

For some time it has been suspected that PCBs could be found in the effluents of other industrial categories which are not recognized as being sources of PCBs entry into the environment. A review of data presented in the draft Development Document For Effluent Limitations Guidelines for the Machinery and Mechanical Products Manufacturing Point Source Category (EPA Contract No. 68-01-2914, Volume 3, June, 1975) indicates high concentrations of PCBs, in the order of 2 to 28 mg/l, in the effluent of the plants grouped in this category.

This group of industries encompasses 173 different product group segments manufacturing over 4000 different products in over 100,000 separate plants. These products include such varied goods as wire, tractors, x-ray equipment, sporting goods, automobiles, television picture tubes, and jewelry.

Because of the variations in manufacturing operations from plant to plant, categorization of this industry was based on the manufacturing processes utilized, whereby a specific plant was defined by the applicable process subcategories which describe its overall operation. Rationale used in subcategorizing this group of industries was that the manufacturing processes, not the product, generate the effluent discharge.

NWMAR116012

Based on the above, this group of industries was divided into the following twelve general manufacturing subcategories:

Subcategory 1	Casting and Molding - Metals
Subcategory 2	Mechanical Material Removal
Subcategory 3	Material Forming - All Materials Except Plastics
Subcategory 4	Physical Property Modification
Subcategory 5	Assembly Operations
Subcategory 6	Chemical-Electrochemical Operations
Subcategory 7	Material Coating
Subcategory 9	Molding and Forming - Plastics
Subcategory 10	Film Sensitizing
Subcategory 11	Dockside Ship Building Activities
Subcategory 12	Lead Acid Battery Manufacture

The PCBs concentrations in the raw waste from the overall machinery and mechanical products manufacturing point source subcategories, as abstracted from the abovementioned draft Effluent Guidelines Document, are presented in Table 8-1. This table shows the minimum, maximum and mean PCBs concentrations as found from sampling and analysis work conducted by the contractor on 240 raw waste streams in the point source category. As reported in this document, all samples were taken downstream of the manufacturing processes, but prior to any treatment.

It can be seen from Table 8-1 that PCBs concentrations in the effluent from this group of industries are much higher than those reported for the major PCBs user industries (capacitor and transformer industries). Within the machinery and manufacturing industries PCBs could be used in paints, inks and plastics, as wax fillers in casting operations, as hydraulic and heat transfer fluids, and in lubricants.

It should be mentioned, however, that there are questions as to the validity of the analytical techniques used during this study. Subsequent studies conducted by Versar Inc. on Subcategory 12 (lead acid battery manufacture) under EPA Contract 68-01-3273 have indicated no detectable levels of PCBs in the

NWMAR116013

REFERENCES

1. Jenkins, R.G., McCullough, R., and Booth, C.F. (Federal Phosphorus Company), Ind. and Eng. Chem., 22, 31 (January, 1930).

2. Schmidt, H., and Schultz, G., Ann. Chem., 207, 338 (1881).

3. Kramers, K., Ibid, 189, 142 (1877).

4. Hutzinger, O., Safe, S., and Zitko, V., Bull. of Env. Contamination and Toxicology, 6, 209 (1971).

5. Wolf, W., and Kharasch, N.; J. Org. Chem., 26, 283, (1961).

6. Gaffney, P.E., Science, pg. 367, February, 1974.

7. Ingols, R.S., Gaffney, P.E., and Stevenson, P.C., J. Water Pollut. Control Fed., 38, 629, (1966).

8. Plimmer, J.R., and Klingebiel, U.I., Chemical Communications, 1969, p. 648.

9. Mosier, A.R., Guenzi, W.D., and Miller, L.L., Science, 164, 1083 (1969).

10. Peakall, D.B., and Lincer, J.L., Bioscience, 20, 958, (1970).

11. Maugh, J.M., Science, May 11, 1973, p. 578.

12. Peakall, D.B., "PCBs and Their Environmental Effects", CRC Reviews, 5, Issue 4, 1975.

13. Kothny, E.L., Letter to the Editor of Chemical and Engineering News, January 19, 1976, p. 5.

NWMAR116014

SECTION XI

MOVEMENT OF PCBs IN THE ENVIRONMENT — GENERAL DISTRIBUTION MODEL

1.0 INTRODUCTION

Thus far in this report, the history and current status of PCBs production and usage, treatment and disposal aspects, and gross estimates of current environmental distribution have been presented and discussed. Transport of PCBs within the environment is extremely important in the assessment of future environmental distribution of PCBs. In turn, knowledge of future PCBs distribution will allow the assessment of potential regulation of PCBs production and usage. Projection of future biological effects also depends upon the distribution of the substance of interest.

Transport of PCBs between soil, water, sediments, the biota, and the atmosphere is of obvious local environmental importance. Measurable amounts of PCBs have been found in Antarctic ice, showing that atmospheric transport over long distances does occur. Transport phenomena at the various phase interfaces are of obvious importance to the mobility of any environmental contaminant, but in most cases, and this is particularly true of PCBs, such transport properties are not known and have not been treated successfully in a theoretical manner. On the other hand, analysis of the transport and distribution of a given contaminant requires sufficient knowledge of basic transport processes on which to base reasonable estimates; the estimates can then be evaluated using an internally consistent model and available experimental data.

A simple, first-order mass balance model has been constructed to treat the overall PCBs economy of an artificially bounded region of the lithosphere. In order to test the validity of the model, it was applied to Lake Michigan and the associated drainage basin. Lake Michigan was selected for this application because of the existence of a considerable body of

NWMAR116015

recent data on PCBs concentrations, because of the environmental and commercial significance of PCBs contamination in Lake Michigan, and because this lake, in spite of its size, represents a relatively closed system (estimated water retention time of 90 years).

The total environmental load of PCBs, and its variation with time, represents a very important input to the mass balance model. An analysis of available data was performed to provide this input, one important result of which was an estimate of the variation of atmospheric fallout rate with time.

Atmospheric fallout appears to be the most important source of PCBs entering Lake Michigan, although this may not be the case for other areas (the lower Hudson River is one possible exception). For example, in 1974, atmospheric fallout onto the lake and its drainage basin accounted for approximately 85 percent of the PCBs input to the lake.

The rationale for the model is described in Section 2.0 below. Subsequent sections describe the application to Lake Michigan and the results and conclusions therefrom. The development of the model is presented, in full, in Appendix D to this report, and the supporting data used are tabulated in Appendix E.

2.0 RATIONALE FOR MODEL DEVELOPMENT

The first order model derives basically from the assertion that the total of PCBs entering a bounded region of the lithosphere must be fully accounted for by: (1) Incorporation into specific phases of the bounded region; (2) Loss from the region via mass transport; and (3) Degradation by processes operating within the region.

In application, the region under study is selected to be sufficiently large and well defined that adequate averaging can be accomplished. The Lake Michigan area, which meets the above criterion, was selected as a suitable region for study. The region included the nominal drainage basin of the lake

NWMAR116016

in order to provide an estimate of the PCBs entering the lake from runoff.

After suitable boundaries were defined, an overall mass balance was constructed. The source function was constructed so as to account for all point and non-point sources. The distribution over the various internal phases of the system (aqueous solution, biota, and sediment) was then estimated. Additional terms were introduced to account for PCBs loss from the region due to mass outflow and surface evaporation. There was apparently no need to introduce a term to account for degradation since such processes are thought to be of small importance for PCBs. The form of the mass balance was then as follows:

$$B(t)\ \Delta t = \Delta M_W + \Delta M_B + \Delta M_S + \Delta M_O + \Delta M_E \qquad (2\text{-}1)$$

where:

- $B(t)$ is the source or driving function which describes the input rate for PCBs;
- ΔM_W is the change in the mass of PCBs dissolved in the aqueous phase of the region;
- ΔM_B is the change in the mass of PCBs contained within the biota of the region;
- ΔM_S is the change in the mass of PCBs contained within the sediment of the region;
- ΔM_O is the mass of PCBs carried out of the region by (water) mass transport; and
- ΔM_E is the mass of PCBs carried out of the region by evaporation (codistillation).

2.1 Time Dependence of the PCB Input Rate [B(t)]

The distribution of PCBs between phases within the region is governed by processes which are assumed to act independently of the actual concentrations involved. The time dependence of equation 2-1 is therefore contained in the driving function, [B(t)].

NWMAR116017

Sensitive analytical methods for PCBs have been available only for a few years; consequently a sufficiently reliable and detailed data base to allow the direct determination of B(t) is not available. In view of this, it was necessary to construct a model which could be fitted to a direct estimate of B(t) for a specific time, in order to approximate the appropriate time dependence of B(t). The details of the computation by which B(t) was determined are contained in Appendix D (Section 2). For the purposes of this summary, it is sufficient to state that the major input of PCBs to the region selected (Lake Michigan) was from atmospheric fallout; thus the time dependence of B(t) was estimated from knowledge of the time dependence of the fallout.

Table 2.1-1 is a summary of the input PCB from all sources during the period 1973-1974 and is a summary of the detailed data which are presented, along with suitable citations to the sources of these data, in Appendix E of this report.

Table 2.1-1

Summary of PCB Input Sources (1973-1974) to Lake Michigan

Point Sources	1.6×10^3 lbs/yr
Lake fallout	6.4×10^3 lbs/yr
Basin fallout*	5.4×10^3 lbs/yr

Then $B(t) = B(1973\text{-}1974) = 13.4 \times 10^3$ lbs/yr

* It is assumed that 50 percent of the basin fallout actually enters the lake as input(1)

3.0 APPLICATION OF THE MODEL TO LAKE MICHIGAN

The results of an analysis of PCBs distribution within Lake Michigan are summarized in Table 3.0-1 (The details of the computation are given in Section 3 of Appendix D).

NWMAR116018

Table 3.0-1

Overall PCBs Balance for Lake Michigan Area During the Period 1930-1975

Total Input	1.49×10^5 lbs.
Total in Solution (Water)	1×10^5 lbs.
Total in Biota	3.64×10^3 lbs.
Total in Sediment	1.7×10^4 lbs.
Total in Outflow	9.07×10^3 lbs.
Total Evaporated	1.93×10^4 lbs.

The last entry in Table 3.0-1 indicates that some 13 percent of the total input to the lake has been lost by evaporation (codistillation) from the surface.

The concentration of PCBs in the aqueous phase and the (average) concentration in the biota were calculated; the results are displayed in Table 3.0-2.

Table 3.0-2

Derived PCB Concentrations in Lake Michigan Water and Biota Over the Period 1930-1975

Date	C_{water} (ppt)	C_{biota}* (ppt)
1930	0	0
1935	4.9×10^{-4}	1.97
1940	1.34×10^{-2}	5.36×10^2
1945	7.12×10^{-2}	2.84×10^3
1950	0.28	1.12×10^4
1955	0.68	2.72×10^4
1960	1.60	6.4×10^4
1965	2.92	1.17×10^5
1970	5.35	2.14×10^5
1975	9.10	3.64×10^5

*The average biotic concentration is taken as $4 \times 10^4 \bar{C}_{water}$.

NWMAR116019

The values presented in Table 3.0-2 are lake-wide averages so that considerable variations from these values are to be expected from point to point within the lake; for instance between the northern portions and the heavily contaminated regions on the southwestern shore. In addition, because of the considerable spread in species-specific concentration factors (and the wide variation in intra-species concentration factors) it can be surmised that PCB concentrations in higher predators could easily have exceeded the ppm level by 1960.

4.0 RESULTS AND CONCLUSIONS

4.1 Results

Even though the model used is only first order, it is apparently able to describe the relative significance of the natural processes which control the distribution of PCBs. The strong focus on fallout as the primary input source of PCB to Lake Michigan suggests the need for further study of the nature of the processes by which PCBs become airborne and thus become part of the available atmospheric reservoir.

The attempt to model the atmospheric reservoir of PCBs, discussed in Appendix D (Section 2), yields results that indicate significantly greater cumulative atmospheric loads than the preliminary estimate, made by Nisbet and Sarofim,[2] of a cumulative atmospheric reservoir of 3×10^4 tons up to 1970. The estimate of Nisbet and Sarofim leads to a half-life, from the model, for PCBs in the atmospheric reservoir on the order of eight years. This value is considerably in excess of the reported lifetime measurements, on the order of 20 to 40 days, for atmospheric PCBs.[3] However, the observation that significant levels of PCBs are found in present snowfalls and in packed snow in the Antarctic[4] suggest that the applicable half-life may indeed be considerably longer than 20 to 40 days.

It is suggested that further refinement of the environmental distribution model presented in Appendix D (Section 2) will lead to a resolution of

NWMAR116020

this apparent discrepancy. This refinement will focus attention on the nature of the physical processes involved in atmospheric transport of PCBs and may suggest methods of reducing PCB fallout in the future.

The observation that evaporation and/or codistillation seems to be a significant process by which PCBs are returned to the atmosphere is of importance. It should be noted that the magnitude of the evaporation rate constant necessary to achieve mass balance in Lake Michigan is in excellent agreement with that computed from the simple kinetic theory of gases and also with that computed from the theory of codistillation discussed by Mackay and Wolkoff[5] (see Section 4 of Appendix D for a detailed treatment of this subject).

The observation that the PCB input to Lake Michigan from point sources seems to be a rather small part of the total input suggests that reduction of point source PCB effluents may only slowly correct the present problem.

4.2 Conclusions

The first order mass balance model described herein seems useful in describing the historical situation as it explicitly addresses the question, "How did we get here?" The model requires refinement before it can be used to allow a reasonable estimate of future conditions. Significantly more detailed data are required as to the temporal variation of inputs and concentrations as well as on the internal transport processes by which localized concentrations are smoothed and distributed over the whole body. While the present model seems to deal very well with the situation that obtains during an interval of rising aqueous concentrations, there seems to be little experimental or theoretical guidance as to what will happen if, in the future, aqueous concentrations begin to fall. It is not known whether the biota and the sediments will act as reservoirs to return their PCB loads to the system. The processes, if any exist, which will eventually remove or inactivate the PCBs already in the lithosphere are not known.

NWMAR116021

The application of this model to the situation in Lake Michigan seems successful. It will be of interest to apply it to regions which are more complex or of larger scale.

5.0 BIBLIOGRAPHY

1. Ruttner, F., Fundamentals of Limnology, Univ. of Toronto Press (1952).

2. Nisbet, C. T. and A. F. Sarofim, Environmental Health Prospectives, Exp. 1:21-38 (1972).

3. a. Sodergren, A., Nature 236:295-397 (1972).
   b. Risebrough, R. W., et al; Nature (12/14), 1098-1102 (1968).
   c. Harvey, G. R., et al; J. Marine Research 32(2):103-118 (1974).
   d. Harvey, G. R. and W. G. Steinhauer, Atmospheric Environment, 8(8):777-782 (1974).

4. Peel, D. A., Nature 254 (3/27):324-325 (1975).

5. Mackay, D. and A. W. Wolkoff, Env. Sci. & Tech. 7(7):611-614 (1973).

NWMAR116022

SECTION XII

REGULATORY ACTIONS ON PCBs

1.0 INTRODUCTION

The risk of increased accumulation of PCBs in the environment as well as appreciation of the difficulties involved in imposing workable environmental controls in most end-use manufacturing operations have led some manufacturers and a number of government agencies to take steps to regulate PCBs or to restrict some uses of PCBs where emission risks are obviously quite uncontrollable.

1.1 Measures Taken by the Manufacturers

In 1971, Monsanto Company, the major producer of PCBs, instituted a program which led to voluntary restriction on sales by the Monsanto of PCBs for all uses except the manufacture of sealed electrical equipment (transformer and capacitor applications). Sales for heat transfer applications were phased out in 1972 while sales for other non-electric applications were discontinued in 1971. As a result, current production related to point source discharges of PCBs are more controllable than in years prior to 1971 when PCBs were widely used in thousands of "Open-End" and "nominally closed" operations.

Furthermore, by 1971, at Monsanto's suggestion, the capacitor and transformer industries formed a standards committee. The members of the committee include representatives from the three affected industries, EPA, Department of the Army, Department of Agriculture, the Tennessee Valley Authority, the National Bureau of Standards, and the General Services Administration. Also represented were the Certified Ballasts Manufacturers Association, the Electronic Industries Association, the Institute of Electrical and Electronic Engineers, and the National Electrical Manufacturers Association. In the fall of 1972, under the auspices of the American National Standards, this committee published PCB handling and disposal guidelines (ANSI-C107-1-1974). This document establishes procedures for labelling, shipping, general handling and proper disposal of liquid and solid materials containing PCBs. This standard

NWMAR116023

has been proposed also by NEMA and is currently being used voluntarily by the transformer and capacitor industries.

The above measures taken by the manufacturers could be effective in PCB control if they were supported, implemented and enforced by the Federal Government.

1.2 Measures Taken by the U.S. Government

The Government of the United States has taken a number of steps with the objective to reduce the PCBs content in foodstuffs and reduce emissions from all sources. The following Federal laws are relevant for the regulation of PCBs.

1.2.1 Food, Drug and Cosmetic Act (21 U.S.C. 301 et seg.)

The Food and Drug Administration has set tolerances for PCBs contamination of animal feeds, foods, and food packaging in its final rule-making document published on July 6, 1973 (Federal Register, Vol. 38, No. 129). These tolerances, expressed as parts per million are as follows:

(1)	Milk (fat basis)	2.5
(2)	Dairy products (fat basis)	2.5
(3)	Poultry (fat basis)	5.0
(4)	Eggs	0.5
(5)	Complete and finished animal feeds for food producing animals	0.2
(6)	Animal feed components	2.0
(7)	Fish and shellfish (edible portion)	5.0
(8)	Infant and Junior food	0.2
(9)	Paper food - packaging material	10.0

The Food and Drug Administration provides, upon request, the analytical methods used for enforcing these tolerances.

The FDA enforces the FDC Act by various means, including inspections of food establishments to determine whether the provisions of the Act are being violated. These inspections include the collection and analysis of food samples. Some of the samples are taken by FDA on a routine surveillance

NWMAR116024

basis to determine the presence of specific contaminants. However, the actual number of FDA conducted routine sample and analyses is few and this agency relies heavily on information on the known or suspected existence of specific instances of food contamination.

1.2.2 The Egg, Meat and Poultry Acts

The Consumer and Marketing Service of the U.S. Department of Agriculture (USDA) administers three acts relevant to the PCB problem: the Egg Products Inspection Act (P.L. 91-597); the Wholesome Poultry Products Act (P.L. 90-492); and Wholesome Meat Act (P.L. 90-201).

These authorities apply to meat, egg or poultry products from the time they reach the processing plant until they are purchased by the consumer. Once they leave the plant, they are also under the FDC Act.

The Department of Agriculture uses FDA guidelines for its Egg, Meat and Poultry Acts.

1.2.3 The Clean Air Act (42 U.S.C. 1857 et seg.)

Mr. David Young of the Southern California Coastal Water Research Project in a report prepared as part of an ORD (Environmental Research Center - Corvallis) contract acknowledges that the air contributes about one-third of the total PCB loading of the ocean. His conclusion that air is a significant route of PCB transport is based on effluent and aerial fallout measurements made in the coastal areas of Southern California.

The current understanding is that air transport of PCBs is a contributor to the PCB loading of other media. However, the conclusion reached by the pollutant strategies board of the Strategies and Air Standard Division is that the air act of 1970 is not an effective legislative measure for control of PCBs; but that monitoring for PCBs should be considered for control. The recommendation made at that time was to control PCBs by regulating the production, use and disposal of PCB-containing products.

The general authorities contained in the clean air act are not applicable to the majority of PCB discharges since PCBs from most PCB applications,

NWMAR116025

such as for closed electric systems, are not emitted into the air by the operation of industrial and municipal facilities. In these applications, PCB emissions are associated with accidental losses and waste disposal in landfills. Additionally, PCBs enter the air via the burning of refuse containing PCB waste products. These types of air emissions can be controlled only by preventing PCB products from being incorporated into the refuse. Control of emissions from landfills may require specifications on how waste is covered and, in some cases, the application of plastic materials to prevent sublimation. However, in the case of PCB applications for the investment casting category, PCBs can enter directly into the environment from the operation of furnaces which are used for purposes of setting the mold and removing the wax from the mold. In this latter application, the air act can be used as an important tool for the regulation of PCB entry into the environment.

1.2.4 Federal Water Pollution Control Act (33 U.S.C. 466 et seq.)

Section 304(a) of FWPCA

Section 304(a) of the Federal Water Pollution Control Act (FWPCA) authorizes the Administrator of EPA to enforce state water quality standards established by the States and approved by the Federal Government, if the State is not adequately enforcing the standards.

In 1973, water quality criteria were proposed to limit PCBs to 2 ppt in ambient waters. The 1973 proposed level has been more recently reduced to 1 ppt due to evergrowing concern on the health and ecological effect of PCBs and on the basis of further review of available data.

Section 307 (a) FWPCA

A national effluent standard for PCBs has been proposed under Section 307(a) of FWPCA.

Section 311 of FWPCA

In 1974, the Office of Air and Water Programs acted to minimize accidental spills of PCB through the enforcement of Hazardous Substances Section of the Water Pollution Control Act. Currently, pursuant to Section 311 of this

NWMAR116026

act, proposed guidelines on the levels of harmful quantities of PCBs accidentally released into navigable waters and rates of penalties for such spills are being developed.

Section 304(d) of FWPCA

Section 304(d) of the effluent guidelines promulgated for several industrial categories contain limitations on PCBs. For example, effluent guidelines promulgated for the steam electric power generating category contain limitations of "No Discharge" for PCBs. Furthermore, EPA reports that NPDES permits limiting PCB discharges have already been issued for several facilities.

1.2.5 The Refuse Act of 1899 (33 U.S. C.407)

Section 13 of the 1899 Refuse Act forbids the discharge of any wastes, other than municipal wastes, into navigable waters without a permit. This act would be an effective tool in the control of PCB discharges into the waterways if the permit program required the reporting of PCBs as a separate item. Presently this is not a requirement.

1.2.6 The Occupational Safety and Health Act (29 U.S.C. 651-678)

Chemical hazards in the workplace are regulated under the Occupational Safety and Health Act (OSHA). The Secretary of Labor, in cooperation with the Secretary of Health, Education and Welfare, is authorized to set and enforce occupational safety and health standards applicable to businesses affecting interstate commerce.

In Title 29, Section 1910.93, the limits set for chlorodiphenyl compounds as an air contaminant are 1 mg per cubic meter for Aroclor 1242 and 0.5 mg per cubic meter for Aroclor 1254, based on 8 hours average exposure. The Department of Labor could enforce these limits on PCBs.

1.2.7 Act to Regulate Transportation of Explosives and other Dangerous Articles (18 U.S.C. 831-835)

The Department of Transportation (DOT) regulates the transport of hazardous substances under the Act to regulate transportation of explosives

NWMAR116027

result, PCB is being imported by a few companies for use in several "open-end" or "nominally-closed" applications.

In 1972, with hopes to bring about a multi-national understanding on PCB uses, the United States asked the Organization for Economic Cooperation and Development (OECD) through its Environment Committee to review national policies on PCBs and also identify products moving in international trade which contained PCBs. In October, 1972, OECD, whose members include all major western industrialized countries plus Japan and Australia, met to discuss the U.S. proposal to control manufacturing and trade of PCBs.

In the October meeting the OECD Council decided that for adequate protection of health and environment, PCBs should be controlled by the actions of individual member countries. It was agreed that in order to insure that home production was not substituted by imports, control action by governments through licensing or other means was essential. It was further recognized that means to insure proper collection of used materials, safety in transport of raw PCBs and assessment of substitutes for PCBs were of utmost importance.

Details on the council's decisions were issued on February 14, 1973. The major thrust of the decision was:

A. PCBs should be used for industrial or commercial purposes in the following applications:

- As dielectric fluids in transformers and capacitors
- In heat transfer applications (other than that for applications in foods, drugs, feeds and veterinary products)
- As hydraulic fluid in mining equipment

With respect to the above uses, the OECD Council recommended that PCBs should only be used if adequate environmental controls were exercised and when the requirement for non-inflammability outweighed the needs.

B. Manufacture, use, recovery, disposal, import and export of PCBs should be controlled and regulated. Special labelling for bulk PCBs and PCB-containing products should be instituted

NWMAR116028

and safety specifications on containers and transport should be established.

C. Manufacture, import, and export of PCB-containing products should be controlled and efforts should be directed to eliminate the use of PCBs in "open end", "nominally-closed", and small capacitor applications.

D. Amount of material manufactured, exported, imported, incinerated and consumed by PCB type should be reported and any substitute used for PCB should be identified, characterized and defined.

The decision of OECD leaves it to the member countries to go beyond the council's agreements and it further encourages the governments to phase out PCB uses wherever possible. OECD council's decision or even more stringent measures are currently being exercised in all member countries.

1.4 Measures Taken by Foreign Governments

The measures taken by foreign governments are, in some instances, quite severe; especially in Japan, where a large scale poisoning episode, resulting in the disease syndrome "YUSHO", occurred in 1968 (after a heat transfer fluid leaked in a rice-oil pasteurization plant). In other countries, like the Netherlands, the control measures are quite informal. The main thrusts for PCB control are found in two main areas; those taken by the manufacturers and those required by the legislative process.

1.4.1 Measures Taken by Manufacturers - Limitations of Sales

Several nations have voluntarily limited sales of PCBs. The spectrum of limitation ranges from restrictions to specific fields of manufacture that are considered to be non-polluting or controllable to total suspension in the manufacturing process.

Since 1972, Japan has banned production and importation of PCBs; the United Kingdom has restricted sales of PCBs to all applications with the exception of their usage as a dielectric fluid, while Germany has lessened

NWMAR116029

and other dangerous articles. Under CFR Title 49, Subpart G amended February 27, 1973, DOT classifies poisonous substances into three categories:

Class A - highly poisonous material
Class B - moderately poisonous material
Class C - irritating material

The responsibility for insuring that this standard is met remains with the manufacturer and the shipper.

1.2.8 Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) (7 U.S.C. 135-135K)

On October 29, 1970, the Pesticides Regulation Division, administered then by the Department of Agriculture, issued a notice (PR Notice 70-25) to all pesticide manufacturers and distributors to eliminate the use of polychlorinated biphenyls and polychlorinated terphenyls from their formulation and products. Presently, there should be no pesticides on the market or in use containing PCBs.

Under the FIFRA act, all pesticides shipped in interstate commerce must be registered with the EPA. Presently, EPA can refuse to register a product if it will cause injury to humans or the environment if used as directed. A product already registered with EPA can be cancelled if it is found that it no longer meets the criteria of registration.

Congress is currently considering bills to renew the FIFRA act. More than 20 amendments to FIFRA are pending in the House and Senate. One of these amendments, if adopted, will give the Secretary of Agriculture the power of veto over EPA by requiring USDA concurrence in procedures leading to pesticide cancellation or changes in classification or regulation. This amendment will loosen EPA's controls on dangerous pesticides.

1.2.9 Needs for Federal Control

It can be summarized that currently four government agencies, the Monsanto Company and NEMA comprise the regulatory forces restricting the use and distribution of PCBs. EPA, OSHA, FDA and USDA have authorities to regulate

NWMAR116030

and monitor food levels, disposal into waterways and housekeeping and safety practices in the work place. EPA forbids the use of PCBs in pesticides and regulates their discharges into the waterway. OSHA can regulate PCB hazards in the work place. FDA forbids PCB use in food processing machinery and limits PCB levels in food, feeds and paper food-packaging material. USDA follows FDA guidelines in egg, meat and poultry products. Monsanto manufactures more degradable PCBs and sells them only for selective uses, and NEMA recommends standards and guidelines for handling and disposal of PCB containing materials. Each of these available authorities has a limited focus and is inadequate to prevent more PCBs from entering the environment.

Both Monsanto's and NEMA's actions are voluntary and have no law behind them for enforcement. The government has no power to control and restrict imports of PCBs and if it desires to restrict the use of PCBs in selected applications, it has no authority to impose this restriction on any manufacturer.

The above actions can only be implemented through the proposed Toxic Substances Control Act (TSCA). TSCA would give EPA the needed authority for formal banning of certain PCB uses and sanctioning National Standards and Guidelines for handling and disposal of PCB containing products. Thus EPA could deal with the PCB problems in a far more orderly and effective manner. Additionally, the TSCA would enable EPA to require testing for health and ecological effects of new chemicals which are being proposed as substitutes for PCBs. Thus, this measure could prevent new chemicals from creating health and ecological problems similar to those from PCBs. This preventive approach of controlling chemicals is a more reasonable and cost effective method than the current approach of corrective measures after the damage has been done. Therefore, the passage of the Toxic Substances Act by Congress is an important step in dealing with problems such as PCBs.

1.3 International Decisions and Agreement

There are currently no regulations to restrict the importation of PCBs as a chemical for use in applications banned by the Monsanto Company. As a

NWMAR116031

this restrictive measure to include the heat-transfer and hydraulic-fluids industries.

1.4.2 Measures Taken by Some Governments

1.4.2.1 PCB Producing Countries

Actions taken by governments differ widely, ranging from acceptance of the measures taken by the manufacturers to a more strict regulation.

France

The government has taken no active legislative action and has accepted the local manufacturers decisions. These include:

- Complete cessation of sales for heat transfer purposes, in pharmaceutical and food industries, paper production of carbonless copying paper, marine paints and cutting oils.
- Providing information to manufacturers about the dangers of PCB, with a view to cancelling their use in or on products in contact with foodstuffs.

Germany

The government is taking the approach of supporting the manufacturers' decision to stop selling PCB and is pursuing the voluntary signing of bilateral agreements to restrict the amount of imports. Additionally, tolerances of PCB in foodstuffs are being established.

Japan

PCBs have been under governmental control since 1972. There have been practically no production, import or export of PCBs in this country since 1972. The two companies, Kanegafuchi Chemical and Mitsubishi-Monsanto, which had been producing PCBs in Japan ceased their operation and suspended their sales in 1972. One exception has been the production of PCBs for railroad transformers which was discontinued in September, 1973. The use of

NWMAR116032

existing stocks in railroad transformers is permitted, subject to the conditions that there be no discharge to the environment. Beginning in 1976, paper plants will be prohibited from accepting PCB contaminated paper for recycling purposes and they will be required to build treatment facilities to meet the general discharge standards.

Imports of equipment using PCBs have been decreased drastically since 1972. For these products importers must cooperate with the users to ensure that the components containing PCBs are properly disposed.

Manufacturing of PCBs are rigidly controlled by the Ministry of International Trade and Industry (MITI). Any company who desires to manufacture PCBs must apply to MITI for a permit. The Japanese government anticipates a total ban on PCBs in 6 to 10 years.

These efforts have had remarkable results, and the environmental levels of PCB in Japan have subsided and are expected to continue diminishing.

United Kingdom

The government is taking no official action and is accepting the decisions of the manufacturers. Additionally, there is a high duty on imported PCBs (about 23%).

1.4.2.2 Non-Producing Countries

Canada

Initial activities are under way to collect necessary data for restricting PCBs pursuant to a new Environmental Contaminants Act which should be enacted by 1976.

Finland

The use of carbonless copying paper is totally banned and legislation is being proposed to require prior authorization for the use of PCBs by the Ministry of Social Affairs and Health. Furthermore, compulsory labelling and disposal instructions are being introduced.

NWMAR116033

Netherlands

A gentleman's agreement is in effect that PCBs will no longer be used in the manufacture of paints, inks, lacquers, adhesives, resins, wire and cable coatings, lubricating oils, hydraulic fluids and copying paper.

Norway

Since October 1971, only the Ministry of Social Affairs can authorize the use of PCBs.

Sweden

Since June 1, 1972, only the environmental protection board can authorize the use of PCBs or compounds containing PCBs. Furthermore, compulsory labelling and identification of PCB content on the wrappings have been introduced.

Switzerland

Since October 1972, PCBs or products containing PCBs may not be sold to the public or to light industry. Heavy industrial use is subject to prior authorization.

1.5 U.S. Customs Regulations

Pursuant to Customs Bureau Directive CIE 36-72, July 4, 1975, the field offices of the Customs Bureau have been specifically monitoring the inflow of PCBs and this information is forwarded to EPA. The information is not public.

NWMAR116034

BIBLIOGRAPHY

1. Bauman, R.D., EPA's Pollutant Strategies Branch, Polychlorinated Biphenyls. Private Communication to Mr. Lindsey, A.W.; Office of Solid Waste Management Program, November 20, 1973.

2. Coleman, J.H., Acting Director Duty Assessment Division, Polychlorinated Biphenyls. Private Communication to Mr. Barden, J.D., Versar Inc., October 15, 1976.

3. Environment Directorate, Organization for Economic Cooperative and Development, "Polychlorinated Biphenyls, Their Use and Control", Paris, 1973.

4. Op. Cit., September 11, 1976.

5. Op. Cit., February 7, 1975.

6. Environmental Regulation Handbook EIC-Environment Information Center, Inc., New York, New York.

7. Polychlorinated Biphenyls and The Environment, Interdepartmental Task Force on PCBs, Washington, D. C., May (1972).

8. Steigerwald, B.J., Director, EPA's Office at Air Quality Planning and Standards, "Air Transport of Polychlorinated Biphenyls (PCBs)". Private Communication to Mr. Strelow, R., Assistant Administrator for Air and Water Management, September 29, 1975.

9. Stottlenyer, J.N., Department of Transportation, "Transportation Regulations for Toxic Substances". Private Communication with Contos, G., Versar Inc., September 10, 1975.

NWMAR116035

APPENDIX A

PCB ADSORPTION TESTING BY XAD-4 RESIN

Experiments and Results

The apparatus and materials used by Rohm and Haas were:

Two glass columns - 1/2 inch in diameter
Adsorbent volume - 50 ml in each column
Adsorbent bed height
XAD-4 Amberlite polymeric adsorbent - 16.5 inches
Activated carbon (Filtrasorb 300) - 15 inches
PCB material used - Aroclor 1254 (manufactured by Monsanto)

A feed solution representing a PCB contaminated waste stream was prepared containing approximately 160 ppb of PCB. Because Aroclor 1254 is very viscous, it was solubilized in methanol prior to dispersion in water. Methanol increases the solubility of PCBs in water. In order to maintain a constant flow throughout the experimental run, two batches of feed solution had to be prepared. The composition of each solution is presented in Table A-1.

Table A-1

Composition of Feed Solutions

Feed Solution A - 13.25 liters
0.0022 gm of PCB or 166 ppb
2 ml of methanol or 119 ppm

Feed Solution B - 13.25 liters
0.0029 gm of PCB or 218 ppb
2 ml of methanol or 119 ppm

The influent solution was passed simultaneously through the column of Amberlite polymeric adsorbent and the column of activated carbon at a flow rate of 2 bed-volumes per hour (0.25 gpm/ft^3 resin). Samples were collected from each column daily, so that each sample nominally represented 48 bed volumes of

NWMAR116036

effluent. Liquid passed through both columns for five days, or until 240 bed volumes of effluent (12 liter total volume) were collected from each column.

Prior to analysis, the PCB in each effluent sample was extracted into a volume of hexane equal to one-tenth the volume of the original sample. The influent material, which was sampled four times during the run, was likewise extracted into the same proportion of hexane. This single stage extraction removed more than 95 percent of the PCBs present in the aqueous samples. The extracted effluent samples were then evaporated to 5 mls, further concentrating the PCBs present. These evaporated samples were then sent to Versar Inc., for analysis. The results are given in Table A-2.

Table A-2

Reductions of PCB (Aroclor 1254) Concentrations Through Use Of Amberlite Polymeric Adsorbents and Activated Carbon

Day	Nominal Throughput (BV)	Influent Concentration (ppb)	Effluent Concentration (ppb) Amberlite Adsorbent	Carbon
1	1-48	25 (Feed A)	0.246	0.050
2	49-96	none detected	0.031	0.055
3	97-144	21.1 (Feed B)	0.023	0.025
4	145-192	0.69	none detected	none detected
5	193-240	0.69	3.478	0.045

A significant amount of PCB was adsorbed onto the walls of the influent container, as can be seen with Feed A, which originally was prepared with 166 ppb of PCBs. This loss by adsorption on equipment surfaces also has been detected in other tests, and must be taken into account.

Both the Amberlite polymeric adsorbent and the activated carbon reduced the concentration of PCBs in water to less than 0.05 ppb. The higher concentration of PCBs for the first day's passage of effluent through the resin beds could be due to an incomplete conditioning of the beds, resulting in some material leaching out of the resin. The high concentration of PCBs in the last sample from the polymeric adsorbent must be viewed with some suspicion,

NWMAR116037

particularly since it indicates an effluent having a concentration higher than that in the influent.

Amberlite polymeric adsorbents can usually be solvent regenerated, because the energy of adsorption is much lower for resins than it is for carbon. Hence, adsorbed solute can be removed simply by passing an appropriate solvent through the resin. Work performed by Musty and Nickles (J. Chromat., 89:185 (1974)) with PCBs and a solution of 10 percent diethyl ether in hexane as a regenerant indicates that 76 percent of the PCBs adsorbed on an Amberlite polymeric adsorbent can be recovered using this mixed solvent. In addition, Rohm and Haas have found that simple alcohols or ketones are effective solvents for these resins. Undoubtedly, a more efficient solvent could be found that would quantitatively remove PCBs from polymeric adsorbents.

Activated carbon, which has a much higher energy of adsorption than do these resins, requires a more energy intensive process of regeneration, such as thermal rejuvenation.

The ability to solvent regenerate Amberlite polymeric adsorbents in situ would provide the advantage of generating only the more-readily-handled-by incineration liquid phase PCBs wastes.

NWMAR116038

APPENDIX B

MACRORETICULAR RESINS FROM ROHM AND HAAS CO.

Description

Ion exchange resins have the capacity to selectively recover ionic constituents, both inorganic and organic, from water through an ion exchange mechanism. Organic compounds are often exchanged or adsorbed irreversibly onto an ion exchange resin. This may cause a decrease in capacity so that the operating life of the resin is diminished. The more recently developed macroreticular type of ion exchange resins are polymeric adsorbents used specifically for adsorbing aromatic and aliphatic compounds from water.

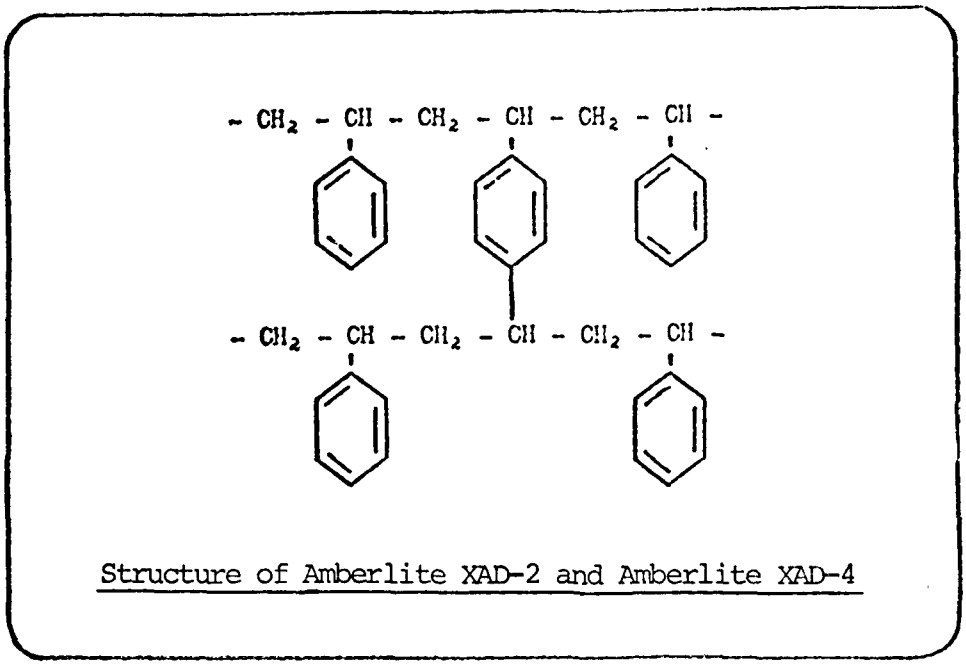
Structures

The macroreticular structures are characterized by having unusually large surface areas as compared with those of conventional gel structures.

Using the newer macroreticular polymerization technique, it is possible to widely vary the particle pore size, pore size distribution, and surface area. Polymers with very small pores (5 nm or less) and high surface areas (in the range of 800 square meters per gram) can be prepared. At the other end of the spectrum, pore sizes on the order of 30 micrometers, visible under modest magnification, are possible.

The macroreticular polymerization technique is applicable to a wide variety of monomers. It is possible to introduce functional groups onto the surface of the preformed macroreticular polymers. Thus, a great range of surface types is possible, limited only by the availability of monomers or the applicability of reactions to introduce functionality. The full line of macroreticular adsorbents constitutes a spectrum of surfaces from the least polar to the most polar. For PCBs removal, the nonpolar and intermediate polarity adsorbents should be used. The chemical structure of Amberlite XAD-2 and Amberlite XAD-4 (see Figure B-1) is representative of the nonpolar adsorbent series. Figure B-2 shows the acrylic-ester composition of Amberlite XAD-7 and Amberlite XAD-8, the intermediate polarity adsorbents. The physical properties of these Amberlite XAD adsorbents are summarized in Table B-1

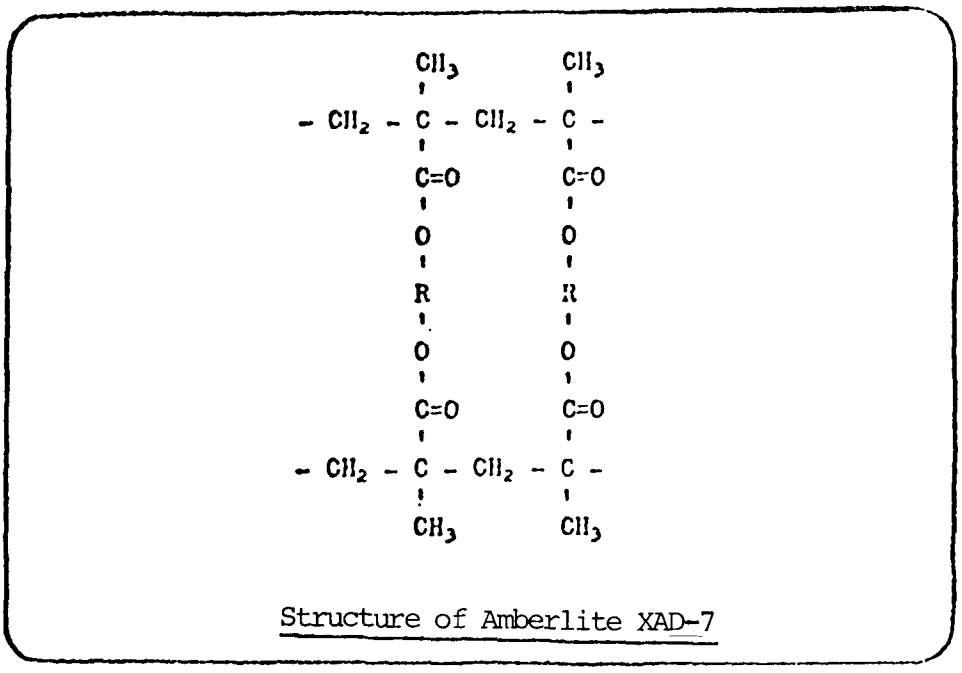
NWMAR116039



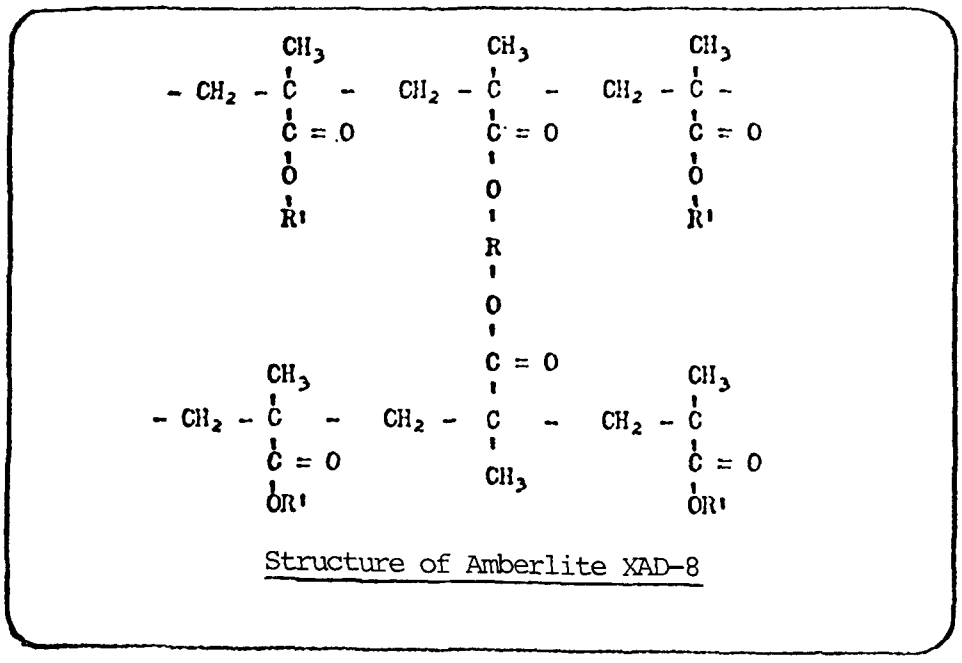
Structure of Amberlite XAD-2 and Amberlite XAD-4

Figure B-1

NWMAR116040



Structure of Amberlite XAD-7



Structure of Amberlite XAD-8

Figure B-2

NWMAR116041

Table B-1

Typical Properties Of Amberlite Polymeric Adsorbents

	Chemical Nature	Helium Porosity		Surface Area m^2/gram	Average Pore Dia. Angstroms	Skelatal Density grams/cc	Nominal Mesh Sizes
		Volume %	cc/gram				
Nonpolar							
XAD-1	Polystyrene	37	0.69	100	200	1.06	20 to 50
XAD-2	Polystyrene	42	0.69	330	90	1.08	20 to 50
XAD-4	Polystyrene	51	0.99	750	50	1.09	20 to 50
Intermediate Polarity							
XAD-7	Acrylic Ester	55	1.08	450	80	1.25	20 to 50
XAD-8	Acrylic Ester	52	0.82	140	250	1.26	25 to 50

NWMAR116042

Macroreticular Adsorption Phenomena

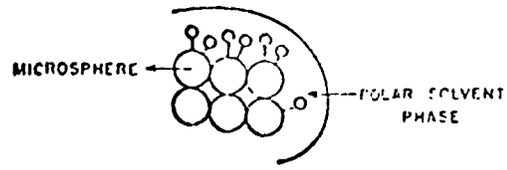
An important aspect of the Amberlite adsorbents is the nature of the different surfaces. The phenomenon of adsorption on solids involves van der Waals' forces which bind the adsorbate on to the solid surface. Many types of interactions, such as hydrophobic bonding, dipole-dipole interaction and hydrogen bonding, are important. It is not possible to predict accurately which materials will be adsorbed well by a given adsorbent; however, from a practical point of view, a useful concept is that hydrophobic or nonpolar molecules or portions of such molecules are attracted to hydrophobic surfaces, while hydrophilic or polar materials are attracted to hydrophilic or polar surfaces. Examples of these interactions are presented in Figure B-3. If each organic molecule is thought of as having both a hydrophobic and a hydrophilic end, then the hydrophobic end will be attracted to hydrophobic adsorbents such as Amberlite XAD-2 and Amberlite XAD-4, while the hydrophilic end will be attracted to hydrophilic adsorbents. This type of reaction is particularly true when the adsorption takes place from aqueous solution.

For PCBs, it would be expected that the biphenyl portion would be typically aromatic and hydrophobic, and thus attracted to an aromatic resin. Increasing the chlorination of a biphenyl would reduce its water solubility and thus reduce what little polar character the PCB might have. Thus, the PCB would not have a "polar end" and would be strongly repelled by the water phase and strongly attracted by the resin.

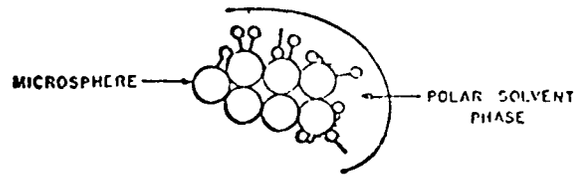
A recent study by James Fritz, et al, of Iowa State University, reported a macroreticular resin method for extracting trace organic contaminants from water. He also demonstrated the feasibility of selective desorption of these contaminants, using appropriate eluants, so that the contaminants could be identified. He also established the performance or retention efficiency of the resin in isolating these compounds. A summary of these results is given here:

NWMAR116043

SORPTION ON AROMATIC SORBENTS FROM POLAR SOLUTIONS



SORPTION ON ALIPHATIC SORBENTS FROM POLAR SOLUTIONS



SORPTION ON ALIPHATIC SORBENTS FROM NON-POLAR SOLVENTS

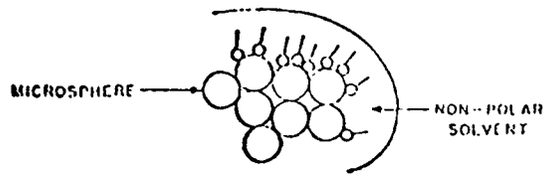


Figure B-3

NWMAR116044

Adsorbent: Amberlite XAD-2 unless otherwise indicated

Particle Size: 100 to 150 mesh

Flow Rate: 10 BV/hr. (1.25 gpm/ft^3 of adsorbent)

Test Compounds	Influent	Effluent	Retention Efficiency %
Benzene	100	0	100
Benzene sulfonic acid	3.0	2.1	31
Phenol	0.4	0.22	45
Phenol (Amberlite XAD-7)	0.4	0.06	86
Aniline (Amberlite XAD-7)	4.0	0	100
Naphthalene	0.05	0	100

It can be seen that Amberlite XAD-2 and Amberlite XAD-7 were 100 percent efficient in recovering the nonionic organic compounds. These results predict good success with PCB adsorption. On the other hand, ionic solutes as well as strongly ionized compounds, such as benzene sulfonic acids and p-toluene sulfonic acids, were not retained with the same high efficiency. It was noted that retention efficiency of a contaminant increases with increasing molecular weight in a homologous series, indicating that the higher chlorinated PCBs would be the best adsorbed.

NWMAR116045

APPENDIX C

NON-CARBON ADSORBTION AND OTHER RESEARCH STAGE
PCB TREATMENT TECHNOLOGIES

1.0 POLYVINYL CHLORIDE (PVC) AND POLYURETHANE FOAMS

John Lawrence and co-workers of Environment Canada have reported preliminary tests using PVC, polyurethane foams, carbon, and the XAD resins for removal of PCBs from both synthetic wastewater solutions and actual raw sewage.

H. D. Gesser (in Analytical Letters 12:883 (1971)), reported that a polyurethane foam column quantitatively adsorbed PCBs from water. Lawrence found that carbons, polyurethane foams and XAD-2 strongly adsorbed PCBs from aqueous solutions, but were much less effective with raw sewage. He found that PVC, however, was very effective in removing PCBs from raw sewage.

Dr. Lawrence is the only investigator known to have worked with PVC for adsorbing PCBs. Following is a summary of his test procedures and results.

1.1 Experimental Method for PCBs Adsorption Tests, by Environment Canada

Two stock solutions of Aroclor 1242 and 1254 were prepared by vigorously mixing an excess of each Aroclor with water for 8 hours, allowing the solutions to stand overnight and carefully decanting off the true aqueous phase. The water used was double distilled, the second distillation being from an all-glass system. The concentration of these solutions, determined by gas chromatography, was 45 $\pm$ 10 ppb, which is consistent with the published solubility for Aroclor 1254 of 56 ppb.

All solvents used were glass distilled pesticide grade (Caledon Laboratories, Inc.). The activated carbons employed were lignite-based hydrodarco 400 (ICI-United States) and anthracite-based Filtrasorb 400 (Calgon Corporation). These were pretreated by heating to 300°C for 12 hours, cooling, and twice extracting each 500 gm with 2 liters of hexane. The extracted carbon was then filtered and air dried. The polyurethane foams used were DiSPo plugs (Canlab Supplies Ltd.) and Foams 1115 and 2328 (B.F. Goodrich Ltd.). (The first

NWMAR116046

two digits in the Goodrich products relate to the density, i.e., 1.1 and 2.3 lb/ft^3 and the second two digits to the hardness). The foams were shredded and successively washed with n-hexane (several times), acetone and distilled water. They were then air dried. This pretreatment was developed to remove trace organic contaminants from the surface of the foams. The macroreticular polystyrene resins Amberlite XAD-2 and XAD-4 (Rohm and Haas Company) were pretreated by successively washing each 500 gm of resin with 1-liter batches of water, methanol, and water. The cleaned resins were stored in sealed glass containers under methanol to prevent them from drying. Polyvinyl chloride chips (Monsanto Company) were washed several times with n-hexane and air dried.

To determine the adsorption characteristics, 100-ml aliquots of stock Aroclor solutions were stirred rapidly for 30 minutes with weighed amounts of adsorbent and then the adsorbent was removed by filtration through a Millipore prefilter pad. Five milliliters of n-hexane were then vigorously stirred with the filtrate for 45 minutes and the organic extract withdrawn. These extracts were analyzed with a gas chromatograph (Varian series) equipped with an electron capture detector (Ni^{63}). The gas column (1.8m x 1.5 mm i.d.) was packed with 4 percent OV-101 and 6 percent OV-210 on Chromosorb W HP $^{80}/_{100}$ mesh. Nitrogen was used as a carrier gas at 50 ml/min. The injection port, column and detector temperatures were 250°C, 200°C, and 300°C, respectively. Extraction and analysis of water samples spiked with known amounts of Aroclor indicated that greater than 98 percent of the PCBs were detected by this method.

Wastewater was collected from the Hamilton Sewage Treatment plant at the raw sewage inlet pipe. Sampling was carried out using all-glass containers to insure against adsorption of PCBs onto container walls. The samples were stored at a constant temperature of 3°C and in all cases were treated and/or extracted within 24 hours of collection. In the evaluation of PCB adsorption from sewage, the procedure described above for pure Aroclor solutions was followed, except that 100-ml samples of raw sewage were stirred vigorously with the adsorbent for 1 hour, and then the adsorbent was separated by filtration through a 60 mesh, stainless-steel screen. After washing, the screen did not retain any raw sewage and, with the exception of activated carbon, 100 percent

NWMAR116047

separation of adsorbent was achieved. The filtrates were then twice extracted with 50 ml of n-hexane in 500-ml separatory funnels. The aqueous portion was discharged and the organic phase, after being dried through 15 g of Na_2SO_4, was reduced in a rotary evaporator to approximately 3 ml. The sample was purified by liquid-solid chromatography on a florisil support column using petroleum ether to elute the PCB fraction and then the eluate was evaporated to 3 ml. Prior to injecting the sample into the gas chromatograph, it was shaken with 0.2 ml of mercury to remove residual sulfur compounds.

The PCBs in the samples were identified by comparison of their chromatograms with chromatograms of standard Aroclors. The total concentrations of PCB in raw sewage usually averaged 9.8 $\pm$ 4 ppb.

1.2 Experimental Results of PCBs Adsorption from Sewage and Synthetic Wastewater

Adsorption data for Aroclor 1254 and 1242 on PVC, activated lignite carbon, anthracite carbon, two polyurethane foams, and Amberlite XAD-2 and XAD-4 resins are shown in log-log form in Figure C-1. The weight of PCB adsorbed per unit weight of adsorbent is expressed as a function of the equilibrium concentration of PCB remaining in solution. The sets of data do not follow any of the common isotherm expressions (e.g., Langmuir, Freundlich, BET), and consequently a theoretical interpretation of the results has not been attempted. It is evident that the two carbons and XAD-2 have the greatest adsorptive capacities; however, a residual concentration of less than 3 ppb could not be obtained with lignite carbon. Both polyurethane foams appear to be good adsorbers, with relatively high adsorptive capacities and low residual levels. DiSPo polyurethane foam plugs are also evaluated but these have identical adsorptive properties to the Goodrich Foam 1115. The lower efficiency of XAD-4 is surprising in view of the similarity between it and XAD-2 (they differ only in pore diameters: 9 nm for XAD-2 and 5 nm for XAD-4). The lower efficiency of PVC, which has no macroreticular structure, can be explained by its lower surface area. The surface area per unit weight is reported as 500 to 2000 m^2/gm for carbon, 750 m^2/gm for XAD-4, and 330 m^2/gm for XAD-2, but only 2 x 10^{-3} m^2/gm for PVC chips - there being no macroreticular structure in PVC. This gives an area ratio for XAD-2/PVC of approximately 10^5.

NWMAR116048

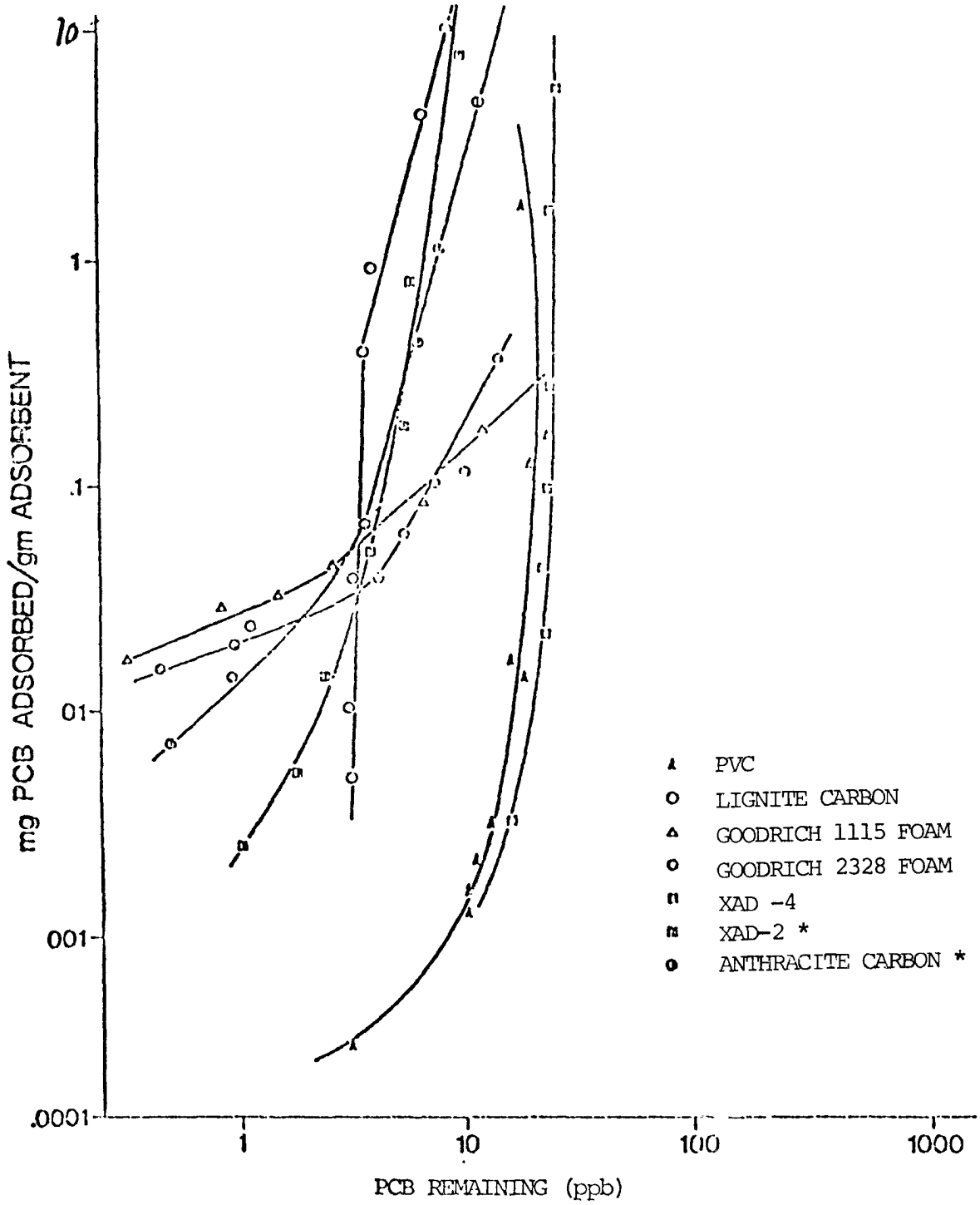


Figure C-1. Adsorption of Aroclor 1254 on P.V.C., Lignite Carbon, Anthracite Carbon, Polyurethane Foams and Amberlite XAD-2 and XAD-4.

* Indicates adsorption of Aroclor 1242 rather than 1254

NWMAR116049

There are two complicating conditions associated with adsorbing PCBs from raw sewage rather than from synthetic aqueous solution: (a) sewage contains other hydrophobic organic matter which competes for the active sites on the adsorbent, and (b) much of the PCB has already adsorbed onto the suspended solids by the time the sewage reaches the treatment plant. Condition (b) can be demonstrated easily by filtering raw sewage and monitoring the change in PCB concentration. With typical raw sewage containing 10 ppb PCB, vacuum filtration through a Millipore prefilter pad results in the removal of about 75 percent of the PCBs. It is therefore necessary to find an adsorbent which is not only relatively specific to PCBs, but which also has sufficient affinity for the PCBs to reverse the PCB-suspended-solid equilibrium.

Table C-1 shows the percentage of PCB (including both Aroclor 1254 and 1260) adsorbed from raw sewage by five different media. With the exception of the PVC, approximately 1 gm of each media was stirred with 200 ml of raw sewage for 45 minutes; approximately 10 gm of PVC were used to compensate for its lower surface area. To minimize the inconsistency of raw sewage, the data have been averaged over several determinations on different days and with different sewage samples. The data indicate that PVC and XAD-4 are more effective than carbon or polyurethane foams in terms of percentage of PCB removed from raw sewage. This is surprising since the graphs for PCB adsorption for pure Aroclor solutions (Figure C-1) predict the opposite. Lawrence believes the reasons for this apparent anomaly are: (a) the active sites on carbon are preferentially occupied by hydrophobic species other than PCBs in the sewage, and (b) suspended solids adhere to the surface of carbon and foam acting as a barrier to further adsorption. These results indicate that PVC is superior to the other media for removing PCBs from sewage.

Lawrence's work is continuing, with studies of methods of scale-up and continuous or multistage operations with PVC. Optimum retention time, and methods for continuous addition of fresh PVC and removal of spent PVC are under study.

The strong competition between organic solids and non-organic media is emphasized further in the following discussion.

NWMAR116050

Table C-1. Adsorption of PCBs from Raw Sewage

ADSORBENT	% PCB ADSORBED*
Lignite Carbon	46
Polyurethane Foam	35
Amberlite XAD-2	23
Amberlite XAD-4	60
PVC	73

* Includes both Aroclors 1254 and 1260. Data are averaged over several determinations to minimize the variations in raw sewage.

NWMAR116051

1.3 PCBs Adsorption on Clays and Organics in the Soil

E. S. Tucker and co-workers at Monsanto reported on studies of migration of PCBs (Aroclor 1016) through various soils as induced by percolating water (Bulletin of Environmental Contamination and Toxicology 13 (1):86 (1975)). The results were to be used for estimating PCBs leached from landfills. Their tests first led them to believe that the higher the clay content of a soil, the better its retention of PCBs.

The experimental procedure employed consisted of percolating water through a column packed with soil coated with Aroclor 1016 and then monitoring the effluent water for PCBs. The soil columns employed were approximately 3 inches in diameter by 12 inches high, and were dry packed in layers. Each soil layer was 3 inches thick, with the first layer being uncoated soil, followed by a layer coated with 2.5 percent (w/w) of Aroclor 1016, and then another layer of uncoated soil. An acetone solution of Aroclor 1016 was used to coat the air-dried soil, followed by removal of the acetone in a rotary evaporator.

Three different types of soils were used in this study. The characteristics of each are shown in Table C-2. The intent was to simulate the various soil types which could be encountered at different landfill sites. The soil types and the procedure employed have been used previously to evaluate the soil mobility of agricultural chemicals.

Distilled water was fed from a reservoir at a constant pressure to each soil column. The effluent flow rates were observed to increase the first few days, then decrease, and finally level out. Apparently, after the wetting phase some channeling occurs until the soil becomes compressed in the column. This effect was most pronounced with the silty soils. The average flow rates for Norfolk Sandy Loam, Ray Silty Loam and Drummer Silty Clay Loam were 0.26, 0.53 and 0.32 liters per day, respectively. The effluents then were quantitatively adsorbed on polyurethane columns, then extracted and analyzed by electron capture gas chromatography.

NWMAR116052

Table C-2

COMPOSITION OF SOILS USED IN THE MONSANTO STUDY

Soil	Norfolk Sandy Loam	Ray Silty Loam	Drummer Silty Clay Loam
% Sand	82.5	6.2	2.8
% Silt	11.0	83.2	55.4
% Clay	5.5	9.6	35.8
% Organic Carbon	1.0	1.0	6.0

NWMAR116053

1.3.1 PCBs Adsorption Results

PCBs adsorption results are given in Table C-3. These results indicate that clay was a strong adsorbent for PCBs. This would be in agreement with the work of R. Hague and co-workers (Environmental Science Technology, 8:139 (1974), in which clay was found to have a high affinity for PCBs. However, in later work with pure clays, the retention was found not to be as good as expected. Attention was then directed to the organic portion of the soils, and Tucker, et al, have tentatively decided that the organic fraction is more important to the adsorption of PCBs; it can be seen from the data that the high-clay-content soil was also the high-organic-content soil.

Further investigation of some clays might be warranted. S. Pearson of Hercules, Inc., in a personal communication, stated that bentonite clay was very effective in removing other pesticide wastes from water. The finely divided clay was then rapidly removed from the water with "Hercofloc".

1.4 Spahgnum Peat (Lignin-Cellulose) as an Adsorbent

The above work by Tucker, and the general finding that in sewage sludge the solid phase contains many times the amount of PCBs the water phase contains, leads to the conclusion that natural organic materials from the earth might make good adsorbents for PCBs.

Although it has not yet been tested for removing PCBs, there is a commercial method of continuous wastewater treatment, called the Hussong/Couplan Water Treatment System, that uses sphagnum peat. The peat is formed into a continuous mat on a mesh belt through which wastewater is sprayed. The system has shown high effectiveness in removing certain organics and metals from wastewaters.

Capital costs for this system average about 60¢ per gallon of daily capacity. Operating costs, when treating a dye house effluent, were 7¢ to 14¢ per 1000 gallons.

2.0 CATALYTIC REDUCTION

In the literature review, two approaches were found for modifying the chemical structure of PCBs in order to aid in waste control. One approach was the

NWMAR116054

Table C-3

PCBs FOUND IN PERCOLATING WATER

Norfolk Sandy Loam		Ray Silty Loam		Drummer Silty Clay Loam	
Total Effluent Volume (ℓ)	ppb PCBs	Total Effluent Volume (ℓ)	ppb PCBs	Total Effluent Volume (ℓ)	ppb PCBs
1.3-8.1	ND	2.7-16.4	ND	1.6-9.9	ND
10.1	ND	20.7	65	12.5	ND
13.5	23	27.6	92	16.6	ND
25.5	63	51.9	153	31.4	ND
48.1	63	98.1	136	59.2	ND

ND = None detected, < 1 ppb

NWMAR116055

complete chlorination of PCBs, to give decachlorobiphenyl, the rationale being that the completely chlorinated biphenyl would have the least solubility in water of any PCB, and thus would be much easier to adsorb and remove. However, decachlorobiphenyls are also the most refractory PCBs.

A better approach is the dechlorination of PCBs to give biphenyl or bicyclohexyl. Berg, et al (in the Bulletin of Environmental Contamination Toxicology 7:338 (1972) state that PCBs can be dechlorinated quantitatively with hydrogen over platinum or palladium catalysts to give bicyclohexyl.

T. Sawai of Japan (in Genshiryohu Kogyo 18(12):43-7 (1972)) reported the degradation of PCBs using the cobalt 60 isotope. Gamma irradiation at a level of 10^{18} ev/gram produced chain dechlorination in an alkaline propanol solution saturated with nitrogen. Alkaline concentrations of 0.01 molar gave about 40 times the dechlorination that a neutral solution gave.

A process of reductive dechlorination, more amenable to low-cost operation and commercial scaleup, is being developed by Sweeny, Saltonstall and co-workers at Envirogenics Systems Co. of El Monte, California.

2.1 Reductive Dechlorination of PCBs at Envirogenics Systems Corp.

Envirogenics, originally working in chlorinated pesticides, has developed catalyzed reduction process methods for the following compounds:

DDT	aldrin	Aroclor 1221
DDD	Chlordane	Aroclor 1242
Kelthane	dieldrin	Aroclor 1254
Perthane	endrin	Aroclor 1232
Methoxychlor	heptachlor	Aroclor 1248
Lindane	toxaphene	Aroclor 1260

The reductive dechlorination reaction has been run at ambient temperature and pressure, by flowing the liquid chlorinated hydrocarbon through a column containing metallic iron granules coated with a metallic copper and blended with sand. The copper exerts a catalytic action. pH is maintained at nearly neutral, since with low pH, say 2.0, the iron conversion rate to ferrous chloride increases 10 times, but the dechlorination reaction is not much faster. The chlorinated hydrocarbon is converted to a hydrocarbon. PCBs, in this process, seem to lose chlorines stepwise, leaving unidentified PCB homologs.

NWMAR116056

Envirogenics is now under EPA contract (68-03-2364) to develop and demonstrate an effective bench-scale (1-3 gpm) low-cost process for the treatment of dilute (ppb to 1 ppm) aqueous manufacturing and processing wastes containing PCBs. Specific objectives and guidelines include:

1. Reduction of PCBs to 5 ppb or less, with levels of < 1 ppb desirable
2. Sufficiently low projected treatment cost to be economically attractive
3. Low expected toxicity of all effluent products, including both degraded PCBs and any added reagents
4. Use of readily available materials, both in construction and as reagents

The process entails simply pumping the liquid to be treated through the catalytic column. Process characteristics that might be proposed for the scaled-up PCB operation, based on what has been learned about the other pesticides thus far, are:

catalyst: 100-mesh metallic iron granules coated with 0.1 milliequivalents of copper per gram of iron

support: 60 to 100 mesh (approx.) sand

number of beds: 4, operable in series or parallel

bed composition: 500 pounds of iron catalyst, plus 3500 pounds of sand

flow rates: 2 to 10 gpm /ft^2

pressure drop: about 10 psi

pH: kept neutral, through caustic addition

piping: 304 ss, with teflon tape seals

tanks: Steel with epoxy coating inside

pretreatment: Wastes are assumed to be free of undissolved solids and oils and are fabric filtered before entering process

The expectations for wastewater PCB reductions with such a pilot plant are based on small 1- to 2-inch-diameter column lab tests that gave reductions of PCBs from 50 ppb to less than 0.1 ppb.

NWMAR116057

The capital cost of the equipment to process 100 gpm is estimated at $65,000, plus tank storage and construction costs. Operating costs, including amortization of capital, is estimated at 72¢ per 1000 gallons of effluent.

3.0 CATALYTIC OXIDATION AND MISCELLANEOUS REACTIONS

The catalytic oxidation of PCBs includes oxidation by: air, oxygen, ozone, hydrogen peroxide and chlorine dioxide. The reaction is usually assisted by catalysts or reaction sensitizers.

PCBs are very resistant to chemical attack. Monsanto states that they are not affected by boiling sodium hydroxide, or by long contact, say 10 days, with concentrated sulfuric acid at ambient temperature. There is no apparent reaction in a bomb of oxygen at 250 psi and 140°C.

3.1 Strong Acids

Russian workers have reported nitric acid decomposition of PCBs. They used nitric acid at a specific gravity of 1.4, and refluxed two PCBs, a pentachloro and a heptachloro homolog, for periods ranging up to 100 hours. They found di- and trichlorobenzoic acids from the former, and tri- and tetra chlorobenzoic acids from the latter. Less concentrated nitric acid would not oxidize these compounds, nor would potassium permanganate or chromic acid. However, mono-, di- and trichlorobiphenyls can be oxidized to the corresponding chlorobenzoic acids with chromic anhydride and acetic acid. The less rigorous conditions can also produce a large mixture of nitrated chlorobiphenyls.

3.2 Electrochemical Oxidation

Notwithstanding these examples of oxidative resistance, J. D. Stuart and co-workers at the Dept. of Chemistry of University of Connecticut have conducted laboratory electrochemical oxidations of PCBs at ambient temperature and pressure. They oxidized PCBs having one to ten chlorine atoms, using very high anodic potentials in a dry methylcyanide solvent. They hypothesize a series of reactions starting with hydrolysis from traces of water present and ending with oxidation.

NWMAR116058

A number of other catalytic oxidation investigations of refractory organics are being conducted in the U.S., with some being sponsored by EPA. Although PCBs have yet to be tested in these investigations, the methods have sufficient power and flexibility to indicate PCBs could be destroyed. In addition, these methods have the potential for zero discharge of pollutants since they have converted refractory organics to CO_2 and water.

3.3 Catalytic Ozonation and Ultrasound Decomposition of Organics

Gerard Smith and J. W. Chen of Southern Illinois University have presented results (68th annual AIChE Meeting in November, 1975) of catalytic ozonations of non-PCB organics in aqueous systems. They have tested catalysis with oxygen, and ozonation without catalyst, and neither method had the effectiveness of catalytic ozonation. An Fe_2O_3 catalyst was used, and phenol and ethyl acetoacetate were used as model compounds in water. The liquid retention time in their flow reactor system was 25 minutes, and the gas flow (using 30 mg/liter concentration of ozone) was 0.1 liter per minute. Under these conditions, TOC was decreased 95 percent for an initial TOC of 100 mg/l, and 85 percent for an initial TOC of 400 mg/l. The packed reactor had the aqueous solution flowing down, and the ozone flowing up.

In experiments comparing the effectiveness against refractory organics of ozone plus Raney nickel and ozone plus ultrasound, Smith found that the reactions were similar. Also, he found that ultrasound and oxygen gave similar reactions. Ultrasound was applied at 800 KHz, and 4 to 5 watts per cm^2. It appeared, however, that these effects were not additive; for example, adding ultrasound to an ozone catalytic reaction did not materially change the reactivity of the ozone and catalyst alone. He also found that at these ambient temperatures and pressures, phenol disappeared rapidly, but other organics, including oxygenated aromatics, resulted rather than compounds expected from rupture of the aromatic ring.

3.4 Wet Catalytic Oxidation of PCBs

L. W. Ross at Denver Research Institute has studied the wet catalytic oxidation of strong wastewaters having COD values of 3,000 to 15,000. Tests

NWMAR116059

showed that reacting $Fe_2 (SO_4)_3$, $Cu SO_4$, and H_2O_2 at a pH of 5.0, and Fenton catalyst at a pH of 2.5 reduced COD concentrations by 95.4 and 96.0 percent respectively after 2 hours at 400°F. Platinum oxide as a solid catalyst also gave good results. Most of the organics were cellubiosics.

3.5 Wet Catalytic Oxidation and Catalyst Durability

J. F. Katzer and co-workers at University of Delaware have been studying elevated pressure and temperature catalytic air-oxidation of refractory organics. They are currently being supported by EPA in a study of the durability of catalysts in wastewater environments. In a paper soon to be published in the Journal of the Water Pollution Control Federation, Katzer reports on studies of the complete oxidation of phenol to CO_2 and water in an aqueous medium using a supported copper oxide catalyst. Rapid degradation rates were found, and the rate data were used to run preliminary design and costs for commercial-scale waste treatment plants. His conclusion is that catalytic oxidation of wastewaters is cost competitive with other physical chemical treatment techniques.

Katzer found that pressures of 10 to 20 atmospheres, and temperatures of 100 to 200°C, were required to get adequate reaction rates yielding up to 99 percent conversion of organics to CO_2 and water. It was found that ambient temperature and pressure generally caused more adsorption on a variety of catalysts than did any reaction.

3.6 Dye-Sensitized Visible Light Photo-Oxidation of Organics

R. L. Sanks and co-workers at the Civil Engineering Dept. of Montana State University are working on the dye-sensitized, aerobic, photo-oxidation of refractory organics. They were able to rapidly break apart the benzene ring of cresol using such dyes as methylene blue and bengal rose. The key to the process is that in the presence of sunlight and air, methylene blue can produce singlet oxygen from the O_2 in air. There are two forms of this singlet oxygen, with a half life of only a millisecond, but with the ability to easily shatter benzene rings. Sanks visualizes a process whereby a lagoon containing wastewater with refractory organics, could have the dye molecules attached to a long chain alkyl

NWMAR116060

or a floc of some kind to keep them at the surface. The sun would provide the photolysis, and little dye would be consumed as it is a catalyst in the reaction. Such a process, if it can be developed, suggests a route to a very low-cost method of obtaining zero discharge, and water recycle systems.

3.7 Chlorine Dioxide Oxidation

International Dioxide, Inc., of New York City is offering a stabilized chlorine dioxide, which is being used by municipalities for taste and odor control of water. It is used as an adjunct to chlorination and can decompose chloramines. It oxidizes and destroys phenol and does not chlorinate. Unstabilized ClO_2 is a dangerous explosive, thus stabilization offers a very powerful oxidizing agent for potential degradation of organics.

4.0 DESTRUCTION OF PCBs BY MICROORGANISMS

The Chemistry of PCBs by Hutzinger reports only two pure cultures of microorganisms showing metabolic activity on individual chlorobiphenyls. One culture, Rhizopus japonicus only converted the mono- or dichlorobiphenyls to chlorohydroxybiphenyls or possibly multi-hydroxybiphenyls.

More promising results were obtained with two species of achromobacter, isolated from sewage effluent. Under aerobic conditions, 4-chlorobiphenyl was converted to 4-chlorobenzoic acid. The organism was apparently able to attack the nonchlorinated benzene ring. Most of these degradations take a number of hours to occur. More recently, chlorinated biphenyls up through pentachlorobiphenyl have been oxidized by achromobacter. Monsanto was able to demonstrate a significant reduction in the mono-, di, and trichlorobiphenyls of Aroclor 1242 after 72 hours of treatment with activated sludge. The higher chlorinated homologs did not seem to be affected.

The degradation of PCBs by microbial action from sludges and from pure cultures of bacteria seemed to give results similar to animal metabolism studies. The lower chlorinated species, again up through the trichloro homolog, were decomposed to phenols, catechols and related compounds.

NWMAR116061

The importance of oxidative conditions was demonstrated in tests with silage containing PCBs. After several months of storage of Aroclor 1242 with silage that had undergone fermentation reactions under anerobic conditions, no change in any of the PCBs had taken place.

The use of DDT degradation as a model for PCB degradation conditions may not be helpful. Results of a study by Johnsen (PCB Newsletter, January, 1973) showed that when di- to hexachlorobiphenyls were incubated for one month with soil and with soil containing cattle manure, no indication of PCB metabolism was found. Under these conditions, p,p' DDT degrades almost completely.

It has also been found that biphenyl itself is more easily degraded or hydroxylated than any of the chlorinated biphenyls.

5.0 REVERSE OSMOSIS AND ULTRAFILTRATION

No tests for PCBs removal by reverse osmosis or ultrafiltration were found in our literature survey. Generally, these methods have found most success in removing dissolved salts from water. However, E.I. DuPont reports, in a private communication, that they have achieved 90 percent removal (rejection) or organics in water at the 1000 to 2000 ppm level. They accomplished this through the development and use of a hollow-fiber permeator system having fibers of aromatic polyamides. The system is reported to work well on organics having molecular weights greater than 100. This would indicate probable success with the PCBs, all of which have molecular weights in the range of 200 to 400.

Based on their experimental work with wound polyamide membranes operating on chlorinated hydrocarbons in water, U.O.P.'s Fluid System Division predicts a 95 to 97 percent removal of aqueous PCBs at 50 ppb concentrations. They point out however, that the reject water stream of concentrated PCBs would contain 10 to 20 percent of the original volume of wastewater so that a certain amount of recycle would have to be built into the system to reduce the generation of concentrated wastewater. Reverse osmosis systems cannot tolerate suspended solids in the feed wastewater; under optimum conditions they can operate for six month to one year before any maintenance or cleaning is required.

NWMAR116062

W. L. Short of the Chemical Engineering Dept. of the University of Mass. reports that with ultrafiltration, 50 percent rejections of phenols and chlorinated phenols has been achieved. He believes that rejection of a given compound can be improved by attaching some of that compound, or a similar material, to the membrane to act as an electronic barrier.

NWMAR116063

APPENDIX D

MASS BALANCE MODEL FOR PCB DISTRIBUTION

1.0 INTRODUCTION AND MASS BALANCE EQUATION

In order to discover the effect of various possible regulatory efforts on the distribution of refractory organics in the general environment, an attempt has been made to determine the manner by which a specific group of such compounds, PCBs, has become so widely dispersed, to determine the dynamics of the distribution process and to determine the changes in specific distribution that may be expected to result from several regulatory alternatives. Specifically, the effect of the voluntary ban introduced by Monsanto in 1970-71 can be demonstrated.

It would be most useful to construct a mathematical representation of a suitable segment of the environment based on the existence of large quantities of valid analytical data taken over a sufficiently long time interval so as to allow the reliable extrapolation of the important time effects. Unfortunately, the necessary data are not available. The recognition that PCBs were an environmental hazard came after their prolonged and widespread use in industry. In addition, the ability to analyze environmental samples for very low levels of PCBs is also a recent development. There has been too little time since the development of these sophisticated and exceedingly sensitive analytical techniques to have allowed anything like a complete spatial and temporal study of the levels of PCBs in any given region.

In view of the serious lack of a truly adequate data base, and because of the need to have at least a first order understanding of the physical processes involved in the transport and distribution of PCBs, an attempt has been made to construct a mathematical model which should contain at least a germ of the true situation. Specifically, the model serves to indicate something of the nature of the problem, and of the types of measurements that will be required to construct a truly satisfactory model to guide future regulatory activities.

To make what follows specific, the derived model is applied to a study of Lake Michigan where a considerable body of information, of late origin, is available.

NWMAR116064

1.1 Mass Balance Model

In order to construct a mass balance model to be applied to a body of water such as Lake Michigan, it is appropriate to determine the manner in which an incremental increase in PCB content is distributed within the various processes available. In what follows, it is explicitly assumed that:

(a) There are no effective mechanisms for the degradation of PCBs which are operative over the time scale involved.

(b) The PCBs that remain in the body of water are distributed between that portion in solution in the aqueous phase, that in "solution" in the biota and that contained within the sediments.

(c) The essential loss mechanisms are evaporation from the lake surface and carry off due to the outflowing waters (in this case - through the Strait of Mackinac).

In terms of these assumptions, a differential equation can be developed that describes the time rate of change of the concentration in the various phases in terms of the input rate of PCBs. This equation may be integrated under various assumptions as to the time dependence of the input rate to yield alternate expressions for the concentration of PCB within the separate phases as a function of time.

1.1.1 Model Development

Let B(t) be the rate of injection (lb/yr) of the PCBs from all sources at a reference time t [where t (years) = 0 in 1930]. Then, within the interval t to t + Δt, an incremental amount of PCBs equal to B(t)Δt will be injected into the system. This quantity of PCBs will be partially partitioned into the various phases, with the balance removed by evaporation and/or outflow.

If Q(lbs) is taken to represent the total water mass in the Lake (assumed to be constant) and $C_w(t)$ the concentration of PCBs in the water

NWMAR116065

at time t, then

$$C_w(t + \Delta t) = C_w(t) + \frac{\Delta C_w}{\Delta t} \Delta t$$

which, in terms of the definition of concentration, causes an increase in soluted PCB of magnitude

$$\Delta m_w = Q \frac{\Delta C_w}{\Delta t} \Delta t. \qquad (1\text{-}1)$$

In a wide variety of environmental situations[1] there appears to exist a rather definite relationship between the concentration of PCBs within the sediment and/or the "average" member of the biota and that of the water in which they are immersed. These relationships are herein defined as

$$\left.\begin{aligned} \rho &\equiv \frac{C_{sed}}{C_{water}} \\ \eta &\equiv \frac{C_{biota}}{C_{water}} \end{aligned}\right\} \qquad (1\text{-}2)$$

and are assumed to be independent of C_{water} and of time.

Using the relationships expressed by Eq. (1-2), the incremental increase in the mass of PCB stored in the biota is given as

$$\Delta m_{biota} = G\eta \frac{\Delta C_w}{\Delta t} \Delta t, \qquad (1\text{-}3)$$

where it is assumed that the concentration of PCB within the biota was in equilibrium with that in the water at time t and that G(lbs), the total mass of the exposed biota, is constant over the period of interest.

Similarily, if the rate of deposition of sediments is taken to be D(lbs/m^2/yr) and the area of the lake to be A(m^2), then, assuming that the principal exchange processes between water and sediment occur within the aqueous phase during the settling out process, the incremental PCB pickup by the sediments is given as:

$$\Delta m_{sed} = AD\rho C_w(t)\Delta t \qquad (1\text{-}4)$$

NWMAR116066

[where the additional term (1/2) $\frac{\Delta C}{\Delta t}\Delta t$ is considered small, especially as $\Delta t \to o$].

If the rate of outflow from the lake (through the Strait of Mackinac) is taken as S(lbs/yr), then the loss of PCB due to this outflow may be taken as:

$$\Delta m_{outflow} = SC_w(t)\ \Delta t \tag{1-5}$$

Finally, the mass of PCB carried out of the system by evaporation is given as:

$$\Delta m_{evap} = KC_w(t)\Delta t \tag{1-6}$$

where K is the evaporation rate constant which will be discussed below.

Now, the principle of conservation of mass requires that all the injected PCB be accounted for, (note that no effective degradation processes are considered to be operative) from which it follows that

$$B(t)\Delta t = \Delta m_w + \Delta m_{biota} + \Delta m_{sed} + \Delta m_{outflow} + \Delta m_{evap}$$

Introducing the definitions of each of the incremental mass loads, and proceeding to the limit $\Delta t \to o$ and dropping the subscript w since the only concentration appearing is that of the PCB in water, the operative differential equation becomes

$$(Q + G\eta)\frac{dc}{dt} + (S + K + AD\rho)C = B(t) \tag{1-7}$$

which, for convenience in what follows, may be rewritten using the substitutions,

$$\left.\begin{aligned} Y &\equiv \frac{1}{Q + G\eta} \\ X &\equiv \frac{S + K + AD\rho}{Q + G\eta} \end{aligned}\right\} \tag{1-8}$$

$$\frac{dc}{dt} + XC = YB(t). \tag{1-8^1}$$

NWMAR116067

The general solution of Equation (1-8[1]) takes the form

$$C(t_f) = e^{-Xt_f} \int_o^{t_f} YB(t) e^{Xt} dt \qquad (1\text{-}9)$$

where $C(t_f)$ is the concentration of PCB in water at the reference time t_f (t_f = 0, 1930).

To solve Equation (1-9), it is necessary to evaluate the various constants [Equation (1-8)] and to discover an appropriate form for the driving function B(t).

2.0 PCB PRODUCTION, SALES AND ENVIRONMENTAL LOAD

In the following section, an attempt is made to evaluate the production and sales of PCBs during the period 1930-1975. Data published by Monsanto[2] have been presented elsewhere in this report. From the derived empirical expression for the total sales as a function of time, as well as from the empirical expressions for transformer, capacitor and other use categories, it will be possible to estimate the total environmental load of PCBs as a function of time. From this analysis, it will be possible to estimate that portion of the total environmental load that is, in fact, free and which therefore is responsible for the widespread distribution of these refractory compounds. As a final step, it will be possible to estimate the time dependence of the free (wild) PCB input to a closed system such as Lake Michigan.

2.1 Empirical Representation of PCB Sales, General and in Specific Use Categories

2.1.1 Period 1930-1970

From the Monsanto sales data for PCBs, it is possible to fit an empirical expression for each category which, to a satisfactory degree, represents the time dependence of that parameter. In each case, it is assumed that the relation is of the general form:

$$\ln Q(t) = a + n \ln t \qquad (2\text{-}1)$$

NWMAR116068

(a) Total Production

The derived empirical expression for the yearly production takes the form, for the period 1930-1970,

$$Q_{prod}(t) = 2.94 \times 10^{2} t^{3.428} \text{ lbs/yr} \qquad (2\text{-}2)$$

The appropriate empirical expression for the yearly sales, for the period 1930-1970, takes the form

$$Q_{sales}(t) = 311\ t^{3.39} \text{ lbs/yr} \qquad (2\text{-}3)$$

The corresponding expressions for capacitor sales and for transformer sales are (for the period 1930-1970)

Capacitor sales: $Q_{cap}(t) = 2.03 \times 10^{2}\ t^{3.289}$ lbs/yr (2-4)

Transformer sales: $Q_{trans}(t) = 2.02 \times 10^{3}\ t^{2.37}$ lbs/yr (2-4[1])

In the above expressions, it should be noted that it is explicitly assumed that

(a) the given Monsanto data are accurate and represent the great preponderance of PCB production and sales within the U.S.

(b) the trends noted in the interval 1954-1970 are simple continuations of earlier trends, so that the curves which fit the period 1954-1970 can, in fact, be used to cover the entire interval, 1930-1970.

Information reported elsewhere in this report suggests that the second assumption above might result in low estimates for total U.S. sales; therefore, the results derived from this analysis must be considered as a lower bound on the actual situation.

NWMAR116069

In any case, numerical evaluation of expressions (2-3) and (2-4) suggest that a weighted average for the proportion of PCB sales that were employed in electrical applications is of the order of

$$\beta = 0.62 \text{ (i.e., 62\%)} \tag{2-5}$$

The remainder of the sales during the period 1930-1970 was for non-electrical applications.

2.1.2 Period 1971-1975

In 1970, Monsanto instituted a voluntary ban on the sales of PCBs restricting their use to electrical applications. As a result of this ban, the empirical relationship appropriate for sales in the post 1970 period is

$$Q'_{sales}(t) = 3.31 \times 10^7 \text{ lbs/yr} \tag{2-6}$$

In addition, during this period essentially 100 percent of PCB production was used for electrical applications; i.e.

$$\beta = 1.00 \text{ (1970-1975)} \tag{2-7}$$

To determine the total sales and total electrical system usage for the period 1930-1975, Equation (2-3) may be combined with Equation (2-6). Integration over the appropriate time frame yields

$$\sum_{1930}^{1975} Q_{sales} = \underline{\underline{9.33 \times 10^8 \text{ lbs}}}$$

and for total electrical system usage, Equations (2-4) and (2-6) with (2-7) may be combined and, on integration, yield,

$$\sum_{1930}^{1975} Q_{electrical}(t) = \underline{\underline{7.12 \times 10^8 \text{ lbs}}}$$

The balance, 2.21×10^8 lbs, were used in non-electrical applications.

NWMAR116070

2.2 Environmental Load of PCBs

2.2.1 Introduction

PCBs, or for that matter any other refractory chemical compound, may exist in the environment in two distinct states: (a) that material which is in a form such as to remain localized and thus is not actually available to enter the sensitive portion of the environment, i.e., the biota; and (b) that material which is not so constrained and is thus free to enter the sensitive portion of the environment. This latter portion of the environmental load will be referred to as "free" or "wild" PCBs. The significance of the first category lies in the fact that the containment is not of infinite life and thus material in category (a) can and will eventually become a component of category (b). For those compounds for which there exists relatively high rates of degradation within the environment, the category (a) is of somewhat lesser importance than for those refractory compounds for which the only inactivation mechanism is the entrapment with non-available forms, for example, in deep ocean sediments.

In order to estimate the rate of accumulation of PCBs in category (b), it is first necessary to determine the rate of entry of PCBs into the category (a). This will be followed by an analysis of the processes by which this total environmental load eventually becomes wild PCBs.

2.2.2 Total Environmental PCB Load, $M_{ev}(t)$

It is assumed that, in any time interval t to t + Δt, a fraction $\alpha < 1$ of the total sales during that interval was directly lost to the environment. It is further assumed that a fraction $\beta < 1$ of the total sales was used in the manufacture of long lived electrical components. If the average lifetime of these electrical components (time of service prior to their being discarded as obsolete) is γ_1 years, then during the time interval t to t + Δt, an amount

$$\beta\, Q_s(t-\gamma_1)\, \Delta t \qquad (2\text{-}8)$$

NWMAR116071

will enter the environment as part of category (a). In addition, the direct entry is given as

$$\alpha\, Q_s(t)\, \Delta t \tag{2-9}$$

The remaining sales $(1-\alpha-\beta)\, Q(t)$ was used in the production of relatively short-lived products, such as carbonless paper, hydraulic fluids, etc., which are assumed to have an average lifetime γ_2 years. Thus, the entry of this material into the total environmental pool is given by

$$(1-\alpha-\beta)\, Q_s(t-\gamma_2)\, \Delta t \tag{2-10}$$

If the three components of the total environmental load, $M_{ev}(t)$ are summed, the resulting differential equation for $M_{ev}(t)$ becomes, in the limit as $\Delta t \to o$

$$\frac{dM_{ev}(t)}{dt} = \alpha\, Q_s(t) + (1-\alpha-\beta)\, Q_s(t-\gamma_2) + \beta\, Q_s(t-\gamma_1) \tag{2-11}$$

or

$$M_{ev}(t) = \alpha \int_o^t Q_s(t)dt + (1-\alpha-\beta) \int_o^t Q_s(t-\gamma_2)dt + \beta \int_o^t Q_s(t-\gamma_1)dt \tag{2-11^1}$$

In order to obtain a numerical evaluation of Equation (2-11^1) it is appropriate to note that β, the fraction of initial sales utilized for electrical applications, is given by Equation (2-5) for the period 1930-1970, and by Equation (2-7) for the post 1970 period.

An estimate of the factor α, the fraction of direct losses, can be obtained by noting that

(a) approximately 10% of the electrical material was lost during transport, production and processing.[3]

(b) approximately 30% of the non-electrical material was lost during transport, production, processing, and use.[4]

NWMAR116072

Hence,

$$\alpha = (0.1)(0.62) + (0.30)(.38)$$
$$\alpha = 0.17 \qquad (2\text{-}12)$$

It is further assumed that

$$\overline{\gamma}_1 = 20 \text{ years}^{(5)}$$
$$\overline{\gamma}_2 = 4 \text{ years}^{(6)} \qquad (2\text{-}12^1)$$

If the expression of $Q_s(t)$ given by Equation (2-3), coupled with the estimated values of α, β, γ_1, and γ_2, is introduced in Equation (2-11), the total environmental load $M_{e\nu}(t)$ may be computed. The integrated form of Equation (2-11) is:

$$M_{e\nu}(t) = 71.07 \left[0.17t^{4.39} + (0.21)(t-4)^{4.39} + (0.62)(t-20)^{4.39} \right] \qquad (2\text{-}13)$$

The numerical results are summarized in Table 2.2.2-1. It should be noted that, in contradistinction to equations such as Equation (2-3), which represent the yearly sales, Equation (2-13) represents the cumulative load in pounds.

2.2.3 Effect of Monsanto's Voluntary Ban on PCB Sales

In the actual situation, as a result of the voluntary Monsanto ban on PCB sales, the expression $M_{e\nu}(t)$ given by Equation (2-13) must be modified to account for post 1970 levels. Thus, for the period 1971 and later,

$$M_{e\nu}(t) = M_{e\nu}(40) + 0.1\int_{o}^{t-40} Q'(t)dt + (1-\alpha-\beta)\int_{40}^{t-40+\gamma_2} Q(t-\gamma_2)dt$$
$$+ (1-\alpha-\beta)\int_{t=40+\gamma_2}^{t} Q'(t-\gamma_2)dt + \beta\int_{40}^{t} Q(t-\gamma_1)dt \qquad (2\text{-}14)$$

NWMAR116073

TABLE 2.2.2-1

$M_{ev}(t)$ = Environmental PCB Load

Date	t(yrs)	Without Partial Ban [From Equation (2-13)] $M_{ev}(t)$ (lbs)	With Partial Ban [From Equation (2-13/2-15)] $M_{ev}(t)$ (lbs)
1930	0	0	0
1935	5	1.42×10^4	1.42×10^4
1940	10	3.35×10^5	3.35×10^5
1945	15	2.32×10^6	2.32×10^6
1950	20	9.1×10^6	9.1×10^6
1955	25	2.62×10^7	2.62×10^7
1960	30	6.23×10^7	6.23×10^7
1965	35	1.31×10^8	1.31×10^8
1970	40	2.54×10^8	2.54×10^8
1975*	45	4.58×10^8	3.76×10^8
1980*	50	7.79×10^8	4.66×10^8

*Equation (2-13) is not actually valid for the post 1970 period, but if the voluntary ban had not been imposed, the estimated $M_{ev}(1975)$ would have been as recorded in Table 2.2.2-1.

NWMAR116074

Substitution of the appropriate forms of $Q_s(t)$ and $Q_s'(t)$ and integration results in

$$M_{ev}(t>44) = \frac{\alpha\delta t^{4.39}}{4.39}\Bigg|_0^{40} + \alpha'\delta'(t-40) + \frac{(1-\alpha-\beta)\delta(t-\gamma_2)^{4.39}}{4.39}\Bigg|_0^{44} + \frac{\beta\delta(t-\gamma_1)^{4.39}}{4.39}\Bigg|_0^{t} \qquad (2\text{-}14^1)$$

which, on introduction of the appropriate numerical values [note $\alpha' = 0.1$, i.e., after 1970, the only use of PCBs was in the manufacture of electrical equipment from which some 10 percent of the material used is discarded as scrap]; becomes

$$M_{ev}(t>44) = 2.99 \times 10^8 + 3.31 \times 10^6\ (t-40) + 44.1\ (t-20)^{4.39} \qquad (2\text{-}15)$$

This latter Equation (2-15) has been used to compute the 1975, 1980 entries in the fourth column of Table 2.2.2-1. By comparison of the last two entries in Table 2.2.2-1, the direct effect of the voluntary ban in 1970 becomes obvious.

2.3 Mobile or Free Environmental PCBs, $m_{ev}(t)$

2.3.1 General Considerations on Mobile PCBs

To consider the processes by which the general environmental load of PCBs $\left(M_{ev}(t)\right)$ becomes free, i.e., the processes by which $m_{ev}(t)$ is generated, it is necessary to consider that some fraction of the direct losses are in a form such that the lost material immediately becomes mobile; i.e., spills and/or evaporation losses. Further, the non-mobile material is usually encased or enclosed in some sort of container which will eventually be degraded thus allowing the subsequent escape of the component PCB.

The fraction of the total sales that is waste occuring in all production uses of PCBs is $\alpha Q_s(t)$ of which some fraction ε is directly mobile.

NWMAR116075

Thus, in the time interval t to t + Δt, this component introduces an amount

$$\varepsilon\alpha Q_s(t)\Delta t \tag{2-16}$$

into the free environmental pool. The remainder $(1-\varepsilon)\alpha Q_s(t)$ which enters the environmental reservoir is contained in a state such that the PCB content is gradually released with a time constant $\tau_2 \equiv 1/\lambda_2$. Thus, within the reference interval t to t + Δt, an amount

$$\lambda_2(1-\varepsilon)\alpha Q_s(t)\Delta t \tag{2-17}$$

enters the mobile pool.

Further, a fraction β of the yearly sales was used to manufacture long lived electrical components, assumed to have a useful life of γ_1 years, after which the components are scrapped. Thus, the contribution of this source to the general environmental pool is

$$\beta\ Q_s(t-\gamma_1)\Delta t \tag{2-18}$$

The electrical containers in which the PCB is enclosed will eventually decay, with a half life $\tau_1 = 1/\lambda_1$. The additional component entering the mobile reservoir will be

$$\lambda_1\beta\ Q_s(t-\gamma_1)\Delta t \tag{2-19}$$

Finally, the remainder $(1-\alpha-\beta)Q_s(t)$ was used in the construction of products assumed to have a useful life of γ_2 years, after which they are discarded, thus contributing a component to the general environmental pool:

$$(1-\alpha-\beta)\ Q_s(t-\gamma_2)\Delta t \tag{2-20}$$

If it is further assumed that these products have a lifetime $\tau_2 = 1/\lambda_2$ against decay, then the contribution to the mobile environmental pool will be

$$\lambda_2(1-\alpha-\beta)\ Q_s(t-\gamma_2)\Delta t \tag{2-21}$$

NWMAR116076

On combining Equations (2-16), (2-17), (2-15) and (2-21), in the limit $\Delta t \to o$, the differential equation for $m_{ev}(t)$ becomes

$$\frac{dm_{ev}(t)}{dt} = \varepsilon\alpha Q_s(t) + \lambda_2(1-\varepsilon)\alpha Q_s(t) + \lambda_1\beta Q_s(t-\gamma_1)$$

$$\lambda_2(1-\alpha-\beta)Q_s(t-\gamma_2) \qquad (2\text{-}22)$$

$$= \left[\varepsilon\alpha + \lambda_2(1-\varepsilon)\alpha\right] Q_s(t) + \lambda_2(1-\alpha-\beta)Q_s(t-\gamma_2) + \lambda_1\beta Q_s(t-\gamma_1)$$

but, from Equation (2-3), $Q_s = 311t^{3.39} = \delta t^{3.39}$

If the parametric values given in Table 2.3.1-1 are substituted into Equation (2-22), the equation becomes

$$m_{ev}(t) = 24.32\int_o^t t^{3.39}\,dt + 6.53\int_o^t (t-4)^{3.39}\,dt + 1.93\int_o^t (t-20)^{3.39}\,dt$$

$$= \frac{24.32}{4.39}\,t^{4.39} + \frac{6.53}{4.39}\,(t-4)^{4.39} + \frac{1.93}{4.39}\,(t-20)^{4.39}$$

Thus,

$$m_{ev}(t) = 5.54t^{4.39} + 1.49(t-4)^{4.39} + 0.44(t-20)^{4.39} \qquad (2\text{-}23)$$

The results computed from Equation (2-23) are tabulated in Table 2.3.1-2

2.3.2 Effect of 1970 Ban on Mobile PCBs

It is now appropriate to discover the effect that the partial ban established in 1970 can be expected to have on the mobile PCB load, $m_{ev}(t)$.

NWMAR116077

TABLE 2.3.1-1

Parameter Values for Equation (2-22) and Equation (2-24)

$\alpha = 0.17$	$\varepsilon = 0.40$	$\alpha' = 0.1$
$\beta = 0.62$	$1-\varepsilon = 0.60$	$\delta = 311$
$1-\alpha-\beta = 0.21$		$\delta' = 3.31 \times 10^{7}$

$\lambda_2 = 0.1$, $\tau_{2-1/2} = 6.9$ years

$\lambda_1 = 0.01$, $\tau_{1-1/2} = 69$ years

$\gamma_2 = 4$ years $\gamma_1 = 20$ years

NWMAR116078

The operative change occurs as a result of the substitution of Equation (2-6) for Equation (2-3) in the time interval after 1970. The resulting expression for $m_{ev}(t \geq 40)$ is given as (recalling that the ban also stopped sales for non-electrical applications):

$$m_{ev}(t > 40) = \varepsilon\alpha\delta\int_{o}^{40} t^{3\cdot 39}dt + \varepsilon\alpha'\delta'\int_{o}^{t-40} dt + \lambda_2(1-\varepsilon)\alpha\delta\int_{o}^{40} t^{3\cdot 39}dt$$

$$+ \beta\lambda_1\delta\int_{o}^{t} (t-\gamma_1)^{3\cdot 39}dt + (1-\alpha-\beta)\lambda_2\delta\int_{o}^{t\leq 44} (t-\gamma_2)dt \quad . \qquad (2\text{-}24)$$

which, on integration and evaluation of the coefficients, becomes, using the parametric values listed in Table 2.3.1-1,

$$m_{ev}(t \geq 45) = 7.59 \times 10^7 + (0.44)(t-20)^{4\cdot 39} + 1.32 \times 10^6\ (t-40). \qquad (2\text{-}24^1)$$

Numerical values derived from Equation (2-24^1) are listed in column 4 of Table 2.3.2-1. Again, the effect of the voluntary partial ban of 1970-71 is apparent.

It will be useful in what follows to express the numerical relationship given by Equation (2-24^1) in the approximate empirical form

$$\left.\begin{aligned} m_{ev}(t \leq 40) &= 4.83t^{4\cdot 5} \\ m_{ev}(t > 40) &= 1.69 \times 10^6 t^{1\cdot 02} \end{aligned}\right\} \qquad (2\text{-}25)$$

2.4 Atmospheric Reservoir of PCBs, $m_a(t)$

Suppose that some fraction θ of the instantaneous addition to the mobile environmental material is vaporized. Then within the interval t to t + Δt

$$\left[\frac{dm_a(t)}{dt}\right]_a = \theta\,\frac{dm_{ev}(t)}{dt}\ \Delta t$$

NWMAR116079

TABLE 2.3.2-1

Estimated Total Environmental PCB Load [$M_{ev}(t)$]
and Mobile Environmental PCB Load [$m_{ev}(t)$]

Date	t (years)	$m_{ev}(t)$ (1) (lbs)	$m_{ev}(t)$ corr (2) (lbs)	$M_{ev}(t)$ corr (3) (lbs)
1930	0	0	0	0
1935	5	6.49×10^3		1.42×10^4
1940	10	1.40×10^5		3.35×10^5
1945	15	8.62×10^5		2.32×10^6
1950	20	3.14×10^6		9.1×10^6
1955	25	8.54×10^6		2.62×10^7
1960	30	1.89×10^7		6.23×10^7
1965	35	3.86×10^7		1.31×10^8
1970	40	7.01×10^7	7.01×10^7	2.54×10^8
1975	45	1.19×10^8	8.31×10^7	3.76×10^8
1980	50	1.90×10^8	9.04×10^7	4.66×10^8
1990	60	4.30×10^8	1.07×10^8	8.41×10^8

Notes: (1) From Equation (2-23)
(2) From Equation (2-24[1])
(3) From Equation (2-15)

NWMAR116080

Further, suppose that the material contained within the mobile pool is vaporized with a time constant $\tau_3 = 1/\lambda_3$, then the additional component of the atmospheric reservoir is given by

$$\left[\frac{dm_a(t)}{dt}\right]_b = \lambda_3 m_{ev}(t)$$

Finally, suppose that the lifetime, $\tau_4 = 1/\lambda_4$, of the atmospheric reservoir results in a decay of $m_a(t)$ given as

$$\left[\frac{dm_a(t)}{dt}\right]_c = -\lambda_4 m_a(t).$$

The total change in $m_a(t)$ with time is then given as

$$\frac{dm_a(t)}{dt} = \left[\frac{dm_a(t)}{dt}\right]_a + \left[\frac{dm_a(t)}{dt}\right]_b + \left[\frac{dm_a(t)}{dt}\right]_c \qquad (2\text{-}26)$$

which on substitution of the appropriate expressions yields the differential equation for $m_{ev}(t)$ as follows:

$$\frac{dm_a(t)}{dt} + \lambda_4 m_a(t) = \theta \frac{dm_{ev}(t)}{dt} + \lambda_3 m_{ev}(t) \qquad (2\text{-}27)$$

for which the general solution is

$$m_a(t) = e^{-\lambda_4 t}\int_o^t \left[\theta \frac{dm_{ev}(t)}{dt} + \lambda_3 m_{ev}(t)\right] e^{\lambda_4 t}\, dt \qquad (2\text{-}28)$$

After substitution from Equation (2-25a) and integrating by parts, the interim result is

$$m_a(t) = \frac{4.83}{\lambda_4}\left\{\lambda_3 t^{4.5} - 4.5\left(\frac{\lambda_3}{\lambda_4} - \theta\right)\left[t^{3.5} - \frac{3.5t^{2.5}}{\lambda_4}\right.\right.$$

$$\left.\left. + \frac{(3.5)(2.5)}{\lambda_4^2} t^{1.5} - \frac{(3.5)(2.5)(1.5)}{\lambda_4^2} e^{-\lambda_4 t}\int_o^t t^{0.5} e^{\lambda_4 t}\, dt\right]\right\} \qquad (2\text{-}29)$$

NWMAR116081

It now becomes important to evaluate the parameters, λ_3, λ_4, and θ which appear in (2-29). First, it is noted that the cumulative total of material entering the environment from 1930 to some time t is given by the sum

$$\sum m_a(t) = \int \left[\theta \frac{dm_{ev}(t)}{dt} + \lambda_3 m_{ev}(t) \right] dt \qquad (2\text{-}30)$$

since the two terms in the integral are simply source terms. On substitution for $m_{ev}(t)$ from Equation (2-25) and carrying out the integration, Equation (2-30) becomes, after simplification,

$$\sum_{1930}^{t} m_a(t) = 4.83 t^{4.5} \left[\theta + \frac{\lambda_3}{5.5} t \right] \quad \text{(lbs)} \qquad (2\text{-}31)$$

It is important at this point to indicate the essential difference between Equation (2-29) and (2-31). The latter, Equation (2-31), represents the cumulative PCB load to the atmosphere in the time from 1930 to the time $t > 1930$. On the other hand, Equation (2-29), which contains the time constant for decay of the atmospheric PCB load, represents the instantaneous PCB load in the atmosphere at time t.

To return to Equation (2-30), Nisbet and Sarofim[7] have estimated that the cumulative load of vaporized PCB in the period 1930 through 1970 was 3×10^4 tons or 6×10^7 lbs. If it is assumed that θ, the fraction of free PCB directly vaporized, is 0.1, then Equation (2-31) may be used to evaluate λ_3 as follows:

$$\sum_{1930}^{1970} m_a(t) = 6 \times 10^7 = 4.83(40)^{4.5} \left[0.1 + \frac{40\lambda_3}{5.5} \right]$$

$$\lambda_3 = 0.0918 \text{ yrs}^{-1}$$

$$\text{and} \quad (\tau_3)_{1/2} = 7.55 \text{ yrs.} \qquad (2\text{-}31^1)$$

NWMAR116082

In view of the results displayed in Equation (2-31[1]) and with the additional assumptions that $\lambda_4 >> \lambda_3$, $\lambda_4 > 1$, Equation (2-29) may be approximated as

$$m_a(t) = \frac{4.83}{\lambda_4} t^{3.5} \left\{ \lambda_3 t + 4.5\theta \right\} \qquad (2\text{-}32)$$

By definition of $\sigma(t)$, the fallout,

$$\sigma(t)A = \lambda_4 m_a(t) = 4.83t^{3.5} \left\{ \lambda_3 t + 4.5\theta \right\}$$

where $A = 8.66 + 10^{13}$ ft^2 as the area of continental United States. Solving for $\sigma(t)$,

$$\sigma(t) = \frac{4.83t^{3.5}}{A} \left\{ \lambda_3 t + 4.5\theta \right\} \qquad (2\text{-}33)$$

where upon, in 1974, $\sigma(t) = 1.06 \times 10^{-8}$ lbs/ft^2/sec, (2-33) yields a value of

$$\sigma(t = 1974) = 1.3 \times 10^{-7} \text{ lbs/ft}^2\text{/yr.},$$

a result clearly not consistent with the known value. The obvious suggestion to account for this discrepency is that the Nisbet[7] value of the cumulative atmosphere load from 1930 through 1970 is incorrect. However, no conclusion as to the reason for this can be reached at present.

2.4.1 Time Dependence of $\sigma(t)$ and of $B(t)$

From Equation (2-33) and the known value of $\sigma(t)$ in 1974 (1.06×10^{-8} lbs/ft^2/yr), it is apparent that Equation (2-33) yields the correct value if the term $\lambda_3 t << 4.5\theta$, so that, it is appropriate to take, where $\theta = 0.1$

$$\sigma(t) = \sigma_0(t)t^{3.5} \text{ lbs/ft}^2\text{/yr} \qquad (2\text{-}34)$$

and, since fallout constitutes the predominant PCB input source to Lake Michigan (see Section 3), the forcing function $B(t)$ will be taken to be of the form

$$B(t) = \alpha t^{3.5} \qquad (2\text{-}35)$$

NWMAR116083

The coefficient α will be evaluated in terms of the specific application for which Equation (2-35) is the driving function.

3.0 DERIVATION OF PHYSICAL CONSTANTS FOR LAKE MICHIGAN

3.1 General Properties[8]

From various atlas and other sources, for Lake Michigan

$A = 2.24 \times 10^4$ mi^2 $= 6.24 \times 10^{11}$ ft^2 = area of lake.

$S = 1.2 \times 10^{14}$ lbs/yr [6×10^4 ft^3/sec in average flow through Straits of Mackinac]

$Q = 1.1 \times 10^{16}$ lbs = total water mass in lake.

$A' = 5 \times 10^4$ m^2 $= 1.29 \times 10^{12}$ ft^2 (average drainage area)

3.2 Proportioning Constants

In order to determine the most appropriate values for the proportionality constants, ρ^* and η, in the absence of a well-founded theoretical explanation of the physical processes which determine them, it is necessary to rely on in-situ measurements of concentration over wide regions of the target water body to establish reasonable statistical reliability. Actually, such a body of data does not exist for Lake Michigan at this time. On the other hand, such data do exist for Lake Ontario which should allow at least a reasonable estimate of the appropriate values for Lake Michigan.

3.2.1 Concentration Ratio of Biota to Water, η

Sampling of Lake Ontario, conducted in 1972 at several nearshore and mid-lake sites, indicated the following:[9]

a. PCB in fish (alewives, smelt, slimy sculpin) = $2.35 - 5.13 \times 10^6$ ppt
b. PCB in water (total conc. dissolved + particulate) = 55 ppt
c. Average PCB in sediments = 1.2×10^5 ppt
d. Average PCB in wet plankton = 7.2×10^6 ppt
e. PCB in the benthos = 4.7×10^5 ppt

NWMAR116084

In view of these data, it appears that a realistic value for the constant η, considering the nature of the food chain, is

$$[\eta \sim 4 \times 10^4]$$

for Lake Ontario which, by inference, should also apply to Lake Michigan. It should be noted that η is taken as an average concentration ratio over all members of the biota; thus, there will be specific species showing considerable variation from the assumed value.

Since the basic physical processes that account for this partitioning of PCB-like materials should be independent of the actual concentration of PCBs in the aqueous phase (so long as the aqueous solution is less than saturated), it is reasonable to assume that η is independent of time.

3.2.2 Concentration Ratio of Sediment to Water, ρ

From a number of measurements of sediment levels within Lake Michigan (24 sites),[10] an average PCB concentration of 38.2 ppb was calculated; this is the presence of an average water concentration of 20 ppt. Since these specific points were taken from the southern part of the lake, where the contamination is known to be higher, an average value of ρ has been taken to be:

$$\rho = 2 \times 10^3$$

The deposition rate for the lake, D, is[11]

$$D = 5.7 \times 10^6 \text{ lbs/mi}^2\text{/yr}$$

3.3 Biota Mass, G, for Lake Michigan

A representative value for the biomass in Lake Michigan, recognizing the relatively limited data that are available on specific species and the absence of a detailed ecological pyramid, may be obtained from the estimates contained in Table 3.3-1.

In addition, the relatively polluted nature of the southernmost portion of the Lake results in large masses of benthic species, such as tubifex

NWMAR116085

TABLE 3.3-1

Estimates of Biota Mass for Lake Michigan

Estimates for the Fish Mass[12]

a. Lake trout (from Michigan waters of the Lake) - 11.2×10^6 lb (1972)

b. Whitefish (in Northern Lake Michigan) - 55×10^6 lb (1972)

c. Chubs (those available to bottom trawls) - 15×10^6 lb (1973)

(note: decline in chubs from 139×10^6 lb in 1963-65)

d. Alewives (those available to bottom trawls + estimate of the midwater individuals) - 2×10^9 lb (1973)

e. Coho Salmon (estimate based on the number stocked) - 7.6×10^6 lb (1972)

Total - 2.1×10^9 lb (1972-73)

Estimates for the Plankton Biomass:

a. Assume 300 kg plankton/hectare of lake

b. Area of Lake = 22,400 mi^2 = 5.8×10^6 hectares

c. Plankton biomass = $(5.8 \times 10^6)(300 \text{ kg}) = 1.74 \times 10^{12}$ g = 3.8×10^9 lb

NWMAR116086

worms. In view of this, it is assumed that the benthic biomass is of the order of 4×10^9 lbs.

Finally, in terms of the above, a representative value for the total biotic mass, G, appears to be of the order of 10^{10} lbs which, in view of its approximate value, is taken to have been constant over the time interval of interest.

3.4 Input Rate [B(t)] for the Period 1973-1974

The PCB inputs to Lake Michigan consist of three parts:

a. that due to fallout on the lake;

b. that due to fallout on the drainage area and subsequent extraction by ground waters; and

c. that due to point sources, industrial and sewage treatment plants.

3.4.1 Point Source Inputs

Data on PCB concentrations are available only for eight of the tributary streams in Michigan. In addition, historical data collections seldom extend back beyond 1970-1972. These data, for the St. Joseph, Kalamazoo, Grand, Muskegon, Marristee, Broadman, Elk and Portage Rivers[13] indicate that, during the recent period, the yearly load of PCBs from these rivers was about 1000 lb/yr. Using these limited data on stream concentration due to industrial and sewage treatment plants, the following estimates of yearly load can be made:[14]

Michigan	-	217.2 lb/yr (1974, STPs)
Wisconsin	-	1,150.0 lb/yr (1974-75, paper plant effluents)
Wisconsin	-	130.3 lb/yr (1974-75, STPs)
Wisconsin	-	20.1 lb/yr (1974, misc. industry)
Indiana	-	123.3 lb/yr (1972, STPs)
Illinois	-	3.1 lb/yr (1971, STPs)
		1,644.0 lb/yr = 1.6×10^3 lb/yr

NWMAR116087

3.4.2 Fallout on Lake Michigan

A variety of fallout rate measurements have been reported[17] indicating rates as high as 0.5 lbs/mi^2/yr = 87 μg/m^2/yr in the heavily industrialized portion of Sweden[15] to the other extreme of 17.5 μg/m^2/yr observed in Iceland.[16] In view of the rather heavy concentration of industry in the Lake Michigan area, it will be assumed that the average fallout in the 1974 era was 50 μg/m^2/yr.

Thus, taking the area of the lake to be 5.8×10^{10} m^2, the annual fallout should be of the order of

$$B_{\text{fallout direct}} \sim 6.4 \times 10^3 \text{ lbs/yr in 1974.}$$

3.4.3 Fallout onto Drainage Basin

In order to compute the contribution of PCB input to the lake due to fallout on the drainage basin, the separate contributions from each of the adjourning states is computed in Table 3.4.3-1.

3.4.4 Total Input to Lake (1974)

From Table 3.4.3-1 and the data in Sections 3.4.1 and 3.4.2, the contributions to the PCB input are taken to be:

Point sources	1.6×10^3 lbs/yr	
Lake fallout	6.4×10^3 lbs/yr	
Basin fallout	5.4×10^3 lbs/yr	(where it is assumed that 50 percent of basin fallout actually enters the lake)[12]

$$B(1973\text{-}74) = 13.4 \times 10^3 \text{ lbs/yr}$$

From Equation (2-35),

$$B(t) = \alpha t^{3.5}$$

NWMAR116088

TABLE 3.4.3-1

PCBs Inputs to Lake Michigan - 1974

a. For the Michigan portion of the drainage basin:[18]

PCB load = $(50\ \mu g/m^2/yr)(6.0 \times 10^{10}\ m^2) = 3 \times 10^{12}\ \mu g$ PCB/yr

$= 6.6 \times 10^3$ lb PCB/yr

b. For the Wisconsin portion of the drainage basin:[19]

PCB load = $(50\ \mu g/m^2/yr)(3.7 \times 10^{10}\ m^2) = 1.9 \times 10^{12}\ \mu g$ PCB/yr

$= 4.1 \times 10^3$ lb PCB/yr

c. For the Illinois portion of the drainage basin:[20]

PCB load = $(50\ \mu g/m^2/yr)(8.0 \times 10^8\ m^2) = 4.0 \times 10^{10}\ \mu g$ PCB/yr

$= 88.1$ lb PCB/yr

d. For the Indiana portion of the drainage basin:[21]

PCB load = $(50\ \mu g/m^2/yr)(1.85 \times 10^8\ m^2 = 9.3 \times 10^9\ \mu g$ PCB/yr

$= 20.4$ lb PCB/yr

e. Total annual fallout from all four sectors of the basin:

$= 1.08 \times 10^4$ lb PCB/yr

NWMAR116089

which for the reference year, 1974, was estimated to be

$$13.4 \times 10^3 = \alpha (44)^{3.5}$$

$$\alpha = .0237$$

so that, in what follows,

$$B(t) = 0.0237t^{3.5} \qquad (3\text{-}1)$$

4.0 APPLICATION OF THE MASS BALANCE EQUATION TO LAKE MICHIGAN

4.1 Physical and Hydrologic Constants for Lake Michigan

The values used for the various physical and hydrologic constants for Lake Michigan are listed below:[23]

- A = surface area of the lake = 6.24×10^{11} ft^2
- S = outflow through Strait of Mackinac = 1.2×10^{14} lb/yr
- Q = water mass in lake = 1.1×10^{16} lbs
- D = sediment deposition rate = 0.204 lbs/ft^{2}yr
- η = biota/water concentration ratio = 4×10^4
- ρ = sediment/water concentration ratio = 2×10^3
- B (1974) = PCB input rate in 1974 = 1.34×10^4 lbs
- K = evaporation rate constant = 2.2×10^{14} lbs/yr
  [this assumption will be discussed below]

Then, from the data above, the various factors appearing in Equation (1-9[1]) may be evaluated as follows:

$$AD\rho = 2.25 \times 10^{14} \text{ lbs/yr}$$

$$Q + G\eta = 1.14 \times 10^{16} \text{ (lbs)}, \quad (Q + G\eta)^{-1} = 8.77 \times 10^{-17} \text{ (lbs)}^{-1}$$

$$S + K + AD\rho = 5.7 \times 10^{14} \text{ lbs}$$

$$X = \frac{S + K + AD\rho}{Q + G\eta} \sim 0.05$$

$$Y = \frac{1}{Q + G\eta} = 8.77 \times 10^{-17}$$

NWMAR116090

4.2 Integration of the Mass Balance Equation

In terms of the parameters for the lake and the assumed form for B(t) from Equation (3-1), the differential equation for C(t), Equation (1-9) becomes:

$$C(t_f) = 2.08 \times 10^{-18} \, e^{-0.05 t_f} \int_0^{t_f} t^{3.5} \, e^{0.05 t} \, dt \qquad (4\text{-}1)$$

where the PCB concentration is taken to be zero in 1930, i.e., at t = 0.

Equation (4-1) cannot be directly integrated in terms of simple algebraic functions so that recourse must be had to numerical integration to yield the results tabulated in Table 4.2-1.

For convenience in what follows, the relationship between $C_w(t_f)$ and t_f will be assumed to be of the form:

$$C_w(t_f) = bt^n$$

where b, and n are determined by a least squares fit to the data in Table 4.2-1. The results of this analysis may be summarized in the equation

$$C_w(t_f) = 4.56 \times 10^{-19} t_f^{4.416} \qquad (4\text{-}2)$$

From Equation (4-2), the change in $C_w(t)$ over a one-year period is found to be

$$\frac{dC_w(t)}{dt} = 2.01 \times 10^{-18} t^{3.416} \qquad (4\text{-}2^1)$$

Thus, for the reference year, 1974, the average water concentration was about 8×10^{-12} and the change in concentration during the reference year was 0.80×10^{-12}. From these data, it is possible to determine the material balance during 1974 as is shown below:

NWMAR116091

Total input	1.34×10^4 lbs
Increase in solution	8.81×10^3 lbs
Increase in biota	0.32×10^3 lbs
Increase in sediment	1.8×10^3 lbs
Increase in outflow	0.96×10^3 lbs
Net loss due to evaporation	1.52×10^3 lbs

From Equation (1-6), it is now possible to estimate the evaporation rate constant K,

$$K = \frac{\Delta m_{evap}}{\overline{C}_w} = \frac{1.52 \times 10^3}{8 \times 10^{-12}} \sim 2 \times 10^{14} \text{ lbs/yr}$$

To discover the material balance over the entire period, 1930 through 1975, the total PCB input to the Lake is given by

$$Q_{input} = \int_0^{45} B(t)dt = 0.0237 \int_0^{45} t^{3.5}\, dt$$

$$= 1.49 \times 10^5 \text{ lbs} \qquad (4\text{-}3)$$

The average concentration $\overline{C}_w(t)$ over the reference period is

$$\overline{C_w(t)} = \frac{4.56 \times 10^{-19}}{45} \int_0^{45} t^{4.416} dt \qquad (4\text{-}4)$$

$$= 1.68 \times 10^{-12}$$

The cumulative loads in Lake Michigan in the various phases are summarized below:

Total input (1930-1975)	$= 1.49 \times 10^5$ lbs
Total in water	$= 1 \times 10^5$ lbs
Total in biota	$= 3.64 \times 10^3$ lbs
Total in sediments	$= 1.7 \times 10^4$ lbs
Total in outflow	$= 9.07 \times 10^3$ lbs
Net loss due to evaporation	$= 1.93 \times 10^4$ lbs

NWMAR116092

TABLE 4.2-1

Concentration of PCB in Solution in Lake Michigan*

Date	t_f	$C_w(t_f)$	$C_w(t_f)$ (ppt)
1930	0	0	0
1935	5	4.94×10^{-16}	4.94×10^{-14}
1940	10	1.34×10^{-14}	1.34×10^{-2}
1950	20	2.79×10^{-13}	0.28
1960	30	1.60×10^{-12}	1.60
1965	35	2.92×10^{-12}	2.92
1970	40	5.35×10^{-12}	5.35
1975	45	9.10×10^{-12}	9.10

*Measurements in 1970 indicate a range of aqueous concentration of 1 to 7.5 ppt[13]

NWMAR116093

From the net loss of PCB due to evaporation from the above data, and the defining equation for the evaporation losses, Equation (1-6), the evaporation rate constant K may be evaluated,

$$K = \frac{\Delta m_{evap}}{\overline{C}_w(t)\Delta t} = \frac{1.93 \times 10^4}{1.68 \times 10^{-12} \times 45} = 2.56 \times 10^{14} \text{ lbs/yr} \qquad (4\text{-}5)$$

The several values of K, from Equation (4-5) and the earlier value determined from the 1974 situation, are averaged to yield a useful value

$$K = 2.2 \times 10^{14} \text{ lbs/yr} \qquad (4\text{-}6)$$

4.3 Temporal Variation of Concentration of PCB in the Various Phases of the Lake

It is now possible to combine the relationship expressed by Equation (4-2) with the definition of the biotic concentration factor η from Equation (1-2), to determine the variation of biotic concentration with time. The data enumerated in Table 4.3-1 indicate the trends. When it is noted that the concentration data in Table 4.3-1 are given in parts-per-trillion, it is clear that the average biota concentration neared the one part-per-million level on as early as 1965. It is also evident, because of the considerable spread in specific biotic concentration factors for specific species, that the higher predictors could easily have exceeded the one ppm level as early as 1960.

NWMAR116094

TABLE 4.3-1

Temporal Variation of Biotic Concentration

Date	C_w (ppt)	C_{biota} (ppt)
1930	0	0
1935	4.9×10^{-4}	1.97
1940	1.34×10^{-2}	5.36×10^{2}
1945	7.12×10^{-2}	2.84×10^{3}
1950	0.28	1.12×10^{4}
1955	0.68	2.72×10^{4}
1960	1.60	6.4×10^{4}
1965	2.92	1.17×10^{5}
1970	5.35	2.14×10^{5}
1975	9.10	3.64×10^{5}

NWMAR116095

4.4 Physical Interpretation of K, the Mass Evaporation Constant

4.4.1 Kinetic Theory

Experimental data[24] on the evaporation rate of Aroclor 1254 indicates that, at 100°C (373°K), the evaporation rate is 1.47×10^{-8} gm/cm^2/sec and the vapor pressure is 5×10^{-2} mm Hg. From elementary kinetic theory of gases,[25] the relationship between evaporation rate and vapor pressure is given

$$m(\text{gm/cm}^2/\text{sec}) = \delta\left[\frac{m}{2\pi RT}\right]^{1/2} P \qquad (4\text{-}7)$$

where δ = the measure of the probability that a collision with the surface does not result in the molecule sticking to the surface

R = the gas constant per mole [8.31×10^7 erg (°K)$^{-1}$]

T = the absolute temperature [°K]

m = the molecular weight [gms]

P = the vapor pressure [dynes/cm^2]

From Equation (4-7) and the known evaporation rate,[24] the numerical value of δ may be computed as follows:

$$1.47 \times 10^{-8} = \delta\left[\frac{325}{2\pi \times 8.31 \times 10^7 \times 373}\right]^{1/2} \frac{5 \times 10^{-2}}{760} \times 10^6$$

$$\text{or} \qquad \delta = 5.47 \times 10^{-6} \qquad (4\text{-}8)$$

If it is assumed that δ is not temperature dependent at temperatures considerably removed from the normal boiling temperature, and that Equation (4-7) may be applied to a solution as well as to the pure liquid, then at ambient temperature (298°K) where the vapor pressure of Aroclor 1254 is 7.7×10^{-5} mm Hg,[24]

$$m(\text{gm/cm}^2/\text{sec}) = 5.47 \times 10^{-6}\left[\frac{325}{2\pi \times 8.3 \times 10^7 \times 298}\right]^{1/2} \frac{7.7 \times 11^{-5}}{760} \times 10^6$$

$$\text{or} \qquad m = 2.53 \times 10^{-11} \text{ gm/sec/cm}^2$$

NWMAR116096

Now the area of the lake is 5.8×10^{14} cm^2, hence

$$m(lbs/year) = 2.08 \times 10^{14} \text{ (lbs/yr)} \qquad (4\text{-}9)$$

The value of m from Equation (4-9) is in excellent agreement with the value of K empirically determined to be 2.2×10^{14} lbs/yr.

4.4.2 Application of the Theory of MacKay and Wolkoff[26]

Following MacKay and Wolkoff,[26] the rate of material loss for a slightly soluble solute from a water-air interface is given, for a system wherein the solute concentration is less than the saturation concentration, by:

$$\frac{dC_i}{dt} = - \frac{EP_{is}M_i}{G'M_w P_w C_{is}} C_i \qquad (4\text{-}10)$$

where: A = area of the lake surface (6.24×10^{11} ft^2)
E = mass evaporation rate of water (1.38×10^{12} lb/yr)[11]
P_{is} = equilibrium vapor pressure of pure solute (7.7×10^{-5} mm Hg)[27]
M_i = molecular weight of solute (325-Aroclor 1254)
G' = mass of water from which evaporation occurs
M_w = molecular weight of water (18)
C_{is} = saturation concentration of solute (6×10^{-8})[27]
P_w = equilibrium vapor pressure water (23.7 mm Hg)
C_i = concentration of solute in the evaporation layer
ρ = density of water (62.5 lbs/ft^3)

Equation (4-10) must be modified for the present situation to take into account the effect of fallout on the solute concentration. Thus, for the case in point,

$$\frac{dC_i}{dt} = \frac{\sigma(t)A}{G'} - \frac{EP_{is}M_i}{G'M_w P_w C_{is}} C_i \qquad (4\text{-}11)$$

NWMAR116097

The expression $\sigma(t)$ which occurs in Equation (4-11) is taken to be of the form [from Equation (2-34)]

$$\sigma(t) = 1.67 \times 10^{-14} t^{3.5} \tag{4-12}$$

Further substitution of $G' = A\rho\xi$, where ξ is the thickness of the layer from which evaporation is occuring, and $E = A\rho l'$, where l is the evaporation rate in ft/year, reduces Equation (4-12) to the form

$$\frac{dC_i}{dt} = \frac{1.67 \times 10^{-14} t^{3.5}}{\xi\rho} - \frac{lP_{is}M_i}{\xi M_w P_w C_{is}} Ci \tag{4-12^1}$$

which is now applicable to a unit area of the lake.

The solution of Equation (4-12^1) is complicated by the fact that ξ, the layer thickness, is unknown. To obtain some idea of the magnitude of ξ, it is reasonable to assume that

$$C_i(t) = \gamma C_w(t) \tag{4-13}$$

where γ may be a function of time. Substitution of Equation (4-13) and the appropriate numerical values with Equation (4-12) and evaluating for $t = 44$ years (1974), yields [after using Equation (4-2) for $C_w(t)$]

$$8.22 \times 10^{-13} \gamma + 2.66 \times 10^{-10} \frac{\gamma}{\xi} = \frac{1.51 \times 10^{-10}}{\xi} \tag{4-14}$$

Now, $\frac{K}{A} = \frac{lP_{is}M_i}{\xi M_w P_w C_{is}} \gamma$ from the definition of K. Hence, from this last relation, evaluated at $t = 44$ years,

$$\frac{\gamma}{\xi} = 10.92 \tag{4-15}$$

Substitution of (4-15) into (4-14) yields

$$\gamma = 0.57$$
$$\xi = 0.052 \text{ ft}^{(28)} \tag{4-16}$$

NWMAR116098

It is apparent, from Equations (4-16) and (4-13), that this analysis suggests that the average concentration in the layer is less than that in the bulk water, i.e., $\gamma < 1$. The reason for this apparent anomaly can be seen by recognizing that Equation (4-12) is in the form

$$\frac{dc}{dt} = \frac{\sigma(t)}{\xi P} - \lambda_i C_i \qquad (4\text{-}17)$$

where $\lambda_i \equiv \frac{1 P_{is} M_i}{\xi M_w P_w C_{is}} = 617 \text{ yrs}^{-1}$

is the effective decay constant for the surface layer concentration. In terms of the half-life

$$(\tau_i)_{1/2} \sim 10 \text{ hours} \qquad (4\text{-}17^1)$$

Equation (4-17) may be integrated from a time t to $t + 1/\lambda$ to yield, where the interval is sufficiently short that $\sigma(t)$ may be assumed to be constant;

$$C_i = 0.37\, C_{io} + 3.34 \times 10^{-12} \qquad (4\text{-}18)$$

If the assumed relationship between C_i and C_w, given by Equation (4-13) is introduced as (C_{io} = PCBs concentration at time t)

$$C_o = \gamma C_{io}$$

$$C_i = \gamma (C_w + \Delta C_w) \sim \gamma C_w$$

then

$$\gamma (1 - 0.37) = \frac{3.34 \times 10^{-12}}{C_w}$$

$$\gamma = 0.74 \qquad (4\text{-}19)$$

This shows good agreement with the results expressed in Equation (4-16).

NWMAR116099

5.0 RESULTS AND CONCLUSIONS

5.1 Results

Even though the model used is only first-order, it is apparently able to describe the relative significance of the natural processes which control the distribution of PCBs. The strong focus on fallout as the primary input source of PCBs to Lake Michigan suggests the need for further study of the nature of the processes by which PCBs become airborne and thus become part of the available atmospheric reservoir.

The attempt to model the atmospheric reservoir of PCBs, discussed in Section 2, yields results that indicate significantly greater cumulative atmospheric loads than the preliminary estimate, made by Nisbet and Sarofim,[7] of a cumulative atmospheric reservoir of 3×10^4 tons up to 1970. The estimate of Nisbet and Sarofim leads to a half-life, from the model, for PCBs in the atmospheric reservoir on the order of eight years. This value is considerably in excess of the reported lifetime measurements, on the order of 20 to 40 days, for atmospheric PCBs.[29] However, the observation that significant levels of PCBs are found in present snowfalls and in packed snow in Antarctica[30] suggests that the applicable half-life may indeed be considerably longer than 20 to 40 days.

It is suggested that further refinement of the environmental distribution model presented in Section 2 will lead to a resolution of this apparent discrepancy. This refinement will focus attention on the nature of the physical processes involved in atmospheric transport of PCBs and may suggest methods of reducing PCB fallout in the future.

The observation that evaporation and/or co-distillation seems to be a significant process by which PCBs are returned to the atmosphere is of importance. It should be noted that the magnitude of the evaporation rate constant necessary to achieve mass balance in Lake Michigan is in excellent agreement with that computed from the simple kinetic theory of gases and also with that computed from the theory of co-distillation discussed by MacKay and Wolkoff.[26]

NWMAR116100

The observation that the PCB input to Lake Michigan from point sources seems to be a rather small part of the total input suggests that reduction of point source PCB effluents may only slowly correct the present problem.

5.2 Conclusions

The first-order mass balance model described herein seems useful in describing the historical situation as it explicitly addresses the question "How did we get here?". The model requires refinement before it can be used to allow a reasonable estimate of future conditions. Significantly more detailed data are required as to the temporal variation of inputs and concentrations as well as on the interval transport processes by which localized concentrations are smoothed and distributed over the whole body. While the present model seems to deal very well with the situation that obtains during an interval of rising aqueous concentrations, there seems to be little experimental or theoretical guidance as to what will happen if, in the future, aqueous concentrations begin to fall. It is not known whether the biota and the sediments will act as reservoirs to return their PCB loads to the system. The processes, if any exist, which will eventually remove or inactivate the PCBs already in the lithosphere are not known.

The application of this model to the situation in Lake Michigan seems successful. It will be of interest to apply it to regions which are more complex or of larger scale.

5.3 Discussion of Results

With regard to Lake Michigan, the mass balance indicates that this fresh water system (water, sediment, biota) serves as a significant sink for PCBs; this must also apply to many other fresh water systems. In the case of toxic metals, the oceans are generally recognized as an important ultimate sink, but this may not be the case for PCBs.

The theory developed by MacKay and Wolkoff,[26] as applied to Lake Michigan conditions, yields a lifetime against (until) evaporation of about

NWMAR116101

ten hours. For seawater, this lifetime is greatly reduced by lower solubility of PCBs and higher evaporation rate, so that the calculated lifetime of PCBs in seawater against evaporation may be as low as ten minutes.

Although attachment to organic and living material may well be a factor, the above result indicates that PCBs tend to evaporate from salt water much more quickly than from fresh water. Then, on this basis, the terrestrial systems, such as fresh water lakes, forests, etc., must be regarded as partial sinks for PCBs in fallout; the PCBs lost from these systems reenter the atmosphere via direct evaporation or transport by rivers to salt water from which further evaporation occurs. New PCBs are added to the atmospheric load by direct evaporation, through inadequate incineration processes, or via water from runoff, industrial discharges, landfill leachate, etc.

NWMAR116102

6.0 GLOSSARY OF SYMBOLS USED

A	Surface area of reference body of water (ft^2)
$B(t)$	PCB injection rate with reference body of water (lbs/yr)
$C_w(t)$	Aqueous PCB concentration
D	Sediment rate in reference body of water ($lb/ft^2/yr$)
G	Mass of biota in reference body of water (lbs)
K	PCB evaporation rate constant (lbs/yr)
$M_{ev}(t)$	Cumulative environmental PCB load (lbs)
$m_{ev}(t)$	Cumulative free environmental PCB load (lbs)
$m_a(t)$	Instantaneous atmospheric reservoir of PCBs (lbs)
Q	Mass of water in reference body of water (lbs)
$Q_{cap}(t)$	Cumulative PCB sales for capacitor application (lbs)
$Q_{electrical}(t)$	Cumulative PCB sales for electrical application (lbs)
$Q_{prod}(t)$	Cumulative PCB sales for production application (lbs)
$Q_{sales}(t)$	Cumulative PCB sales for all applications (lbs)
$Q_{trans}(t)$	Cumulative PCB sales for transformer application (lbs)
S	Water outflow rate from reference body of water (lbs/yr)
t	Time (yrs), (t = 0 in 1930)
α	Fraction of PCB sales directly lost to the environment
β	Fraction of PCB sales devoted to electrical applications
γ_1	Average in-service life of electrical components (yrs)
γ_2	Average in-service life of non-electrical products (yrs)
ε	Fraction of production waste initially free
θ	Fraction of initially free PCBs that are vaporized

NWMAR116103

λ_1	Decay constant for discarded PCB-containing electrical components (yr^{-1})
λ_2	Decay constant for discarded PCB-containing non-electrical products (yr^{-1})
λ_3	Decay constant for vaporization of free PCBs (yr^{-1})
λ_4	Decay constant for fallout of atmospheric PCBs (yr^{-1})
η	Ratio of biota PCB concentration to aqueous PCB concentration
ρ	Ratio of sediment PCB concentration to aqueous PCB concentration
$\sigma(t)$	Fallout rate per unit area ($lbs/ft^2/yr$)
τ_1	Half-life of containment of discarded PCB-containing electrical components (yr)
τ_2	Half-life of containment of discarded PCB-containing non-electrical components (yr)
τ_3	Half-life of free PCBs for vaporization (yr)
τ_4	Half-life of atmospheric PCBs against evaporation (yr)

NWMAR116104

7.0 BIBLIOGRAPHY

The literature resulting from analytical measurements on a wide variety of biological and geological specimens has become very large. The following list, while in no sense complete, represents those sources used in this work.

1. Addison, R.F., S.R. Kerr, J. Dale, and D.E. Sergeant, J. Fish Res. Board Can., 30, 595, 1973.

Anonymous, "Chemicals Found in Lake Fish: State PCB Ban Urged." Michigan Out-of-Doors, July, 1975.

Bailey, S., P.J. Buryan, and F.B. Fishwick. Chemistry and Industry 22: 705, 1970.

Bowes, G.W. and C. Jonkel, in PCB in the Environment, Marcel Dekker Inc., New York, 1974.

Carey, A.E., G.B. Weirsma, H. Tai, and W.G. Mitchell. Pesticides Monitoring Journal 6(4): 369-376, 1973.

Crump-Weisner, H.J., H.R. Feltz, and M.L. Yates. Pesticides Monitoring Journal 8(3): 157-161, 1974.

Doguchi, M., New Methods in Environmental Chemistry and Toxicology. Proceedings of the International Symposium, Susono, Japan, 1973; Coulston, F., Korte, F., and Goto, M., Eds., International Academic Printing Co., Tokyo, Japan, 1973.

Duke, T.W., J.I. Lowe, and A.J. Wilson, Jr. Bulletin of Environmental Contamination and Toxicology; 5(2): 171-180, 1970.

Edwards, R. "Polychlorinated Biphenyls, Their Occurence and Significance: A Review." Chemistry and Industry (No Volume) Issue 47: 1340-8 (21 November, 71), 1971.

Fog, M., and I. Kraul, Acta Vet. Scand., 14, 350, 1973.

Frank, R., K. Ronald, and H.E. Braun, J. Fish Res. Board Can., 30, 1053, 1973.

Giam, C.S., M.K. Wong, A.R. Hanks, and W.M. Sackett, Bull. Environ. Contam. Toxicol., 9, 376, 1973.

Greichus, Y.A., A. Greichus, and R.J. Emerick, Bull. Environ. Contam. Toxicol., 9, 321, 1973.

Gustafson, C.G., Environmental Science and Technology 4(10): 814-819, 1970.

Harvey, G.R., H.P. Mlklas, V.T. Bowen, and W.G. Steinhauer. Journal of Marine Research 32(2): 103-118, 1974.

NWMAR116105

Heppleston, P.B., Mar. Pollut. Bull., 4, 44, 1973.

Hidaka, K., T. Ohe, and K. Fujiwara, Shokuhin Eiseigaku Zasshi, 13, 523, 1972: C.A., 79, 028100, 1973.

Huschenbeth, E., Schr. Ver. Wasser-, Boden-, Lufthyg., Berlin-Dahl, 37, 103, 1972.

Hom, W., R.W. Risebrough, A. Soutar, and D.R. Young. Science 184 (4142).

Interdepartmental Task Force on PCBs. "Polychlorinated Biphenyls and the Environment." COM-72-10419. 1-192. National Technical Information Service, Springfield, Virginia (U.S. Dept. of Agriculture, Commerce, Health-Education and Welfare, EPA, and other agencies), 1972.

Lunde, G., J. Gerber, and B. Josefsson. Bulletin of Environmental Contamination and Toxicology 13(6): 656-661, 1975.

Law, L.M., and D.P. Oberlitz. Pesticides Monitoring Journal 8(1): 33-36, 1974.

Martell, J.M., D.A. Rickert, and F.R. Siegel. Environmental Science and Technology, 9: 872-75, 1974.

Oloffs, P.C., L.J. Albright, and S.Y. Szeto. Canadian Journal of Microbiology 18(9): 1393-1398, 1972.

Oloffs, P.C., L.J. Albright, S.Y. Szeto, and J. Lau. Journal of Fisheries Research Board of Canada, 30(11): 1619-1623.

Panel on Hazardous Trace Substances. "Polychlorinated Biphenyls-Environmental Impact." Environmental Research 5(3): 249-362. 1972.

Peel, D.A., Nature, 254: 324-325, 1975.

Risebrough, R.W., P. Reiche, D.B. Peakall, S.G. Harman, and M.N. Kirven, Nature (12/14): 1098-1102, 1968.

Risebrough, R.W., and B. deLappe. Environmental Health Perspectives Exp 1: 39-45, 1972.

Saschenbrecker, P.W., Can. J. Comp. Med., 37, 203, 1973.

Smith, W.E., K. Funk, and M.E. Zabik, J. Fish. Res. Board Can., 30, 702, 1973.

Walker, W.H., "Where Have All the Toxic Chemicals Gone?" Ground Water 11(2): 11-20, 1973.

2. Monsanto Industrial Chemicals Company, "PCB Manufacture and Sales-Monsanto Industrial Chemicals Company - 1957 thru 1964." (unpublished data), 1974a.

Monsanto Industrial Chemicals Company, "PCB Manufacture and Sales-Monsanto Industrial Chemicals Company - 1965 thru 1974." (unpublished data), 1974b.

NWMAR116106

3. Ruopp, D.J. and V.J. DeCarlo, U.S. Environmental Protection Agency, Washington, D.C. - Private communication.

4. Nisbet, C.T. and A.F. Sarofim, Environmental Health Perspectives, Exp 1, 21-38, 1972.

5. Section V, "Industrial Characterization" and Section IX, "PCBs Release and Cumulative Environmental Loads" of this report.

6. Section V, "Industrial Characterization" and Section IX, "PCBs Release and Cumulative Environmental Loads" of this report.

7. Nisbet, C.T., and A.F. Sarofim. Environmental Health Perspectives Exp 1: 21-38, 1972.

8. Annon., World Almanac, Washington Star News, Washington, D.C., 1975.

9. National Water Quality Inventory. Report to the Congress. Vol II. EPA-440/9-74-001. Office of Water Planning and Standards. Appendices C-1 to C-69, D-1 to D-55, E-1 to E-76., 1974.

International Joint Commission on the Great Lakes. Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River, Vol 3, 1969.

10. Hesse, J.L. Status Report on Polychlorinated Biphenyls in Michigan Waters. Report to Michigan Water Resources Commission., 1973.

11. Annon, World Almanac, Washington Star News, Washington, D.C., 1975.

12. Great Lakes Fisheries. Summary of United States and Canadian Landings (Preliminary Data)., 1974.

Michigan Department of Natural Resources Fisheries Division. Estimates of Biomass of Principal Fish Species in the Great Lakes (first report). Fisheries Research Report No. 1813., 1974.

13. State of Michigan Water Resources Commission, Bureau of Water Management. Polychlorinated Biphenyl Survey of the Kalamazoo River and Portage Creek in the Vicinity of the City of Kalamazoo, 1972.

State of Michigan Water Resources Commission, Bureau of Water Management. Monitoring for Polychlorinated Biphenyls in the Aquatic Environment. Report to Lake Michigan Toxic Substances Committee, May, 1973.

Haile, C.L., G.D. Veith, G.F. Lee, and W.C. Boyle, Chlorinated Hydrocarbons in the Lake Ontario Ecosystem., 1975.

14. Veith, G.D. Environmental Health Perspectives Exp 1: 51-54, 1972.

NWMAR116107

Veith, G.D., and G.F. Lee. Water Research 5(11): 1107-1115, 1971.

Schmidt, T.T., R.W. Risebrough, and F. Gress. Bulletin of Environmental Contamination and Toxicology 6: 235-243, 1971.

15. Panel on Hazardous Trace Substances. Environ. Res., 5, 1972.

16. Bengston, S.A., Ambio, 3 No. 2, p. 84, 1974.

17. Bevenue, A., J.M. Ogata, and J.W. Hylin. Bulletin of Environmental Contamination and Toxicology 8(4): 238-241, 1972.

Bidleman, T.F., and C.E. Olney. Science 183 (4142): 516-518. 2nd Copy, 1974.

Bidleman, T.F., and C.E. Olney. Bulletin of Environmental Contamination and Toxicology 11(5): 442-450, 1974.

Harvey, G.R., and W.F. Steinhauer. Atmospheric Environment 8(8): 777-782, 1974.

Holden, A.V. Nature 228(12/19): 1220-1221, 1970.

Södergren, A. Nature 236: 395-397, 1972.

Tarrant, K.R., and J.O.G. Tatton. Nature 219: 725-727, 1968.

18. United States Geological Survey. Water Resources Data for Michigan. Part 1. Surface Water Records, 1974.

19. United States Geological Survey. Water Resources Data for Wisconsin. Part 1. Surface Water Records, 1974.

20. United States Geological Survey. Water Resources Data for Illinois. Part 1. Surface Water Records, 1974.

21. United States Geological Survey. Water Resources Data for Indiana. Part 1. Surface Water Records, 1974.

22. Ruttner, F., Fundamentals of Limnology. University of Toronto Press., 1952.

23. Saylor, J.H., and P.W. Sloss. Water Volume Transport and Oscillatory Current Flow through the Straits of Mackinac. (Contribution No. 38, Great Lakes Environmental Research Laboratory)., 1975.

24. Hutzinger, O., S. Safe, and V. Zikto. "The Chemistry of PCBs." CRC Press, Cleveland, Ohio, 1974.

25. Kennard, E.H., "Kinetic Theory of Gases", McGraw-Hill, N.Y., 1938.

Langmuir, "Phenomena, Atoms and Molecules", Philosophical Library, N.Y. Chapt. 15., 1950.

NWMAR116108

26. Mackay, D., and A.W. Wolkoff. Environmental Science and Technology 7(7): 611-614, 1973.

27. Haque, R., and D.W. Schmedding. Bulletin of Environmental Contamination and Toxicology 14: 13-18, 1975.

Haque, R., D.W. Schmedding, and V.H. Freed. Environmental Science and Technology 8(2): 139-142, 1974.

Wallnöfer, P.R. , M. Koniger, and O. Hutzinger. Analabs, Inc. Research Notes 13(3): 14-16, 1973.

28. Duce, R.A., J.G. Quinn, C.E. Olney, S.R. Piotrowicz, B.J. Ray, and T.L. Wade. Science 176(4031): 161-163, 1972.

29. Södergren, A., Nature 236: 395-397, 1972.

Risebrough, R.W., et al; Nature (12/14), 1098-1102, 1968.

Harvey, G.R., et al; J. Marine Research 32(2): 103-118, 1974.

Harvey, G.R., and W.G. Steinhauer, Atmospheric Environment, 8(8): 777-782, 1974.

30. Peel, D.A., Nature 254(3/27): 324-325, 1975.

NWMAR116109

APPENDIX E

BACKGROUND DATA USED TO CONSTRUCT
THE MODEL FOR PCBs IN LAKE MICHIGAN

Table E-1

Concentration of PCBs in Sediments
Along the Southwestern Shore of Lake Michigan (1970-1971)[1]

Sample Locations	PCBs (ppb)	
Along SW shore of lake;	13.09 A	15.24 B
sampling 1-3 mi. off-shore*	6.73 A	16.09 ?
(see Figure E-1).	11.81 ?	12.69 ?
	26.07 A	23.53 A
	87.89 A	17.53 A
	130.27 ?	36.7 ?
	26.61 B	58.81 A
	64.32 A	41.06 A
	3.72 A	132.61 A
	3.87 A	80.63 ?
	35.8 A	29.29 A
	8.31 A	13.34 A
	Total = 896.01	
	Ave. [PCB] = 37.3	

NOTE: Estimated location of sampling sites with respect to thermocline: A - above thermocline
B - below thermocline
? - questionable

* Sampling sites are located in an area with several known STP discharges. Data were not available on PCB concentrations in these STP effluents; however, judging from PCB data for other area STPs, it is probable that these plants discharge PCBs, thereby producing higher concentrations in the adjacent sediments.

NWMAR116110

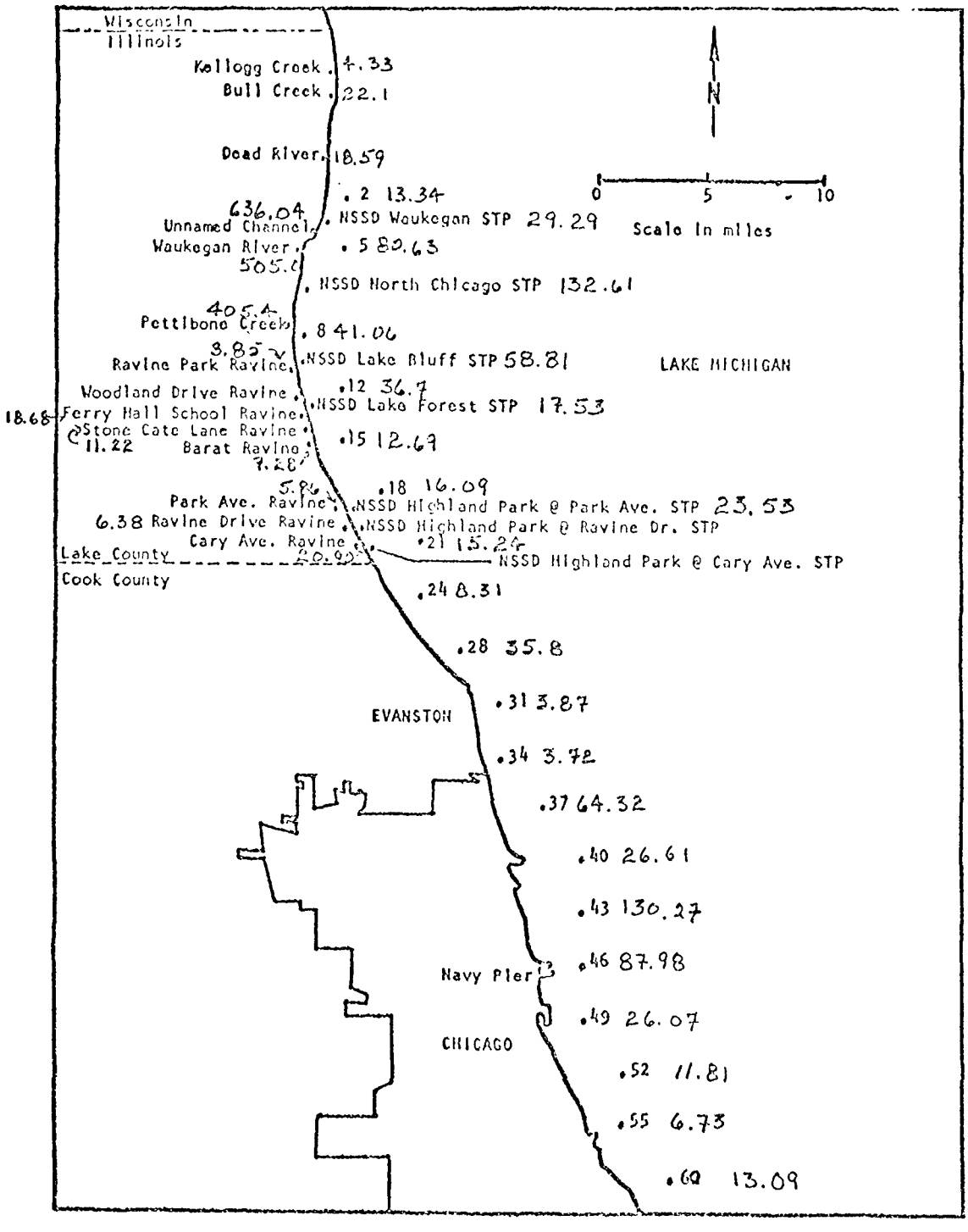


FIGURE E-1. LOCATIONS OF SEDIMENT SAMPLING STATIONS

PCBs in sediments of Lake Michigan & Tributary streams, ravines sediments.

NWMAR116111

Table E-2

Concentration of PCBs in Michigan Streams Tributary to Lake Michigan[2,3,4]

Stream	PCB (ppb; mean 1971-72)	Stream Discharge (1974) (CFS)	(MGD)	PCBs lb/day	lb/yr
St. Joseph	0.013	4,204	2,716	0.29	105.9
Kalamazoo	0.065	2,162	1,397	0.75	275.1
Grand	0.041	5,814	3,756	1.28	466.5
Muskegon	0.010	2,489	1,608	0.13	47.5
Manistee	0.014	2,047	1,322	0.15	54.8
Boardman	0.017	187	121	0.02	7.3
Elk	0.012	575	371	0.04	14.6
Portage	0.47*	18	12	0.045	16.5
TOTAL		17,478	11,291		988.2

*One-time measurement taken in 1972.

NWMAR116112

Table E-3

PCBs Entering Lake Michigan From
Known Industrial and STP Discharges*

State	PCB Load (lb/yr)	Source
Michigan	217.2	STPs
Wisconsin	1170.1	Industries
Wisconsin	130.3	STPs
Indiana	122.3	STPs
Illinois	3.1	STPs
Total	1643	

*See Tables E-4 - E-9 for tabulations of the individual waste discharges.

NWMAR116113

TABLE E-4

Concentration of PCBs in Reported Michigan STP Effluents Tributary to Lake Michigan[1,2,3,4]

STP Location	Design Flow (MGD, 1974)	[PCB] (ppb, 1971-72)	PCB Load (lb/day)
Albion	4.0	0.44	0.015
Battle Creek	22.0	0.39	0.017
Benton Harbon, St. Joseph Plant	13.0	0.65	0.070
Menominee	1.2	0.35	0.004
Muskegon	10.0	0.28	0.023
Niles	10.0	0.68	0.056
Portage	3.6	1.9	0.057
East Lansing	8.5	0.5	0.035
Escanaba	2.2	0.29	0.005
Holland	4.5	0.6	0.022
Jackson	20.0	<0.1	
Kalamazoo	34.0	0.66	0.186
Lansing	34.0	0.18	0.051
Total	147.0*		0.595*

PCB Load = 0.595 lb/day = 217.2 lb/yr.

* Total does not include flows with [PCB] <0.1 ppb.

NWMAR116114

TABLE E-5

Concentration of PCBs in Reported Wisconsin Paper Plant Effluents Discharging to Green Bay (1974-75) (5)

Plant	Flow (mgd)	[PCB] (ppb)	PCB Load (lb/day)
Badger Paper Mills	4.78	<.1	-
Scott Paper			
Marinette	5.91	<.1	-
Oconto Falls	11.03	<.1	-
Shawano Paper	2.43	<.1	-
John Strange Paper	1.11	4.00	0.037
Bergstrom Paper	5.22	28.40	1.26
Kimberly Clark	4.30	0.28	0.010
Thilmany Paper	25.1	<.1	-
Fort Howard Paper			
Mill Effluent	7.3	2.60	0.158
Deinking	11.04	6.40	0.586
Deinking & Mill Effluent	18.1	7.07	1.06
American Can			
Sulfite Sewer	2.23	0.1	0.002
Paper Mill Lagoon	10.35	0.14	0.012
Charmin Paper	16.3	0.14	0.019
Green Bay Packaging	1.77	0.45	0.006
Total*	77.65		3.15

PCB load = 3.15 lb/day - 1,150 lb/yr.

* Total does not include flows with [PCB] <0.1 ppb.

NWMAR116115

TABLE E-6

Concentration of PCBs in Reported Wisconsin Miscellaneous Industrial Effluents Discharged to Lake Michigan[5]

Plant	Flow (mgd)	[PCB] (ppb)	PCB Load (lb/day)
Motor Casting Co.	0.22	<0.1	
Grey Iron Foundry, Inc.	0.339	<0.2	
Howmett, Corp. - Crucible Steel	0.796	<0.1	
Maynard Steel Casting Corp.	0.133	<0.1	
Milwaukee Solvay Coke Co.	4.3	<0.1	
Briggs & Stratton	1.523	<0.2	
Wehr Steel Co.	0.228	<0.1	
EST Co.	0.069	2.95	0.001
Milwaukee Die Casting Co.	0.012*	32.2	0.003
Meta-Mold Daton Malleable Inc.	0.033*	170.3	0.047
Babcock & Wilcox Co. Tubular Products Div.	0.6	0.9	0.004
Total**	0.714		0.055

PCB load - 0.055 lb/day = 20.1 lb/yr.

---

* Average of two readings.

** Total does not include flows with [PCB]<0.1 ppb.

NWMAR116116

TABLE E-7

Concentration of PCBs in Reported Wisconsin STP Effluents Discharged to Green Bay (1974-75) (5)

STP Location	Flow (mgd)	[PCB] (ppb)	PCB Load (lb/day)
Marinette	2.5	<0.1	
Portage	0.736	5.0	0.031
Oshkosh	8.49	0.1	0.007
Neenak-Menash	12.75	0.16	0.017
Appleton	11.05	0.12	0.011
Kaukauna	1.25	<0.1	
DePere	23.45	0.5	0.01
Green Bay	30.64	<0.1	
Kewaunee	0.315	0.18	0.001
Two Rivers	2.28	0.2	0.004
Manitowoc	9.3	<0.1	
Sheboygan	11.04	1.1	0.11
Port Washington	1.59	0.2	0.003
Milwaukee (South Shore)	66.7	0.29	0.160
Milwaukee (S. Milwaukee)	2.42	0.12	0.003
Racine	16.92	<0.1	
Kenosha	18.88	<0.1	
Total	119.8*		0.357*

PCB load = 0.357 lb/day = 130.3 lb/yr.

* Total does not include flows with [PCB]<0.1 ppb.

NWMAR116117

TABLE E-8

Concentration of PCBs in Reported Indiana STP Effluents Tributary to Lake Michigan (6)

STP Location	Flow (mgd)	[PCB] (ppb)	PCB Load (lb/day)
Michigan City	12.2	1.32	0.134
Valparaiso	4.0	0.24	0.008
Hobart	2.9	0.23	0.006
Hammond	42.6	<0.1	
East Chicago	18.7	0.1	0.016
Chestertown	1.6	<0.1	
Gary	50.5	0.38	0.159
South Bend	35.8	<0.1	
Mishawaka	10.39	0.13	0.011
Elkhart	17.5	<0.1	
Goshen	4.8	<0.1	
Nappanee	0.9	<0.1	
Kendallville	1.2	<0.1	
La Grange	0.185	<0.1	
Ligonier	0.434	<0.1	
Angola	0.784	0.17	0.001
Syracuse	0.305	0.13	0.0003
Total*	99.8		0.335

PCB load = 0.335 lb/day = 122.3 lb/yr.

* Total does not include flows with [PCB] <0.1 ppb.

NWMAR116118

TABLE E-9

Concentration of PCBs in Reported
Illinois STP Effluents Discharging to Lake Michigan[1]

STP Location	Flow (mdg)*	[PCB] (ppb)**	PCB Load (lb/day)
N.S.S.D., Waukegan	0.002	2.635	.00004
N.S.S.D., North Chicago Plant	1.2	0.831	.0083
Total	1.202		0.00834

PCB Load = 8.34×10^{-3} lb/day = 3.04 lb/yr.

---

* Data for 1975

** Data for 1971

NWMAR116119

TABLE E-10

Lake Michigan Basin Hydrology[7,8,9,10,11]

Total mean river discharge (1974) of the 4 states (Michigan, Illinois, Wisconsin, and Indiana) into Lake Michigan = 34,508 cfs

$= 1.1 \times 10^{12}$ cf/yr

Total flow of water in the basin = 9.4 billion gpd

Flow diverted from Lake to Chicago = 2 billion gpd

Flow diverted through Straits of Mackinac = 67,000 cfs

Other withdrawl's from the Lake = 11.7 mgd

Volume of STP effluents entering Lake:

from Illinois = 27.6 mgd

from Indiana = 110.5 mgd

from Michigan = 161.6 mgd

from Wisconsin = 183.4 mgd

NWMAR116120

TABLE E-11

Estimates of Fish Biomass in Lake Michigan (1972-73) [12]

Michigan Waters of Lake Michigan	- 11.2×10^6 lb. of lake trout (age group II & older); 1972
Northern Lake Michigan	- 55×10^6 lb. of whitefish (age groups I-VI); 1972
From bottom trawls of the Lake	- 220×10^6 lb. of alewife (age groups I & over); 1973
	- 15×10^6 lb. of chubs (age groups I & over); 1973
Total (1972-73)	- 3×10^8 lb.

If midwater alewives are included, the total could be in the range of 2.3×10^9 lb.

NWMAR116121

Background Calculations Used to Construct the Model for PCBs in Lake Michigan

The concentration and total weight of PCBs in Lake Michigan at the present was calculated on the basis of PCB input to the lake from the following sources: 1) atmospheric fallout directly on the lake, 2) atmospheric fallout over the drainage basin of the lake, and 3) documented point source discharges from tributary industries and sewage treatment plants (STPs). The derived concentration in the water of 0.078 ppb PCB (or 8.4×10^5 lb.) represents the expected maximum amount of the chemical in the water, assuming a constant annual input PCBs over the past 40 years, and no loss of PCB from the lake.

A. Estimation of PCBs in the Lake Water Phase.

1. PCB load from atmospheric fallout directly on the lake surface:

area of lake = 22,400 mi^2 = 5.8×10^{10} m^2 (13)

Assume that the atmospheric fallout of PCBs has a constant annual rate of 50 $mg/m^2/yr.$, that PCBs are evenly distributed across the lake surface, and that the total accumulation over the past 40 years represents the present load;

then the annual PCB fallout on the lake = (50 $mg/m^2/yr$) (5.8×10^{10} m^2)

= 2.9×10^{12} µg/yr.

= 6.4×10^3 lb/yr of PCB

The total fallout on the lake after 40 yrs = 2.6×10^5 lb. of PCB.

2. PCB load from atmospheric fallout on the lake drainage basin:

Assume that fallout (at a constant annual rate of 50 µg $PCB/m^2/yr$) over the basin contributes the majority of the PCBs to the lake via runoff, and that all of the PCBs falling on the drainage basin eventually enter the lake,

then the annual PCB load = (50 $\mu g/m^2/yr$) (area of drainage basin)

For the Michigan portion of the drainage basin -(7)

PCB load = (50 $\mu g/m^2/yr$) (6.0×10^{10} m^2) = 3×10^{12} µg PCB/yr

= 6.6×10^3 lb PCB/yr

NWMAR116122

For the Wisconsin portion of the drainage basin -[8]

PCB load = $(50\ \mu g/m^2/yr)(3.7 \times 10^{10}\ m^2) = 1.9 \times 10^{12}\ \mu g$ PCB/yr
$= 4.1 \times 10^3$ lb PCB/yr

For the Illinois portion of the drainage basin -[9]

PCB load = $(50\ \mu g/m^2/yr)(8 \times 10^8\ m^2) = 4 \times 10^{10}\ \mu g$ PCB/yr
$= 88.1$ lb PCB/yr

For the Indiana portion of the drainage basin -[10]

PCB load = $(50\ \mu g/m^2/yr)(1.85 \times 10^8\ m^2) = 9.3 \times 10^9\ \mu g$ PCB/yr
$= 20.4$ lb PCB/yr

Total annual PCB fallout from all four sectors of the basin = 1.08×10^4 lb/yr and total fallout on the basin after 40 yrs = $(1.08 \times 10^4\ lb/yr)(40) = 4.3 \times 10^5$ lb PCB.

3. Total annual PCB load in the lake due to fallout = PCB load from drainage basin + PCB load from lake surface
$= 1.08 \times 10^4$ lb/yr + 0.64×10^4 lb/yr
$= 1.7 \times 10^4$ lb PCB/yr

4. Total fallout load of PCB after 40 years = $(1.7 \times 10^4\ lb/yr)(40\ yrs) =$
6.9×10^5 lb PCB

5. PCB load entering the lake via tributary stream discharges:

Assume that the concentration of PCBs in the streams has remained constant over the past 40 years, with an annual PCB load equivalent to that in the most recently recorded data.

Data on PCB concentrations are available only for eight tributary streams from the state of Michigan (see Table 2). PCB measurements along the St. Joseph, Kalamazoo, Grand, Muskegon, Manistee, Boardman, Elk, and Portage Rivers indicate a total of 988.2 lb PCB/yr.[2,3,4]

NWMAR116123

6. PCB load entering the lake from reported industrial and STP discharges:

Assume that the concentration of PCBs in the industrial and STP effluents has remained constant over the past 40 years, with an annual PCB load equivalent to that in the most recently recorded data, and that all the PCBs in the discharges eventually enter the lake.

The annual PCB load from the four tributary states is as follows: (see Tables 4-9):[2,3,4]

Michigan - 217.2 lb PCB/yr (from STPs)
Wisconsin - 1150.0 lb PCB/yr (from paper plant effluents)
- 130.0 lb PCB/yr (from STPs)
- 20.1 lb PCB/yr (from misc. industry)
Indiana - 123.3 lb PCB/yr (from STPs)
Indiana - 3.1 lb PCB/yr (from STPs)
TOTAL - 1644.0 lb PCB/yr = 1.6×10^3 lb/yr

7. The total PCB load in the water phase from all the above sources (i.e., fallout, industry, STPs, Michigan streams) = 1.98×10^4 lb/yr. = 7.9×10^5 lb PCB after 40 years of constant accumulation at this annual rate.

8. Concentration of PCBs in the lake water phase:

Calculation based on the lake water volume = 4.91×10^{15} l.

Annual concentration of PCBs =

$$\frac{(1.98 \times 10^4 \text{ lb PCB/yr})(454 \times 10^6 \text{ µg/lg})}{4.9 \times 10^{15} \text{ l}} = 0.002 \text{ ppb/yr}$$

Total maximum concentration of PCBs at present (after 40 years of constant accumulation) =

$$\frac{(7.9 \times 10^5 \text{ lb PCB})(454 \times 10^6 \text{ µg/lb})}{4.91 \times 10^{15} \text{ l}} = 0.073 \text{ ppb PCB}$$

NWMAR116124

9. The above calculations estimate PCB fallout over the drainage basin based on the size of the drainage areas as computed from USGS stream flow data, and totaling 9.8×10^{10} m^2. These data were obtained from flow gaging stations, which were not all located at the mouths of the tributary streams; therefore, the calculated size of the drainage basin may be underestimated.

As an alternative to the above, the same calculations were performed, but using a value of 1.76×10^{11} m^2 for the area of the drainage basin (this area was estimated by the Lake Michigan Federation.[13]

Then, the annual PCB fallout over the basin =

$$\frac{(50\ \mu g\ PCB/m^2/yr)(1.76 \times 10^{11}\ m^2)}{454 \times 10^6}$$

$$= 1.9 \times 10^4 \text{ lb PCB/yr.}$$

After 40 years of constant accumulation at this rate, PCB load =

7.6×10^5 lb PCB (from fallout)

For this larger basin, the total PCBs in the water phase (i.e. fallout + industrial & STP discharges)

$= 1.9 \times 10^4$ lb/yr + 0.16×10^4 lb/yr

$= 2.1 \times 10^4$ lb/yr of PCB

After 40 years of constant accumulation at this rate, the PCB load would be 8.4×10^5 lb.

The PCB concentration in the water phase is:

$$\text{on an annual basis} = \frac{(2.1 \times 10^4)(454 \times 10^6)}{4.91 \times 10^{15}\ l} = 0.002 \text{ ppb}$$

After 40 years of constant accumulation at this rate =

$$\frac{(8.4 \times 10^5)(454 \times 10^6)}{4.91 \times 10^{15}\ l} = 0.078 \text{ ppb}$$

NWMAR116125

B. Estimates of PCB Transport in Lake Ontario, with Application to Lake Michigan.

Sufficient data were not available for Lake Michigan to determine the relationship of PCB concentrations between the water, sediment, and biotic phases. Adequate data were available to determine this relationship for Lake Ontario, and due to the similarities between the two lakes, the calculations were then used to estimate the present situation in Lake Michigan.

1. Sampling of Lake Ontario, conducted in 1972 at several near-shore and mid-lake sites, indicated the following:[14,15]

   PCB in fish (alewives, smelt, slimy sculpin) = $2.35 - 5.13 \times 10^6$ ppt.
   PCB in water (total concentration dissolved + particulate) = 55 ppt.
   Average PCB in sediments = 1.2×10^5 ppt.
   Average PCB in net plankton = 7.2×10^6 ppt.
   Average PCB in benthos = 4.71×10^5 ppt.

   It was assumed that these concentrations are the result of PCB accumulations at a constant rate for the past 40 years.

2. Determination of the rate of PCB deposition in the sediments:

   The average sedimentation rate of Lake Ontario is 1.2 mm/yr (as compared to a rate of 1.0 mm/yr for Lake Michigan.

   Therefore, the thickness of sediment today in Lake Ontario, after 40 years of deposition = 48 mm.

   At this constant rate of deposition, PCBs accumulate in the sediments at a rate = $\frac{1.2 \times 10^5 \text{ ppt PCB}/40 \text{ yrs}}{48 \text{ mm sediment}/40 \text{ yrs}} = 2.5 \times 10^3$ ppt PCB/mm of sediment

   $= 3 \times 10^3$ ppt PCB/yr.

3. Annual accumulation of PCBs in the biota =

$$= \frac{PCB_{fish} + PCB_{Plankton} + PCB_{benths}}{(3)(40 \text{ yrs})}$$

$$= \frac{(5.13 \times 10^6 \text{ ppt}) + (7.2 \times 10^6 \text{ ppt}) + (.471 \times 10^6 \text{ ppt})}{(3)(40 \text{ yrs})}$$

$$= 0.11 \times 10^6 \text{ ppt/yr.}$$

NWMAR116126

4. Annual accumulation of PCBs in the water = $\frac{55 \text{ ppt}}{40 \text{ yrs}}$ = 1.38 ppt/yr.

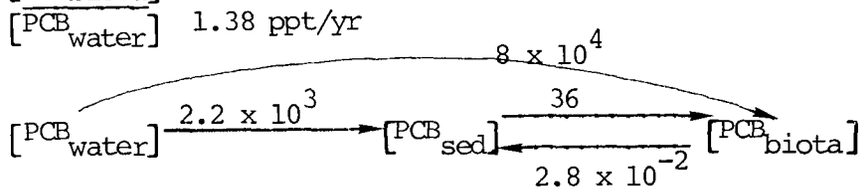
5. Concentration ratios of PCBs in the three phases are:

$$\frac{[PCB_{sed.}]}{[PCB_{water}]} = \frac{3 \times 10^3 \text{ ppt/yr}}{1.38 \text{ ppt/yr}} = 2.2 \times 10^3$$

$$\frac{[PCB_{biota}]}{[PCB_{sed.}]} = \frac{0.11 \times 10^6 \text{ ppt/yr}}{3.0 \times 10^3 \text{ ppt/yr}} = 36$$

$$\frac{[PCB_{biota}]}{[PCB_{water}]} = \frac{0.11 \times 10^6 \text{ ppt/yr}}{1.38 \text{ ppt/yr}} = 8 \times 10^4$$

Therefore,



6. Applying these ratios to Lake Michigan:

$$[PCB_{biota}] = [PCB_{water}](8 \times 10^4)$$
$$= (.078 \text{ ppb})(8 \times 10^4)$$
$$= 6.24 \text{ ppm}$$

$$[PCB_{sed.}] = [PCB_{water}](2.2 \times 10^3)$$
$$= (.078 \text{ ppb})(2.2 \times 10^3)$$
$$= 0.172 \text{ ppm}$$

C. Estimates of Plankton Biomass in Lake Michigan:

1. Assume a density of 300 kg. plankton/hectare of lake[16]
Area of lake = 22,400 mi.^{2} = 5.8×10^6 hectare
Therefore, plankton biomass = $(5.8 \times 10^6)(300 \text{ kg}) = 1.74 \times 10^{12}$g.
$= 3.8 \times 10^9$ lb.

NWMAR116127

D. Estimate of Flow of PCBs Through the Straits of Mackinac:

1. Water flows out of the lake via Straits at a rate = 67,000 cfs.
$= 1.3 \times 10^{14}$ lb of water/yr.

Using the concentration of PCB in the water as 0.013ppb,[17] the loss of PCBs through the Straits is: $= (1.3 \times 10^{14}$ lb/yr)(0.013 ppb)
$= 1.7 \times 10^{3}$ lb PCB/yr.

Assuming a constant loss over the past 40 years, 6.8×10^{4} lb of PCB would have been lost through the Straits.

NWMAR116128

BIBLIOGRAPHY

1. Schacht, R.A.; Pesticides in the Illinois Waters of Lake Michigan, Project #16050 ESP., 1974.

2. State of Michigan Water Resources Commission, Bureau of Water Management, Polychlorinated Biphenyl Survey of the Kalamazoo River and Portage Creek in the Vicinity of the City of Kalamazoo 1972.

3. Hesse, J.L.; Status Report on Polychlorinated Biphenyls in Michigan Waters. Report to Michigan Water Resources Commission, 1973.

4. State of Michigan Water Resources Commission, Bureau of Water Management, Monitoring for Polychlorinated Biphenyls in the Aquatic Environment. Report to Lake Michigan Toxic Substances Committee, May, 1973.

5. Kleinert, Stan; Chief of Water Quality Surveillance Section, DNR Wisconsin, Personal Communication, 1975.

6. Winters, John; Acting Chief of Water Quality and Standards Branch of Illinois EPA, Personal Communication, 1975.

7. United States Geological Survey, Water Resources Data for Michigan. Part 1. Surface Water Records, 1974.

8. United States Geological Survey, Water Resources Data for Wisconsin. Part 1. Surface Water Records, 1974.

9. United States Geological Survey, Water Resources Data for Illinois. Part 1. Surface Water Records, 1974.

10. United States Geological Survey, Water Resources Data for Indiana. Part 1. Surface Water Records, 1974.

11. Saylor, J.H., P.W. Sloss; Water Volume Transport and Oscillatory Current Flow through the Straits of Mackinac. (Contribution No. 38, Great Lakes Environmental Research Laboratory), 1957.

12. Michigan Department of Natural Resources Fisheries Division, Estimates of Biomass of Principal Fish Species in the Great Lakes (first report). Fisheries Research Report No. 1813, 1974.

13. The Lake Michigan Federation, "The Lake Michigan Basin", March, 1975.

14. International Joint Commission on the Great Lakes. Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River, Vol 3, 1969.

NWMAR116129

15. Haile, C.L., G.D. Veith, G.F. Lee, W.C. Boyle; Chlorinated Hydrocarbons in the Lake Ontario Ecosystem, 1975.

16. Ruttner, F., 1952. Fundamentals of Limnology. University of Toronto Press. 295 p., 1952.

17. Nealy, Brock; Chemist with Dow Chemical Co., Midland, Michigan. Personal Communication, 1975.

NWMAR116130

APPENDIX F

TOXICOLOGICAL ASPECTS

1.0 TOXICOLOGICAL ASPECTS OF POLYCHLORINATED BIPHENYLS (PCBs)

1.1 Introduction

A critical biological effect of polychlorinated biphenyls (PCBs) is the induction of tumors in mice and rats, which implies potential human activity. Cancer is typically progressive and irreversible, in the absence of medical intervention. Virtually all chemicals known to cause cancer in man have been shown to cause tumors in animals, including mice and rats. The use of experimental animals to test chemicals is generally accepted as a reliable basis for estimating potential carcinogencity to humans. Pathological development of chemically induced tumors in experimental animals and in humans is very similar, and most of the major types of human cancer can be reproduced in animals by chemical induction. Mice and rats are generally the preferred experimental animals because their relatively short lifespan permits lifetime testing within two to three years, whereas chemical carcinogenesis in humans is usually manifested by a latent period of 30 to 40 years between exposure and the appearance of symptoms. This long latency period coupled with the lack of adequate human data, and the lack of identifiable control groups for widespread agents such as PCBs, make it difficult to identify PCBs as a "human" carcinogen by conventional epidemiological studies. However, most experts in chemical carcinogenesis, including researchers at the National Cancer Institute of NIH and the World Health Organization, accept animal data as predictive of potential human activity.

To date, no minimum effective dose or maximum safe dose has been established for carcinogenic chemicals in man or animals; therefore in approaching the problem of formulating regulatory action all mammalian systems are considered sensitive and man must be considered the target system.

Although in at least one positive study on PCBs the dosage level used would be considered low, high levels are generally used in animal tests because the limited number of animals may render the tests relatively inconclusive. In addition, the strain or species used may also render the tests comparatively insensitive. Failure to demonstrate response at low doses of an oncogen is not an adequate basis to establish a "no-effect" level.

NWMAR116131

Virtually no chemical that has been adequately studied is known to cause only benign tumors. Furthermore, oncogens may cause tumors at different sites in different animals species or strains depending upon factors such as routes of metabolism and excretion.

In considering the current status of medical knowledge, a lack of understanding of the carcinogenic mechanism within cellular biochemistry is evident. One issue that must be resolved in order to establish effective control legislation is whether or not there is a level of carcinogenic exposure below which there are no effects.

The two points of view are known as the "threshold" and the "no-threshold" concepts. The threshold concept is based on the theory that there is a dose level below which no effect will occur regardless of the number of test animals exposed; since this no-effect dose level would be higher than any resultant legally-established exposure limit, humans would not be harmed by doses at or below the limit. The assumption is made that the number of animals affected will decrease at a greater rate than the rate of decrease in the dose until a zero-point is reached. This assumption is unverified. Proponents of the threshold concept believe that for every toxic chemical there is an exposure level below which no effect can occur in a given organism, and that no effect, or possibly even beneficial effects at subthreshold doses, gives way to undesirable effects as the dose is raised. No valid data have been developed to support the concept of safe levels of exposure to carcinogens since the extremely large numbers of animals needed for such experiments preclude such testing, and extrapolation of animal data to man is tenuous.

The no-threshold proponents insist that any substance which is carcinogenic at any level must be regarded as such at all levels. They further insist that it is not possible to predict safe levels of carcinogens based on an arbitrary fraction of the lowest effective animal dose, regardless of how many test animals are used. For those chemicals which have been shown to be carcinogens in experimental animals, no thresholds have been demonstrated. Thus neither the no-threshold theory (or zero-dose concept) nor the threshold concept can be demonstrated or disproved at the present time.

NWMAR116132

In the development of a standard for a carcinogen, the following recommendations, taken from the April 22, 1970 report to the Surgeon General by the Ad Hoc Committee on the Evaluation of Low Levels of Environmental Chemical Carcinogens, National Institutes of Health, should be considered:

1. No level of exposure to a chemical carcinogen should be considered toxicologically insignificant for man. For carcinogenic agents, a 'safe level for man' cannot be established by application of our present knowledge. The concept of 'socially acceptable risk' represents a more realistic notion.

2. The principle of a zero tolerance for carcinogenic exposures should be retained in all areas of legislation presently covered by it and should be extended to cover other exposures as well. Only in the cases where contamination of an environmental source by a carcinogen has been proven to be unavoidable should exception be made to the principle of zero tolerance. Exceptions should be made only after the most extraordinary justification, including extensive documentation of chemical and biological analyses and a specific statement of the estimated risk for man, are presented. All efforts should be made to reduce the level of contamination to the minimum. Periodic review of the degree of contamination and the estimated risk should be made mandatory.

3. A basic distinction should be made between intentional and unintentional exposures.

   (a) No substance developed primarily for uses involving exposure to man should be allowed for wide-spread human intake without having been properly tested for carcinogenicity and found negative.

NWMAR116133

(b) Any substance developed for use not primarily involving exposure in man but nevertheless resulting in such exposure, if found to be carcinogenic, should be either prevented from entering the environment or, if it already exists in the environment, progressively eliminated.

The same report states:

> The production of specific carcinogenic chemicals for uses that do not primarily involve an intentional exposure of man, but which result in such environmental contamination that extensive human exposure becomes inevitable, must also be controlled. The most effective prevention of exposure in man is the elimination of carcinogen production, or control of entry into the environment.

More recently, the Subcommittee on Estimation of Risks of Irreversible, Delayed Toxicity to the Department of Health, Education and Welfare Committee to Coordinate Toxicology and Related Programs published their report (Hoel et al, J. Toxicol. Environ. Health 1, 133, 1975).

> The Subcommittee suggests (on an interim basis only) a computational procedure to assist in setting levels of qualitatively unavoidable chemicals (both natural and manmade) in the environment compatible with a socially acceptable level of risk. It includes a simple arithmetic procedure to compute an exposure dose of a chemical for humans so that there will be a high probability that this dose will give a risk equal to or below the specified level.
>
> Data from experiments designed to detect irreversible self-replicating changes (carcinogenesis) in experimental animals will be used. Through this arithmetic, the results will be translated to appropriately low levels for humans. In

NWMAR116134

addition, human exposure data need to be considered. All the knowledge necessary to evaluate these factors does not yet exist. We suggest here an interim procedure to be used until research points to better procedures such as methods for obtaining direct or best estimates of risk at a given dose with their corresponding confidence limits. Some of this research is now under way. These suggestions must be reviewed as new research is available, but not longer than within two years.

Specifically, the so-called linear straight-line arithmetic method combined with a 99% confidence level for extrapolation to very low levels works this way:*

1. Say an experiment at a dose, d, using 100 animals has shown no induced tumors, for example, in the animals, that is, 0/100=0%.

2. The upper 99% confidence limit on this result (which can be found in standard statistical tables) is 0.045, that is, 4.5%.

3. For a dose, d_s, that will produce, as an upper limit, fewer than 1 in 1,000,000 tumors, divide 1/1,000,000 by .045. This gives (in standard notation) $2.22 \times 10^{-5} d$ as the appropriate dose. If one were to aim for fewer

---

* For certain compounds, some knowledge of the carcinogenicity process may be available, such as with renal concretions resulting in bladder tumors. In these instances, models other than the linear model may be more appropriate.

For illustration we consider only the case of one experimental dose. In practice, however, it is expected that several dose levels will be available and their treatment can be found in the literature (Gross et al., 1970; Mantel and Bryan, 1961; Mantel et al., 1975).

NWMAR116135

than 1 in 100,000,000, (i.e., 1×10^{-8}), the appropriate dose would be $2.22 \times 10^{-7}d$; for fewer than 1 in a hundred thousand (1×10^{-5}), the appropriate dose is $2.22 \times 10^{-4}d$, etc. If 10 of the 100 animals showed a response (i.e., 10/100 = 10%), then the 99% confidence limit is 0.19, that is, 19%. The appropriate dose for 1 in a million is then $5.3 \times 10^{-6}d$ and for 1 in 100,000,000, the dose would be $5.3 \times 10^{-8}d$.

For corrections to a 'natural' incidence, the normal distribution is used to approximate a 99% confidence interval on the difference between the response at dose d and the background. Suppose at dose d 60 of 200 (30%) animals were affected while the natural incidence gave 20 of 200 animals (10%). The upper 99% confidence limit is then approximately

$$.3 - .1 + 2.327[.3(.7)/200 + .1(.9)/200]^{1/2} = 0.29$$

where 2.327 is the 99% point of the standard normal distribution. For a dose, d_s, that will produce as an upper limit of fewer than 1 in a million changes in excess of the natural incidence, 1/1,000,000 is divided by 0.29. This gives $3.4 \times 10^{-6}d$ as the dose, and for 1 in 100,000,000 excess changes the dose is $3.4 \times 10^{-8}d$.

Two questions need to be answered in converting results in animals to man:

1. In what units should the dose conversion be made (i.e., weight basis, surface basis, etc.)? At present it appears that the appropriate dose unit is the 'surface' unit, that is, use the 2/3 power of the weight of the two species (test animal-man) as the surface area conversion factor. For example, if a 25-g mouse receives a dose stated on a milligram basis, then the corres-

NWMAR116136

ponding dose (mg) for a 70-kg man would be (70 kg/25g)$^{2/3}$ = 200 times the mouse dose. Thus, on a mg/kg basis, the use of surface units would require that the corresponding relative dose become (70 kg/25 g)$^{1/3}$ = 14 times the mouse dose. Dose expressed in concentration (ppm) should lead to approximately the same levels as dose expressed in surface area units.

2. Should any additional safety factor be added in going from animals to man? Yes, but not the same factor for all substances. This species conversion factor should be determined substance-by-substance using appropriate biological considerations (and allowing for any safety factors implicit in other parts of the calculation).

A statutory provision exists, however, which provides some sanction to the no-threshold concept. This is, of course, the "Delaney clause", Section 409(c) (3) (A) of the Federal Food, Drug, and Cosmetic Act (21 U.S.C. 321 et seq.), which became law in 1958. This clause provides "... that no additive shall be deemed to be safe if it is found to induce cancer when ingested by man or animal, or if it is found, after tests which are appropriate for the evaulation of the safety of food and additives, to induce cancer in man or animal..."

In spite of all of the furor concerning this clause, it is interesting to note that since its introduction in 1958, it has been invoked only twice to ban food additives and both of these were trivial components of food packaging.

The Food and Drug Administration, in addition to its responsibility for regulating food additives, is also supposed to protect the public from carcinogens which appear naturally or incidentally in our food. These substances are not covered by the Delaney clause. Aflatoxins, DDT, aldrin, nitrosamines, and vinyl chloride are examples. Presently, these problems are handled on the basis of practicality and not on any assessment of risk. That PCBs presently exist in our diet has been amply demonstrated. But the pressure to eliminate such carcinogens from entering our food must fall upon other regulator agencies such as EPA.

NWMAR116137

In summary, there is no generally accepted toxicological basis upon which to establish a no-effect level for any carcinogenic material. Methods which arrive at estimates of acceptable exposure levels for carcinogens in man are, therefore, based on the concept of a "socially acceptable level of risk." In general, the methods employ statistical extrapolation of laboratory animal test data to man, whereupon a political decision as to the socially acceptable incidence of tumors is made. Such estimates of socially acceptable level of risk to determine human exposure tolerances to ionizing radiation have been employed by the Atomic Energy Commission and adopted by the Environmental Protection Agency. Estimates based on acceptable level of risk are only conceptual and must not be taken as calculated no-effect levels.

1.2 Mammalian Toxicity

The current knowledge of the interaction of PCBs with life forms will not be reviewed in detail in this report; an exhaustive review will be submitted in the final report on Task I. This report will highlight only those data relating tumor induction. This review, however, is complete in the sense that major adverse effects are mentioned including those within the major target organs.

PCBs have low acute toxicity. But because of their near complete absorption, high lipid (fat) solubility, low water solubility, and relative chemical inertness, PCBs tend to concentrate in the food chain, accumulate in body fat, persist in biological tissue, and show persistent toxicity. Consequently, short-term studies are not adequate indicators of the long-term effects of PCB exposure. Latent effects, those effects that occur some time after exposure has ceased, and cumulative effects, those effects that occur only after a threshold level of PCB or tissue damage has been reached, may be easily missed over the short term. Since most toxicity studies with PCBs have been short-term, there is limited scientific evidence establishing or predicting the chronic effects.

1.2.1 Subacute and Chronic Toxicity

"No-effect" levels of PCBs in rats and dogs fed three Aroclors for two years were reported by Monsanto in 1971. A summary of their results is presented here.

NWMAR116138

Rats - Method

A two-year chronic toxicity study was conducted using rats fed diets containing Aroclors 1242, 1254 and 1260. The animals employed in the test were Charles River strain albino rats. Four hundred rats (200 male and 200 female) were selected for each of the experiments.

Outline of Each Experiment

Group	Number of Animals		Dietary Level (ppm)
	Male	Female	
Control	50	50	None Administered
T-I	50	50	1
T-II	50	50	10
T-III	50	50	100

Rat Results - Aroclor 1242

At sacrifice after 3, 6 or 12 months on test, organ weights, organ to body weight and organ to brain weight ratios disclosed several randomly occurring intergroup differences. The lack of any consistent dose-related response and the absence of any deleterious tissue changes confirm that these differences were not related to the ingestion of Aroclor 1242.

At the final sacrifice after 24 months on test, the liver weights and liver to body weight or brain weight ratios were significantly elevated in females from the T-III group. Histologic examination of the livers from the T-III group revealed several animals with vacuolar changes indicative of fatty degeneration. Specific fat stains confirmed the presence of fat in these vacuoles. Focal hypertrophy and focal hyperplasia were also found in the livers from animals fed Aroclor 1242.

Hyperplasia of the urinary bladder was found in animals from the control group and from each of the test groups. This hyperplasia was usually associated with cystitis.

NWMAR116139

The incidences and types of all tumors were about the same in all groups, including the control group, and are considered normal for rats of this age.

Rat Results - Aroclor 1254

At sacrifice after 3, 6, or 12 months on test, organ weights, organ to body weight and organ to brain weight ratios disclosed several randomly occurring intergroup differences. The lack of any consistent dose related response and the absence of any deleterious tissue changes confirm that these differences were not related to the ingestion of Aroclor 1254.

At the final sacrifice after 24 months on test, the absolute liver weight and liver to body weight or brain weight ratios were significantly elevated in both T-III males and females. Histologic examinations of the livers from the T-III group revealed several animals with vacuolar changes indicative of fatty degeneration. Specific fat stains confirmed the presence of fat in these vacuoles. Focal hypertrophy and focal hyperplasia were also found in the livers from animals fed Aroclor 1254.

Hyperplasia of the urinary bladder was found in animals from the control group and from each of the test groups. This hyperplasia was usually associated with cystitis.

None of the tumors found could be related to the ingestion of Aroclor 1254 and are considered normal for a random population of rats this age.

Rat Results - Aroclor 1260

At sacrifice after 3, 6, or 12 months on test organ weights, organ to body weight and organ to brain weight ratios disclosed several randomly occurring intergroup differences. The lack of any consistent dose related response and the absence of any deleterious tissue change confirm that these differences were not related to the ingestion of Aroclor 1260.

At the final sacrifice after 24 months on test, the liver weights and liver to body weight or brain weight ratios were significantly elevated in the rats from the T-III group. Histologic examination of the livers from the T-III

NWMAR116140

group revealed several animals also with vacuolar changes indicative of fatty degeneration. Specific fat stains confirmed the presence of fat in these vacuoles. Focal hypertrophy and focal hyperplasia were also found in the livers from animals fed Aroclor 1260.

Hyperplasia of the urinary bladder was found in an animal from the control group but not in any of the test animals.

The incidences and types of all tumors were about the same in all groups, including the control group, and are considered normal for rats of this age.

Dogs - Method

The two-year toxicity study utilized an untreated control group and three test groups, each consisting of eight purebred beagle dogs (four males and four females). The beagles were all eligible for A.K.C. registration and had been previously immunized.

The material to be tested, Aroclors 1242, 1254,aand 1260 were incorporated into a stock diet and fed to the dogs seven days a week in three graded dietary levels. The levels were 1, 10 and 100 ppm.

An outline of the test organization is presented here:

Outline of Each Experiment

Group	Number of Animals		Dietary Level (ppm)
	Males	Females	
UC	4	4	None
I	4	4	1
II	4	4	10
III	4	4	100

Dog Results - Aroclor 1242, 1254 and 1260

No significant abnormalities were observed in the following parameters:

NWMAR116141

Body Weight
Food Consumption
Behavioral Reactions
Hematology
Urine

Animals receiving 100 ppm of Aroclor 1260 exhibited increases in serum alkaline phosphatase activity at the conclusion of the investigation.

A female receiving 100 ppm of Aroclor 1242 was sacrificed in extremis after 60 weeks of testing; gross and histologic examinations revealed severe chronic peritonitis. A male receiving 10 ppm died after 32 weeks of testing; death was attributed to chronic pneumonia. Histologic examination revealed no abnormalities related to the test material ingestion.

Two fatalities occurred during the Aroclor 1254 study: a 100 ppm female after 33 weeks of testing and a 10 ppm female after 37 weeks. The female receiving 100 ppm died from injuries received in a fight. Gross and histologic examinations of the 10 ppm female revealed chronic peritonitis.

Two fatalities occurred during the Aroclor 1260 study: a 100 ppm female after 29 weeks and a 100 ppm male after 33 weeks. Gross and histologic examinations revealed severe chronic peritonitis in the female and acute pneumonia in the male.

All animals receiving 100 ppm of Aroclor 1260 exhibited elevations in liver to body weight ratios.

Gross and histologic examination of all remaining animals revealed no significant abnormalities.

Work by Dr. James Allen (U. of Wisconsin) on simians is discussed in the following paragraphs.

Simians - Method

The hazards to simians of low level PCB exposure have been demonstrated only very recently. Allen in 1974 reported the results of feeding

NWMAR116142

six adult female rhesus monkeys a diet containing 25 ppm of Aroclor 1248 for two months. The average total intake of PCBs for five animals fed for two months was approximately 250 mg, or 0.78 mg/kg body weight per day. The sixth monkey consumed a total of 450 mg at 1.34 mg/kg/day; this animal died 68 days after feeding was stopped.

The effects in all six animals included facial swelling, severe hyperplastic gastritis and liver necrosis. All but one of the surviving were unable to conceive. The one live birth was a smaller than average infant.

The surviving monkeys continued to have high adipose tissue levels, acne, tissue swelling and hair loss two years after this short term, low level exposure. As will be seen, these signs were similar to those encountered in humans during the "Yusho" intoxication in Japan (described later in this report).

1.2.2 Reproduction

PCBs have been shown to affect reproduction in several different species. Egg production, egg hatchability, and shell thickness were decreased by feeding low levels of various PCB formulations to chickens. Female rats fed 20 ppm of Aroclor 1254 (1.5 mg/kg/day) had a decrease in the number of litters and in litter size. In a two-generation study, 5 ppm was the no effect level for rat reproduction. Higher dietary levels caused decreased rat offspring survival and decreased mating performance. Even at 1 ppm, male rats were born with enlarged livers. In a more recent study, Allen has reported that levels in the diet as low as 2.5 ppm resulted in a marked decrease in the ability of monkeys to conceive.

1.2.3 Pathology

One of the most studied toxic effects of PCBs has been in liver pathology in rats and rabbits. PCBs cause similar damage when administered by injection, inhalation, or by mouth. In cases of PCB poisoning, early liver damage has been noted. Many researchers have described the now classical pathological changes in the liver of animals exposed to PCBs. These include infiltration by fat, increased cell and liver size, degeneration of cellular contents, and ultimately cell death. The latent nature of these effects is demonstrated by the fact the most severe histopathology known occurred 5 to 13 weeks after PCB ingestion had ceased.

NWMAR116143

Additional pathological changes have recently been noted. These were classified as adenofibrosis and are often seen in association with liver carcinoma. Abnormal growth and development of the gastric mucosa has also been reported and is further evidence of the carcinogenic potential of PCBs.

For reasons completely independent of any possible association with cancer, the significance of fibrosis, adenofibrosis, and liver necrosis are very grave. These lesions may be associated with carcinomas in rodent liver.

1.2.4 Carcinogenicity

Unfortunately, statistically sound dose-carcinogenic response studies necessary to treat many environmental problems, including PCBs, are currently not available. A review of the world scientific literature reveal only six studies pertinent to carcinogenesis. These are listed and discussed below.

1. Kimbrough, R.D., Linder, R.E., and Gaines, T.B., "Morphological Changes in Livers of Rats Fed Polychlorinated Biphenyls", Arch. Envon. Health 25, 354 (1972).

   An extensive chronic study of Sherman rats, using Aroclors 1260 and 1254, with dietary levels of 0, 20, 100, 500 and 1000 ppm, documented a variety of histopathological effects after 8 months of exposure. Degenerative liver changes observed in both male and female test animals at all dosages of both PCBs included hypertrophy of individual liver cells, hyperchromatic pleomorphic nuclei, cytoplasmic lipid vacuoles, and porphyria, all characteristics of chlorinated hydrocarbon (DDT, dieldrin) intoxication. In some cases, adenofibrosis (uncertain significance) was observed. All of the mortalities that occurred during exposure to the Aroclor 1260 were female. In nearly all gross

NWMAR116144

pathological examinations, males demonstrated enlarged livers, while females did not; liver effects of Aroclor 1254 were adjudged more pronounced than those of Aroclor 1260.

The short duration of this study is a drawback for its inclusion in evaluation of carcinogenic effects.

2. Kimura, N.T. and Baba, T., "Neoplastic Changes in the Rat Liver Induced by Polychlorinated Biphenyl", Gann 64, 105 (1973).

Following the observation, by electron microscopy, of specific morphological alterations (previously observed with other carcinogens) in liver cell nucleoli of animals ingesting PCBs, a preliminary study on PCB carcinogenic activity was instituted. Using rats of the Donry strain, Kanechlor 400 mixed in oil was fed at dietary levels ranging upwards from 38.5 ppm. Ten male and ten female rats were in the experimental group with five of each sex in the control group. Using body weight gains (compared to controls) the concentration of the Kanechlor was increased or decreased according to the following schedule.

Period of Feeding (days)	Concentration of Kanechlor-400 (ppm)
26	38.5
57	77
21	154
21	308
56	616
39	462
29	0
98	462
28	0
82	462
Total 400	

NWMAR116145

Multiple adenomatous nodules were observed in all livers of the female experimental group ingesting more than 1200 mgs of Kanechlor 400. In sharp contrast, however, the liver specimens of the male experimental rats revealed no such changes even in animals receiving comparable or higher amounts of Kanechlor 400 than females. Although these authors refer to this lesion as benign in nature, further discussion of this lesion is presented later in this report.

The variable dosage schedule and the small numbers of animals used present drawbacks for its inclusion in evaluation of carcinogenic effects.

3. Ito, N., et al. "Histopathologic Studies on Liver Tumorigenesis Induced in Mice by Technical Polychlorinated Biphenyls and its Promoting Effect on Liver Tumors Induced by Benzene Hexachloride", J. Natl. Cancer Inst., 51, 1637 (1973).

This paper reports the histopathologic and ultrastructural observations of livers of dd mice fed PCBs in their diet for a period of 32 weeks. Twelve male mice were used at each of three dosage levels. Three PCBs were investigated, Kanechlor 500, 400, and 300. The results indicate hepatocellular carcinomas and nodular hyperplasia were induced by Kanechlor 500 but not by the two other PCBs, as seen below:

NWMAR116146

PCBs Diet (ppm)	Cellular Hypetrophy	Nodular Hyperplasia	Hepatocellular Carcinoma
Kanechlor 500 (500)	++	7/12	5/12
Kanechlor 500 (250)	+	0/12	0/12
Kanechlor 500 (100)	±	0/12	0/12
Kanechlor 400 (500)	++	0/12	0/12
Kanechlor 400 (250)	+	0/12	0/12
Kanechlor 400 (100)	±	0/12	0/12
Kanechlor 300 (500)	±	0/12	0/12
Kanechlor 300 (250)	±	0/12	0/12
Kanechlor 300 (100)	-	1/12	0/12
Control	-	0/6	0/6

The effect of PCBs on neoplastic changes induced by isomers of benzene hexachloride (α, β and γ) in the livers of mice fed a diet containing BHC with and without PCBs for 24 weeks was also studied. The authors concluded that in addition to the carcinogenic activity of PCBs, these materials, also promote tumors induced by α BHC and β BHC.

4. Kimbrough, R.D., and Linder, R.E., "Induction of Adenofibrosis and Hepatomas of the Liver in BALB/cj Mice by Polychlorinated Biphenyls (Aroclor 1254)", J. Natl. Cancer Inst., 53, 547 (1974).

Two groups of 50 BALB/cj inbred male mice were fed 300 ppm of Aroclor 1254 in the diet for 11 and 6 months. The six-months group was given a recovery period of 5 months. The results are presented below:

Dietary Level (ppm)	Exposure Time (Mo.)	Total Survivors	Hepatoma
0	0	34	0
0	0	24	0
300	11	22	9
300	6	24	1

NWMAR116147

In addition, all 22 mice in the group receiving Aroclor 1254 demonstrated adenofibrosis which was not observed in any other group.

5. Makiura, S., et al, "Inhibitory Effect of Polychlorinated Biphenyls on Liver Tumorigenesis in Rats Treated with 3'-Methyl-4-Dimethylaminoazobenzene, N-2-Fluorenylacetamide, and Diethylnitrosamine", J. Natl. Cancer Inst., 53, 1253 (1974).

   The effect of PCBs (Kanechlor 500) on liver carcinogenesis induced by 3-methyl-4 dimethylaminoazobenzene (3' Me-DAB), N-2-fluorenylacetamide (2-FAA) and/or diethylnitrosamine (DEN) was studied in male Sprague-Dawley rats. Duration of exposures were 20 weeks. Liver tumors developed with the three known liver carcinogens, i.e., 3' Me-DAB, 2 FAA, and DEN. No tumors developed in the animals fed PCBs alone and when fed with the above mentioned carcinogens a marked reduction in tumor incidence was observed. The lack of tumors in the PCBs fed rats may have been the result of low dose (500 ppm) and/or the short period of administration since these same authors had induced tumors in rats treated with Kanechlor 500 at 1000 ppm for 72 weeks. Histopathology findings of the livers were similar as previously reported; i.e., fatty changes and cell hypertrophy.

6. Kimbrough, R.D.; Squire, R.A.; Linder, R.E.; Strandberg, J.D.; Montali, R.J. and Burse, V.W., "Induction of Liver Tumors in Rats by Polychlorinated Biphenyl Aroclor(R) 1260", J. Natl. Cancer Inst. (in press, 1975).

NWMAR116148

Two hundred Sherman Strain female rats were fed 100 ppm of polychlorinated biphenyl (Aroclor 1260) for approximately 21 months, and 200 female rats were kept as controls. The rats were sacrificed when 23 months old. Twenty-six of 184 surviving experimental rats and 1 of 173 surviving control rats examined had hepatocellular carcinomas. None of the controls, but 146 of the 184 experimental rats, had neoplastic nodules in their liver. Areas of hepatocellular alteration were noted in 28 of the 173 controls and 182 of the 184 experimental rats. It was concluded that Aroclor 1260 had a hepatocarcinogenic effect in female Sherman Strain rats. The incidence of tumors in other organs did not differ appreciably between the experimental and control groups.

1.2.5 Bryan-Mantel and One Hit Model Calculations of Animal Data for Extrapolation to Humans

As indicated previously, statistical handling of experimental data helps resolve questions of experimental design and the problems of threshold in setting safe doses. We have applied the Bryan-Mantel and One Hit Model calculations to two studies. The results of these analyses are presented in Tables I and II.

Therefore, using the recommendations set forth previously, we conclude that the use of the Bryan-Mantel Probit Model should be used to calculate the "safe" level of PCBs using a theoretical maximum acceptable lifetime risk of $1/10^6$ of development of hepatomas (neoplastic nodules). This dose is 167 ppt at the 99-percent confidence limits if the latest data in rats (Kimbrough 1975) is used. In the case of development of hepatocarcinomas, the level would be 11,887 ppt.

The rather low "safe" dose relative to the hepatomas reflects that the dosage level used in the experiment (i.e., 100 ppm) was too high for that response (146 hepatomas in 184 rats). These neoplasms are mostly benign tumors

NWMAR116149

Table I

Analysis of Carcinogenic Risk to Humans from Ingested PCBs Based on Kimbrough 1975 Study (Rats)

Analytical Method	Confidence Limits (%)	Intake Level in ppt for Specified Levels of Risk for Hepatocarcinomas			
		$1/10^8$*	$1/10^7$*	$1/10^6$*	$1/10^5$*
Bryan-Mantel	95	1963	5080	14,187	43,640
Bryan-Mantel	99	1645	4257	[11,887]	36,566
One Hit	95	4	45	447	4,472
One Hit	99	4	39	391	3,906

Analytical Method	Confidence Limits (%)	Intake Level for ppt for Specified Levels of Risk for Neoplastic Nodules			
		$1/10^8$	$1/10^7$	$1/10^6$	$1/10^5$
Bryan-Mantel	95	27	70	197	605
Bryan-Mantel	99	23	60	[167]	512
One Hit	95	0	2	21	205
One Hit	99	0	2	18	180

Analytical Method	Confidence Limits (%)	Intake Level for ppt for Specified Levels of Risk for Foci			
		$1/10^8$	$1/10^7$	$1/10^6$	$1/10^5$
Bryan-Mantel	95	0	1	3	10
Bryan-Mantel	99	0	1	2	6
One Hit	95	0	0	0	3
One Hit	99	0	0	0	1

*Risk level of one tumor per 10^8,10^7,10^6, or 10^5 population

NWMAR116150

Table II

Analysis of Carcinogenic Risk to Humans from Ingested PCBs based on Kimbrough-1974 Study (Mice)

Analytical Method	Confidence Limits (%)	Intake Level in ppt for Specified Level of Risk for Hepatoma (Neoplastic Nodules)			
		$1/10^{8}$*	$1/10^{7}$*	$1/10^{6}$*	$1/10^{5}$*
Bryan-Mantel	95	451	1167	3258	10022
	99	297	768	2145	6597
One Hit	95	2	21	214	2140
	99	2	16	160	1596

*Risk level of one tumor per 10^{8}, 10^{7}, 10^{6}, or 10^{5} population.

NWMAR116151

occurring late in life. There is little time left for them to become malignant in the remaining life-time of the rat. Until further data become available or other means are used to handle existing data, one should assume the "safe" dose in lifetime human diet to be between 0.2 ppb and 12 ppb.

It is interesting to note that if the simian reproduction data is used and the classical 1/100 safety factor is applied to the lowest dose studied (2.5 ppm), a "safe" dose of 25 ppb is obtained. This dose (2.5 ppm), however, appears to be a minimal effective dose, whereas normally the highest no-effect level is used. Use of minimum effect levels and even other safety factors have been used; e.g., 1/10 to 1/5000. These would result in dosage levels ranging from 250 ppb to as low as 0.5 ppb.

These calculations must be considered preliminary since time has not permitted consideration of other factors, such as:

1) Body surface area instead of body weight in determining daily intake

2) Comparison with most likely human daily intake

3) Further calculations of existing data

4) Combination of all existing animal data

5) Consideration of metabolism, storage and excretion data among animals species as compared to man

1.3 Observations in Humans

In addition to data provided by continuing studies of the various effects of PCBs on laboratory animals, some information is available on the subacute or chronic effects of PCBs on humans.

Human intoxication with Kanechlor 400, a PCB manufactured in Japan (48-percent chlorine) was observed after a heat exchanger leaked fluid into rice oil which was then consumed by Japanese families in 1968. Approximately 1,000 persons were affected, and typical clinical findings included:

NWMAR116152

1. Increased eye discharge
2. Acne-like eruptions
3. Dark brown pigmentation of nails
4. Pigmentation of skin
5. Transient visual disturbance
6. Feeling of weakness
7. Numbness in limbs
8. Headache
9. Weight loss
10. Vomiting
11. Diarrhea
12. Fetal toxicity

Items 5 through 8 represent symptoms of damage to the nervous system seen in "Yusho" patients. PCBs are known to enter the brain, but they do not have a predominant central neurotoxic effect like the related hexachlorophene.

Laboratory findings in the severe cases included:

1. Red blood cells and hemoglobin decreased; leukocytes increased
2. Total serum lipids, triglycerides, alpha 2-globulins increased
3. Slight increase in alkaline phosphatase
4. Liver biopsy-reduction of rough endoplasmic reticulum; hypertrophy of smooth endoplasmic reticulum; giant mitochondria were frequently encountered

When 159 "Yusho" patients were examined in 1969 and 1970, it was found that 50 percent showed no clinical improvement and 10 percent were worse, another indication of the persistence of PCBs in the human body. The chemical was found to be stored primarily in the adipose tissue but also passed into the placenta and fetus.

A very early and common symptom in these patients was chloracne. Chloracne is an occupational skin disease caused by many chemicals. Chloracne resembles adolescent acne in some ways, but is generally more severe. Its symptoms consist of comedones with or without cysts and pustules. The openings of the hair

NWMAR116153

follicles are filled with oil and protein material. Darkening of the skin and secondary inflammation may also occur. During the 1930s and 1940s several large outbreaks occurred in workers engaged in the manufacture of PCBs and closely related chemicals.

The disease can be produced by both direct skin exposure and by oral intake of PCBs. The ability of oral consumption of PCBs to cause persistent chloracne was convincingly demonstrated in the "Yusho" incident, where chloracne was still present in several people three years after oral consumption of PCBs had ceased.

The same study showed no significant difference among sexes, but a significant difference in clinical severity by age was observed, with the 13- to 29-year-old group being the most sensitive. Of the 11 babies born to affected mothers, 2 were stillborn, 9 had dark-brown stained skin, and increased eye discharge was noticeable in most. Growth rates of affected children, as measured by both height and weight gains, were monitored and compared with unaffected classmates; a significant decrease in growth rate was detected in the males who were poisoned, but no definitive change was observed in the females.

Rice oil exposure levels were calculated at approximately 15,000 mg/day (average); the oil itself was reported to be contaminated at about 2,000 ppm Kanechlor 400 (derived from the known organic chlorine content of rice oil in relation to the known organic chlorine content of the PCB). The average total dose of PCBs causing an effect in these victims was reported as 2,000 mg. The lowest PCB level that produced human effects (50 kg man) was 500 mg consumed over a period of 50 days at a rate of approximately 200 ug/kg/day. The effect level was based, however, on overt symptoms, rather than on sensitive biochemical indicators that might have demonstrated effects at even lower levels. Since PCBs probably have a long biological half-life in humans, a toxicological analysis of the human data must be based on the assumption that ingested PCBs would continue to accumulate in tissues for a long period of time.

The apparent human health threat from chronic ingestion of PCBs prompted the U.S. Food and Drug Administration to issue proposed limitations on the levels

NWMAR116154

of PCBs in foods, animal feeds, and food packaging materials. On July 6, 1973, final regulations were promulgated that established temporary tolerances for PCB residues arising from unavoidable contamination. These tolerances are:

1. 2.5 ppm in milk (fat basis)
2. 2.5 ppm in manufactured dairy products (fat basis)
3. 5 ppm in poultry (fat basis)
4. 0.5 ppm in eggs
5. 0.2 ppm in finished animal feed for food-producing animals (except the following finished animal feeds: feed concentrates, feed supplements, and feed premixes)
6. 2 ppm in animal feed components of animal origin, including fishmeal and other by-products of marine origin and in fish animal feed concentrates, supplements, and premixes intended for food-producing animals
7. 5 ppm in edible portions of fish and shellfish (the edible portion of fish excludes head, scales, viscera, and inedible bones)
8. 0.2 ppm in infant and junior foods
9. 10 ppm in paper food-packaging material intended for or used with human food, finished animal feed and any components intended for animal feeds (the tolerance does not apply to paper food-packaging material separated from the food by a barrier impermeable to migration of PCBs)

1.4 Conclusions

PCBs localize in certain tissues and do not break down easily in the body. This persistence leads to cumulative toxicity. Early toxicological evidence concerning the chronic adverse health effects of PCBs from experimental animals such as mice and rats and from observational data in humans has been more recently

NWMAR116155

supplemented by additional experimental findings in monkeys. A close correlation exists between the symptoms noted in humans and those noted in the monkeys, suggesting that the dose response relationships and metabolic and excretion phenomena of PCBs are similar in both humans and monkeys. According to some pathologists, PCB exposure can cause cancerous liver lesions.

Evidence from relatively short-term exposure (several months) and chronic exposure in animals or humans demonstrates that PCBs are a significant health hazard.

NWMAR116156

EVALUATION OF RISK FOR POTENTIAL SUBSTITUTES FOR PCBs

2.0 INTRODUCTION

Although unattainable, absolute safety (i.e., absolute control) is the goal society would like to achieve with regard to all chemicals introduced by industry. Safety as practiced, however, always entails some degree of risk. But experience has shown that maximization of chemical, physical, and toxicological information will minimize risk. For example, if a given compound is known to end up in man's food supply, information on its chemistry and potential chronic toxicity would be essential to minimizing the public health hazard.

The experience with PCBs illustrates the enormous range of complexity of risk evaluation that many new compounds may require for maximum public safety. We believe no one could have foreseen the present situation with PCBs. Thus we strongly feel all substances should not be subjected to a single rigid routine of study, as such action would be self defeating.

Instead, we propose that an orderly step-wise approach be made. Information gathered on specific chemicals should show the direction for the acquisition of additional information. The continuous use and especially the increasing use of new chemicals should be paralleled by additional testing of the chemicals. Such a hierarchy or sequential testing will: (1) result in avoidance of unnecessary test procedures and (2) answer those questions which will in the long run reveal the most productive information.

2.1 Estimation of Dose to the Target System

Mass production of chemicals invariably results in some degree of environmental contamination, but the route by which a given contaminant affects humans varies according to the type of compound. Vinyl chloride, for instance, presents a hazard almost entirely on the occupational level - that is, among workers dealing with vinyl chloride. For PCBs, on the other hand, exposure through direct contact is not the issue; bioaccumulation through the food chain is the exposure route of interest.

NWMAR116157

The pattern of use is one of the most significant factors in determining the exposure of the target system. The use of PCBs in carbonless paper prior to the voluntary ban on this use in 1971 has proven to be an excellent example of the devious routes by which pollutants find their way into our food — carbonless paper is recycled to paperboard for food packaging, and, in addition to PCB release to the waterways during the recycling process, the paperboard itself leaches PCBs to food it contains.

The method of disposal of waste also presents problems, especially with such highly stable compounds as PCBs. Ease of disposability and rapid decomposition to inert compounds after disposal are characteristics which are highly desirable in substitutes for PCBs.

For some PCB substitutes an elaborate examination of their movement through the environment, their transformation by chemical, physical or biological interactions and the dissemination and transport of the resultant compounds may be essential.

The nature of injury must be considered. A reversible functional effect, though undesirable, would be of vastly less consequence than irreversible and fatal effects. Mutagenesis and teratogenesis are more subtle forms of injury, but the testing methods for these grave threats generally are elaborate and involved. This field, however, is advancing rapidly.

With respect to wildlife, considerations are substantially different than with man. Because of the impossibility of pretesting all species with all new chemicals, concern must of necessity be on the endangerment of a species or of a local animal population. This type of information frequently can only be obtained by constant surveillance of the environment within which a compound is released.

2.2 Nature of Tests Needed to Evaluate Human Health Effects

The major determinants of the effects of chemicals upon the health and well-being of the individual and society are:

1. The nature of the chemical *per se*

NWMAR116158

2. The duration of exposure

3. The quantity of the chemical

If a relatively large amount of a toxic chemical acts for a short period of time, the effects are acute, while relatively small amounts acting over long periods tend to produce chronic effects. Other more subtle effects have been noted, and cancer, modification of behavior, genetic effects, potentiation of the toxicity of other environmental compounds may also have to be investigated.

Clearly there is no one protocol by which to evaluate toxicity of every chemical. The following protocols are presented as guidelines only.

2.3 Physical and Chemical Properties

Basic information on physical and chemical properties are, of course, essential. These data are needed not only for analysis and monitoring, but to assess stability and determine whether and where a chemical is likely to be found in the environment. The following data can be easily gathered in a laboratory:

1. Chemical composition
2. Common name, if established
3. Chemical name (Chemical Abstracts, Wiswesser nomenclature)
4. Trade name
5. Structural formula
6. Melting point
7. Boiling point
8. Vapor pressure
9. Density or specific gravity
10. Solubility in water and in selected organic solvents and oils
11. Dissociation constants (pKa or pKb)
12. Physical state
13. Color
14. Odor
15. pH
16. Flashpoint
17. Viscosity

NWMAR116159

Reactions and other characteristics of a chemical in relation to other compounds such as, water, air, and soil should include the following:

1. Oxidizing properties
2. Reducing properties
3. Corrosive hazard
4. Explosive characteristics
5. Hydrolysis rate
6. Photochemistry

2.3.1 Structure and Reactions

Elemental composition, structure, and formula weight may suffice to suggest various reaction a compound is capable of, but the chemistry of new compounds may be highly specialized, and predictive characteristics may not be apparent. In addition to the oxidative, reductive and hydrolysis reactions, reactions of biological importance should also be considered; for example, alkylation, dealkylation, esterification, isomerization, and conjugation with animal and plant constituents may aid in the choice of future testing procedures. Rates and degree of completion of reactions also are useful; for example, the rate of dehydrohalogenation of organochlorine compounds at high pH could provide leads to relative persistence.

2.3.2 Physical Properties

Knowledge of physical properties assists not only in determination of purity, but more importantly, aids in assessment of the potential behavior in and flow through the environment. Physical properties are also useful to the toxicologist in the design of his studies.

2.3.3 Impurities

Impurities such as residues of reactants, residual solvent and congeners, and the products of side reactions must be identified. Many final commercial products are deliberate mixtures. The toxicologist must recognize the problems of impurities and mixtures. The recent experience of 2,4,5T having dioxin contamination is an example. This impurity later was shown to have an LD_{50} for

NWMAR116160

guinea pigs of 1 µg/Kg. Chlorobenzofuran appears to be not only a likely impurity of the parent PCBs, but may also be produced in the intended use of the PCBs; indeed it may even be a metabolic transformation product.

2.4 Information on Manufacturing Process and Possible Losses

The following data on manufacture will be useful in the assessment of PCB substitutes:

1. Description of the basic manufacturing process
2. Purity of starting and intermediate materials
3. Description of quality controls
4. Composition of the technical product including the names and amounts of impurities
5. Annual production reports
6. Present and anticipated uses
7. Means of transportation to site of use
8. Disposal of waste of production
9. Disposal of "spent" material that may contain the chemical
10. Accidental losses likely to occur

2.4.1 Production, Use, Disposal

Knowledge of the production, use and disposal of a chemical will be extremely helpful, along with physical and chemical properties, to estimate exposure levels to specific target systems. These estimates then can be used to identify the control systems that might be instituted to minimize release to the environment. In general, releases associated with production are amenable to controls on manufacturers; releases associated with use are amenable controls on users. Voluntary control over releases during use (equivalent to the voluntary controls exercised by Monsanto with regard to production) warrant further investigation, because the use of a chemical is intimately related to its potential release to the environment. Releases associated with disposal are also related to production and use, but are most easily controlled at the municipal level.

NWMAR116161

2.4.2 Production Specifics

Production is the first level at which a chemical is likely to be introduced to the environment (i.e., through emissions); it is also at this stage that human toxicological data may be first obtained, through occupational exposure. Records of health and exposure levels of employees as now required by the Occupational Health and Safety Administration will be of inestimable value in assessing health effects; the discovery of hemangiosarcoma in workers exposed to vinyl chloride is an example.

Data on production and production losses must be obtained from manufacturers. Inventory statistics and data on methods of transport to major clients will be essential in quantifying losses. All data should be expressed on the final product, i.e., commercial grade, since impurities may prove more harmful than the product itself. Data on the losses from production and transport processes are of critical importance. Much of these data are company confidential and allowances will be necessary to protect confidentiality.

2.4.3 Uses

By far the most important information needed to estimate the exposure of a target population is a knowledge of the uses of a chemical. The first step in understanding how chemicals get to the environment would be to classify the uses into two categories: (1) contained uses, and (2) dispersive uses.

In general those uses designated as contained will not introduce large quantities of chemicals to the environment. However, experience with PCBs has shown that accidents, when they occur, frequently result in massive spills. Information on possible methods and amounts of release during normal contained usage should be carefully considered. The ultimate air route of dispersal of PCBs was never considered a serious threat, though it now appears this may be the major route of dispersal.

The use of consumer products containing toxic materials can result in significant direct exposure as well as affect the disposal pattern of these materials.

NWMAR116162

2.4.4 Disposal

The disposal of chemicals in contained uses is, of course, a major concern, especially with persistent materials such as PCBs. Labelling and refund incentives may be necessary in order to get "spent" materials into the hands of persons knowledgeable in proper disposal techniques. The flow of discarded consumer products, however, presents a much more serious threat. Lack of ability to control this type disposal is obvious.

For products having a short life, disposal rates are approximately equal to production rates. For products with a longer life and rapidly growing consumption rate, the rate of disposal will be smaller than the rate of production and may be estimated from the service life of the product and from production records.

2.5 Environmental Rate - Chemodynamics, Environmental Alteration, and Bioaccumulation

2.5.1 Outline

The following outline lists the type of information needed to investigate adequately the toxicological consequence of introduction of a new chemical such as a PCB substitute. It is not meant to be conclusive but is only intended as a guideline. These data will assist the toxicologist in relating the adverse effect levels in animals to appropriate exposure levels for humans.

I. Movement and fate in water
   - A) Dissipation rate in distilled water
     1. hydrolysis rate at acid, basic, and neutral pH
     2. photodegradation
   - B) Degradation in water containing suspended solids
   - C) Degradation in bottom sediments
   - D) Rate and extent of movement in flowing water — chemical analysis of water downstream
   - E) Bioaccumulation in aquatic microorganisms

NWMAR116163

II. Movement and fate in soil

A) Soil metabolism studies — aerobic and anaerobic

B) Soil persistence studies

C) Leaching studies

III. Movement into and fate in air

A) Volatilization from water, soil and normal use

B) Photodegradation

IV. Fish uptake — in flowing water until plateau is reached and clearing in clean water

V. Biodegradability under sewage treatment conditions

2.5.2 Behavior in Aquatic Environment

The major factors contributing to the partition of a chemical into the aquatic environment are its solubility and latent heat of solution. Because so many organic compounds are hydrophobic, exact solubilities are difficult to obtain. Many of these compounds tend to accumulate at the air/water interface and to form clusters of varying particle size. Temperature, pH, salt content, and other variables affect solubility.

Microbial, photochemical and chemical transformations in aquatic systems play an important role in the ultimate fate of chemicals. Bioaccumulation occurs through:

1.) Direct, active ("intended") transport into an organism's system
2.) Active transport, where the compound is mistaken for one with similar properties (e.g., arsenic being taken up in place of phosphorus)
3.) Passive complex formation, with ligands in the organism
4.) Solubility equilibrium between fat (in the organism) and water

NWMAR116164

II. Movement and fate in soil

A) Soil metabolism studies — aerobic and anaerobic

B) Soil persistence studies

C) Leaching studies

III. Movement into and fate in air

A) Volatilization from water, soil and normal use

B) Photodegradation

IV. Fish uptake — in flowing water until plateau is reached and clearing in clean water

V. Biodegradability under sewage treatment conditions

2.5.2 Behavior in Aquatic Environment

The major factors contributing to the partition of a chemical into the aquatic environment are its solubility and latent heat of solution. Because so many organic compounds are hydrophobic, exact solubilities are difficult to obtain. Many of these compounds tend to accumulate at the air/water interface and to form clusters of varying particle size. Temperature, pH, salt content, and other variables affect solubility.

Microbial, photochemical and chemical transformations in aquatic systems play an important role in the ultimate fate of chemicals. Bioaccumulation occurs through:

1.) Direct, active ("intended") transport into an organism's system
2.) Active transport, where the compound is mistaken for one with similar properties (e.g., arsenic being taken up in place of phosphorus)
3.) Passive complex formation, with ligands in the organism
4.) Solubility equilibrium between fat (in the organism) and water

NWMAR116165

EPA-600/2-77-227
November 1977

Environmental Protection Technology Series

MANUAL FOR THE CONTROL OF HAZARDOUS MATERIAL SPILLS: VOLUME I - Spill Assessment and Water Treatment Techniques

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

NWMAR116166

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

NWMAR116167

EPA-600/2-77-227
November 1977

MANUAL FOR THE CONTROL OF HAZARDOUS MATERIAL SPILLS
VOLUME ONE
SPILL ASSESSMENT AND WATER TREATMENT TECHNIQUES

by

K. R. Huibregtse, R. C. Scholz, R. E. Wullschleger
J. H. Moser, E. R. Bollinger, and C. A. Hansen
Envirex (A Rexnord Company)
Milwaukee, Wisconsin 53214

Contract No. 68-03-2214

Project Officer

Ira Wilder
Oil and Hazardous Materials Spills Branch
Industrial Environmental Research Laboratory-Cincinnati
Edison, New Jersey 08817

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

NWMAR116168

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory-Cincinnati, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

NWMAR116169

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory, Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains suggested procedures for control of hazardous material spills using improvised treatment processes. The methods presented should be used as a last resort in hazardous spill control but do provide an alternative treatment approach if more sophisticated equipment is not available. This Manual includes sections regarding: notification procedures, an inventory of information sources, methods for spill identification and assessment, a thought guide for determining the best method of handling a spill, plus suggested treatment schemes for the 303 designated hazardous chemicals, a limiting factor system design approach, and design, construction and operation steps for each of the five treatment processes applicable to improvised systems. The Manual will be updated periodically to insure the contents are current. Further information on the control of hazardous material spills may be obtained from the Oil and Hazardous Materials Spills Branch (IERL-Ci), Edison, New Jersey 08817.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

NWMAR116170

ABSTRACT

This report involved the development of a Manual for hazardous material spills control. This manual is intended for use by people in charge of a spill clean-up operation or their designated representative, and is not limited to EPA or U.S. Coast Guard on-scene coordinators. Prior familiarization with the contents is critical for effective use of the procedures outlined. Since development equipment is often unavailable for immediate use at a spill site, emphasis has been placed on using improvised systems to treat hazardous materials. However, it is stressed that the procedures presented have not been field tested, and that any improvised system is inherently unsafe. Therefore, extreme care must be taken to follow all safety precautions and additional instruction in dealing with hazardous material spills through training courses, is desired.

This Manual has emphasized spill control, although it is recognized that prevention techniques are critical and a brief overview of these methods is included. The control section has been subdivided into eight chapters with paragraph numbering to aid in cross-referencing. Chapter 1 involves notification procedures which are established by the location of the manual user. An inventory of sources which will provide additional chemical information is included in Chapter 2.

Chapter 3 presents possible identification methods and then relies on CHRIS-Vol. 3, Hazard Assessment, for establishing human danger potential. Chapter 4 presents a thought guide approach for determining the best spill handling method for a given situation. In addition, suggested treatment schemes for 303 hazardous chemicals are included. Necessary safety procedures and process design, using a limiting factor approach, are presented in Chapter 5. Chapter 6 includes construction and operation details for the five improvised treatment processes (filtration, carbon adsorption, ion exchanges, gravity separation and chemical reaction). Treatment components and chemical considerations are included in Chapter 7 and Chapter 8 includes sampling and record keeping instruction.

This report was submitted in fulfillment of Contract No. 68-03-2214 under sponsorship of the Environmental Protection Agency. The project was performed by the Environmental Sciences Division of Envirex Inc. This report covers work begun in June, 1975 and completed in June, 1977.

NWMAR116171

CONTENTS

		Page
FOREWORD		iii
ABSTRACT		iv
LIST OF FIGURES		viii
LIST OF TABLES		xii
ACKNOWLEDGMENTS		xiv
SECTION		
I	INTRODUCTION	1
II	CONCLUSIONS	5
III	RECOMMENDATIONS	8
IV	METHODOLOGY FOR SPILL CONTROL	10
	CHAPTER 1 - NOTIFICATION	11
	1.1 General	11
	1.2 Pertinent Federal Regulations	11
	CHAPTER 2 - INFORMATION SOURCES	24
	2.1 Introduction	24
	2.2 EPA Oil & Hazardous Materials Technical Assistance Data System	24
	2.3 US Coast Guard CHRIS	33
	2.4 Interagency Radiological Assistance Plan	35
	2.5 US Coast Guard National Strike Force	36
	2.6 US Army Technical Escort Center Chemical Emergency Response Team	36
	2.7 Chemical Transportation Emergency Center	37
	2.8 NACA Pesticides Safety Team Network	38
	2.9 Transportation Emergency Assistance Plan	39
	2.10 Chlorine Emergency Plan	39
	2.11 Information Retrieval Systems	40
	2.12 National Emergency Equipment Locator System	40
	2.13 National Analysis of Trends for Emergencies System	41
	2.14 Useful Guides and Reference Handbooks	41

NWMAR116172

CONTENTS (continued)

SECTION		Page
CHAPTER 3 -	IDENTIFICATION AND ASSESSMENT	45
3.1	General	45
3.2	Directions for the First Man on Scene	45
3.3	Directions for the OSC	65
CHAPTER 4 -	DETERMINATION OF THE BEST METHOD FOR SPILL HANDLING	93
4.1	General	93
4.2	Containment of Spilled Materials	93
4.3	Collection of Spilled Materials	108
4.4	Decision on Spill Handling	117
4.5	Handling a Spill by Hauling	124
4.6	Handling by Dilution and Dispersal	125
4.7	Handling by Treatment on Site	125
CHAPTER 5 -	SAFETY CONSIDERATION & PROCESS DESIGN	185
5.1	General	185
5.2	Available Equipment Sources	188
5.3	Safety Precautions	188
5.4	System Design Criteria	195
CHAPTER 6 -	PROCESS CONSTRUCTION AND OPERATION	239
6.1	General	239
6.2	Filtration	239
6.3	Carbon Adsorption	253
6.4	Ion Exchange	267
6.5	Gravity Separation	281
6.6	Chemical Reaction	304
CHAPTER 7 -	PROCESS COMPONENTS & TREATMENT CHEMICALS	336
7.1	General	336
7.2	Process Pumps	336
7.3	Process Tanks	359
7.4	Process Components and Flow Control	373
7.5	Chemical Feed Components	382
7.6	Air Compressors and Blowers	390
7.7	Selection of Corrosion Resistant Materials of Construction	390
7.8	Information on Treatment Chemicals	399
7.9	Suppliers Information	423
7.10	Calculation Aids and Definitions	427

NWMAR116173

CONTENTS (continued)

SECTION		Page
	CHAPTER 8 - STANDARD OPERATING PROCEDURES DURING CLEANUP	439
	8.1 Sampling Procedures	439
	8.2 Records	445
V	METHODOLOGIES FOR SPILL PREVENTION	447
	In Plant Prevention	447
	Spill Prevention During Transport	455
	Safety or Prevention Devices	462
	REFERENCES	467

NWMAR116174

LIST OF FIGURES

No.		Page
1	Information segment headers in OHM-TADs	30
2	Identification questions for train spills	47
3	Typical freight bill for rail shipment	48
4	Identification questions for truck spills	49
5	Typical truck bill of lading accompanying shipment	50
6	Identification questions for bus spills	51
7	Typical bus bill attached to package	52
8	Identification questions for spills from marine vessels	53
9	Identification questions for spills from barges	54
10	Identification questions for spills from airplanes	55
11	Identification questions for spills from pipelines	55
12	Identification questions for spills from storage tanks	56
13	Typical packaging label	57
14	Estimating stream widths	62
15	Beaufort scale for wind speed estimation	64
16	Hazardous materials warning labels	71
17	Hazard assessment computer system (HACS) hazard assessment tree	76
18	Information needs for CG-446-3 summary	77
19	Rate of chemical discharge from triangular notch-shaped openings	84
20	Rate of chemical discharge from rectangular slot-shaped openings	85
21	Chemical discharge from irregularly shaped holes	86
22	Comparative carbon loss vs. time for the three types of openings	87
23	Effects of toxic gases	89
24	Wind effect on hazard zone	91
25	Use of Chapter 4	94
26	Containment of spills on land	97
27	Containment of spills heavier than water	98

NWMAR116175

LIST OF FIGURES (continued)

No.		Page
28	Containment of an entire water mass	99
29	Containment of floating spills	102
30	Suppression of air spills	107
31	Establishing the feasibility of spill containment on land	114
32	Establishing the feasibility of containment for heavier than water spills	114
33	Establishing the feasibility of containment for soluble spills	115
34	Establishing the feasibility of containment for ligher than water spills	115
35	Establishing the feasibility of air spill suppression	116
36	Spill handling thought guide	118
37	Stepwise use of Chapters 4, 5, 6 and 7	187
38	Summary of a safety director's responsibilities	190
39	Limiting factors in system design	196
40	Schematic of carbon column operation	200
41	Pump requirements for unit processes	201
42	Equipment requirements by process element	203
43	Questions to establish limiting factors	204
44	Filter area and media requirements	242
45	Amounts of underdrain material required for column systems	244
46	Preferred option and operating modes - filtration	245
47	Construction details for filters	247
48	Fines scoop	249
49	Backwash volumes for column processes	252
50	Required surface area for carbon columns	257
51	Preferred option and operating modes - carbon adsorption	259
52	Carbon column construction details	261
53	Carbon bed preparation by backwashing for fines removal	264
54	Operating modes for carbon transfer	266
55	Required surface	271
56	Preferred option and operating modes - ion exchange	273
57	Ion exchange column construction details	275
58	Backwash volume for ion exchange	278

NWMAR116176

LIST OF FIGURES (continued)

No.		Page
59	Operating modes for ion exchange resin transfer	280
60	Example of settling test graphs	286
61	Batch sedimentation tank schematic	300
62	Serrated outlet hose	301
63	Continuous operated swirl tank presettler	303
64	Schematic diagrams of chemical treatment options	318
65	Installation of jet mixer in rapid mix tank	319
66	Construction of a mechanical flocculator	321
67	Blower size as a function of process volume for an aeration tank	330
68	Aeration header alternative plan view layouts and schematic of header support	334
69	Examples of typical system sketches showing pump head relationships	339
70	Equivalent length of pipe fittings and valves	342
71	Friction loss in water piping	347
72	Typical determinations made from friction loss chart	348
73	Calculation information for tank volumes	360
74	ASTM head volumes	363
75	Information needed to obtain suitable chemical feed equipment	384
76	Data sheet on acetic acid	405
77	Data sheet on aluminum sulfate	406
78	Data sheet on calcium chloride	407
79	Data sheet on calcium hydroxide	408
80	Data sheet on calcium oxide	409
81	Data sheet on ferric chloride	410
82	Data sheet on ferrous sulfate	411
83	Data sheet on hydrochloric acid	412
84	Data sheet on polyelectrolytes	413
85	Data sheet on potassium permanganate	414
86	Data sheet on sodium bicarbonate	415
87	Data sheet on sodium bisulfate	416

NWMAR116177

LIST OF FIGURES (continued)

No.		Page
88	Data sheet on sodium carbonate	417
89	Data sheet on sodium hydroxide	418
90	Data sheet on sodium hypochlorite	419
91	Data sheet on sodium sulfate	420
92	Data sheet on sodium sulfide	421
93	Data sheet on sulfuric acid	422
94	Format for chemical suppliers information	428

NWMAR116178

LIST OF TABLES

No.		Page
1	INITIAL NOTIFICATION FOR HAZARDOUS MATERIAL SPILLS	12
2	EPA REGIONAL OFFICES	13
3	US COAST GUARD DISTRICTS	14
4	CANADIAN ENVIRONMENTAL PROTECTION SERVICE CONTACT LIST	15
5	APPROPRIATE STATE AGENCIES TO CONTACT	17
6	LIST OF INFORMATION SYSTEMS	25
7	INFORMATION RETRIEVAL SYSTEMS	29
8	REFERENCES TO USE IN CONJUNCTION WITH THIS MANUAL	42
9	METHODS OF IDENTIFYING SPILL LOCATION	60
10	COMPATIBILITY CHART TAKEN FROM CHRIS CG 446-1	67
11	SUMMARY OF HOW TO OBTAIN SHIPPING PAPER COPIES	69
12	HAZARDOUS CHEMICALS DESIGNATED BY THE COAST GUARD	73
13	CALCULATIONS AVAILABLE IN CHRIS HAZARD ASSESSMENT	75
14	USABLE VOLUME OF SHIPPING CONTAINERS	78
15	TYPICAL CARRIER CAPACITIES	81
16	OIL CONTAINMENT REFERENCES	96
17	SPILLS ON LAND	109
18	SPILLS IN WATER - HEAVIER THAN WATER SPILLS	110
19	SPILLS IN WATER - SOLUBLE OR MISCIBLE SPILLS	111
20	SPILLS IN WATER - FLOATING SPILLS	112
21	SPILLS IN AIR	113
22	POSSIBLE TREATMENT SCHEMES	132
23	EQUIPMENT SOURCES	189
24	MANPOWER REQUIREMENTS FOR VARIOUS UNIT PROCESSES PER SHIFT	198
25	COLUMN OPERATION DISCHARGE LINE SIZING	248
26	DESIGN PARAMETERS USED FOR ION EXCHANGE	269
27	TREATMENT CHEMICAL INFORMATION	292

NWMAR116179

LIST OF TABLES (continued)

No.		Page
28	CHEMICAL REACTION OPERATING PARAMETERS	307
29	FLUID PUMPING TERMS	340
30	PRELIMINARY LINE SIZING CHART	341
31	FORM FOR CALCULATION OF TOTAL DYNAMIC HEAD AND TOTAL SUCTION LIFT	343
31a	COMPLETED FORM FOR CALCULATION OF TOTAL DYNAMIC HEAD AND TOTAL SUCTION LIFT	350
32	PUMP SELECTION CHART	354
33	TYPICAL RATING FOR MEDIUM PRESSURE CENTRIFUGAL PUMPS	353
34	TYPICAL AIR PUMP SPECIFICATIONS	357
35	SYNTHETIC LINER MATERIALS	367
36	INFORMATION ON CORROGATED STEEL	369
37	REINFORCED CONCRETE PIPE INFORMATION	370
38	SOIL STRENGTH AND DENSITY INDICATORS	371
39	COMMERCIALLY AVAILABLE HOSES	374
40	MATERIALS OF CONSTRUCTION FOR TYPE A PUMPS	386
41	MATERIALS OF CONSTRUCTION FOR POSITIVE DISPLACEMENT PUMPS	387
42	TYPICAL THERMOPLASTIC TUBE SIZE	389
43	SOURCES AND SIZES OF AIR COMPRESSORS	391
44	PROPERTY COMPARISONS - NATURAL AND SYNTHETIC RUBBERS	396
45	PROPERTIES OF COMMERCIALLY AVAILABLE PLASTICS	397

NWMAR116180

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance from many individuals and organizations in the preparation of this document. Special thanks are extended to the staff of the Oil and Hazardous Material Spills Branch of the Industrial Environmental Research Laboratories in Edison, New Jersey. In particular, the direction and support of Mr. Ira Wilder, Branch Chief and Project Officer, is especially appreciated. In addition, helpful advice from Mr. Frank Freestone, Dr. Joseph LaFornara and Dr. John Brugger is acknowledged.

Input from Coast Guard officials, various strike teams and EPA on-scene coordinators was also appreciated during the preparation of this Manual, since their experience provided vital background information. Finally, thanks are extended to the entire staff of the Environmental Sciences Division--technical, clerical and administrative--who participated in this project and contributed to its success.

NWMAR116181

SECTION I

INTRODUCTION

Increased concern over and regulations concerning the spills of hazardous materials into the environment, along with increasing use of toxic chemicals, have resulted in a growing necessity for treating spills. A spill situation requires immediate response for containment and then treatment of the contaminated media. However, only a limited supply of existing equipment is available for hazardous spill control. Therefore, this Manual was developed to present possible improvised treatment processes for hazardous spill mitigation. In addition, general information required by those using this Manual, including notification procedures, additional information sources, and identification and assessment techniques, are included. Suggested treatment processes for each of the 303 hazardous chemicals are included, but it must be emphasized that they have not been field tested.

This Manual is intended for use by people in charge of a spill cleanup operation and/or their designated representative at the scene of the spill. It is not limited to use by EPA or US Coast Guard on-scene coordinators, but is applicable to various industry personnel or others dealing with hazardous chemicals. The main requirement for effective use of this Manual is to understand the basis for its development and be familiar with the contents prior to a spill occurrence. It is also desirable to have additional instruction in dealing with hazardous chemical spills through training courses such as those offered by National Fire Protection Association (NFPA) or Vanderbilt University. Finally, the Manual should be used in conjunction with many other references that must be readily available to the user.

Prior to the detailed use of this Manual, several important factors must be considered. The first factor is that the improvised treatment processes as proposed are presented as a last resort method for treatment. More sophisticated and, therefore, safer equipment might be available and should be used, if possible. Another consideration is that the proposed equipment designs are just one alternative approach to the development of the unit processes. Imaginative spill control coordinators can modify the design depending upon available materials, site restrictions, etc. It must also be re-emphasized that these methods and the treatment schemes have not been field tested. Interfering factors at a spill site may affect the treatment in an adverse manner and a spill control coordinator must be aware of these possible problems. Strict enforcement of safety procedures is mandatory for safe spill control. Also, an appointed safety director must be aware of potential safety hazards and inform personnel of the risks involved.

NWMAR116182

Due to the complexity of potential spill events, this Manual has presented a generalized approach to spill control. Each of the 303 hazardous chemicals have been considered separately when the suggested treatment schemes were developed. Mixtures must be handled with care by consulting references and manufacturing experts who can indicate possible chemical by-products. The treatment schemes presented in this Manual are basically concentration processes. The residuals of treatment, including sludges and spent media, must be disposed of properly. However, this Manual does not attempt to address the complicated problems of disposal.

This Manual considers both spill control and spill prevention. The emphasis has been on spill control. A summary section which considers spill prevention techniques is included. Further reference to other documents dealing with spill prevention is recommended. Section IV, entitled "Methodology for Spill Control" contains the major emphasis for on-site spill handling. It has been divided into chapters with subdivision numbering for cross-references. The eight chapters deal with different, but related aspects of spill control. Reference to specialized documents in certain areas has been included and it will be necessary for the spill coordinator to have this additional information readily available. Also, there are certain sections of this Manual which require major input by the spill control coordinator who may use this Manual. This is the situation when considering local spill notification requirements, and identifying local suppliers of equipments and auxiliary chemicals.

The following chapters are included:

Chapter 1: Notification

This chapter briefly discusses the legal requirements for notification. However, it requires some preparatory work by the user since individual notification requirements vary by locality. The local government and appropriate state agency must be contacted to determine actual notification requirements, and lists of these agencies are included.

Chapter 2: Information Sources

This chapter provides a brief inventory of various information sources that are available to aid in the event of a spill situation. The sources have not been evaluated but have only been listed with their information capabilities and access telephone numbers.

Chapter 3: Identification and Assessment

In this chapter, various steps to allow identification of the chemical spilled and then to assess the human danger potential are included. It is emphasized that only an on-scene coordinator or a designated representative should follow the procedures and then only if the appropriate safety precautions are taken. If the identity of a spill is completely unknown, it is not recommended that the spill be approached. The assessment portion of the chapter relies heavily on reference to CHRIS Volume 3 "Hazard Assessment",

NWMAR116183

since duplication of the information presented there was not desirable. Suggestions for collecting needed information at the spill site are included for field use.

Chapter 4: Determination of the Best Method for Spill Handling

Chapter 4 presents a brief overview of containment methods and relies on oil spill control references to provide the needed details. The next portion of the chapter includes a thought guide model which allows determination of the best method for handling a spill given various considerations.

Once this decision is reached, the various handling methods are discussed with emphasis on off-stream but on-site treatment methods. Suggested methods of treating the 303 hazardous chemicals are included, but none of the methods have been field tested. They were developed based on industrial wastewater treatment methods, when available, chemical properties and the knowledge of experienced personnel. References are included to allow further research.

Chapter 5: Safety Precautions and System Design

Once it has been established from Chapter 4 that treatment off-stream but on-site is desirable, then the system must be designed. Chapter 5 first lists other equipment sources that should be used if available. If it is necessary to jury-rig a treatment process, strict safety procedures outlined in this chapter should be followed. Finally, in order to design the most effective system prior to construction, a limiting factor approach is desirable. In this procedure, several different variables are considered and the limiting design flow rate is established. Three examples illustrate the technique.

Chapter 6: Process Construction and Operation

This chapter provides description of each of the five unit processes plus detailed instructions regarding performance of appropriate bench tests. Their individual design and construction steps are included. Finally, operation and troubleshooting directions are included for use in the actual treatment.

Chapter 7: Process Components and Treatment Chemicals

A wide variety of critical information is included in this chapter regarding the individual components of the treatment train. Information given includes tank and pump sizing and selection, hoses and fitting specification, and materials of construction. Treatment chemical information includes data sheets providing pertinent properties and a partial list of suppliers. It is recommended that the user of this Manual list potential suppliers of all treatment chemicals and other equipment before a spill occurrence.

Chapter 8: Standard Operating Procedure During Clean-Up

Information regarding sampling and record keeping procedures to be used dur-

NWMAR116184

ing the clean-up operation are included. Both composite and grab samples are discussed along with the mechanics of collection and appropriate sample locations. Sample bottle preparation, sample identification and chain of custody procedures are also presented. Record keeping involves a detailed notation of the field occurrences. Several important records are presented.

This Manual provides a broad range of information for the spill coordinator. But it must be re-emphasized that none of the procedures, with the possible exception of safety precautions are mandatory. The various situations which occur at a spill site cannot be anticipated, so that the procedures presented in this Manual must be applied with caution. The dangers associated in handling a spilled hazardous material cannot be underestimated, so it is strongly recommended that safety be the first priority of those on the scene of a spill.

NWMAR116185

SECTION II

CONCLUSIONS

GENERAL

In order for this Manual to be effective, it is essential that its potential users be thoroughly familiar with its contents and method of use prior to an actual spill situation.

This Manual contains the minimum required information for treating hazardous spills in improvised field situations. It is necessary to have available for immediate use other, more detailed, references specified in this text.

In addition to this Manual, training courses are available to aid personnel in charge of Hazardous Materials spill control. Among the courses offered are a week-long program through Vanderbilt University, a National Fire Protection Association course on control of accidental releases of hazardous chemicals, and others.

SAFETY AND HAZARD ASSESSMENT

The control of hazardous materials spills presents inherently unsafe conditions for personnel and these problems are compounded when improvised equipment is utilized. Therefore, the suggested procedures included in this Manual should be used only when other equipment is not available. Extreme caution is necessary when performing any task and prior awareness of the risks involved is essential. If the identity of the materials spilled is unknown, the safety hazards cannot be defined. Therefore, the spill should not be approached, without a complete protective enclosure or suit offering maximum isolation from the "worst case" spilled material.

This Manual presents only the basic requirements for one method of field implementation of the suggested treatment processes. It is anticipated that in many field situations, even these requirements cannot be met. Therefore, this Manual is not intended to replace well-trained quick thinking personnel in charge of spill control, but rather it is to serve as an aid and primary reference for their use.

Each person likely to be confronted with a spill should determine the proper reporting procedure before any actual spill occurs. In addition to the requirements of National and Regional Contingency Plans, the state reporting requirements must also be met. According to U.S. Coast Guard Regulation, spills of hazardous substances that may affect water sources should be reported to the National Spill Response Center, 800-424-8802.

NWMAR116186

Information sources presented in this document have not been evaluated, but rather have been included to provide a broad base of additional needed input.

Identification of a hazardous spill material can be accomplished and verified by the following methods: examination of shipping papers, recognition of physical properties, analysis for chemical properties, or confirmation with the manufacturer or shipper.

Information needed for proper assessment of the hazard potential of a spill should be collected by the spill control coordinator or a designated representative (defined in this Manual as the Man on the Scene (MOS) and relayed to others for further analysis, if needed.

RESPONSE DECISION ANALYSIS

Immediate remedial action, including proper containment methods, is specific to each spill situation. Instructions for implementing remedial action can only be issued after the spill has been identified and assessed.

There are three basic methods available for handling a hazardous spill. The methods are 1) collecting and hauling the material to a remote location, 2) in-situ treatment of the contaminated media, and 3) treatment in an off-stream but on-site treatment system. As a means of last resort, dilution and dispersal may have to be used to minimize the local impact of a concentrated spill.

Determining the best method of handling a spill requires the evaluation of many variables which affect the situation and will ultimately lead to a logical solution.

Although improvised treatment schemes have been suggested for the 303 chemicals designated as hazardous by the U.S. Environmental Protection Agency, many factors, including personnel safety, may dictate on-site treatment to be the least feasible of all available alternatives.

A "limiting factors design" approach has been developed to allow a determination of those variables that control the rate (and thus the time required) at which the hazardous spill may be treated.

Generally, on-site or in-situ treatment (as opposed to hauling or pumping to a remote location) is the best method of spill cleanup only when the hazardous material has entered a body of water or has been highly diluted by some other means.

WATER TREATMENT METHODS

It was found that five basic unit processes would be sufficient for the combination of treatment processes required for treating most of the 303 materials of concern. These processes are 1) filtration, 2) carbon adsorption, 3) ion exchange, 4) gravity separation, and 5) chemical reaction (oxidation/reduction, neutralization, and precipitation).

NWMAR116187

Batch processes are necessary in improvised treatment systems for many processes because of the unavailability of sophisticated instrumentation for synchronization. However, by constructing a number of batch processes in parallel, a near continuous mode of operation can be achieved.

The use of equalization tanks between individual unit processes simplifies the operation and interconnection logistics between batch processes (e.g., gravity separation and chemical treatment) and continuous flow-through processes (e.g., filtration, carbon adsorption and ion exchange).

Design procedures are outlined for sizing holding tanks for the effluent from the treatment process until analytical results are available. However, the turnover time of the analytical tests, if not performed on site, may require the implementation of an unreasonably large number of storage tanks.

The suggested materials for construction of the treatment processes are those that are readily available from many sources. However, in cases where the easily accessible materials cannot accomplish a task safely (e.g., pumping of corrosive treatment materials), it was necessary to specify special equipment.

The suggested treatment process chemicals have been limited to those that are readily available from chemical supply houses.

NWMAR116188

SECTION III

RECOMMENDATIONS

1. Identification of people in a given geographical area with expertise in control of hazardous materials should be made and then listed with phone numbers for immediate reference. Also, sources of reliable supplies of common materials and equipment used for spill cleanup should be listed and continually updated.

2. Central storage locations should be developed where common equipment items such as chemicals, tanks, booms, carbon, filter media, etc., can be stored in inventory so that these materials will be readily available on a payback basis when a spill occurs.

3. This Manual should ultimately be divided into two separate parts. The first part would contain the appropriate chapters on notification, spill identification, and assessment. This document would have very broad distribution, including local fire departments, etc. The second part, that would contain extensive information on spill treatment, would have a much smaller distribution.

4. The number of hazardous materials covered in this Manual should be increased to include all those presently listed in OHM-TADS and CHRIS.

5. The treatment schemes suggested in this Manual were based on the existing literature coupled with the contractor's experience in this field. Although the treatment schemes are considered to be applicable, many of these schemes should be field tested. These tests would uncover any obvious shortcomings in design or approach, safety hazards and possible problem areas and would allow recommendation for improved construction and treatment procedures.

6. Since bench scale treatability studies are an integral part of using this Manual, persons intending to use them should be trained in these techniques. Also, bench scale test kits containing the required chemicals and equipment should be assembled and available in each central hazardous spill response location.

7. A research study should be performed to develop simple tests for quantitative and rapid analysis of toxic and hazardous materials. These tests must be applicable for on-site use with a minimum of sophisticated equipment.

NWMAR116189

8. All sources providing information with regard to the potential safety hazards of a spilled material should devise a common reporting format of input for use by on-site personnel.

NWMAR116190

SECTION IV

METHODOLOGY FOR SPILL CONTROL

This section of the report contains the main thrust of the manual itself. The techniques to control spills have been presented using a numbered chapter format for ease of cross-reference. The section has been divided into 8 chapters as follows:

Chapter 1: Notification
Chapter 2: Information Sources
Chapter 3: Identification and Assessment
Chapter 4: Determination of the Best Method for Spill Handling
Chapter 5: Safety Considerations and Process Design
Chapter 6: Process Construction and Operation
Chapter 7: Process Components and Treatment Chemicals
Chapter 8: Standard Operating Procedure During Clean-up

As previously stated, it is important for the user of this Manual to be familiar with the content and have previously completed certain information sections. The chapters have been presented in the basic order in which they will be most useful, however, it will be necessary to refer to other chapters, especially during the process design. Therefore overall familiarity with the manual is critical for its most effective use.

NWMAR116191

1.0 CHAPTER 1 - NOTIFICATION

1.1 GENERAL

The objective of this chapter is to assist and encourage the user of this manual to determine the proper initial notification procedure for the immediate reporting of a hazardous material spill in his area. This procedure should be determined before any actual spill occurs. It is intended that each user enter the proper contacts and telephone numbers in Table 1 as he finds appropriate. In this regard the National, State, and Regional Contingency Plans should serve as reference documents and should be kept with this manual. It should be pointed out that all reporting requirements must be met and that State reporting requirements are often more encompassing than Federal requirements. For example, a spill on land only may be covered by State but not by Federal regulation. Also, this discussion covers initial and immediate reporting only; there may also be requirements for later detailed reports to the Regional or State Response Centers and the U.S. Department of Transportation.

It is the responsibility of the user of this Manual to be aware of the regional reporting requirements. To aid in this determination, Tables 2-5 have been included. These tables include the appropriate State and Federal agencies to be contacted in various areas. Telephone numbers have been included where possible although they change periodically; the appropriate agencies should be contacted to determine their current reporting numbers. The needed information regarding notification requirements should be transferred to Table 1 for future reference.

1.2 PERTINENT FEDERAL REGULATIONS

The National Oil and Hazardous Substances Pollution Contingency Plan was developed in compliance with the Federal Water Pollution Control Act (Public Law 92-500). The Plan provides for a pattern of coordinated and integrated response by Departments and Agencies of the Federal Government to protect the environment from the damaging effects of pollution discharges. The Plan as published in the Federal Register, Vol. 40, No. 28- outlines the notification requirements. In this regard Annex V of the Plan states:

> "1503.2 The initial reporting of a pollution discharge by agencies participating in this plan shall be in accordance with the information and format as described in the regional plans. Reports of medium or major discharge received from discharges or the general public by the National Response Center (NRC) shall be relayed by telephone to predesignated On-Scene Coordinator (OSC)."

The Plan also specified the National Response Center, located at Headquarters, U.S. Coast Guard, Washington, D.C., as the headquarters site for activities relative to pollution emergencies. The National Response Team, consisting of representatives from various Federal agencies, serves planning and response functions and is to work closely with the National Response Center.

NWMAR116192

TABLE 1. INITIAL NOTIFICATION PROCEDURE FOR HAZARDOUS MATERIAL SPILLS (to be completed by user)

Agency	Comments
1. Name: National Response Center Address: Headquarters, U.S. Coast Guard Washington, D.C. Contact: NRC Duty Officer Tel. No.: 800/424-8802 (24-hr)	
2. Name: U.S. EPA Regional Office Region No. _____ Address: _____ _____ Contact: _____ Tel. No.: _____ (day) _____ (night)	
3. Name: U.S. Coast Guard District Office District No. _____ Address: _____ _____ Contact: _____ Tel. No.: _____ (day) _____ (night)	
4. State Agency: _____ Address: _____ _____ Contact: _____ Tel. No.: _____ (day) _____ (night)	
5. For spill on or near international waters Foreign Govt. Agency: _____ Address: _____ _____ Contact: _____ Tel. No.: _____ (day) _____ (night)	

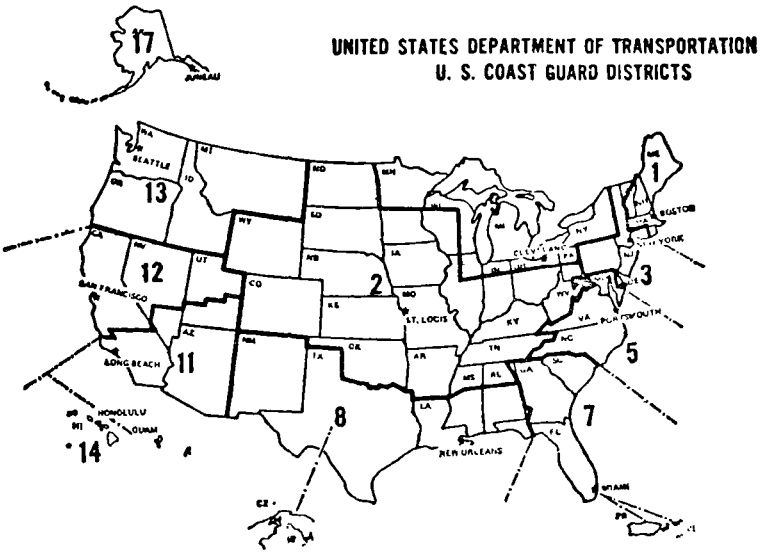
NWMAR116193

TABLE 2. EPA REGIONAL OFFICES

Region		States Included
I.	Environmental Protection Agency Region I, Room 2303 John F. Kennedy Federal Building Boston, Massachusetts 02203 Tel: (617) 223-7265	Maine, Vermont, New Hampshire, Massachusetts, Rhode Island and Connecticut
II.	Environmental Protection Agency Regional II, Room 908 26 Federal Plaza New York, New York 10007 Tel: (201) 548-8730	New York, New Jersey and Puerto Rico
III.	Environmental Protection Agency Region III Curtis Bldg. 6th and Walnut Streets Philadelphia, Pennsylvania 19106 Tel: (215) 597-9898	Pennsylvania, Maryland, Delaware, West Virginia and Virginia
IV.	Environmental Protection Agency Region IV 1421 Peachtree St., N.E. Atlanta, Georgia 30309 Tel: (404) 526-5062	Kentucky, Tennessee, North Carolina, South Carolina, Georgia, Alabama, Mississippi and Florida
V.	Environmental Protection Agency Region V 230 South Dearborn Street Chicago, Illinois 60604 Tel: (312) 896-7591	Ohio, Michigan, Indiana, Illinois Wisconsin and Minnesota
VI.	Environmental Protection Agency Region VI, Suite 1600 1600 Patterson St. Dallas, Texas 75201 Tel: (214) 749-3840	Arkansas, Louisiana, Oklahoma, Texas and New Mexico
VII.	Environmental Protection Agency Region VII 1735 Baltimore Ave. Kansas City, Missouri 64108 Tel: (816) 374-3778	Iowa, Missouri, Nebraska and Kansas
VIII.	Environmental Protection Agency Region VIII, Suite 900 1860 Lincoln Street Denver, Colorado 80203 Tel: (303) 837-3880	North Dakota, South Dakota, Montana, Wyoming, Utah and Colorado
IX.	Environmental Protection Agency Region IX 100 California Street San Francisco, California 94111 Tel: (415) 556-6254	Nevada, Arizona, California, Hawaii and Guam
X.	Environmental Protection Agency Region X 1200 Sixth Avenue Seattle, Washington 98101 Tel: (206) 442-4343	Idaho, Oregon, Washington and Alaska

NWMAR116194

TABLE 3. U.S. COAST GUARD DISTRICTS



1st Coast Guard District
150 Causeway Street
Boston, Mass. 02114
Duty Officer: (617) 223-6650

2nd Coast Guard District
Federal Building
1520 Market Street
St. Louis, Mo. 63101
Duty Officer: (314) 622-4614

3rd Coast Guard District
Governors Island
New York, N.Y. 10004
Duty Officer: (212) 264-4800

5th Coast Guard District
Federal Building
431 Crawford Street
Portsmouth, Va. 23705
Duty Officer: (703) 393-9611

7th Coast Guard District
Room 1018, Federal Bldg.
51 S.W. 1st Avenue
Miami, Fla. 33130
Duty Officer: (305) 350-5611

8th Coast Guard District
Customhouse
New Orleans, La. 70130
Duty Officer: (504) 527-6225

9th Coast Guard District
1240 East 9th Street
Cleveland, Ohio 44199
Duty Officer: (216) 522-3984

11th Coast Guard District
Heartwell Bldg.
19 Pine Avenue
Long Beach, Calif. 90802
Duty Officer: (213) 590-2311

12th Coast Guard District
630 Sansome Street
San Francisco, Calif. 94126
Duty Officer: (415) 556-5500

13th Coast Guard District
618 2nd Avenue
Seattle, Washington 95104
Duty Officer: (206) 524-2902

14th Coast Guard District
677 Ala Moana Blvd.
Honolulu, Hawaii 96813
Duty Officer: (808) 546-7109
(Commercial Only)
AUTOVON 421-4845

17th Coast Guard District
P.O. Box 3-5000
Juneau, Alaska 99801
Duty Officer: (907) 586-7340
(Commercial Only)
AUTOVON 388-1121

NWMAR116195

TABLE 4. CANADIAN ENVIRONMENTAL PROTECTION SERVICE EMERGENCY CONTACT LIST

ATLANTIC REGION

Halifax

RD: Dr. C. J. Edmonds
P.O. Box 2406
Halifax, N.S.

EEC: Mr. H. T. Doane
P.O. Box 2406
Halifax, N.S.

Newfoundland

DM: Mr. I. G. Sherbin
Building 310
Pleasantville
St. John's,
Newfoundland A1A 2Y3

NATIONAL HEADQUARTERS

Ottawa

National Manager: Mr. R. A. Beach
15th Floor
Place Vincent Massey
Ottawa, Ontario
K1A 0H3

Assistant Manager
National Environmental
Emergency Centre:

15th Floor
Place Vincent Massey
Ottawa, Ontario
K1A 0H3

QUEBEC REGION

Montreal

RD: Mr. G. M. Gauthier
P.O. Box 1330
Station B
Montreal 110, Quebec

EEC: Mr. Y. Plunier
P.O. Box 1330
Station B
Montreal 110, Quebec

Toronto

RD: Dr. R. W. Slater
135 St. Clair Ave., N
Toronto, Ontario
M4V 1P5

EEC: Mr. N. Vanderkooy
135 St. Clair Ave., W
Toronto, Ontario
M4V 1P5

Ottawa

National Capital Area Manager:

Mr. L. J. Kamp
45 Spancer St.
Ottawa, Ontario
K1Y 2P5

continued

NOTE: RD: Regional Director EEC: Environmental Emergency Coordinator DM: District Manager

NWMAR116196

TABLE 4 (continued)

NORTHWEST REGION

Edmonton

RD: Mr. J. J. Eatock
10th Floor
Imperial Oil Building
10025 Jasper Ave.
Edmonton, Alberta
T5J 2X9

EEC: Mr. R. K. Pettigrew
10th Floor
Imperial Oil Building
1005 Jasper Ave.
Edmonton, Alberta
T5J 2X9

Winnipeg

DM: Mr. H. C. R. Gavin
9th Floor
303 Main St.
Winnipeg, Maintoba
R3C 3G7

Yellowknife

DM: Mr. W. J. Bryant
9th Floor
Bellanca Bldg.
Yellowknife, N.W.T.

Vancouver

RD: Mr. R. E. McLaren
Kapilano 100
Park Royal
Vancouver, B.C.
V7T 1A2

Whitehorse

DM: Mr. C. E. Wykes
Room 102
Mainsteele Building
212 Main St.
Whitehorse, Y.T.
Y1A 2B1

NWMAR116197

TABLE 5. APPROPRIATE STATE AGENCIES TO CONTACT

ALASKA	Dept. of Environmental Conservation Pouch 0 Juneau, AK 99801
ALABAMA	Alabama Water Improvement Commission State Office Bldg. Montgomery, AL 36104
ARIZONA	State Department of Health Services Environmental Health Services Division Bureau of Water Quality Control 1740 W. Adams Phoenix, AZ 85007
ARKANSAS	Department of Pollution Control and Ecology Water Division 8001 National Drive Little Rock, AR 72209
CALIFORNIA	State Water Resources Control Board Legal & Enforcement Section P.O. Box 100 Sacramento, CA 95801
COLORADO	Colorado Dept. of Health Water Quality Control Division 4210 E. 11th Avenue Denver, CO 80220
CONNECTICUT	Department of Environmental Protection 165 Capitol Avenue Hartford, CT 06115
DELAWARE	Department of Natural Resources Division of Environmental Control Tatnall Building Dover, DE 19901
FLORIDA	Department of Environmental Regulation 2562 Executive Center Circle East Montgomery Building Tallahasee, FL 32301

continued

NWMAR116198

TABLE 5. (continued)

GEORGIA	Department of Natural Resources Environmental Protection Division 270 Washington Street, S.W. Atlanta, GA 30334
HAWAII	Environmental Protection & Health Services Division P.O. Box 3378 Honolulu, HI 96801
IDAHO	Dept. of Health & Welfare Division of Environment Statehouse Boise, ID 83720
ILLINOIS	Environmental Protection Agency 2200 Churchill Road Springfield, IL 62706
INDIANA	Indiana Stream Pollution Control Board 1330 West Michigan Street Indianapolis, IN 46206
IOWA	Iowa Water Quality Commission Department of Environmental Quality P.O. Box 3326 Des Moines, IA 50319
KANSAS	State Department of Health & Environment Division of Environment Topeka, KS 66620
KENTUCKY	Department for Natural Resources and Environmental Protection Division of Water Capitol Plaza Tower Frankfort, KY 40601
LOUISIANA	Louisiana Stream Control Commission P.O. Drawer FC University Station Baton Rouge, LA 70803

continued

NWMAR116199

TABLE 5 (continued)

MAINE	Maine Department of Environmental Protection State House Augusta, ME 04330
MARYLAND	Water Resources Administration Tawes State Office Building Annapolis, MD 21401
MASSACHUSETTS	Division of Water Pollution Control 100 Cambridge St. Boston, MA 02202
MICHIGAN	Dept. of Natural Resources Water Quality Commission 84 Mason Bldg. Lansing, MI 48926
MINNESOTA	Minnesota Pollution Control Agency 1935 W. County Rd. B2 Roseville, MN 55113
MISSISSIPPI	Mississippi Air & Water Pollution Control Commission P.O. Box 827 Jackson, MS 39205
MISSOURI	Department of Natural Resources Division of Environmental Quality Water Quality Program P.O. Box 1368 Jefferson City, MO 65101
MONTANA	Dept. of Health & Environmental Sciences Water Quality Bureau Cogswell Building Helena, MT 59601
NEVADA	State Environmental Commission 102 Johnson St. Carson City, NV 89701
NEW HAMPSHIRE	New Hampshire Water Supply & Pollution Control Commission 105 Loudon Rd. Concord, NH 03301

continued

NWMAR116200

TABLE 5 (continued)

NEW JERSEY	N.J. Dept. of Environmental Protection Division of Water Resources P.O. Box 2809 Trenton, NJ 08625
NEW MEXICO	Environmental Improvement Agency Water Quality Division P.O. Box 2348 Santa Fe, NM 87503
NEW YORK	State Dept. of Environmental Conservation Bureau of Monitoring & Surveillance 50 Wolf Road, Rm 306 Albany, NY 12201
NORTH CAROLINA	Dept. of Natural & Economic Resources Division of Environmental Management P.O. Box 27687 Raleigh, NC 27611
NORTH DAKOTA	State Dept. of Health Division of Environmental Engineering State Capital Building Bismarck, ND 58501
OHIO	Ohio Environmental Protection Agency P.O. Box 1049 Columbus, OH 43216
OKLAHOMA	State Dept. of Health Occupational & Radiological Health Service P.O. Box 53551 Oklahoma City, OK 73105
OREGON	State Department of Environmental Quality 1234 S.W. Morrison Portland, OR 97205
PENNSYLVANIA	Dept. of Environmental Resources Bureau of Water Quality Management P.O. Box 2063 Harrisburg, PA 17120

continued

NWMAR116201

TABLE 5. (continued)

PUERTO RICO	Environmental Quality Board San Juan, Puerto Rico 00910
RHODE ISLAND	Rhode Island Dept. of Health Division of Water Supply & Pollution Control 209 Health Building Davis Street Providence, RI 02908
SOUTH CAROLINA	Office of Environmental Quality Control Monitoring Division J. Marion Sims Building 2600 Bull St. Columbia, SC 29201
SOUTH DAKOTA	Dept. of Environmental Protection Joe Foss Building Pierre, SD 57501
TENNESSEE	Tennessee Division of Water Quality Control 621 Cordell Hull Building Nashville, TN 37219
TEXAS	Water Quality Control Board P.O. Box 13246, Capital Station Austin, TX 78711
UTAH	State Division of Health Bureau of Water Quality 44 Medical Drive Salt Lake City, UT 84113
VERMONT	Agency of Environmental Conservation Water Quality Division State Office Bldg. Montpelier, VT 05602
VIRGINIA	State Water Control Board Bureau of Surveillance & Field Studies P.O. Box 11143 Richmond, VA 23219

continued

NWMAR116202

TABLE 5. (continued)

VIRGIN ISLANDS	Health Department St. Thomas, Virgin Islands 00801
WASHINGTON	State Dept. of Ecology Olympia, WA 98504
WISCONSIN	Department of Natural Resources Bureau of Water Quality P.O. Box 450 Madison, WI 53701
WEST VIRGINIA	Dept. of Natural Resources Division of Water Resources 1201 Greenbrier St. Charleston, WV 25311
WYOMING	Dept. of Environmental Quality Water Quality Division State Office Building West Cheyenne, WY 82002

NWMAR116203

The Plan also provides for Regional Response Centers and Regional Response Teams. The Regional Response Center is the regional site for pollution emergency response activities. Each region has prepared a contingency plan to deal with oil and hazardous material spills in its region. The Regional Response Team performs response and advisory functions in its specific region.

The user of this Manual should obtain a copy of the contingency plan for his region if he does not have one. The regional contingency plan contains detailed information on the response center location, telephone numbers of the appropriate agencies to contact, and geographic boundaries for the various agencies.

NWMAR116204

2.0 CHAPTER 2 - INFORMATION SOURCES

2.1 GENERAL

There are a number of information systems whose main function is to provide assistance during hazardous materials spills. These systems are listed in Table 6. There are also information retrieval services - both computerized and manual - which provide information or a list of titles or abstracts of articles dealing with a specific subject. The organizations which provide these services are listed in Table 7. The availability of an on-line computer usually indicates a short turn-around time for responses. This is often important in an emergency situation. There are also available numerous reference texts and handbooks which contain information on the properties of hazardous chemicals. Those likely to be faced with a hazardous material spill may find it helpful to obtain one or more of these books for future reference. Several useful handbooks are listed in this section. Each system designed specifically to provide information on hazardous materials is discussed in terms of what it is, what information it contains, how it operates, and how it can be accessed by responsible people at the emergency scene. The manual does not attempt to provide an evaluation of these information sources, but rather it is only an inventory with pertinent information required for use.

2.2 EPA OIL AND HAZARDOUS MATERIALS TECHNICAL ASSISTANCE DATA SYSTEM (OHM-TADS)

2.2.1 Description

The OHM-TADS is a computerized information retrieval file on more than 850 oil and hazardous substances. The system is presently on-line and available to assist in identification of a spilled material from certain observations (color, smell, etc.) made at the site. For each substance there are 123 information segments (see Figure 1) covering a wide variety of physical, chemical, biological, toxicological, and commercial data with the greatest emphasis on the effects on water quality. Of the 123 segment headers 95 can be used as search components.

2.2.2 Mode of Operation

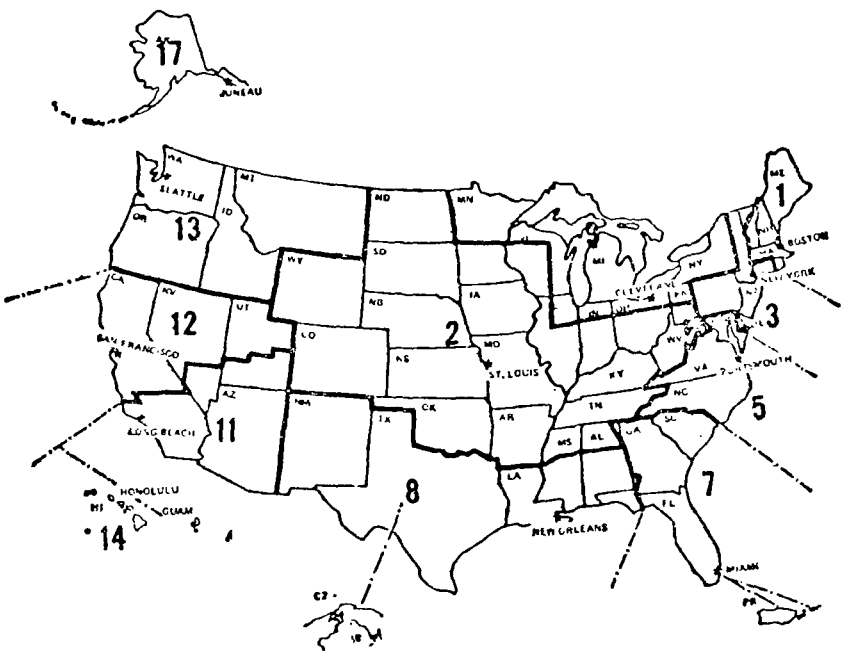
The OHM-TADS has a random access provision which enables the user to solve problems involving unidentified pollutants by inputting color, odor or other physical/chemical characteristics as observed on-scene. The system automatically takes each word and processes it into an inverted index file, making each word a search component of the data base. The search is made using Boolean logic and the system responds with a list of the materials meeting the input characteristics. The output is displayed on the user's terminal. The user can then refine the search if necessary to narrow the list of possible materials.

In looking for characteristics of the spill to aid in identification, the 95 searchable headers should be examined to see if any of them can serve as identifiers.

NWMAR116205

TABLE 6. SOURCES OF INFORMATION/ASSISTANCE FOR HAZARDOUS MATERIAL SPILLS

Information source	Type of Organization	Type of Information Assistance[a]	Access
EPA Oil and Hazardous Materials - Technical Assistance Data System (OHMTADS)	Federal	2-A	EPA Regional Office
Coast Guard Chemical Hazards Response Information System (CHRIS)	federal	2-A	National Response Center Regional Response Centers District Offices:



1st Coast Guard District
150 Causeway Street
Boston, MA 02114
Duty Officer: 617/223-6650

2nd Coast Guard District
Federal Building
1520 Market Street
St. Louis, MO 63101
Duty Officer: 314/622-4614

3rd Coast Guard District
Governors Island
New York, NY 10004
Dity Officer: 212/264-4800

5th Coast Guard District
Federal Building
431 Crawford Street
Portsmouth, VA 23705
Duty Officer: 703/393-9611

7th Coast Guard District
Room 1018, Federal Bldg.
51 S.W. 1st Ave.
Miami, FL 33130
Duty Officer: 305/350-5611

8th Coast Guard District
Customhouse
New Orleans, LA 70130
Duty Officer: 504/527-6225

9th Coast Guard District
1240 East 9th Street
Cleveland, OH 44199
Duty Officer: 216-522-3934

11th Coast Guard District
Heartwell Bldg.
19 Pine Avenue
Long Beach, CA 90802
Duty Officer: 213-590-2311

12th Coast Guard District
630 Sansome Street
San Francisco, CA 94126
Duty Officer: 415-556-5500

13th Coast Guard District
618 2nd Avenue
Seattle, WA 93104
Duty Officer: 206/524-2902

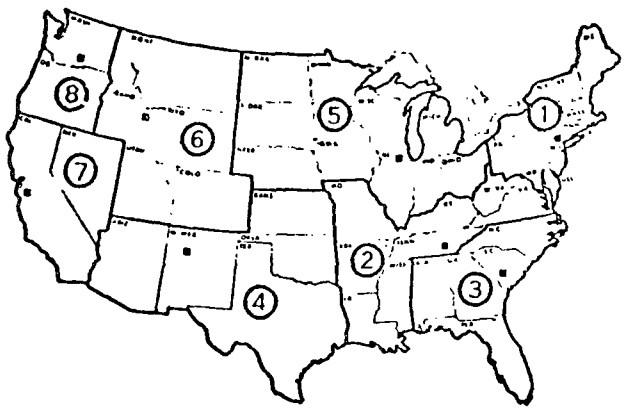
14th Coast Guard District
677 Ala Moana Blvd.
Honolulu, HA 96813
Duty Officer: 803/456-7109
(COMMERCIAL ONLY)
AUTOVON 421-4845

17th Coast Guard District
P.O. Box 3-5000
Juneau, Alaska 99801
Duty Officer: 907/586-7340
(COMMERCIAL ONLY)
AUTOVON 388-1121

NWMAR116206

TABLE 6. (continued)

Information source	Organization	Type of Information Assistance	Access
Interagency Regiological Assistance Plan (IRAP)	Federal	1,2	1. CHEMTREC 800/424-8300 (202/483-7616 in Washington, D.C.) 2. Regional Offices:



	Office	P.O. Address	Telephone	DDD Area Code
1.	Brookhaven Area Office	Upton L.I. New York 11973	345-2200	516
2.	Oak Ridge Oper. Office	P.O. Box E Oak Ridge, TN 37830	480-8617 Ext. 4510	615
3.	Savannah River Operations Office	P.O. Box A Aiken, S.C. 29801	N. August, SC 824-6331 Ext. 3333	803
4.	Albuquerque Operations Office	P.O. Box 5400 Albuquerque New Mexico 87115	264-4667	505
5.	Chicago Operations Office	9300 S. Cass Ave. Argonne Illinois 60439		312
6.	Idaho Operations Office	P.O. Box 2108 Idaho Falls Idaho 83401	526-0111 Ext. 1515	208
7.	San Francisco Operations Office	2111 Bancroft Way Berkeley California 94704	841-5121 Ext. 664 duty hrs 841-9244 off hrs	415
8.	Richland Operations Office	P.O. Box 550 Highland Washington 99352	942-7381	509

NWMAR116207

TABLE 6. (continued)

Information source	Type of Organization	Type of Information Assistance[a]	Access
Coast Guard National Strike Force	Federal	1	National Response Center (800/424-8802)
U.S. Army Technical Escort Center, Chemical Emergency Response Team	Federal	1	Dept. of Army Operation Center 703/521-2185
Chemical Transportation Emergency Center (CHEMTREC)	Privately sponsored	2,3	Through CHEMTREC 800/424-9300 (in Washington, D.C. 202/483-7616)
Pesticides Safety Team Network	Privately sponsored	1,2,3	Through CHEMTREC 800/424-9300 (in Washington, D.C. 202/483-7616)
Transportation Emergency Assistance Plan (TEAP)	Canadian, privately sponsored	1,2,3	Each regional Control Center has 24 hour number: 1. Hooker Chemicals Division Vancouver, British Columbia 604/929-3441; geographic location: British Columbia 2. Celanese Canada Ltd., Edmonton, Alberta 403/477-8339; geographic location: Prairie Provinces 3. Canadian Industries Ltd., Copper Cliff, Ontario 705/682-2881 geographic location: Northern Ontario

NWMAR116208

TABLE 6. (continued)

Information source	Organization	Type of Information Assistance[a]	Access
			4. Dow Chemical of Canada, Ltd., Sarnia, Ontario 519/339-3711 geographic location: Central Ontario
			5. Cyanamid of Canada, Ltd., Niagara Falls, Ontario; 416/356-8310 geographical location: Eastern Ontario
			6. DuPont of Canada, Ltd., Maitland, Ontario; 613-348-3616; geographical location: Western Ontario
			7. Allied Chemical Canada Ltd., Valleyfield, Quebec, 514-373-8330 geographical location: Quebec - south of St. Lawrence
			8. Gulf Oil Canada Ltd., Shawinigan, Quebec, 819-537-1123; geographical location: Quebec, north of St. Lawrence
Chlorine Emergency Plan (CHLOREP)	Privately sponsored	1,2,3	Through CHEMTREC - 800/424-9300 (in Washington, D.C. 202/483-7616

[a]. 1. Respond to scene with trained personnel if required.
2. Provide information on identity, hazards, or what to do.
3. Refer to knowledgeable contact

A. On-line computer available.

NWMAR116209

TABLE 7. INFORMATION RETRIEVAL SYSTEMS

Information source	On-line computer system	Contact
Lockheed Information Systems	yes	415/493-4411 Ext. 45635
Editec Inc.	yes	312/427-6760
Illinois Institute for Environmental Quality Library	yes	312/793-3870
Institute for Scientific Information	yes	215/923-3300
NIOSH Technical Information Center	yes	301/443-3063
National Technical Information Service	yes	202-967-4349
National Emergency Equipment Locator System (NEELS-Canadian)	yes	819-997-3742
National Analysis of Trends in Emergencies System (NATES-Canadian)	yes	819/997-3742
NASA - Scientific & Technical Information Office	yes	202-755-3548
NASA - Indus. Applications Cntrs:		
Univ of Conn., Storrs, Ct.	yes	203/486-4533
Research Triangle Park, NC	yes	919/549-8291
Univ of Pittsburg, PA	yes	412/624-5211
Indiana Univ, Bloomington, IN	yes	812-337-8884
Univ of N. Mexico, Albuquerque	yes	505/277-3622
Univ. of S. Cal, Los Angeles, CA	yes	213/746-6132

Information Source	On-line computer system	Contact
Global Engineering Documentation Services	no	714/540-9870 213/624-1216
U.S. Dept. of Commerce Maritime Administrator	no	212/967-5136
National Bureau of Standards Fire Technology Library	no	301/921-3246
NASA/Aerospace Safety Research & Date Institute	no	216/443-4000 Ext. 285
Chemical Abstract Service Ohio State University	no	614/421-6940
Computer Search Center Illinois Institute of Tech. Research Institute	no	312/225-9630
Fire Research Section Southwest Research Institute	no	512/684-5111 Fxt. 2415
Environmental Engineering Div., Texas A&M University	no	713-845-3011
Toxicology Data Bank, Natl Library of Medicine	no	301-496-1131

NWMAR116210

*1. TADS Accession No.
2. Material Name
3. Synonyms
4. Trade Names
5. Chemical Formula
*6. Species in Mixture
7. SIC Code
8. Common Uses
*9. Rail (%)
*10. Barge (%)
*11. Truck (%)
*12. Pipeline (%)
13. Containers
14. Shipment Size
15. General Storage Procedures
*16. General Handling Procedures
*17. Personal Safety Precautions
18. Production Sites
*19. Use Areas
20. Hydrolysis Product Of
*21. % Additive
22. Flammability
23. Explosiveness
24. Air Pollution
*25. Action Levels
*26. Field Detection, Limit (ppm) Techniques
*27. Laboratory Detection Limit (ppm), Techniques
28. Major Hazards
29. Standard Codes
30. Melting Point (^{o}C)
31. Melting Characteristics
32. Boiling Point (^{o}C)
33. Boiling Characteristics
34. Solubility (ppm 25^{o}C)
35. Solubility Characteristics
36. Specific Gravity
37. Probable location and state of material
38. Binary Reactants
39. Lower Flammability Limit (%)
40. Upper Flammability Limit (%)

(continued)

(Asterisk indicates non-searchable components, for display only)

Figure 1. Information segment headers in OHM-TADS.

NWMAR116211

41. Toxic Combustion Products
42. Extinguishing Methods
43. Lower Explosive Limit (%)
44. Upper Explosive Limit (%)
45. Flash Point (^{o}C)
46. Auto Ignition Point (^{o}C)
47. Inhalation Limit (Value)
48. Inhalation Limit (Text)
49. Irritation Levels (Value)
50. Irritation Levels (Text)
51. Direct Contact
52. General Sensation
53. Lower Odor Threshold (ppm)
54. Lower Odor Threshold (Text)
55. Medium Odor Threshold (ppm)
56. Medium Odor Threshold (Text)
57. Upper Odor Threshold (ppm)
58. Upper Odor Threshold (Text)
59. Lower Taste Threshold (ppm)
60. Lower Taste Threshold (Text)
61. Medium Taste Threshold (ppm)
62. Medium Taste Threshold (Text)
63. Upper Taste Threshold (ppm)
64. Upper Taste Threshold (Text)
65. Corrosiveness
66. Synergistic Materials
67. Antagonistic Materials
68. Degree of Hazard to Public Health
69. Exchange Capacity with Natural Soils
70. Industrial Fouling Potential
71. Effect on Water Treatment Process
72. Direct Human Ingestion (mg/kg wt)
*73. Reference for Direct Human Ingestion
74. Recommended Drinking Water Limits (ppm)
*75. Reference for Recommended Drinking Water Limits
76. Body Contact Exposure (ppm)
*77. Reference for Body Contact Exposure
78. Fresh Water Toxicity
79. Limiting Water Quality
80. Salt Water Toxicity
81. Animal Toxicity
82. Livestock Toxicity (ppm)
*83. Reference for Livestock
84. Waterfowl (ppm)

(continued)

Figure 1 (continued).

NWMAR116212

*85. Reference for Waterfowl
86. Aquatic Plants (ppm)
*87. Reference for Aquatic Plants
88. Irrigable Plants (ppm)
*89. Reference for Irrigable Plants
90. Major Species Threatened
91. Acute Hazard Level
92. Etiological Potential
93. Emergency Water Quality Std (ppm)
94. Prolonged Human Contact (ppm)
*95. Reference for Prolonged Human Contact
96. Potential for Accumulation
97. Chronic Aquatic Toxicity Limits (ppm)
*98. Reference for Chronic Aquatic Toxic Limit
99. Taste Imparting Characteristics (ppm)
*100. Reference for Taste Imparting Characteristics
101. Chronic Animal Toxicity Limits (ppm)
*102. Reference for Chronic Animal Toxicity Limits
103. Chronic Waterfowl Toxicity Limits (ppm)
*104. Ref. for Chronic Waterfowl Toxicity Limits
105. Chronic Plant Toxicity Limits (ppm)
*106. Ref. for Chronic Plant Toxicity Limits
107. Soil Transformation Properties
108. BOD (lb/lb)
109. In Situ Amelioration
110. Beach and Shore Restoration
*111. Availability of Countermeasure Material
112. Disposal Methods
*113. Disposal Notification
114. Chronic Hazard Level
115. Food Chain Concentration Potential
116. Persistency
117. Major Water Uses Threatened
118. Adequacy of Data
119. Carcinogenicity
120. Mutagenicity
121. Teratogenicity
122. Color in Water
123. Fields Containing Data

Figure 1 (continued)

NWMAR116213

2.2.3 Access

Access to OHM-TADS is through the oil and hazardous material spill coordinator at the EPA Regional office (Regional Response Center).

2.3 U.S. COAST GUARD CHRIS

2.3.1 Description

This system consists of four manuals, a regional contingency plan, a hazard-assessment computer system (HACS), and an organizational entity at the Coast Guard Station. The four manuals are as follows:

Vol. 1-CG-446-1 - Condensed Guide to Chemical Hazards - contains essential information on those hazardous chemicals that are shipped in large volumes by marine transportation.

Vol. 2-CG-446-2 - Hazardous Chemical Data Manual - contains detailed information on the chemical, physical, and toxicological properties of hazardous chemicals, in addition to all the information in Vol. 1.

Vol. 3-CG-446-3 - Hazard Assessment Handbook - contains methods of estimating the rate and quantity of hazardous chemicals that may be released and methods for predicting the potential toxic, fire, and explosive hazards.

Vol. 4-CG-446-4 - Response Methods Handbook-contains information on existing methodology for handling spills; the Appendix to this volume contains a list of manufacturers of equipment which may be useful in a spill situation.

The contingency plan is part of the National Contingency Plan as mentioned in Chapter 1. The Hazard - Assessment Computer System is the computerized counterpart of Volume 3 and makes it possible to obtain detailed hazard evaluations. Although calculations can be performed by hand using Vol. 3, the HACS permits one to make a more complex and usually more accurate assessment of the spill situation.

2.3.2 Mode of Operation

Volume 1, Condensed Guide to Chemical Hazards, is intended for use by port security personnel and others who may be first to arrive at the scene of the accident. It contains easily understood information about the hazardous nature of the chemical, assuming the chemical is identified. It is intended to assist those present in quickly determining the actions that must be taken immediately to safeguard life, property and the environment. Volume 1 contains a list of the information needed to assess potential hazardous effects through the use of Volume 3.

Volumes 2, 3, and 4 are intended for use by the On-Scene Coordinator's (OSC) office and the Regional and National Response Centers. Coast

NWMAR116214

Guard stations, especially those in major ports, will usually also have these manuals. The computer system (HACS) is also designed for use by OSC personnel.

Volumes 2 and 3 are designed to be used together. For example, Vol. 2 The Hazardous Chemical Data Manual contains a hazard-assessment code for each chemical. This code is used in Vol. 3 The Hazard-Assessment Handbook to select the appropriate calculation procedures for the hazard assessment, enabling the user to estimate the rate and quantity of hazardous chemicals that may be released under different situations. For example, procedures are provided for estimating the concentration of hazardous chemicals (both in water and in air) as a function of time and distance from the spill. The Hazard-Assessment Computer System (HACS) is the computerized counterpart of Vol. 3 and makes it possible to obtain detailed hazard evaluations quickly. The HACS system is intended primarily for use by OSC personnel through Coast Guard headquarters. While the input needed for evaluation will depend on the specific accident situation and that part of the system which is to be used, the following information should be supplied to Coast Guard headquarters as applicable.

Material discharged
Quantity spilled
Quantity originally in tank
Location of spill
Time of occurrence
Tank dimensions
Other cargos or nearby chemicals
Hole diameter
River depth
River width
Stream velocity
Temperature (air)
Temperature (water)
Cloud cover (percent)

Depending on which model it is decided to use, other information may be needed by Coast Guard headquarters. In this case a call back number should be given so that headquarters personnel can request additional information if necessary. More information on the use of Vol. 3 is given in Chapter 3 of this report.

Volume 4, The Response Methods Handbook, contains descriptive and technical information on methods of spill (primarily oil) containment. This manual is intended for use by Coast Guard OSC personnel who have had some training or experience in hazard response.

2.3.3 Access

Access to the CHRIS manuals can be obtained through the Coast Guard District office (see Table 6). The HACS can be assessed on an emergency basis

NWMAR116215

through the Regional Response Center, the Coast Guard District office, or directly through the Department of Transportation National Response Center at Coast Guard headquarters.

2.4 INTERAGENCY RADIOLOGICAL ASSISTANCE PLANT (IRAP)

2.4.1 Description

The Interagency Radiological Assistance Plan (IRAP) is designed to assist any person in obtaining technical guidance in coping with radiation emergencies. It operates through the U.S. Energy Research and Development Administration but works closely with other Federal, state, military, and regional groups. In the IRAP the U.S. is divided into eight geographical areas of responsibility each with a regional coordinating office. These areas and the offices with telephone numbers are given in Table 6.

2.4.2 Mode of Operation

Upon receiving an emergency call, the regional coordinator investigates the situation to assess the potential radioactive hazard. He tries to get as much information over the phone on the specifics of the situation and the type of material (e.g. from the shipping papers). Advice will be given over the phone if the potential hazard appears minimal. If the spill or leak appears serious, a technical response team will be dispatched. This team will work jointly with state personnel (civil defense, public health) whenever possible. In any case the coordinating office will notify the appropriate state office of the radioactive spill. When the response team is dispatched, the Nuclear Regulatory Commission is notified especially if the spilled material is licensed. The main functions of the response team are to assess the hazard, to inform people of the hazard, and to recommend emergency actions to minimize the hazard. The responsibility for clean-up rests with the shipper or carrier (the party who has possession of the material at the time of the spill).

2.4.3 Access

Access to the IRAP is through the regional coordinating offices given in Table 6. Each office has a 24-hour emergency telephone number. When reporting an incident, the following information should be given:

1. Name and title of caller
2. Call back number
3. Location and magnitude of problem
4. Information of shipping papers
   - type of material
   - manufacture or shipper
   - carrier

IRAP can also be accessed through CHEMTREC.

NWMAR116216

2.5 U.S. COAST GUARD NATIONAL STRIKE FORCE

2.5.1 Description

The Coast Guard's National Strike Force (NSF) is part of the National Contingency Plan established under authority of the Federal Water Pollution Control Act Amendments of 1972, Section 311 **(1)**. It consists of high-seas equipment and trained personnel available to assist the On-Scene Coordinator upon request during Phase III (Containment and Countermeasures), Phase IV (Cleanup, Mitigation and Disposal), and Phase V (Documentation and Cost Recovery), as defined in the National Contingency Plan. There are three Coast Guard Strike Teams located on the East, West, and Gulf coasts. Each strike team consists of 18 or 19 men, including 3 or 4 officers. Each strike team is capable of responding to a pollution incident in its area with four or more men within 2 hours and at full strength in 12 hours. The Strike Team can provide communications support and assistance and advice on ship salvage, diving and removal techniques. Available equipment primarily designed for air transport, consists of the following:

1. Air Deliverable Antipollution Transfer System (ADAPTS), consists of a pumping system to off-load stricken cargo vessels.
2. Yokohama fenders, used for side protection during vessel-to-vessel cargo transfer.
3. High-seas containment barrier.
4. High-seas skimmer.

2.5.2 Access

The services of the National Strike Force are available to any On-Scene Coordinator anywhere in the country. Requests for assistance can be made through the National Response Center through its 24-hour emergency telephone number (see Table 6). The specific details of the emergency situation should be given.

2.6 U.S. ARMY TECHNICAL ESCORT CENTER CHEMICAL EMERGENCY RESPONSE TEAM

2.6.1 Description

The U.S. Army Technical Escort Center maintains, on standby, a 14-man alert team at Aberdeen Proving Ground, Maryland, ready to respond to chemical emergencies within 2 hours. If necessary, additional personnel are available for mobilization. The team is trained and experienced in handling chemical emergencies and has available to it special equipment such as decontamination trucks, detection devices, and protective clothing.

NWMAR116217

2.6.2 Mode of Operation

The U.S. Army Technical Escort Center's team responds to a chemical emergency when directed by the higher command. While the team was formed mainly to respond to emergencies involving Department of the Army chemicals, it has assisted other agencies such as the U.S. Coast Guard.

2.6.3 Access

To obtain the assistance of the escort team, initial contact should be made with the regional EPA office. EPA personnel will then contact the Dept. of the Army Operations Center at the commercial number listed in Table 6. Upon receipt of each request, the Army Operations Center determines if the specific services of the Technial Escort Center are needed. If the determination is made for the emergency team to respond, intermediate commands are notified and the team dispatched. The Commander of the Technical Escort Center should be contacted.

2.7 CHEMICAL TRANSPORTATION EMERGENCY CENTER (CHEMTREC)

2.7.1 Description

CHEMTREC serves a clearinghouse function by providing a single emergency 24-hour telephone number for chemical transportation emergencies. Upon receiving notification of a spill, CHEMTREC immediately contacts the shipper of the chemicals involved for assistance and follow-up. CHEMTREC also provides warning and limited guidance to those at the scene of the emergency if the product can be identified either by the chemical or trade name. The CHEMTREC system covers over 3,600 items which have been submitted by manufacturers as their primary items of shipment. CHEMTREC is sponsored by the Manufacturing Chemists Association although non-members are also served. The system is not computerized.

2.7.2 Mode of Operation

The CHEMTREC emergency telephone number is widely distributed to emergency service personnel, carriers, and throughout the chemical industry. The number is usually given on the bill of lading. When an emergency call is received by CHEMTREC, the person on duty records the essential information in writing. He tries to obtain as much information as possible from the caller. The person on duty will give out information as furnished by the chemical producers on the chemical(s) reported to be involved. This would include information on hazards of spills, fire, or exposure. After advising the caller, the person on-duty immediately notifies the shipper of the chemical by phone, giving him the details of the situation. At this point, responsibility for further guidance passes to the shipper.

NWMAR116218

CHEMTREC'S function is basically to serve as the liaison between the person with the problem and the chemical shipper and/or manufacturer, the theory being that the manufacturer of the chemical or material will know the most about his product and its properties. CHEMTREC also serves as a contact point for the Chlorine Institute, the National Agricultural Chemicals Association (pesticides), and the Energy Research and Development Administration (radioactive materials).

2.7.3 Access

CHEMTREC can be accessed through its emergency telephone number listed in Table 6. As much of the following information should be provided by the caller as possible:

1. Name of caller and call back number.
2. Location of problem.
3. Shipper or manufacturer
4. Container type
5. Rail car or truck number
6. Carrier name
7. Consignee
8. Local conditions

2.8 NACA PESTICIDES SAFETY TEAM NETWORK

2.8.1 Description

The National Agricultural Chemicals Association through its members operates a national pesticide information and response network. Its function is to provide advice and on-site assistance when the spill situation warrants it.

2.8.2 Mode of Operation

The network operates through the CHEMTREC office. Upon receiving notification of an emergency involving a pesticide, the manufacturer is contacted by CHEMTREC. The manufacturer will provide specific advice regarding the handling of the spill. If necessary, spill response teams are available on a geographical basis to assist at the emergency scene.

2.8.3 Access

Access to the network is through CHEMTREC (see Table 6 for telephone no.)

NWMAR116219

2.9 TRANSPORTATION EMERGENCY ASSISTANCE PLAN (TEAP), Canadian Chemical Producers' Association (CCPA)

2.9.1 Description

TEAP serves a function in Canada similar to that of CHEMTREC in the U.S. Canada is divided into eight geographic areas, each served by a regional control center. Depending on the location of the spill, one of these control centers is called and notified of the emergency. The functions of TEAP are to provide emergency advice, to get knowledgeable personnel (usually the manufacturer) in touch with responsible people at the emergency scene, and to see that on-the-scene assistance is provided if needed.

2.9.2 Mode of Operation

When a call is received at a regional control center, the attendant records basic information on a record sheet and obtains a call-back number. He may also give preliminary information from standard references if the name of the product is known. The attendant will then call one of the center's technical advisers with the preliminary information. The technical adviser will then call the accident scene to determine as much detail as possible. At this time he may also be able to provide additional advice on coping with the emergency. The adviser will then try to contact the producer from the listed references. If the producer can be contacted, the adviser will turn the problem over to them as the most knowledgeable contact. If the producer cannot be reached, or if distances are great, the regional control centers will contact a company familiar with the product. The center is also prepared to send men and equipment to the scene if necessary. Once contact has been established between the producer and the local authorities on the scene, the technical adviser assumes a follow-up role and notifies the CCPA of the incident.

2.9.3 Access

Access to TEAP is through the regional control centers given in Table 6. Essential information that should be provided includes:

1. Exact name of the product spilled
2. Name of the producer
3. Name of the carrier

2.10 CHLORINE EMERGENCY PLAN (CHLOREP)

2.10.1 Description

Chlorine manufacturers in the U.S. and Canada through the Chlorine Institute have established the Chlorine Emergency Plan to handle chlorine emergencies. This is essentially a mutual aid program whereby the manufacturer closest to the emergency will provide technical assistance even if it involves another manufacturer's product.

NWMAR116220

2.10.2 Mode of Operation

The CHLOREP system operates through CHEMTREC. Upon receiving an emergency call, CHEMTREC notifies the appropriate party in accord with the mutual aid plan. This party then contacts the emergency scene to determine if it is necessary to send a technical team to provide assistance. Each participating manufacturer has trained personnel and equipment available for emergencies.

2.10.3 Access

Access to CHLOREP on a 24-hour basis is through CHEMTREC (telephone number in Table 6).

2.11 INFORMATION RETRIEVAL SYSTEMS

Organizations providing information retrieval should be considered as secondary sources of information because information is from the published literature or past events, and because interaction is limited since the contact usually has no special expertise in spills technology or hazardous chemicals. A list of information retrieval sources was given in Table 7. Because of the emergency nature of most spills, a short response time is important. In this regard an on-line computerized system is desirable, although a manual search could also have a short turnaround time. Data bases range from spill specific to general scientific. Examples of specific bases are the Canadian NEELS data base which covers the location of publicly and privately owned cleanup equipment and the NATES data base which covers the history of past spills and their cleanup. These two systems are discussed below.

The mode of operation for the computerized systems involves inputting applicable key words as search components. These might include the name of the chemical and words such as "pollution", "water", "removal", "toxicity", "reactivity", and "hazards".

2.12 NATIONAL EMERGENCY EQUIPMENT LOCATOR SYSTEM (NEELS)

2.12.1 Description

NEELS is an on-line computer system designed and operated by the Environmental Protection Service (EPS), Environment Canada. Its function is to provide information on equipment available near the spill scene which may be useful. This includes containment and treatment equipment held both publicly and privately.

2.12.2 Mode of Operation

Connection can be made with the NEELS computer system through any EPS regional office. The longitude and latitude of the spill must be entered

NWMAR116221

as input and the desired output must be selected from the following choices:

1. All equipment at the nearest location.
2. Nearest specific type of equipment.
3. Nearest particular piece of equipment.

Depending on the selection, the computer prints out the location of the equipment and the name of the person and telephone number to call.

2.12.3 Access

Information on gaining access to NEELS can be obtained from the National Environmental Emergency Center by calling the 24-hour emergency number listed in Table 6.

2.13 NATIONAL ANALYSIS OF TRENDS IN EMERGENCIES SYSTEM (NATES)

2.13.1 Description

NATES is an on-line computer system designed and operated by the Environmental Protection Service (EPS), Environment Canada. Its function is to provide information on how a similar spill was handled.

2.13.2 Mode of Operation

Connection can be made with the NATES computer system through any EPS regional office. Main input to the system is the type of material spilled. Output includes data on location, date, material spilled, cause, environment including site conditions and contingency plans, cleanup including method used, weather, agencies involved, legal actions, and cost.

2.13.3 Access

Information on gaining access to NATES can be obtained from the National Environmental Emergency Center by calling the 24-hour emergency number, listed in Table 6.

2.14 USEFUL GUIDES AND REFERENCE HANDBOOKS

There are many handbooks and reference texts which may prove helpful in the event of a hazardous material spill. Any person who may be confronted with a spill emergency should have access to one or more of the commonly used references. In addition, the Regional Response Center maintains a hazardous materials reference library. In particular, the references listed in Table 8 should be available.

NWMAR116222

TABLE 8. REFERENCES TO USE IN CONJUNCTION WITH THIS MANUAL

Critical References	Critical Reference Source
OHM-TADS Data Sheets	US EPA Office of Hazardous Materials, Wash. DC 20400.
CHRIS Manuals 1-4 (CG-446-1-4)	US Gov't Printing Office, Wash. DC 20402.
Regional Contingency Plan	US EPA-Regional Environmental Emergency Section.
Regulation for Shipping Hazardous Materials	
49 CFR-Code of Federal Regulations, Transportation Vol. 49 Pts. 170-189	US Dept. of Transportation Office of Hazardous Materials.
FAR 103-Federal Aviation Regulations Vol. VI Pt. 103	US Dept. Federal Aviation
CAB 82-Official Air Transport Restricted Articles Tariff No. 6-D	
IATA-International Air Transport Association Restricted Articles Regulations	
EPA Field Detection and Danger Assessment Manual for Oil and Hazardous Material Spills	US EPA Office of Water and Hazardous Materials Wash., DC 20400.
Official Motor Freight Directory	
Official Railway Guide	
Dangerous Properties of Industrial Materials, by N. Irving Sax	Van Nostrand Reinhold Co., 450 W. 33rd Street, New York, NY 10001
Chemical Transportation and Handling Guide	RSMA, 181 E. Lake Shore Drive, Chicago, IL 60611

NWMAR116223

TABLE 8. (continued)

Critical References	Critical Reference Source
Laboratory Waste Disposal Manual	Manufacturing Chemists Association, 1825 Connecticut Ave. N.W., Wash., DC 20009.
Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste (Vol. 1-16) by TRW Systems Group	NTIS US Dept. of Commerce Springfield, VA 22151.
Hazardous Chemicals Data	National Fire Protection Association 470 Atlanta Ave. Boston, MA 02110

Desirable References	
Merck Index	Chemical Engineers' Handbook, Perry, John H., et al., eds., & 5th ed., 1973
Chemical Rubber Corporation, Handbook of Chemistry and Physics, CRC Press	Chemical Safety Data Sheets (SD-1 - SD-96), Manufacturing Chemists' Association
Handbook of Chemistry - Handbook Publishers Inc. by NA Lange	Handbook of Analytical Toxicology, Sunshine, I., ed., Chemical Rubber Co., 1969
Behavior of Organic Chemicals in the Aquatic Environment - Part I - A Literature Critique, Manufacturing Chemists' Association	MCA Chem-Card Manual
Behavior of Organic Chemicals in the Aquatic Environment - Part II - Behavior in Dilute Solutions, Manufacturing Chemists' Association, April 1968	Mineral Facts and Problems, US Bureau of Mines Bull. 630, 1965
1963 Census of Manufacturers - Location of Manufacturing Plants by Industry, County, and Employment Size	Organic Chemistry, Morrison, R.T., and R.N. Boyd, 2nd ed., 1966
Chemical Data Guide for Bulk Shipment by Water, US Coast Guard, 1966	Orsanco Quality Monitor, July 1970
	Orsanco Quality Monitor, July 1970
	The Pesticide Review, US Dept. of Agriculture, 1970

NWMAR116224

TABLE 8. (continued)

Desirable References

Hygienic Guide Series, American Industrial Hygiene Association

Pesticide Poisoning Of Pond Lake, Ohio, Investigation and Resolution (for the EPA, Ryckman, Edgerly, Tomlinson and Associates, Inc.

Proceedings of Conference On Hazardous Cargos, (US Coast Guard) July, 1970, New London, CT

Proceedings Of the 1972 National Conference On Control of Hazardous Material Spills (For the EPA) University of Houston, Houston, TX

Spill Prevention Techniques For Hazardous Polluting Substances, (For the EPA), Arthur D. Little Co.

Standard Methods For the Examination of Water and Wastewater, American Public Health Association, American Public Water Works, and Water Pollution Control Federation

Water Quality Criteria, McKee, J.E. and H. W. Wolf, The Resources Agency of California, State Water Quality Control Board

Water Quality Criteria - Report Of the National Technical Advisory Committee To the Secretary Of The Interior, April 1, 1968, F.W.P.C.A., Wash.

Pollution and Marine Ecology, Olson, T.A., and R.J. Burgess, 1967

Railroad Accident Report - Southern Railway Company Tranin 154 Derailment with Fire & Explosion, Laurel, MS., Jan. 25, 1969

Safety Guides (SG-1 - SG-19) Manufacturing Chemists' Association

Spillages of Hazardous Chemicals (Chart)

Water Pollution Abatement Manual, Manuals Sheets W-1, W-2, W-3, W-4 & W-6, Manufacturing Chemists' Association

Waterborne Commerce of the United States, US Corps of Engineers, Parts 1-5, 1968

Control of Spillage of Hazardous Polluting Substances, 15090 FOZ (for the EPA), Battelle Memorial Institute

Dangerous Articles Emergency Guide, Bureau of Explosives, Association of American Railroads

Explosives and Other Dangerous Articles, Bureau of Explosives, Association of American Railraods

Fire Protection For Chemicals, Bahme, C.W., National Fire Protection Association

NWMAR116225

3.0 - CHAPTER 3 - IDENTIFICATION AND ASSESSMENT

3.1 GENERAL

The information in this chapter deals with stepwise identification and assessment of the danger potential in a spill situation. The material presented has been divided into two parts which are directed at two people associated with the spill control effort. One person is called the Man on the Scene (MOS) who is the on-scene coordinator for the region or his designated representative at the spill site. The MOS is to provide information to a remote On-Scene Coordinator who has available to him the additional information critical to accurate spill identification and assessment. This Manual provides the remote OSC with directions for using information provided by the MOS and directing his further activity.

3.2 DIRECTIONS FOR THE MAN ON THE SCENE

3.2.1 Assumptions

There are various assumptions inherent in this presentation of the duties of the MOS. These assumptions include:

1. The Man on the Scene (MOS) is the on-scene coordinator or his designated representative at the site of a spill situation. The MOS is aware of the risks involved in spill control.

2. The responsibility of the MOS is to provide information to a remote OSC which will aid in spill identification and assessment of the human danger potential.

3. The responsibility for evacuation, fire fighting, or crowd control is not the duty of the appointed MOS but is assigned to other agencies, divisions, or personnel.

4. More than one person is available to perform the functions of the MOS, if necessary. Therefore, notification can be done concurrently with information gathering for identification.

3.2.2 Safety

The safety of the people who arrive on the scene of a hazardous spill is critical to consider before any action is taken. All spills are considered extremely hazardous. If the identity of the spill is not known, then the MOS should not approach the spill and should await the arrival of more highly trained, experienced personnel or a volunteer who is more aware of the risks involved with hazardous materials. In all cases, fully protective clothing should be worn by personnel at the spill site. In addition, the following general safety precautions should be followed:

1. Always approach a spill from upwind.

NWMAR116226

2. Don't touch the material and avoid any indirect or direct contact with it.

3. Remove all possible ignition sources. Do not smoke.

4. Restrict access to the area.

5. Do not touch any container unless full knowledge of the hazards involved is available.

6. If unidentified fuming liquids or gases are present, do not approach.

3.2.3 Identification Procedures - MOS

3.2.3.1 General - The MOS is the eyes and ears of a remote OSC. There are a series of steps to follow which will allow the MOS to specifically gather sufficient information for transfer to the OSC so an identification can be made.

3.2.3.2 Establish the type of soil - The first step is to determine what type of spill is involved by identifying the source of the spill. The following types of spills are possible:

a. Trains
   1. Tank car
   2. Box car

b. Trucks
   1. Tank
   2. Trailer

c. Bus

d. Aircraft
   1. Cargo
   2. Passenger

e. Ship
   1. Dry Cargo
   2. Tank Ship
   3. Com. Pass. Vessel
   4. Fishing Vessel
   5. CG Vessel
   6. Pleasure Craft
   7. Tugboat
   8. Unidentified

f. Barge

g. Pipeline
   1. Offshore
   2. On Shore

h. Storage Tank
   1. Offshore
   2. On Shore
   3. Other

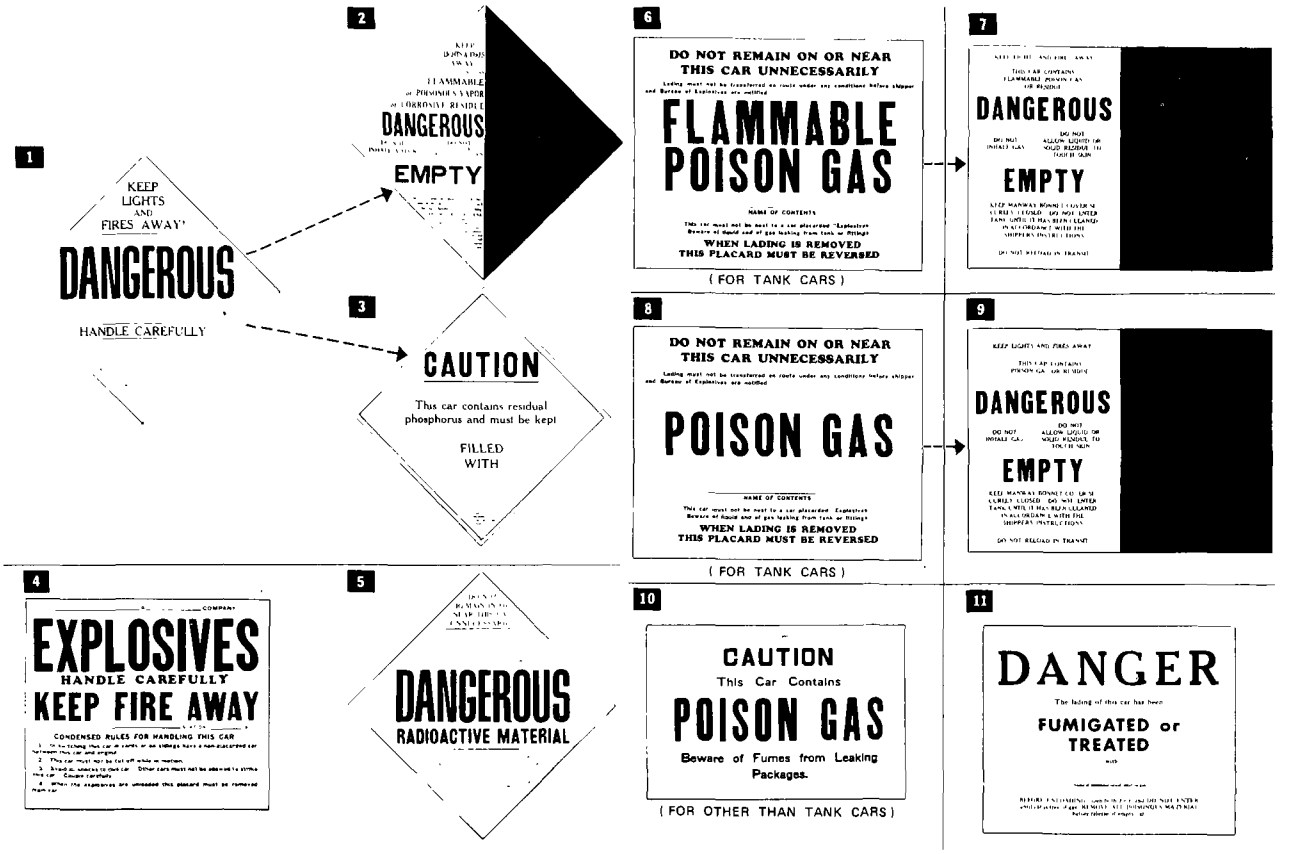
Once the location and source of spill has been specified, the MOS should refer to the specific Figure (no. 2-12) which allows him to answer pertinent questions that lead to identification.

3.2.3.3 Notation of visible label - There are two types of package labels.(2) The MOS should answer the following questions if the packages can be safely investigated:

1. Are any warning labels visible?

NWMAR116227

1. Are any of the following hazardous placards or labels visible on the train car: (2)



2. If so, what is the contents identification on the placard?

_____

3. What is the identification, number and type of the car?
   ID No. _____
   TYPE: Tank _____ Boxcar _____ Other _____

4. Can the waybill (freight bill) be obtained from the conductor, in the engine or in the caboose? (3) (Typical waybill in Figure 3)
   Yes _____ No _____

5. If yes, what is the office of the dispatcher? (Get information from train conductor if possible.) _____

6. What is the train's location?
   a. Railroad track owner _____
      (name on engine or caboose)
   b. Nearest town and distance _____
   c. Nearest railroad milepost _____
   d. Distance from nearest:
      Highway, and _____
      Highway number _____

Figure 2. Identification questions for train spills.

NWMAR116228

THIS MEMORANDUM

CARRIER C & NW

AT MILWAUKEE, WIS. 5-22-75 19 From REXNORD INC. CHAIN & CONVEYOR DIVISION

Consigned to U.S. STEEL CORP UNIVERCAL ATLAS CEMENT DIV'N ATTN.: CONSTR. LDRS.

Destination LEEDS State ALABAMA Zip 35094 County

Route C & NW - (CHICAGO) - PC - (CINCINNATI) - SOU

Car/Trl Initials PC No. 533883

Number	Kind of Package	Kind of Package Description of Articles Special Marks and Exceptions	# WEIGHT (Sub to Corr)
		CHAIN BELTING, STEEL Other than machine finished or Silent	
		CHAIN BELTING Malleable Iron	
		BELTING CONVEYOR PLASTIC o/t V-type	
		WHEELS SPROCKET fibre or plastic	
		WHEELS SPROCKET Iron	
		ELEVATOR BUCKETS Cast Malleable Iron nested	
		ELEVATOR BUCKETS FAB. I/S Nested	
		BELT CONVEYOR IDLERS (Rolls)	
		SHAFT HANGERS PILLOW BLOCKS	
		SHAFTS, STEEL O/T CRANK SHAFTS With flgs., brgs., cplgs., whls	
		SHAFTS, STEEL O/T CRANK SHAFTS w/o flgs Key Seated	
		HARDWARE, NOI Steel	
		NOZZLES, BRASS, NOI	
		MOTORS, ELECTRIC - GEAR MOTOR Over 5# each	
		INCREASING OR REDUCING MACHINES Gear or Speed - over 5# each	
		CASTINGS ROUGH I/S	

Number	Kind of Package	Kind of Package Description of Articles Special Marks and Exceptions	(Sub to Corr)
		MACHINERY PARTS NOI Iron or steel	
		MACHINERY PARTS NOI Alum., brass or bronze	
		MACHINERY PARTS NOI PLASTIC OR RUBBER Sep or Comb etc	
		MACHINE GUARDS I/S S.U. not nested	
1	C/L	ELEV. OR CONVEYORS STATY KD and parts thereof	39,770#
		CONVEYORS INTERMEDIATE SECTIONS K.D or frames or idler supports	
		SPIRAL SCREW CONVEYOR PARTS Boxes w or w/o gear	
		CHUTES OR SPOUTS NOI IRON 7 ga. or thicker	
		CHAIN AND STEEL FLIGHTS ASSEMBLED	
		FLIGHTS, STEEL	
		FLIGHTS, CONVEYOR, WOODEN	
		PLASTIC ARTICLES NOI o/t expanded cubage	
		Declared density #/C.F	
		The resultant billing wt	
		RAILS - BAR IRON I/S NOI	
		BRACES, BRACING, BRACKETS OR FORMS NOI I/S fabricated from material 3/16" or thicker	
		BOLTS OR NUTS NOI Iron or steel	

Shipper hereby certifies that he is familiar with all the terms and conditions of the said bill of lading, including those on the back thereof set forth in the classification or tariff which governs the transportation of this shipment and the said terms and conditions are hereby agreed to by the shipper and accepted for himself and his assigns.

Mail or street address of consignee — For purposes of notification only.

If the consignee is described by name only, or if shipment is consigned to order, the applicable bill of lading for this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:

The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.

REXNORD INC

(Signature of consignor)

If charges are to be prepaid, write or stamp here: "To be Prepaid."

PREPAID

Received $ to apply in prepayment of the charges on the property described hereon.

Per Agent or Cashier

(The signature here acknowledges only the amount prepaid.)

Charges advanced $

* If the shipment moves between two ports by a carrier by water, the law requires that the Bill of Lading shall state whether it is carrier's or shipper's weight.

NOTE - Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.

The agreed or declared value of the property is hereby specifically stated by the shipper to be not exceeding.

RECEIVED AT MILWAUKEE
MITCHELL BELT
C. & N. W. TRANSP.
MAY 22 1975
Subject to conditions of Local Freight Tariff & Uniform Bill of Lading
Shippers Load and Count
E. F. RIVARD, AGENT

CAPY 154000#
LT WT 55500#
52' 6" GON ORDERED
52' 6" GON FURNISHED
1000# BLOCKING FREE

NON-DIMENSIONAL-LOAD

CAR INSPECTED & APPROVED FOR SHIPMENT
BY _____ C&NW R.R.

02 40 001 C 213

This shipment is carrying Gross weight is 39770 lbs. Subject to verification by the Uniform Weighing and Insp. Bureau According to Agreement No. SM 828
Thomas A. Weber
Shipper

3 REXNORD INC. CHAIN & CONVEYOR DIVISION

Shipper _____ Agent

Per T. WEBER Plant # Per

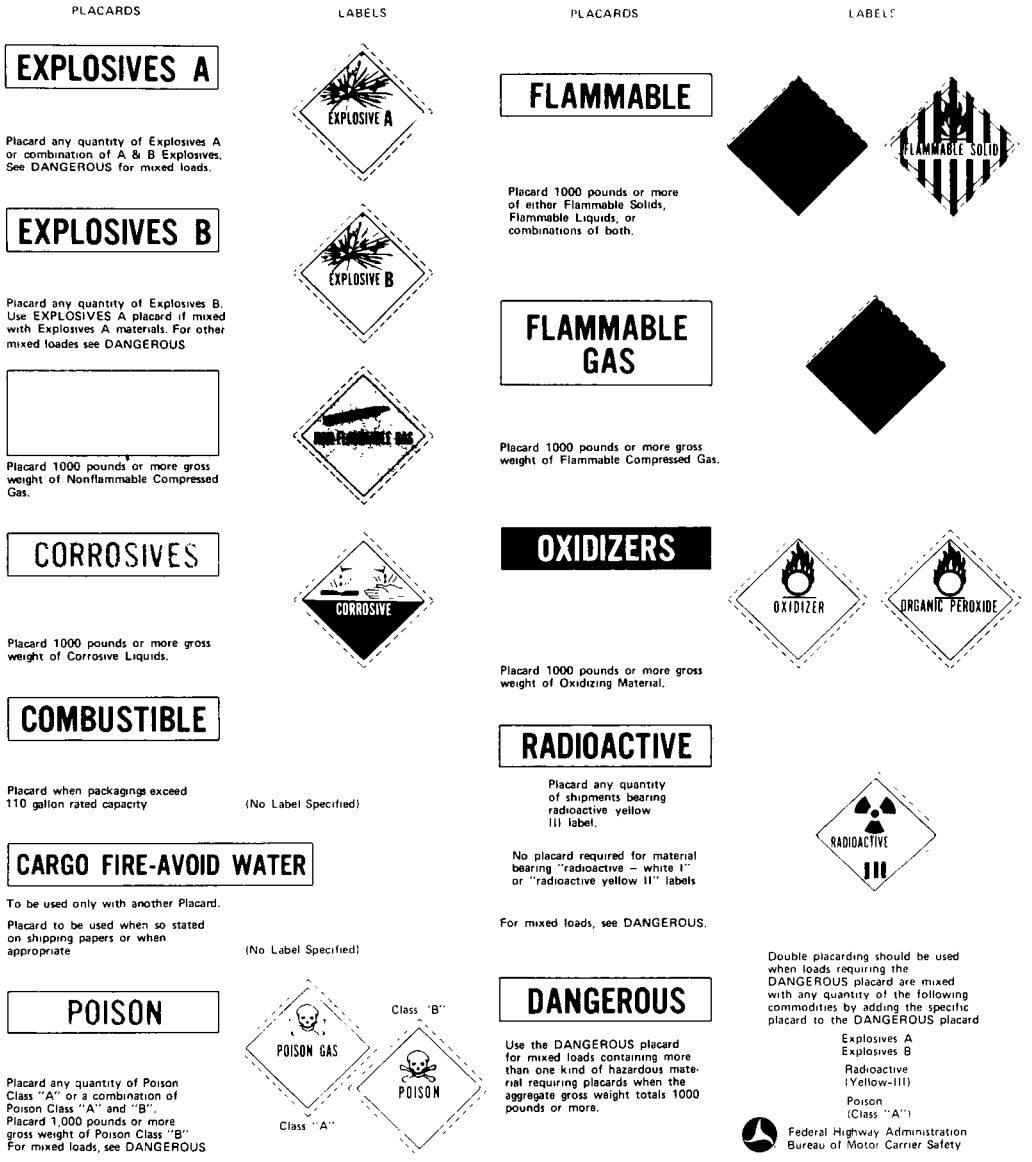
Permanent post-office address Shipper 4751 W. Greenfield Ave., MILWAUKEE, WIS. 53214

FORM H835 C&C (4-73)

Figure 3. Typical freight bill for rail shipment.

NWMAR116229

1. What Placards are visible? (2)



2. If possible, obtain bill of lading from driver (typical bill of lading in Figure 5).

3. If not: Record trucking company on cab _____
Record truck I.D. number _____
and type _____
Record highway number _____
Record distance from nearest town _____
Record highway market _____
Record distance from road _____
Record time of accident _____

Figure 4. Identification questions for truck spills.

NWMAR116230

STRAIGHT BILL OF LADING—SHORT FORM—ORIGINAL—NOT NEGOTIABLE

RECEIVED, subject to the classifications and tariffs in effect on the date of the issue of this Bill of Lading.

Shipper's No _____

CARRIER: _____ Cust. No _____

At MILWAUKEE, WIS. _____ **19** _____ **From REXNORD INC.** CONSTRUCTION MACHINERY DIV.

the property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown), marked, consigned, and destined as indicated below, which said carrier (the word carrier being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its route, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property, over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the terms and conditions of the Uniform Domestic Straight Bill of Lading set forth (1) in Uniform Freight Classifications in effect on the date hereof, if this is a rail or a rail-water shipment, or (2) in the applicable motor carrier classification or tariff, if this is a motor carrier shipment.

Shipper hereby certifies that he is familiar with all the terms and conditions of the said bill of lading, including those on the back thereof, set forth in the classification or tariff which governs the transportation of this shipment, and the said terms and conditions are hereby agreed to by the shipper and accepted for himself and his assigns.

Consigned to _____

_____

Destination _____ **State** _____ **Zip** _____ **County** _____

Route _____

Car/tlr Initials _____ **No.** _____

COD AMT. $ _____

REMIT COD PROCEEDS TO:
REXNORD INC.
P.O. BOX 50018
MILWAUKEE, WIS. 53201

Subject to Section 7 of Conditions of applicable bill of lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.
REXNORD INC.

NOTE. Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property. The agreed or declared value of the property is hereby specifically stated by the shipper to be not exceeding.

Per _____

If charges are to be prepaid, write or stamp here, "To be Prepaid."

Number	Kind of Packages	Description of Articles Special Marks and Exceptions	*WEIGHT Sub to Corr	Number	Kind of Packages	Description of Articles Special Marks and Exceptions	*WEIGHT Sub to Corr	Number	Kind of Packages	Description of Articles Special Marks and Exceptions	*WEIGHT Sub to Corr
		CONCRETE MIXERS concrete mixer parts				MACHINERY PARTS NOI I/S				ELECTRICAL INSTRUMENTS NOI	
										ELEC. SWITCHBOARDS NOI or parts	
										SCALES, FACTORY OR WHSE KD Auto or o/t Auto	
						MACHINERY PARTS RUBBER NOI Plastic or Rubber				COUPLERS-TRACTOR TRAILER OR PARTS I/S	
						MACHINERY PARTS NOI Alum, Brass or Bronze				FORMS, LAYOUTS OR ASS'Y JIGS wood or metal	
		CHUTES CONCRETE DISTRIBUTING IRON				GRADING OR ROAD IMPLEMENT PARTS NOI I/S				BOLTS-NUTS NOI Iron or Steel	
										CASTINGS-ROUGH I/S	
		TANKS-NOI-SU i/s 16 ga. to ¼" n/nsld				SCARIFIERS & MIXERS COMBINED, POWER				RINGS, ROLLED STEEL NOI	
		TANKS-NOI-SU ALUM. 18 ga. or thicker								UNFINISHED SHAPES NOI I/S 16 ga. or thicker	
		HARDWARE NOI STEEL				ROAD ROLLERS SELF PROPELLING				BRACES-BRACING BRACKETS OR FORMS NOI I/S structural fabr. from material ¼" or thicker	
		CHAINS, BELTING STEEL o/t machine finished				MOTORS ELEC-GEAR MOTOR over 5# each				GREASE, LUBRICATING NOI	
		SHAFTS O/T CRANKSHAFTS W/flgs, brgs, cplgs.				INCREASING OR REDUCING MACHINES-gear or speed over 5#				PAINT, LIQUID NOI O/T [metal tubes or glass]	
		SHAFTS O/T CRANKSHAFTS w/o fittings				HEAT EXCHANGERS-NOI-w or w/o metering					
						ALUMINUM CASTINGS NOI w/o inserts					

1

REXNORD INC. CONSTRUCTION MACHINERY DIV.

Shipper _____ **Agent**

Per _____ **Plant #** _____ **Per** _____

Permanent post-office address of shipper:
4751 W. Greenfield Ave.,
MILWAUKEE, WIS. 53214

FORM H835 CMD (4-73)

Figure 5. Typical truck bill of lading accompanying shipment.

NWMAR116231

1. Is a bus bill available from the driver? (typical bus bill in Figure 7)

Yes _____

No _____

2. If yes, obtain the bus bill from the driver.

3. If no, record:

bus company _____

bus vehicle number _____

highway number _____

distance from nearest town _____

name of nearest town _____

highway marker _____

distance from road _____

time of accident _____

Figure 6. Identification questions for bus spills.

NWMAR116232

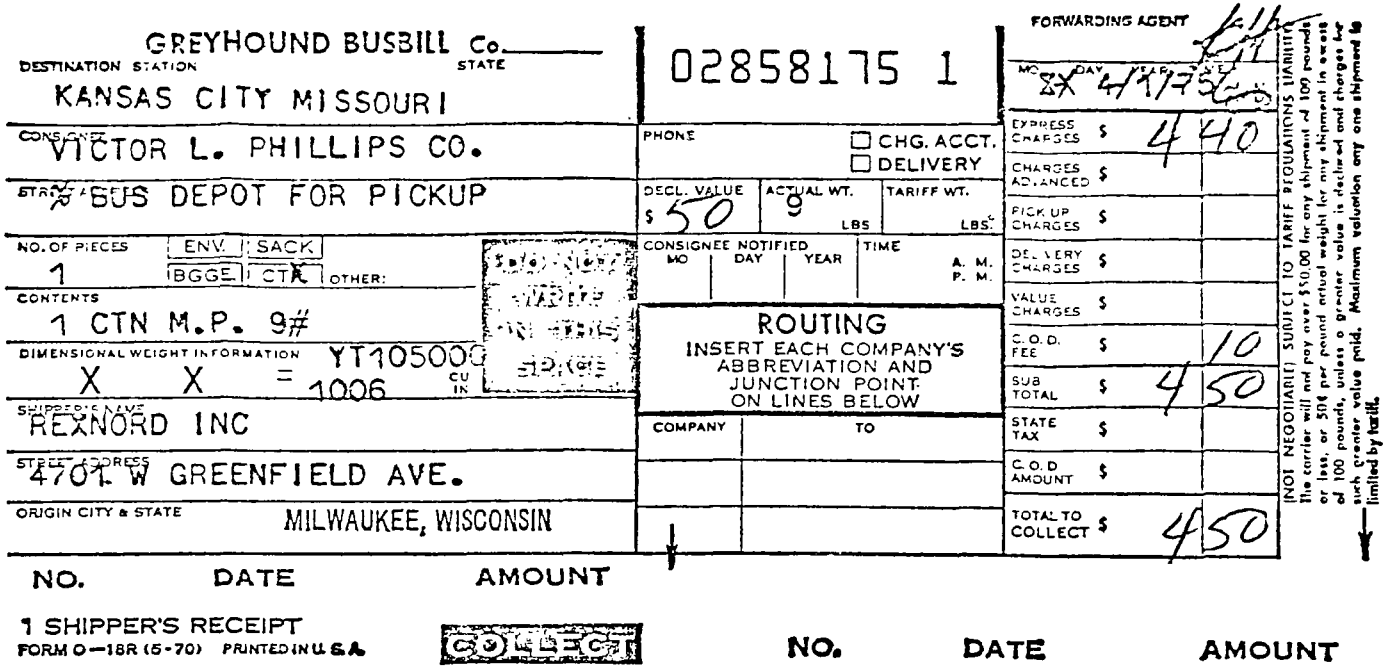


Figure 7. Typical bus bill attached to package .

NWMAR116233

1. Are the shipping papers available from the captain of the ship?

Yes _____ No _____

2. If yes, obtain papers from the captain.

3. If no,

1. What is the ship's flag configuration?

_____

_____

_____

_____

2. Record the vessel Name _____

Number _____

Nationality _____

3. Location:

Name of nearest city _____

Distance from nearest city _____

Water body involved _____

Distance from shore _____

Figure 8. Identification questions for spills from marine vessels.

NWMAR116234

1. What warning placards are visible?

   a. Warning
   b. Dangerous Cargo
   c. No Visitors - indicates possible poisonous cargo
   d. No Smoking
   e. No Open Lights
   f. Other _____
   g. None

   (These placards are generally 3 feet x 2 feet with black letters on a white background.)

2. Does the barge captain have the shipping papers?

   Yes _____ No _____

3. If yes, obtain these papers.

4. If no, record:

   Barge Name _____

   Barge Number _____

   Name of Waterway _____

   Distance from Shore _____

   Name of Nearest City _____

   Distance from Nearest City _____

Figure 9. Identification questions for spills from barges.

NWMAR116235

1. Does the pilot have the shipping papers? (4)

Yes _____ No _____

2. If yes, obtain these papers.

3. If no, record:

Airline of Plane _____
Number of Plane _____
Number of Nearest Highway _____
Highway Marker _____
Distance from Highway _____
Name of Nearest Town _____
Distance from Nearest Town _____
Time of Accident _____

Figure 10. Identification questions for spills from airplanes

1. Is a pipeline marker available?

2. If yes, record all information from marker.

_____

3. If no, record:

Name of Pipeline owner (if available) _____
Nearest Highway Number _____
Distance from Highway _____
Highway Mile Marker _____
Nearest Town _____
Distance from Nearest Town _____
Time of Spill _____

Figure 11. Identification questions for spills from pipleines

NWMAR116236

1. Is an identification plate attached to the tank?

   Yes _____ No _____

2. If yes, copy information: _____

   _____

3. If no, record:

   Address of spill by nearest streets _____

   Time of spill _____

4. Are any additional coding systems visible? For example:

   If gas cylinders are involved, what is the color of the cylinder? _____

   And, what is the name of the distributor? _____

   _____

   If chemicals are used, what is the color of the cap?

   _____ or printing _____

   and what is the name of the distributor _____

   _____

Figure 12. Identification questions for spills from storage tanks

NWMAR116237

2. Are any identifying labels visible?
(An example appears in Figure 13).

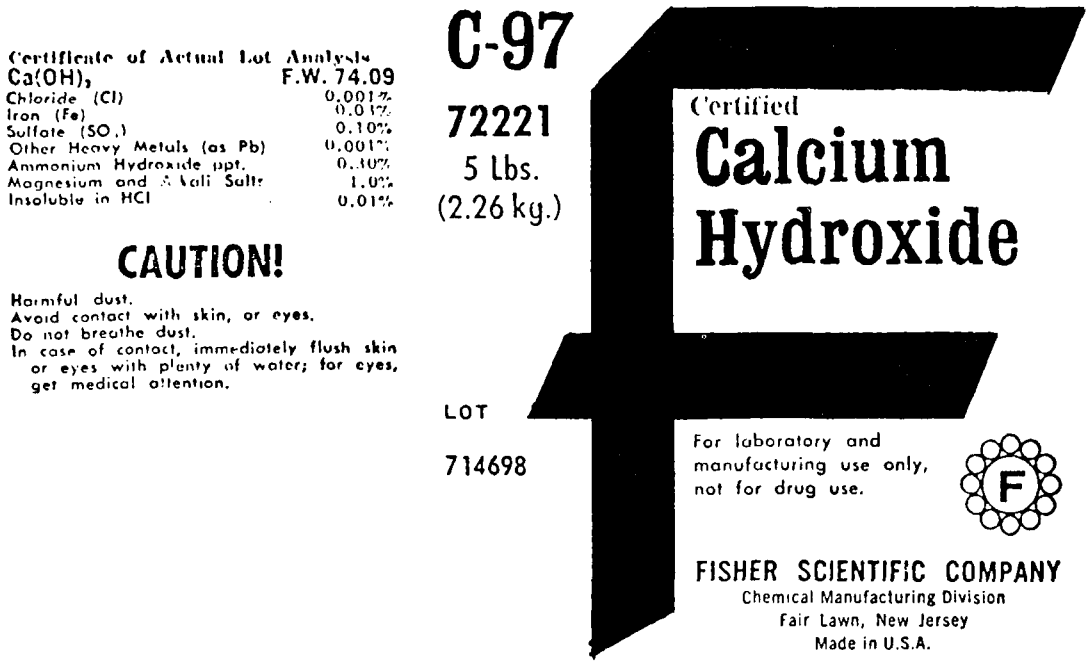


Figure 13. Typical chemical packaging label.

NWMAR116238

3.2.3.4 Record easily visible physical properties - Observation of the following properties of the spilled material can confirm an identification or possibly identify the specific chemical involved (5). However, the MOS must approach the spill cautiously and not endanger himself and others in determining the characteristics. If a certain physical property cannot be readily identified, do not answer that question and go on to the next one.

1. What state is the spill:
   1. Solid (powder, pellet, granular)
   2. Liquid
   3. Gas

2. Is there a noticeable odor from a safe distance?

   Pleasant - almond, ammonia, benzene, fragrant, lysol, vinegar, sweet

   Unpleasant - sulfur, irritant, foul, skunk, onion, sharp, biting, mothball, cleaning fluid, paint

3. What color is it?

4. Is it turbid?
   Opaque -
   Clear -
   Cloudy -
   Other -

5. If it is in water, does it
   float
   sink
   mix (soluble)
   remain unmixed

6. Does it cause your eyes to water?
   Yes
   No

7. Is it
   fuming
   flaming
   foaming
   or is a gas being given off
   or is another noticeable reaction occurring

3.2.3.5 Contact the OSC - Once this information has been assembled, the OSC should be contacted. The information can be transmitted to the OSC who will then direct the MOS to perform additional steps to aid in identification or will direct him to begin to assess the danger potential of the situation.

3.2.3.6 Further steps for identification - If so directed by the OSC the MOS can take one or more of the following steps to aid in specific identification of the spilled material:

1. Make on-site inspections to determine which cargo is damaged and undamaged:

NWMAR116239

This procedure requires the MOS to be very cautious and board the vehicle to check the cargo. The procedure is only required for mixed loads and will allow elimination of various cargoes which have not been damaged from the list of possible materials involved in the spill.

2. Take samples for chemical testing: The OSC may direct the MOS to collect samples and then ship or deliver these samples to a specified laboratory. Care must be taken at all times to protect the MOS. The spill should not be approached without fully protective clothing.

3.2.4 Assessment of Spill Magnitude and Human Danger Potential by the MOS

3.2.4.1 General - Once the spill has been identified as to its specific constituents, the magnitude of the spill and its potential danger to human safety must be established. To determine this, the MOS must answer a series of questions which pertain to the spill situation. The OSC can then establish the effect of the spill using various references.

3.2.4.2 Magnitude of the spill - The MOS can gather the needed information regarding the spill to give to the OSC by answering the following questions:

1. Note the label information, if available.

2. What type and size of individual containers have spilled the material?

   1. Metal drums — approx. height _____ diameter _____

   2. Fiber drums — approx. height _____ diameter _____

   3. Bags
      Paper Length _____ Width _____ Height _____
      Polyethylene Length _____ Width _____ Height _____

   4. Cylinders Length _____ Width _____ Height _____

   5. Carboys Diameter _____ Height _____

   6. Boxes Type Length _____ Width _____ Height _____

   7. Other Dimensions

3. How many of each type of container have been spilled?

4. If large tank trucks or cars or barge and ship holds are involved, the approximate size can be estimated by pacing off

NWMAR116240

a similar distance at a remote location.

Size_____ X_____ X_____

Often the tank cars and trains are labeled so the capacity should be recorded _____

3.2.4.3 Human Danger Potential - Information regarding environmental conditions and location of the spill is necessary to determine the danger which exists from the spill itself. There are various questions which must be answered by the MOS and then this information transferred to the OSC.

1. What time did the discharge start, _____ Determine this information by questioning eyewitnesses to the spill.
2. Where is the discharge occurring? (ie. location of spill) The same information is required as was indicated in the identification section. Necessary information for each spill source is summarized in Table 9.

Table 9. METHODS OF IDENTIFYING SPILL LOCATION

Transportation Mode	Method
Train	Railroad track owner/nearest town (name and distance) railroad track milepost (alternate as for trucks)
Truck	Highway name/highway number/nearest town (name and distance)/distance from road
Bus	Same as for truck
Airplane	Distance and direction from highway/location on highway as for truck
Ship	Name of waterway/nearest coastline/distance and direction from shore/location & name of nearest town
Barge	Same as for ship
Pipeline	Pipeline marker or distance and direction from highway/location on highway as for truck
Storage Tank	Address in relation to nearby streets, distance and direction from highway/location on highway as for truck.

3. How close is the spill to populated areas?_____
4. What is the spill affecting?
   a. In water

NWMAR116241

b. On land

c. In air

d. Combination (indicate which)

5. Are any water intakes or wells in the near vicinity? _____

6. What is the rate of discharge? _____

7. This rate can be estimated by noting indirect factors including:

   a. What is the shape or type of hole or leak?

      Triangular hole_____

      Rectangular hole_____

      Split seam_____

      Valve leak _____

      Puncture _____

      Breakage _____

   b. How high is the liquid above hole/water? (If in water)

   c. Is the hull listing? (Ship or barge)

   d. How much material is left in the tank? (Approximately 1/2, 1/4, etc.)

   e. If the source of the spill can be safely approached, the rate can be estimated by measuring depth differences and the area of the tank measured as follows: (6)

      1. Determine the length and width of the leaking tank. length_____ width_____

      2. Stick a long, straight pole (gage pole) or "dipstick" down into the tank either through an "ullage" hole, or through a hatch cover, pull it up, note what time it is, and measure the length of the pole which is "wet". time (1)_____ length(1)____

      3. Wait 15 minutes or so if the leak is slow, or a shorter period of time if it is relatively fast. time (2)_____

      4. Repeat step 2 above. length (2)_____

   f. If stopped, how long did the discharge last?_____

NWMAR116242

8. How much area is affected by the spill?

Land: Pace off the length and width of the affected area from a remote similar distance and record.

length _____ width _____

Water: a. Indicate the type of water body affected.

Ocean / River / Lake / Bay / Harbor / Stream / Swamp

(Other) _____

b. Estimate the size of the water body. Pace off the affected distances from shore or use Figure 14 to estimate stream width.

Stream Width (feet)		Stream Width (feet)	
0-75	_____	1200-1800	_____
75-200	_____	1800-2200	_____
200-400	_____	2200-2800	_____
400-800	_____	2800-3400	_____
800-1200	_____	greater than 3400	_____

ft x 0.305 = m

Figure 14 Estimating Stream Widths (6)

c. Estimate the flow rate if any.
Use the following procedure:

1. Measure a straight distance along length of water body. length _____
2. Drop floating object into water and record time time (1) _____
3. Record time when object reaches end of measured length time (2) _____
4. Current speed in ft/sec (ft/sec x 0.305 = m/sec)

$$0.8 \left[\frac{\text{length (ft)}}{\text{time 2 - time 1 (sec)}} \right] \quad (7)$$

d. Estimate direction of flow (N., S., E., W., etc.)

e. Estimate depth of waterway.
If accessible use a stick plunged straight into the bottom and measure wet level as a depth.
Measure in the middle of a stream if possible.

NWMAR116243

If direct measurement is impossible, use topographical maps of the area to establish depths.

f. Estimate depth of water near point of discharge. _____
The stick technique is best, if access is possible. If not, choose a similar configuration upstream of the spill and measure that depth.

g. If a gas spill is occurring:

a. What is the approximate diameter of the hole in the cylinder? _____

b. Is a vapor cloud visible? Yes
No

c. If yes, is the cloud rising
lying on ground
other_____

9. Is a pool of liquid visible on land or on the water?

10. Where is the leak originating?

Barge	Type	Size
Ship	Type	Size
Tank Truck	Type	Size
Train Tank Car		Size
Airplane Hull		Size
Individual container	Type	
Pipeline		Diameter
Storage tank	_____Diameter	_____ Height

11. What is the condition of the source?

Repairable leak
Uncontrollable leak
Easily moved
Unmovable
Other

3.2.4.4 Meteorological Conditions - Information regarding the weather conditions is also important in assessing the potential danger of a spill. The MOS can also answer the following questions:

1. What is the wind speed and direction? The wind speed can be estimated using the Beaufort scale. (Figure 15) The wind direction is that direction from which the wind is blowing and observation of a lightweight object will give this information.

NWMAR116244

Beaufort number	Wind Speed: Knots	Wind Speed: mph	Hydrographic Office: Term and height of waves, in feet	International: Term and height of waves, in feet	Estimating Wind Speed: Effects observed at sea	Estimating Wind Speed: Effects observed on land
0	under 1	under 1	Calm, 0		See like mirror	Calm: smoke rises vertically
1	1-3	1-3	Smooth, less than 1	Calm, glassy, 0	Ripples with appearance of scales, no foam crests	Smoke drift indicates wind direction; vanes do not move.
2	4-6	4-7	Slight, 1-3	Rippled, 0-1	Small wavelets; crests of glassy appearance, not breaking	Wind felt on face; leaves rustle; vanes begin to move.
3	7-10	8-12	Moderate, 3-5	Smooth, 1-2	Large wavelets; crests begin to break; scattered whitecaps.	Leaves, small twigs in constant motion; light flags extended.
4	11-16	13-18		Slight, 2-4	Small waves, becoming longer; numerous whitecaps.	Dust, leaves, and loose paper raised up; small branches move
5	17-21	19-24	Rough, 5-8	Moderate, 4-8	Moderate waves, taking longer form; many whitecaps; some spray.	Small trees in leaf begin to sway.
6	22-27	25-31		Rough, 8-13	Larger waves forming; whitecaps everywhere; more spray.	Larger branches of trees in motion, whistling heard in wires.
7	28-33	32-38			See heaps up; white foam from breaking waves begins to be blown in streaks.	Whole trees in motion, resistance felt in walking against wind.
8	34-40	39-46	Very rough, 8-12	Very rough, 13-20	Moderately high waves of greater length; edges of crests begin to break into spindrift; foam is blown in well marked streaks.	Twigs and small branches broken off trees; progress generally impeded.
9	41-47	47-54	High, 12-20		High waves; sea begins to roll; dense streaks to foam; spray may reduce visibility.	Slight structural damage occurs; slate blown from roofs.
10	48-55	55-63	Very high, 20-40	High, 20-30	Very high waves with overhanging crests; sea takes white appearance as foam is blown in very dense streaks; rolling is heavy and visibility reduced.	Seldom experienced on land; trees broken or uprooted; considerable structural damage occurs.
11	56-63	64-72	Mountainous, 40 and higher	Very high, 30-45	Exceptionally high waves; sea covered with white foam patches; visibility still more reduced.	Very rarely experienced on land; usually accompanied by widespread damage

Knots x 1.185 = km/hr mph x 1.61 = km/hr ft x 0.305 =

Figure 15. Beaufort scale for wind speed estimation.

NWMAR116245

2. What are the weather conditions?

ie. Temperature of air _____
humidity of air _____
percentage of sky which is cloudy _____
weather conditions _____
rainy _____
snowy _____
dry _____
humid _____

This information can be obtained by direct observation and the weather bureau reports.

3. What is the weather forecast?
This information is important especially when precipitation is expected and it can be determined from weather bureau reports.

Weather forecast _____
_____
_____

3.3 DIRECTIONS FOR THE OSC

3.3.1 Assumptions

There are two assumptions basic to this section regarding the OSC:

1. The OSC has experience in handling a spill situation and will give immediate information or instructions over the phone 24 hours/day.
2. The OSC has many spill response references available including those listed in Table 8.

In addition, the OSC will have direct access to other reference material at the Regional Response Center.

3.3.2 Identification

3.3.2.1 General - The OSC will use the information relayed to him from the MOS and apply his experience and resources to establish a positive identification of the material involved. This identification process may require only one or two steps plus confirming identification by physical properties or it may require lengthy phone calls and searches. The following paragraphs discuss the possible procedures which can be followed.

3.3.2.2 Step 1 - Collect Information From MOS - The OSC first must assimilate the MOS information. The answer is placed on sheets identical to those the MOS has completed, Sections 3.2.3.2-3.2.3.4.

NWMAR116246

Then the OSC can begin to use the information.

3.3.2.3. Step 2 - Identification From Shipping Papers - If papers are available with the vehicle, the process of identification is as follows:

Determine if a multiple or single load is involved.

a. If a single load is being shipped, the identification is almost complete but the shipping company should be contacted for confirmation.

b. If multiple loads are involved, a further study is needed. First, study the list of materials from the freight bill and then investigate the following possibilities.

   1. Is an extremely posisonous gas involved?

   2. Is a flammable or explosive material involved?

   3. Are incompatible chemicals on the same vehicle? (See Table 10)

However, the chart should not be used as an infallible guide. It should only provide general guidelines regarding chemical incompatibility. An expert should be consulted regarding any known mixture and the potential compatibility confirmed.

If the situation is not safe for a close investigation, the OSC must require identification by physical properties or sampling. (See Section 3.2.3.6.) However, if the MOS can enter the vehicle and check the cargo for damaged and undamaged containers, this should be done. Then the specific hazard may be identified.

However, if shipping papers are not available or are not available in readable form, the OSC must obtain a copy of the papers or expert advice regarding the information. Table 11 summarizes the knowledge necessary for obtaining copies of the material involved. The reference will indicate telephone number of the shipping company and the Vice President in charge of operations must be contacted. If it is not working hours, the police in that city may be able to contact the person needed.

Usually copies are available at the origin of the shipment with the manufacturer and possibly with the company receiving the material. The copy at the shipment origin (ie. loading location) is generally the easiest to obtain.

3.3.2.4 Step 3 - Identification Using Placards and Labels - If the shipping papers are not immediately available, labels and placards can be used to indicate the hazard involved. Extreme caution must be used and care should be taken to insure that correct information has been gathered. The two general types of information are available as warning placards or labels and specific identification labels.

NWMAR116247

TABLE 10. COMPATIBILITY CHART TAKEN FROM CHRIS CG-4464-1 (8)

1	Inorganic Acids	1																					
2	Organic Acids	X	2																				
3	Caustics	X	X	3																			
4	Amines & Alkanolamines	X	X		4																		
5	Halogenated Compounds	X		X	X	5																	
6	Alcohols, Glycols & Glycol Ethers	X					6																
7	Aldehydes	X	X	X	X		X	7															
8	Ketones	X		X	X			X	8														
9	Saturated Hydrocarbons									9													
10	Aromatic Hydrocarbons	X									10												
11	Olefins	X				X						11											
12	Petroleum Oils												12										
13	Esters	X		X	X									13									
14	Monomers & Polymerizable Esters	X	X	X	X	X	X								14								
15	Phenols			X	X			X							X	15							
16	Alkylene Oxides	X	X	X	X		X	X							X	X	16						
17	Cyanohydrins	X	X	X	X	X		X									X	17					
18	Nitriles	X	X	X	X												X		18				
19	Ammonia	X	X					X	X					X	X	X	X	X		19			
20	Halogens			X			X	X	X	X	X	X	X	X	X	X				X	20		
21	Ethers	X													X						X	21	
22	Phosphorus, Elemental	X	X	X																	X		22
23	Sulfur, Molten									X	X	X	X				X						X	23
24	Acid Anhydrides	X		X	X		X	X							X		X	X	X	X				24

X Represents unsafe combinations.

The following pages list the chemicals by chemical name and by reactivity groups. Obtain the group for the chemical and then read chart, first from left to right, then down.

Chemicals Not On Chart

Carbon Bisulfide forms an unsafe combination with reactivity groups 1, 4, 19, 20, and epichlorohydrin.

Epichlorohydrin forms an unsafe combination with reactivity groups 1, 2, 3, 4, 14, 15, 19, 20, 22, 23, 24, and carbon bisulfide.

Motor Fuel antiknock compounds form unsafe combinations with reactivity groups 1, 4, 5, 6, 7, 15, 19, and 20.

NWMAR116248

TABLE 10. (continued)

Procedure for use of compatibility chart (8)

1. Determine the reactivity of the product by reference to CHRIS (CG-446-1).

2. Enter the Chart with the reactivity group. Proceed across the page. An "X" indicates a reactivity group which forms an unsafe combination with the product in question

3. At the end of the line, proceed downard. An "X" again indicates groups that form unsafe combinations.

REMEMBER that this chart is only a guide, further confirmation should be obtained before assuming the condition is safe. See CG-446-1, A Condensed Guide to Chemical Hazards, page 7-1 to 7-14 for additional information.

NWMAR116249

Table 11. SUMMARY ON HOW TO OBTAIN SHIPPING PAPER COPIES

Type of Vehicle	Information required	Reference
Truck	Cab number Trailer number Name trucking company Location and time of truck spill	Official Motor Freight Directory
Train	Car number Name of railroad (from engine or caboose)	Official Railway Guide
Bus	Bus number Name of bus company Location and time of bus spill	Call Bus Company (Yellow Pages)
Ships	Signal flag Vessel name and number Location and time of ship spill	Merchant Vessels of the U.S. U.S. Army Corp of Engineers Ship I.D. book
Barges	Barge name and number Location and time of spill	Call nearest Harbor or Port Commission for reference
Airplane	Airplane number and name (if any) Airlines Location and time of spill	Nearest Airport and the name of the airlines

NWMAR116250

The placards are usually general and indicate only hazards rather than specific identities. The materials which require these placards are listed in DOT regulations 49CFR and identities can be confirmed using this cross reference. However, mixtures or small amounts of materials are not clearly placarded and, therefore, the lack of a placard or a "dangerous" warning may be misleading.

Labels are of two types: warning and identification. The required warning labels are also listed in DOT 49CFR (2) and the types are shown in Figure 16. As with placards, the information is of a general nature and does not specifically identify the chemical. On the other hand, individual chemical labels (See Figure 13) provide specific information and identity of the chemical involved.

To determine information from labels, the OSC must direct the MOS to closely examine the cargo if this action can be safely accomplished. The information, carefully recorded, can then be relayed to the OSC for identification.

3.3.2.5 Step 4 - Identification Using Miscellaneous Aides - In addition to the shipping papers and placards, other information is also available. One of the most helpful are the Chemcards recommended and produced by the Manufacturing Chemists Association. The information on the Chemcards includes (9):

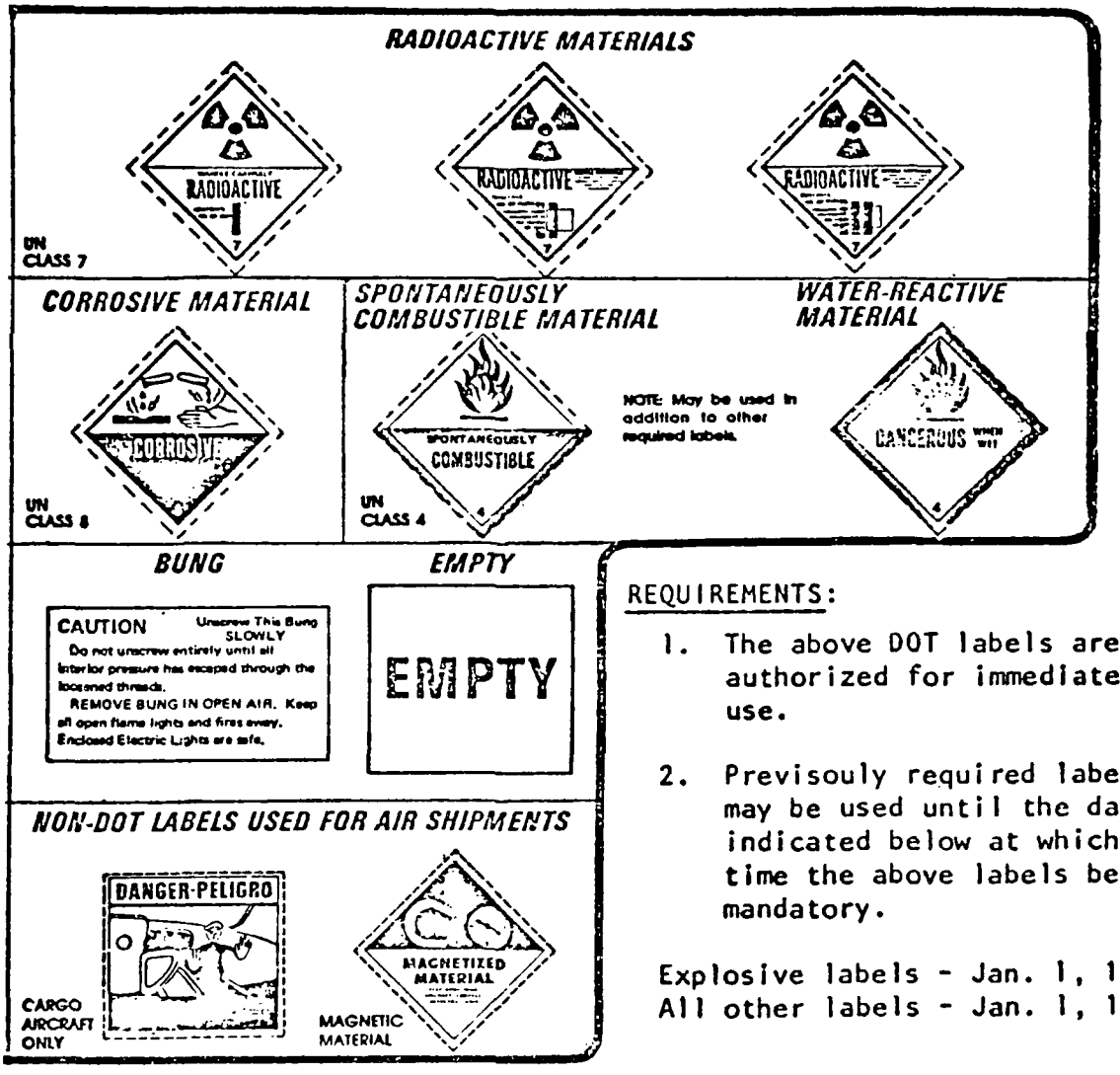
- Identification of the cargo
- Appearance and odor
- Statement of hazards involved and instructions for safe handling and, as applicable, the need for special cargo environments
- Emergency procedures and precautions
- Fire fighting procedures and precautions

However, if mixed loads of hazardous materials are involved, further identification steps are necessary.

Another aid to the OSC is a requirement by the Coast Guard that all foreign vessels carrying hazardous materials register the intended route of the ship with the nearest Captain of the Port Coast Guard Office. Also, all vessels carrying any of the 40 specified dangerous cargoes (See Table 12) must notify the Captain of the Port at least 24 hours prior to arrival. Therefore, when ships are the source of a spill, more detailed information can be obtained from the Coast Guard.

3.3.2.6 Step 5 - Identification Through Physical Properties - If there is no direct information available from shipping papers or other sources, the physical properties can aid in establishing the identity of the material involved. These properties are also

NWMAR116251



REQUIREMENTS:

1. The above DOT labels are authorized for immediate use.

2. Previsouly required labels may be used until the dates indicated below at which time the above labels become mandatory.

Explosive labels - Jan. 1, 1974.
All other labels - Jan. 1, 1975.

(continued)

Figure 16. Hazardous materials warning labels.

NWMAR116252

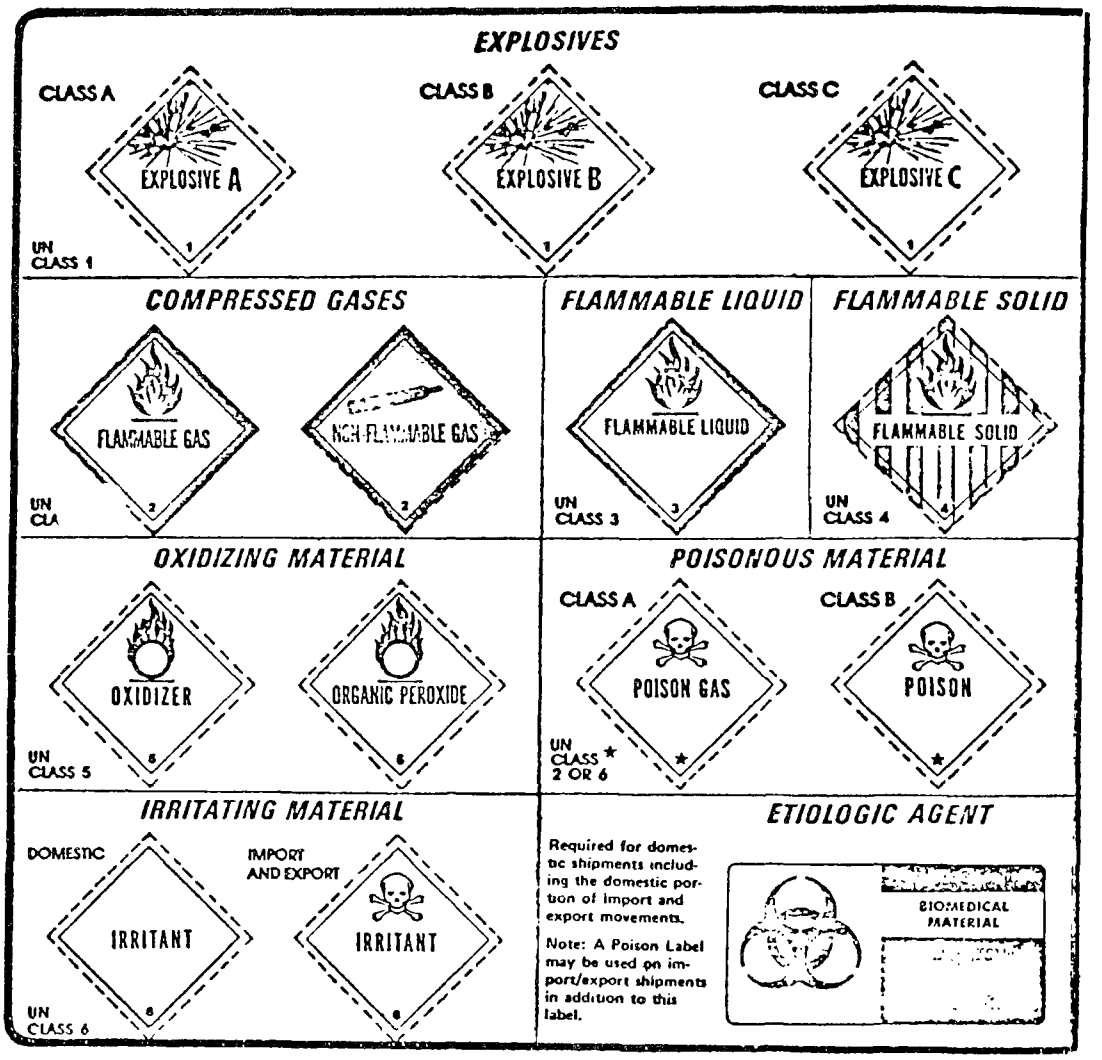


Figure 16 (continued).

NWMAR116253

Table 12. HAZARDOUS CHEMICALS DESIGNATED BY THE COAST GUARD

Acetaldehyde	Hydrochloric acid
Acetone cyanohydrin	Methane
Acetonitrile	Methyl acrylate
Acrylonitrile	Methyl bromide
Allyl alcohol	Methyl chloride
Allyl chloride	Methyl methacrylate (Monomer)
Ammonia, anhydrous	Nonyl phenol
Aniline	Oleum
Butadiene	Phenol
Carbolic acid	Phosphorus, elemental
Carbon disulfide	Propane
Chlorine	Propylene
Chlorohydrins, crude	Propylene oxide
Crotonaldehyde	Sulfuric acid
1,2 dichloropropane	Sulfuric acid, spent
Dichloropropane	Tetraethyl lead
Epichlorohydrin	Tetraethyl lead mixtures
Ethylene	Vinyl acetate
Ethyl ether	Vinyl chloride
Ethylene oxide	Vinylidene chloride

useful in confirmation of the identity of the spill. The specific properties required are outlined in Section 3.2.3.4. Once these properties are recorded, then OHMTADS (10) can be contacted to run a computer search for chemical identity. This source can be easily referenced and the information obtained as soon as possible. Another way to utilize the information is through the EPA publication "Field Detection and Assessment Manual for Oil and Hazardous Material Spills" (5) The physical properties of many chemicals are listed in this manual and eliminations can be done to establish the identity or eliminate non-spilled chemicals.

3.3.2.7 Step 6 - Identification Through Sampling and Analysis - The final type of identification is done by sampling the spill in the contaminated area and then analyzing to determine the specific chemical involved. The simplest approach is to indicate to the laboratory performing the analysis what the possible contaminants are. This information can be established from shipping papers, warning labels or physical property identification.

The OSC must contact a qualified analytical laboratory and then relay their specifications to the MOS for sampling. It is important that the sample be delivered to the laboratory as soon as possible to hasten identification of the chemical. Therefore, a laboratory in close proximity to the spill is desirable.

NWMAR116254

3.3.3 Assessment

3.3.3.1 General - Once the identity of the chemical spilled is known, the assessment of spill magnitude and human danger potential must be established. This process requires utilization of the input from the MOS into prepared programs to assess the danger involved. The OSC will need to contact the CHRIS system and access the HACS computer. This procedure, however, does require both knowledge of the CHRIS system and gathering of necessary input data.

3.3.3.2 Assessment of Human Danger - The most comprehensive resource available is the CHRIS Hazard Assessment Handbook, CG-446-3, the third volume in the four volume set of CHRIS manuals. This handbook and HACS, the associated computer program, can provide extensive information for many types of spill situations. Some of the computer outputs are listed in Table 13. Determination of the appropriate program to use is directly related to the identity of the chemical spill. The second CHRIS manual lists a hazard assessment code for which various calculation procedures can be followed to determine the extent of the hazard involved. This procedure is shown schematically in the Hazard Assessment tree shown in Figure 17.

The geometric shape of the outlined information indicates the type of input required. The oval shapes are indicative of physical properties of the chemical, the triangles indicate the environmental conditions at the spill site, and the rectangles represent the information calculated by the program. Various inputs are required in order to establish the hazard potential. For example, CHRIS requires inputs of primary and secondary information to directly assess the effect of the hazard (See Figure 18). This information is gathered by the MOS and must be transformed into an acceptable form for the HACS or CHRIS input.

3.3.3.3 Magnitude of the Spill - Prior to the use of CHRIS or any other reference, the size of the spill must be determined. There are various ways to establish this information including:

a. Approximate size and description of packages damaged.

b. Determine number of damaged packages.

c. Estimate amount of material released.
(eg. 1/2, 1/4, etc.)

d. Confirm package size and volume estimates from Table 14 and 15 and the data found in the DOT regulations on hazardous materials which regulates amount of material per package. (3)

NWMAR116255

TABLE 13. CALCULATIONS AVAILABLE IN CHRIS HAZARD ASSESSMENT

- Gases (Toxic or Flammable)
  - Flame Length
  - Flame Angle
  - Safe Distances
    - a. For People
    - b. For people with protective clothing
    - c. For wooden buildings
  - Travel Time of Gas Cloud
  - Duration of Hazard
- Liquids
  - Flammable
    - Pool size
    - Flame length
    - Safe distances
      - For people
      - For people with protective clothing
      - For wooden buildings
- Water Pollution
  - Human toxic levels
  - Concentration of water at downstream location
  - Time of arrival at downstream location
  - Maximum distance hazardous to humans
- Volatility Hazard
  - Maximum downwind extent of flammability hazard
  - Maximum half-width of flammability hazard
  - Maximum downwind extent of toxic hazard
  - Maximum half-width of toxic hazard
  - Maximum duration of flammability hazard
  - Maximum duration of toxic hazard
- Solids
  - Reactive Solids
    - Amount of projected reaction products
    - Specific hazard as related to product type
- Soluble (same calculations as liquid)

NWMAR116256

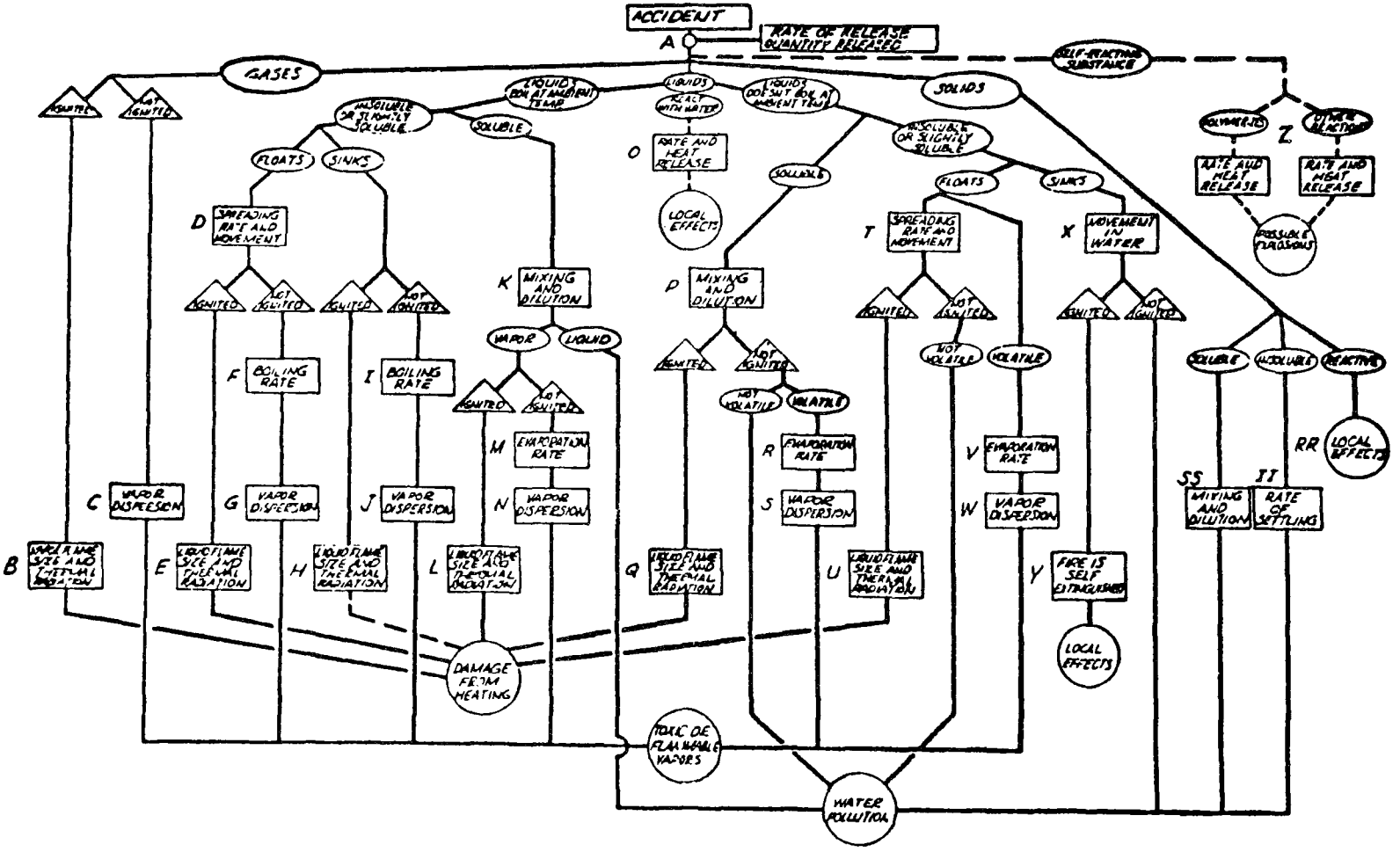


Figure 17. Hazard Assessment Computer System (HACS) Hazard Assessment Tree (6).

NWMAR116257

PRIMARY INFORMATION

1. NAME of chemical _____
2. TIME discharge began _____
3. WHERE discharge occurred _____
4. HOW MUCH was originally present _____
5. WIND speed and direction _____
6. CLOUD cover _____
7. CURRENT speed and direction _____
8. WIDTH and DEPTH of waterway _____
9. HOLE DIAMETER (if gas) _____

SECONDARY INFORMATION

1. a) RATE OF RELEASE if still leaking _____
   b) TIME TO EMPTY TANK if discharge stopped _____
   c) AMOUNT LEFT in tank _____
   d) SIZE, SHAPE of HOLD _____
   e) LENGTH, WIDTH, SHAPE of TANK _____
   f) HEIGHT OF LIQUID ABOVE HOLE/WATER _____
2. WATER TEMPERATURE _____
3. DEPTH of water near discharge _____
4. WIDTH if river or channel _____
5. POOL SIZE if visible _____
6. ACTION ON RELEASE _____
7. a) VAPOR CLOUD VISIBLE? _____
   b) If yes, RISING OR LYING LOW _____
8. CONDITION OF VESSEL _____
9. TYPE, SIZE OF VESSEL _____

Figure 18. Information needs for CG-446-3 summary (6).

NWMAR116258

TABLE 14. USABLE VOLUME OF SHIPPING CONTAINERS (11)

Container size & description	Usable volume, cu m	Usable volume, cu ft
METAL DRUMS		
55 gal. steel std., 18 gage plate, DOT-17E, new	0.205	7.35
55 gal. steel std., 16 gage plate, DOT-17C, new	0.205	7.35
55 gal. steel, removable head, 18 gage, Rule 40, new	0.205	7.35
55 gal. steel, removable head, 18/16 gage, DOT-17H, new	0.205	7.35
55 gal. steel, removable head, 18 gage, used, reconditioned	0.205	7.35
55 gal. steel, std., 18 gage, used, inspected, cleaned	0.205	7.35
55 gal. aluminum, std., 0.102 in. plate	0.205	7.35
55 gal., type 304 stainless steel, std., 16 gage, DOT-5C	0.205	7.35
30 gal., steel, std., 20 gage, DOT-17E	0.112	4.00
30 gal., steel, removable head, 20-gage, Rule 40	0.112	4.00
16 gal., steel, removable lug cover, 22 gage	0.059	2.14
55 gal., steel-mill galvanized, std., 18 gage, DOT-17E	0.205	7.35
55 gal., steel, removable head, 40-mil polyethylene liner, external fittings, 20/18 gage, 53.5 gal. usable volume, DOT-37M	0.201	7.20
FIBER DRUMS		
61 gal., 9 ply, 400 lb load limit, dry products only, Rule 40	0.228	8.15
55 gal., 9 ply, 400 lb load limit, dry products only, Rule 40	0.205	7.35
47 gal., 9 ply, 400 lb load limit, dry products only, Rule 40	0.175	6.28
41 gal., 9 ply, 400 lb load limit, dry products only, Rule 40	0.153	5.48
30 gal. 9 ply, 400 lb load limit, dry products only, Rule 40	0.112	4.00
30 gal. 7 ply. 225 lb load limit, dry products only, Rule 40	0.112	4.00
15 gal. 6 ply, 150 lb load limit, dry products only, Rule 40	0.056	2.00
55 gal. 9 ply, polyethylene barrier, 400 lb load limit, Rule 40	0 .205	7.35
55 gal. 9 ply, polyethylene-aluminum foil liner, 400 lb load limit, Rule 40	0.205	7.35
55 gal. 10 ply blow-molded 15 mil polyethylene liquid-tight liner, tight head, steel cover with 2 3/4" NPT openings, 600 lb load limit, DOT-21C.21CP liquid products	0.205	7.35
30 gal. 9 ply, same as preceding except 450 lb load limit	0.112	4.00
30 gal. 8 ply. 300 lb load limit, removable fiber cover no barrier	0.112	4.00
15 gal. 6 ply. same as preceding except 150 lb load limit	0.056	2.00
1 gal. 5 ply, same as preceding except 150 lb load limit	0.003	0.1335
55 gal. 9 ply, 400 lb load limit, semisquare removable fiber cover, "Rocon" style	0.205	7.35
45 gal., same as preceding	0.168	6.01

continued

NWMAR116259

TABLE 14 (continued)

	Usable volume, cu m	Usable volume, cu ft
BAGS, MULTIWALL PAPER, POLYETHYLENE (PE) FILM		
Pasted-valve bag, 20 1/2 x 22-in. face, 5 1/2-in. top and bottom with 1-mil free film, 2/50, 1/60 kraft, plain, no printing, PE internal sleeve	0.037	(1.33)
Sewn-valve bag, 15 x 5 1/2 x 30 1/4 in. 5 1/2-in. PE internal sleeve with 1-mil free film, 2/50, 1/60 kraft, plain, no printing	0.0037	(1.33)
Pasted-valve bag, 18 1/2 x 22 3/4 in., 3 1/2-in. top and botton, PE internal sleeve, 3/50 kraft, plain, no printing	0.023	(0.84)
Sewn open-mouth bag, 20 x 4 x 30 3/4 in., 3/50, 1/60 kraft, plain	0.056	(2.00)
Sewn-valve bag, 19 x 5 x 33 1/2 in., 5 1/2-in. tuck-in sleeve, 3/50, 1/60 kraft, plain	0.056	(2.00)
Pasted-valve bag, 24 x 25 1/4 in., 5 1/2-in. top and bottom, tuck-in sleeve, 3/50, 1/60 kraft, plain	0.056	(2.00)
Pasted open-mouth baler bags, 22 x 24 in., 6-in. bottom, 1/130 kraft (or 2/70), plain	--	
Flat-tube, open-mouth bag, 10-mil PE film, plain, 20 1/2 x 34 1/4 in.	0.037	(1.33)
Square - end valve bag, 20 1/2 x 22-in. face, 5 1/2-in. top and bottom, 10-mil PE film, plain	0.037	(1.33)
SMALL BAGS, POUCHES, FOLDING BOXES		
Pouch, 8 3/4 x 16 3/4 in., 2-ply PE film. 2-ml thickness/ply	0.003	(0.12)
Bag, sugar-pocket style, 6 x 2 3/4 x 16 3/4 in., 2- to 40-lb. basis weight, natural kraft paper	0.003	(0.12)
Bag, pinch style, 8 3/4 x 3 x 21 in., 2- to 40-lb. basis weight, natural kraft	0.003	(0.12)
Folding box, 5 x 1 x 8 in., reverse-tuck design, 12-point kraft board with bleached white exterior	0.0008	(0.028)
Folding box, 9 1/2 x 4 1/2 x 15 in., full overlap top and bottom, 30-point chip board with bleached white exterior	0.01	(0.37)
CORRUGATED CARTONS, BULK BOXES		
Regular slotted carton (RSC), 24 x 16 x 6 in., 275-lb. test double wall, stapled (stiched) joint	--	
RSC, 16 x 6 x 24 in., 275-lb. test double wall, stitched joint, end-opening style	--	

continued

NWMAR116260

TABLE 14 (continued)

Bag-in-box, RSC, 15 x 15 x 22 in. 275-lb. test double wall, stitched liner, 600-lb. test	0.08 (2.86)
Bulk box 200/600 (test in lb. for both pieces), laminated inner lining approximately 41 x 34x 36 in., less PE liner and pallet	0.14 (5.00)
CARBOYS, PLASTIC DRUMS, JARS, BOTTLES	
Carboy, 13 1/2 gal., polyethylene, blow-molded	0.037 (1.35)
Drum, polyethylene, 15 gal., blow-molded, ICC-34 (DOT-34)	0.056 (2.00)
Carboy, 15 gal., glass, nitric acid service, wooden crate	0.056 (2.00)
Jug, 1 gal., glass, with finger handle, plastic cap	0.003 (0.1335)
Bottle, 1 qt. glass, "Boston" round, plastic cap	0.0009 (0.034)
Jar, 1 qt., glass, wide mouth, plastic cap	0.0009 (0.034)
Jar, 1 gal., polyethylene, wide mouth, plastic cap	0.0037 (0.1335)
Bottle, 1 gal. polyethylene, narrow neck, plastic cap	0.0037 (0.1335)
Bottle, 1 qt. polyethylene, wide mouth, plastic cap	0.0009 (0.034)
Jar, 1 pt. polyethylene, wide mouth, plastic cap	0.0004 (0.017)
CANS, PAILS	
Pail, 5 gal., steel, tight head, 26-gage black steel, PE pour spout, unlined	0.0187 (0.67)
Pail, 5 gal., 26-gage black steel, removable head, unlined, lug cover, wire bail handle	0.0187 (0.67)
Can, 1 gal., friction wedge lid, handle (paint can)	0.0037 (0.1335)
Can, 1 qt. friction wedge led (paint can)	0.0037 (0.034)
Can 1 gal. oblong "F" style, handle, screw cap	0.0037 (0.1335)
Can 1 qt. oblong "F" style, screw cap	0.0037 (0.034)

NWMAR116261

TABLE 15. TYPICAL CARRIER CAPACITIES

Tank Truck	(11)	Average 70,000 lb. Total Wt. 30,000 lb/for tandem axles 60 ft. in length Labeled according to capacity
Tank Car	(11)	Labeled according to capacity
Ship Tankers		Size not limited (estimate cubic size)
Barges	(12)	a. 35 ft. wide x 195 ft. long x 9' draft b. 52.5 ft. wide x 520 ft. long x 14' draft

No. Containers per car load truck or train (11)	Fiber Drums	Number/Carload
	61 gal. size	300
	55 gal. size	318
	47 gal. size	424
	41 gal. size	552
	30 gal. size	592
	15 gal. size	1,272
	1 gal. size	17,365
	Metal Drums	
	55 gal. size	360
	30 gal. size	592
	16 gal. size	1,225

lbs x 0.454 = kg gal x 3.785 = l

ft x 0.305 = m

NWMAR116262

8. Width and Depth of Waterway or Size of Land Area Affected - The MOS can transfer this information or the OSC can determine this from maps available from USGS.

9. Hole Diameter (if gas) - The MOS must estimate this information from a distance and relay it to the OSC.

SECONDARY INFORMATION (FOR HACS USAGE)

1. a. Rate of Release, if still leaking - Various methods are available for estimating the rate of the leak. The MOS can transfer the information to the OSC who can do the necessary calculations. For ship holds, the rate of leakage can be estimated if knowledge of the type of hole, water depth and list of the ship is known (Figures 19-22). If the source can be approached, the rate of leak can be determined by depth differences over a known amount of time. An example follows:

Steps 1-4:

At time 10:30 a.m. a "dipstick" is put down into a 20-foot long by 10-foot wide tank. It is pulled up and it is noted that 96 inches of the pole are "wet". At 10:45 a.m. the procedure is repeated and it is determined that 72 inches of the pole are "wet".

Step 5:

$96'' - 72'' = 24''$

$24'' \times 1\ ft/12'' = 2\ ft$

Step 6:

$2\ ft \times 20\ ft \times 10\ ft = 400\ cubic\ ft$

$$\frac{400\ cubic\ ft}{15\ min} = 26.66\ \frac{cubic\ ft}{min}$$

Step 7:

$$26.66\ \frac{cubic\ ft}{min} \times \frac{7.48\ gal.}{cubic\ ft} = 199.3\ \frac{gal.}{min.} = \text{rate of release}$$

$$\frac{gal.}{min.} \times 3.784 = \frac{l}{min.}$$

NWMAR116263

b. Time to Empty Tank (if discharge is stopped) - This information can be obtained by the MOS by eyewitnesses at the scene.

c. Amount left in Tank - The estimate based on the percent of material left in the tank is made by the MOS.

d. Size, Shape of Hold (if applicable) - If a hold is involved, the size can be estimated by the MOS, alternately the ship's registration papers should include this information.

e. Length, width and shape of tank - The MOS should also give this information or the best estimates. If these are not available, the registration papers of the tank car should give the information.

f. Height of Liquid Above Hole/Water - The height is determined by the MOS and relayed to the OSC.

2. Water Temperature - The MOS can establish the temperature by borrowing a thermometer or possibly certain agencies may have this information available.

3. Depth of Water Near Discharge - This information can be relayed to the OSC by the MOS. If an on site depth measurement is not possible, a similar upstream location can be measured.

4. Width (if river or channel) - The MOS can estimate this or the OSC can use maps of the water body to get an approximate value.

5. Pool Size, if visible - The MOS must estimate the pool size and relay the information to the OSC.

6. Action on Release - Specific action of the chemical on release must be reported to the OSC.

7. Vapor Cloud Visibility and Action - The existence of a vapor cloud and its action regarding low lying or rising is needed to be reported by the MOS.

NWMAR116264

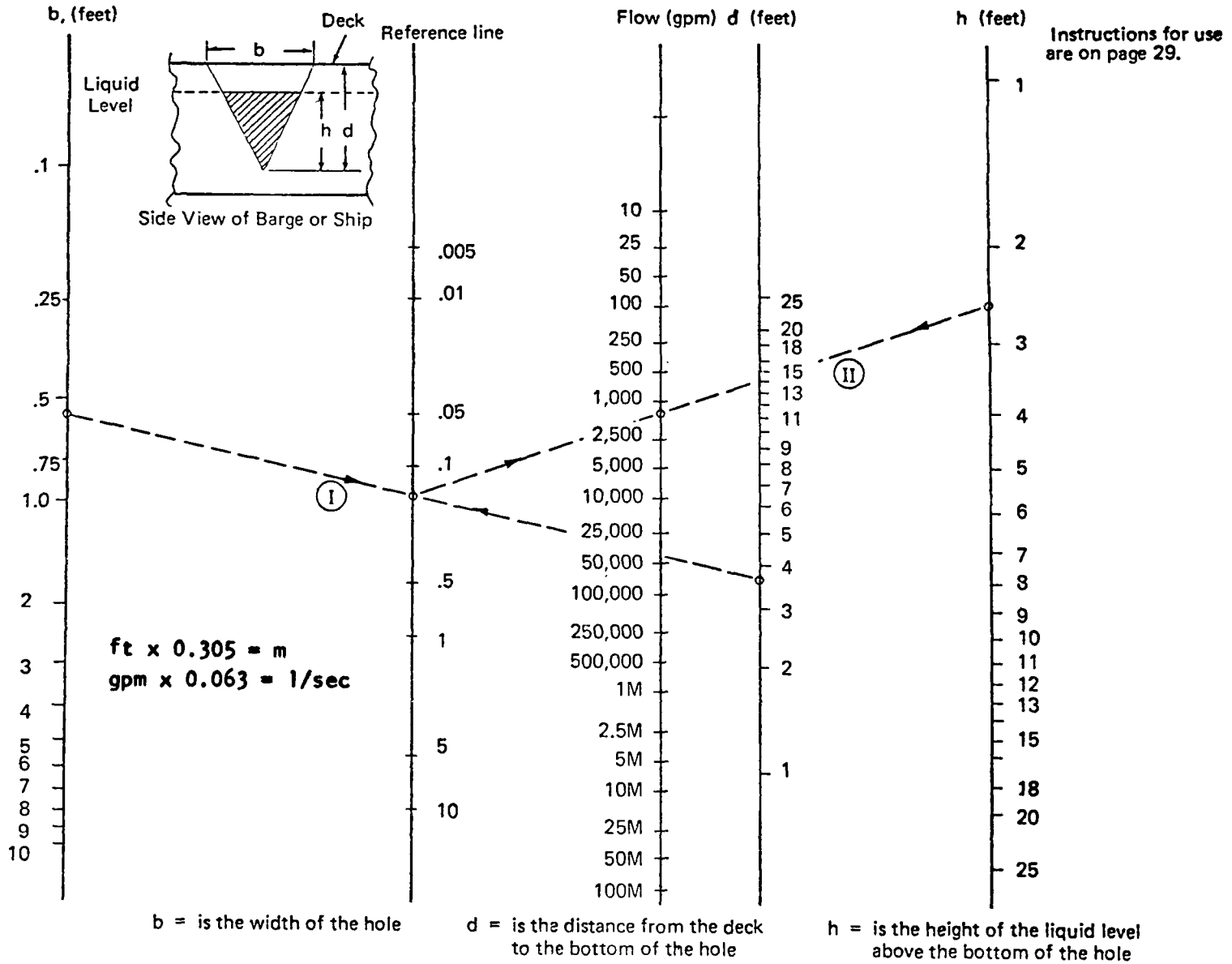


Figure 19. Rate of chemical discharge from triangular notch-shaped openings. (6)

NWMAR116265

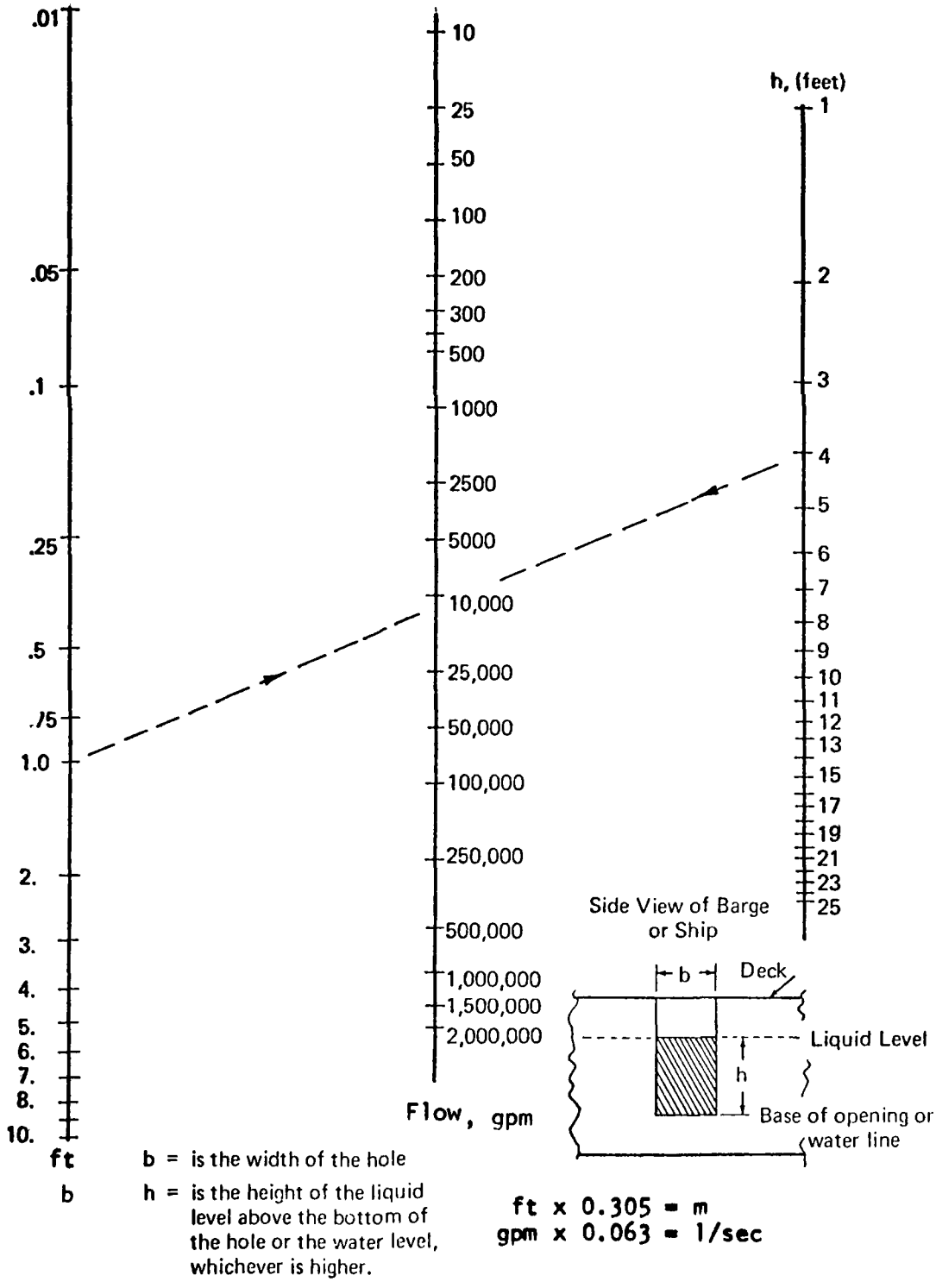


Figure 20. Rate of chemical discharge from a rectangular slot-shaped opening. (6)

NWMAR116266

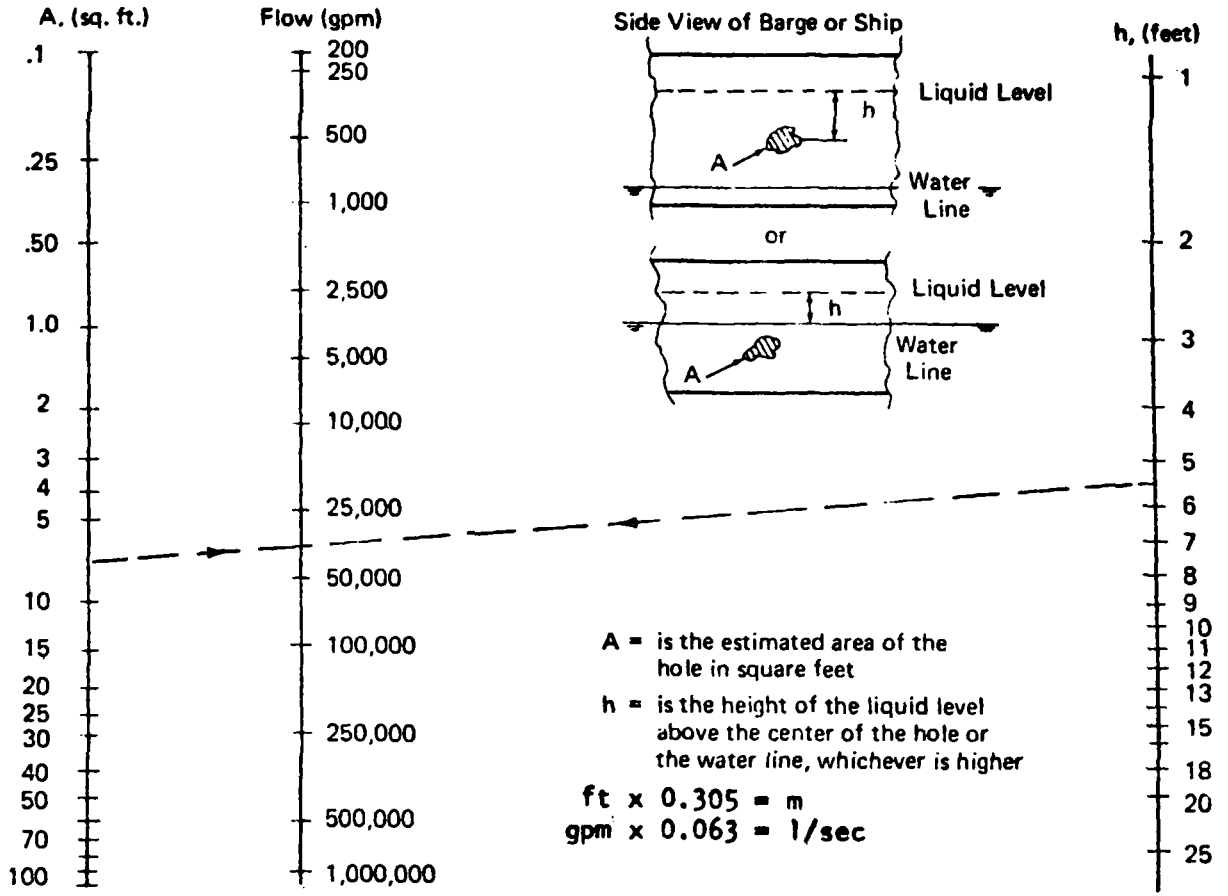


Figure 21. Chemical discharge from irregularly shaped holes. (6)

NWMAR116267

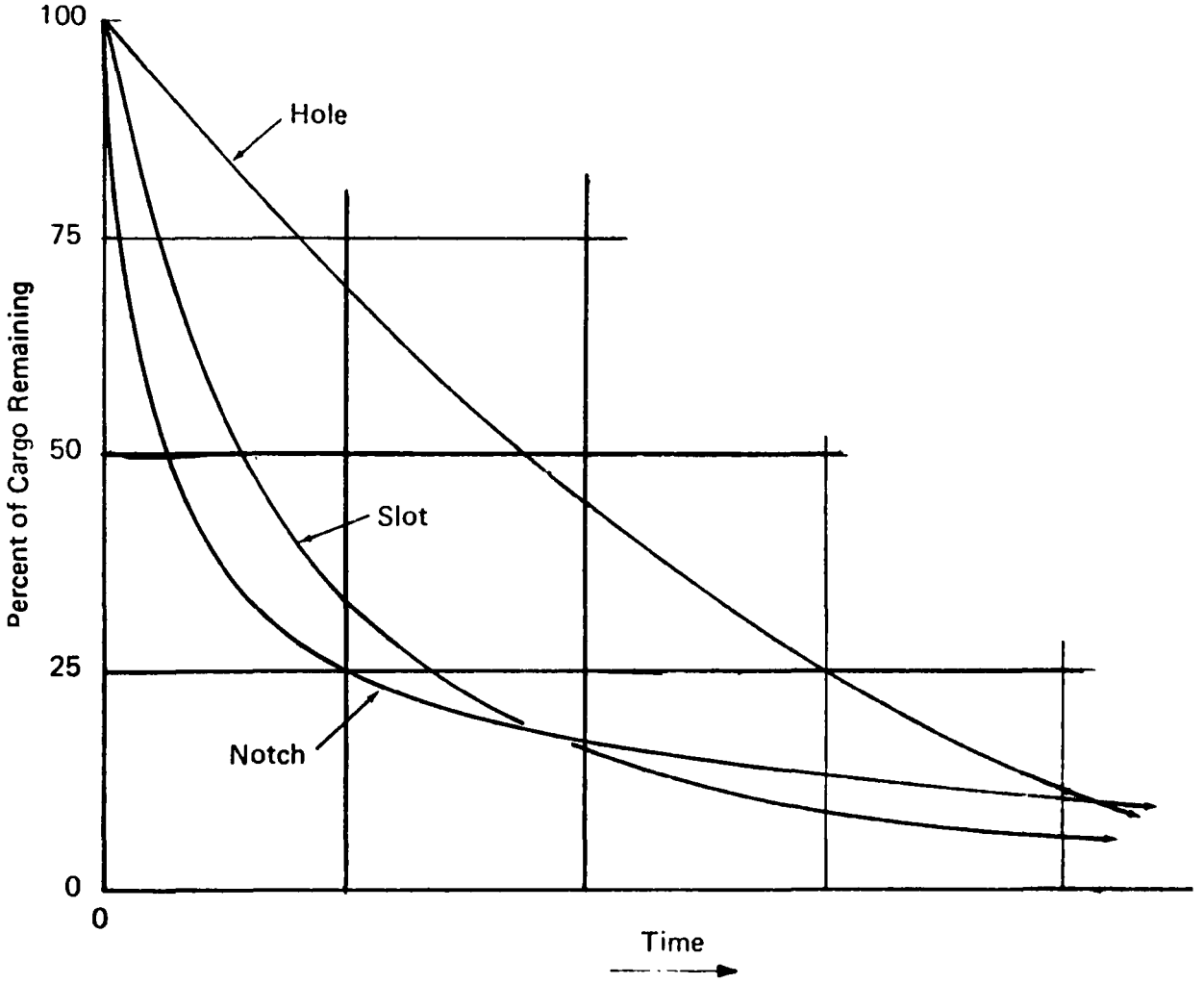


Figure 22. Comparative cargo loss versus time for three types of opening (6)

NWMAR116268

3.3.3.4 Establishing Inputs for Assessment Calculations - Required inputs for the CHRIS manual CG 446-3 and the HACS computer program are shown in Figure 18. The MOS will have answered various questions regarding the spill problems and must relay this information to the OSC (Section 3.2.4.3) The OSC can copy the answers, direct the MOS to further action and then begin compilation of data to input CHRIS.

PRIMARY INFORMATION (for hand calculations in CHRIS CG446-3)

1. Name of Chemical - The identity will have to be established by one of the steps outlined in Section 3.3.2

2. Time Discharge began - The information on the specific discharge time can be determined from the MOS who has interviewed various on scene witnesses.

3. Where Discharge Occurred - The specific location of the discharge is indicated by the MOS in Question 2. This information is augmented by Questions 3 and 4 regarding the proximity to populated areas and drinking supplies. The OSC should also consult maps of the area to pinpoint other hazards.

4. How Much Was Originally Present? - The information is established from the size, and number of containers involved and then confirmed by consulting DOT shipping regulations (3)

5. Wind Speed and Direction - The MOS will relay the information from either Beaufort Chart or Weather Bureau summaries.

6. Cloud Cover - Again, the MOS can relay the percent of the sky covered with clouds.

7. Current Speed and Direction (when applicable) - The current speed is found using the following formula.

$$\text{Current Speed} \left(\frac{\text{ft.}}{\text{sec.}}\right) = 0.8 \times \frac{\text{distance measured (straight) ft.}}{\text{time to cover distance (sec)}}$$

The direction is given by the MOS or found on maps. (ft/sec x 0.305 = m/sec)

NWMAR116269

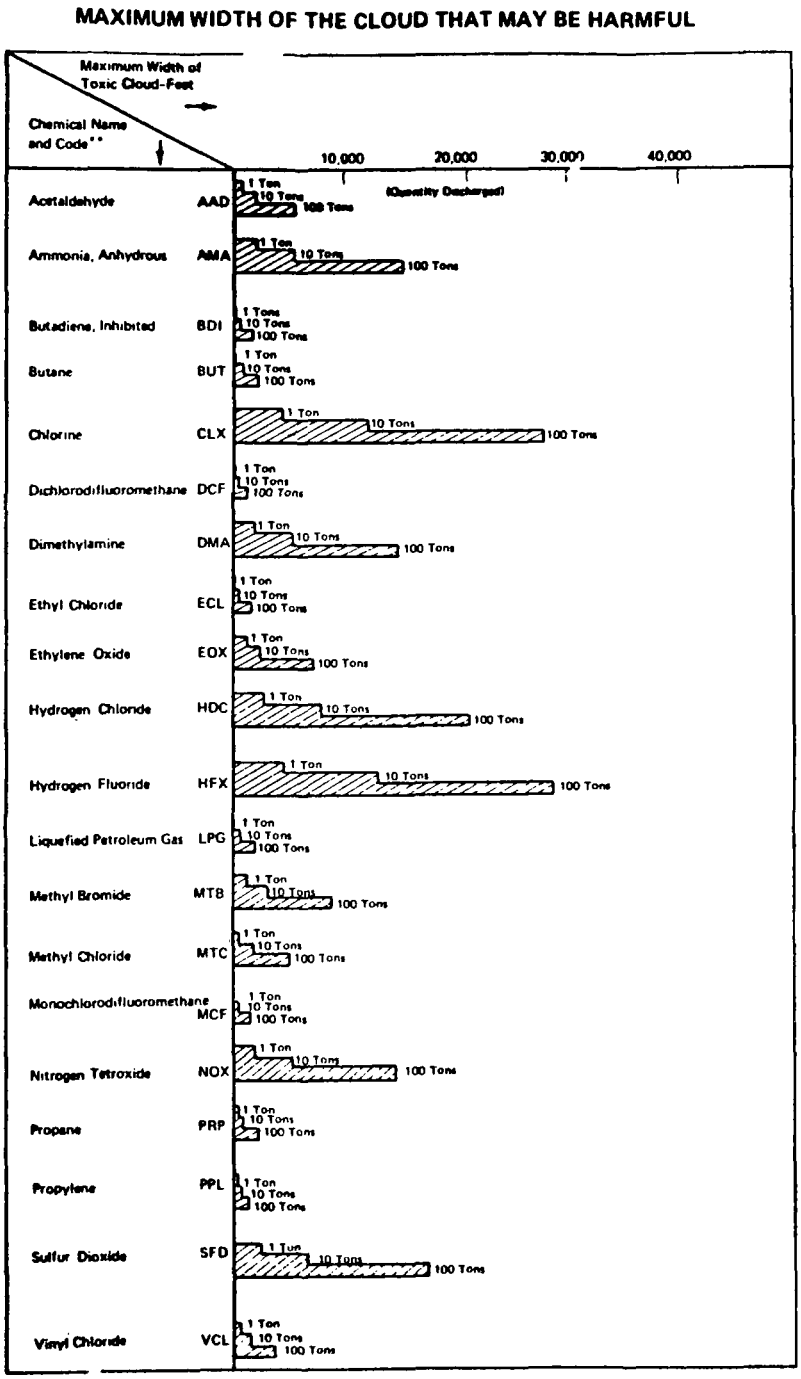
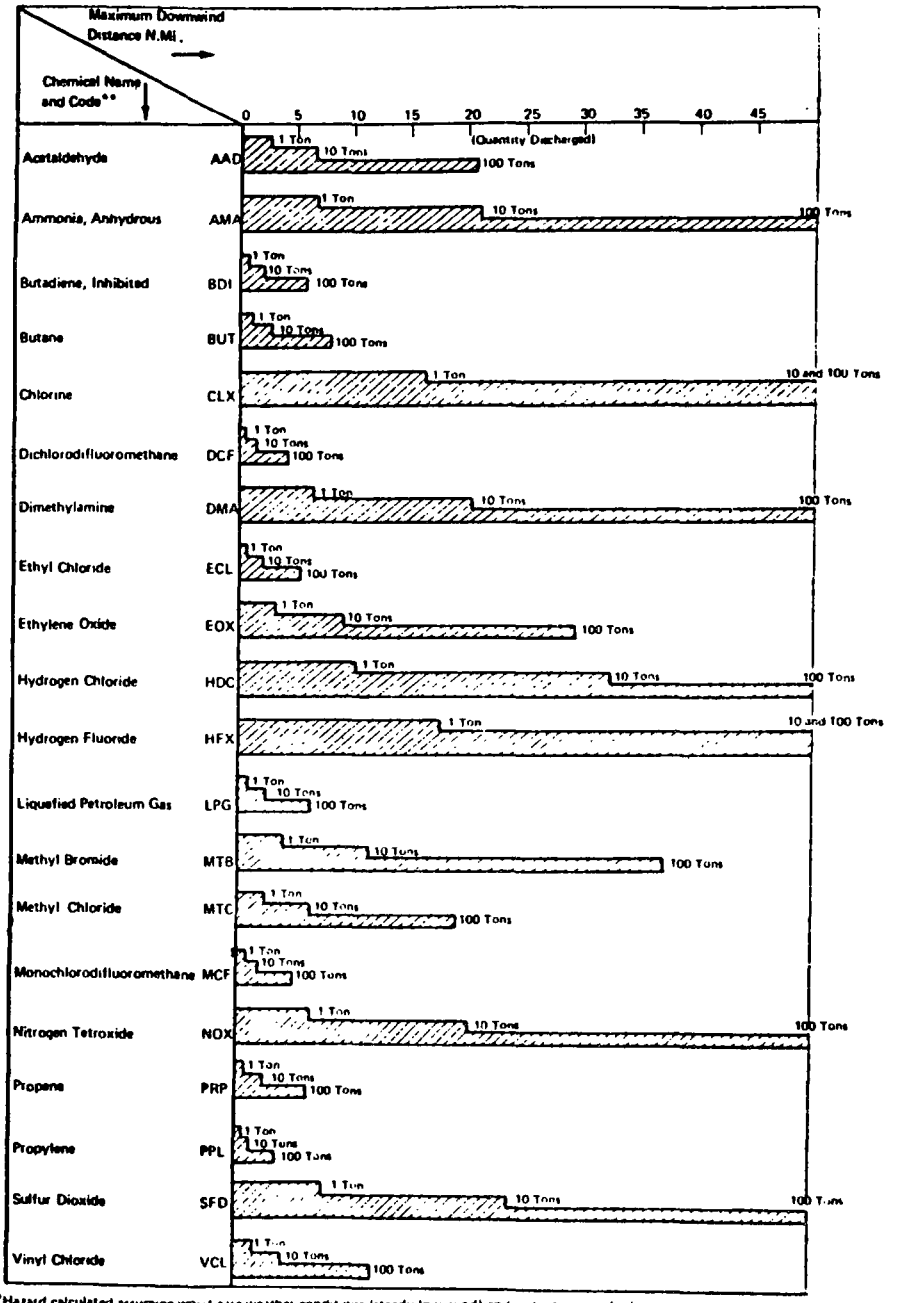


Figure 23. Effects of Toxic Gases (6).

NWMAR116270

MAXIMUM DOWNWIND DISTANCE OVER WHICH GASES MAY BE HARMFUL*†

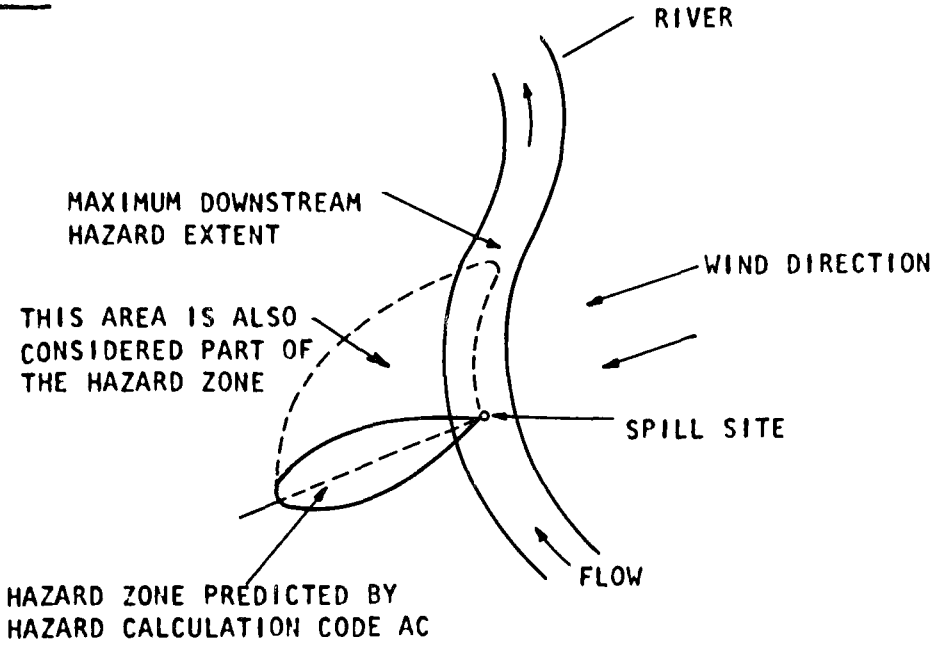


*Hazard calculated assuming worst case weather conditions (steady low wind) and instantaneous discharge
†See Table 5 3 for time of arrival and duration of cloud
**See Condensed Guide to Chemical Hazards (CG-446-1).

Figure 23. (continued)

NWMAR116271

EXAMPLE 1



EXAMPLE 2

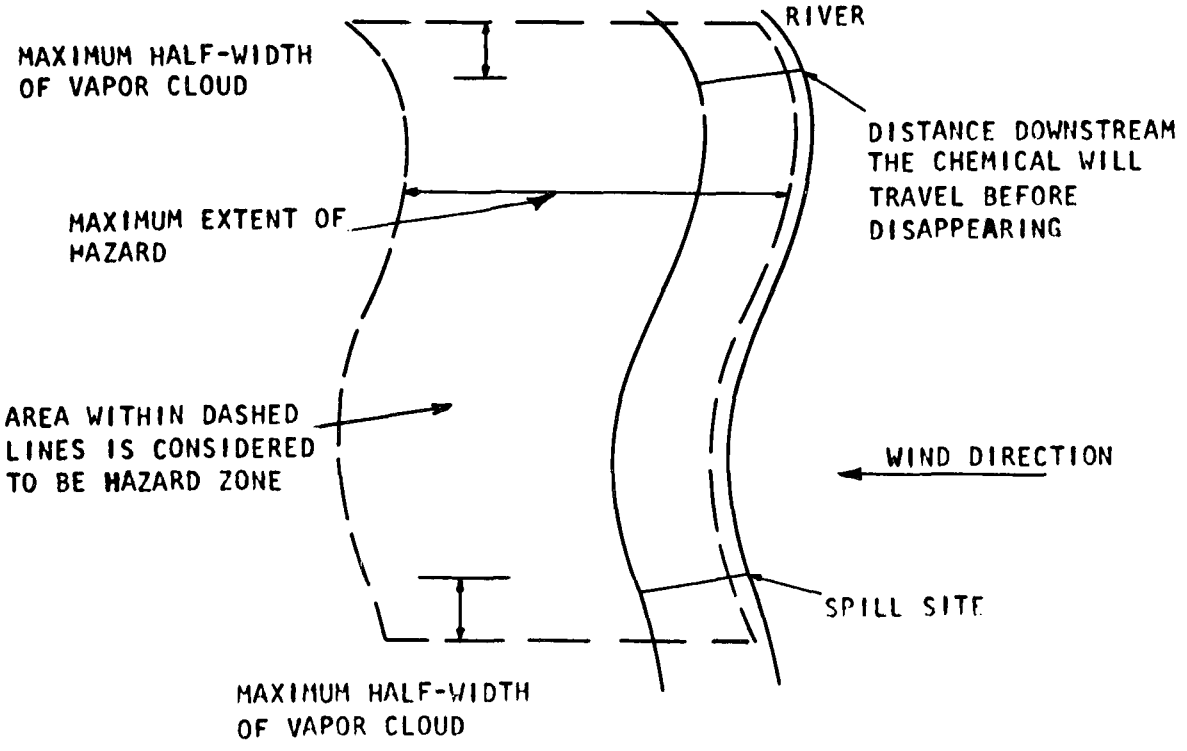


Figure 24. Wind effect on hazard zone (6).

NWMAR116272

8. Condition of Vessel or Vehicle - This indicates the stability of the situation and the possibility for leak stoppage.

9. Type and Size of Vessel - This information reported by the OSC pertains mainly to ships at sea.

3.3.3.5 Application of the Assessment Information - The OSC will then receive output from the HACS computer system indicating the affect of the hazards on downwind or downstream populations. (See Figures 23-24)

This information can then be relayed to the Civil Defense Agency or police department so appropriate action to safeguard the population can then be taken.

3.3.4 Remedial Action

Various methods of remedial action are appropriate, once the identity and danger of the spill has been assessed. The remedial action may involve covering the spill, absorption, chemical addition to change the pH or other actions. The comments section of the chemical treatment scheme in Chapter 4 indicates some remedial action. CHEMTREC and other emergency agencies should be consulted regarding other possible steps to take.

NWMAR116273

4.0-CHAPTER 4 - DETERMINATION OF THE BEST METHOD FOR SPILL HANDLING

4.1 GENERAL

Once the spill has been identified and assessed, the best containment and handling method must be determined. This chapter presents methods to allow the user to determine the best techniques for a specific situation. The chapter covers containment, choosing the best handling method, and specifics regarding handling techniques including over 300 schemes for treatment of different hazardous chemicals. The chapter is used in conjunction with Chapters 5-7 to complete the construction of a treatment system if treatment has been selected as the best handling method. The methods of following Chapter 4 and its integration with other chapters is shown in Figure 25.

4.2 CONTAINMENT OF SPILLED MATERIALS

4.2.1 Stepwise Approach to Containment

The following steps should be taken when containment of a spill is necessary: (a discussion follows)

1. Establish identity. (Chapter 3)

2. Establish human safety hazard and take appropriate safety precautions and/or remedial action. (Chapter 3)

3. Stop discharge whenever possible.

4. Note location of spill

   on land
   on water
   in water
   under water
   in air

5. Refer to appropriate figure (or figures for combined spills), the accompanying text, and the appropriate oil spill containment references, if necessary.

6. Choose a method of containment which seems best.

7. Evaluate choice by answering the corresponding questions.

8. If all answers lead to containment, proceed taking adequate safety precautions.

9. If containment by that method is not feasible, choose another possible technique and evaluate it.

NWMAR116274

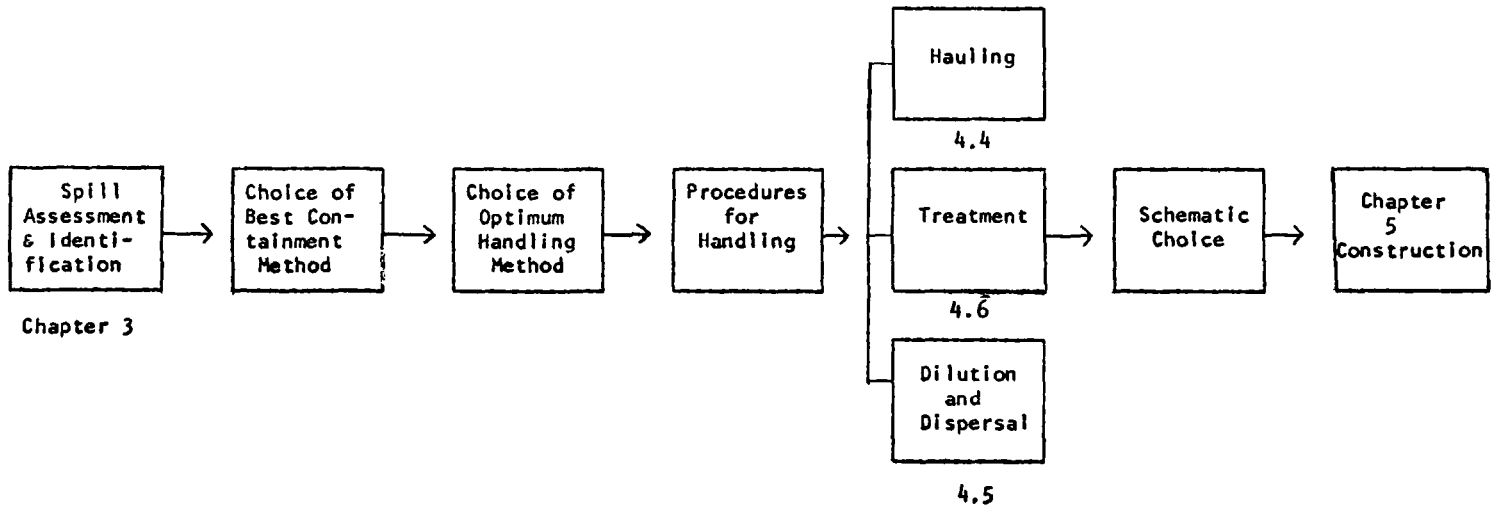


Figure 25. Use of Chapter 4.

NWMAR116275

10. Continue to evaluate alternatives until a method is established or no feasible containment method is found.

Steps 1 & 2 Identification and Assessment - Use the procedures outlined in Chapter 3 to identify and assess the spill. Do not contain the spill without knowing the identity and hazard potential because the MOS may be exposed to great danger.

Step 3 Stop Discharge Whenever Possible - To do this the MOS must approach the spill so adequate safety measures must be taken. Procedures to stop the discharge are listed below and are only included as possible suggested methods:

1. Close valves and shut off pumps - especially if a transfer operation is involved.

2. Rebuild or repair container - includes rebuilding, reinforcing, patching and insertion of plugs (13) both to the inside (rags to get caught in the leak) and from the outside (wooden plugs forced into hole to reduce area of leak).

3. Change the position of the container - move the container so the leak is at the highest level.

4. Transfer or collect the material from the leaking container - usually into an undamaged container of the same or similar type.

5. Encase the entire container or construct a suitable alternate - either overpacks or actual containment can be done in this circumstance (14).

The situation must be evaluated and then the MOS must determine if one of these procedures is applicable, or safe.

Steps 4 & 5 Locate Spill and Refer to Figure Summaries - The next step involves establishing the specific location of the spill, i.e., on land, in, on or under water, or in air. The spill could be located in a combination of media and this factor must be noted. Then the MOS must refer to Figures 26-30 which summarize the containment methods for various spills (15). It must be emphasized that the figures present diagrams to illustrate the containment technique. Details regarding its implementation are not included. The MOS must refer to the references listed in Table 16 for the needed background on containment.

Step 6 Choose Apparent "Best" Containment Method - The choice is made from knowledge of the type and size of the area affected by the spill, meterological conditions, and the materials available to the MOS. These materials can either be immediately on hand, which is the best situation, or can be brought to the scene in a short time. Other considerations are the safety hazard and the toxicity of the material spilled, the proximity to populated areas or water sources, and the accessibility to the spill

NWMAR116276

TABLE 16. OIL CONTAINMENT REFERENCES

Ayers, R.R., A Rigid Perforated Plate Oil Boom for High Currents, Report No. EPA 600/2-76-263, National Technical Information Service, Springfield, Virginia 22161, 1976.

Bonz, P.E., Fabric Boom Concept for Containment of Floating Oils, Report No. EPA 670/2-73-069, National Technical Information Service, Springfield, Virginia 22161, 1973.

Breslin, M.K., Testing of Boom Configurations for Calm Water Spill Containment, EPA Report, Oil and Hazardous Materials Spills Branch, U.S. E.P.A., Edison, New Jersey 08817, 1977.

Guide to Water Cleanup - Materials and Methods, Arthur D. Little/Learning Systems, Cambridge, Massachusetts 02140, 1974.

McCracken, W.E., Hydrodynamics of Diversionary Booms, EPA Report, Oil and Hazardous Materials Spills Branch, U.S. E.P.A., Edison, New Jersey 08817, 1977.

McCracken, W.E., Performance Testing of Selected Inland Oil Spill Control Equipment, Report No. EPA 600/2-77-150, National Technical Information Service, Springfield, Virginia 22161, 1977.

McCracken, W.E. and Schwartz, S.H., Performance Testing of Spill Control Devices on Floatable Hazardous Materials, EPA Report, Oil and Hazardous Materials Spills Branch, U.S. E.P.A., Edison, New Jersey 08817, 1977.

Proceedings, 1973 Oil Spill Conference, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, 1973.

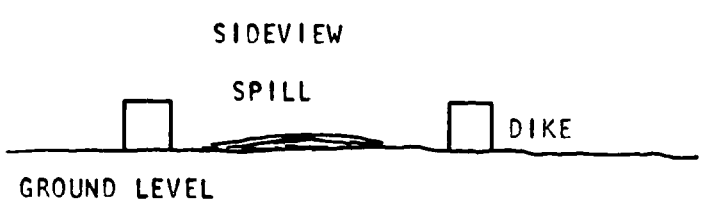
Proceedings, 1975 Oil Spill Conference, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, 1975.

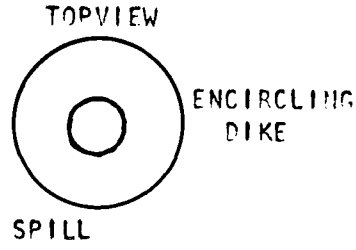
Proceedings, 1977 Oil Spill Conference, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037, 1977.

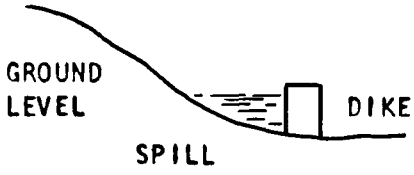
Schwartz, S.H., Performance Testing of the Navy Standard Boom and P.A.A. Boom, EPA Report, Oil and Hazardous Materials Spills Branch, U.S. E.P.A., Edison, New Jersey 08817, 1977.

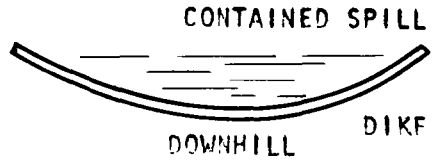
NWMAR116277

I. DIKING









1. Suitable dike materials must be available, either natural soil, sand bags or foam.
2. Proper earth moving equipment or specialized foam dike equipment must be obtainable.
3. An advantageous site must be available.
4. This procedure may not eliminate percolation of the spill through the soil.

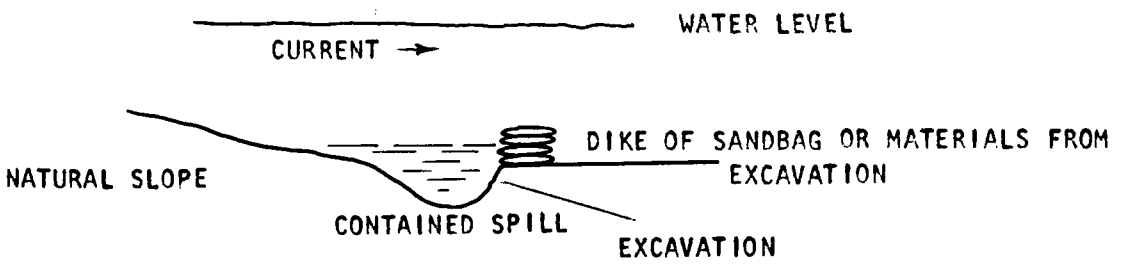
II. EXCAVATIONS

1. Equipment and land must be available to accommodate the excavation.
2. In certain areas, soil or subsoil nature may render excavation impossible or ineffective.

Figure 26. Containment of spills on land.

NWMAR116278

1. EXCAVATION AND DIKING



1. Difficulties may be encountered when attempting excavations under water.

2. Natural forces such as currents or slope of the bottom may be utilized advantageously.

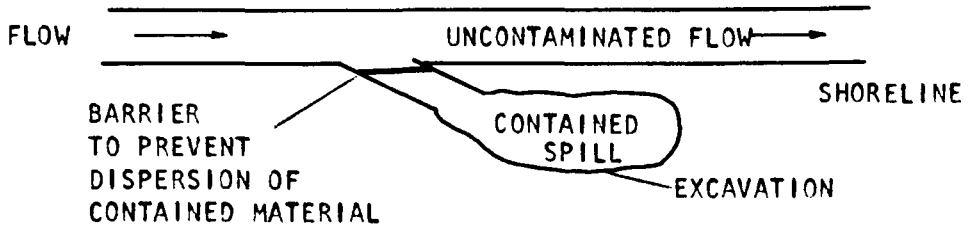
3. Increased turbidity may hamper the activity of scuba divers.

4. Material needs may include divers, pumps, earthmoving equipment, dredges, and diking material.

Figure 27. Containment of spills heavier than water.

NWMAR116279

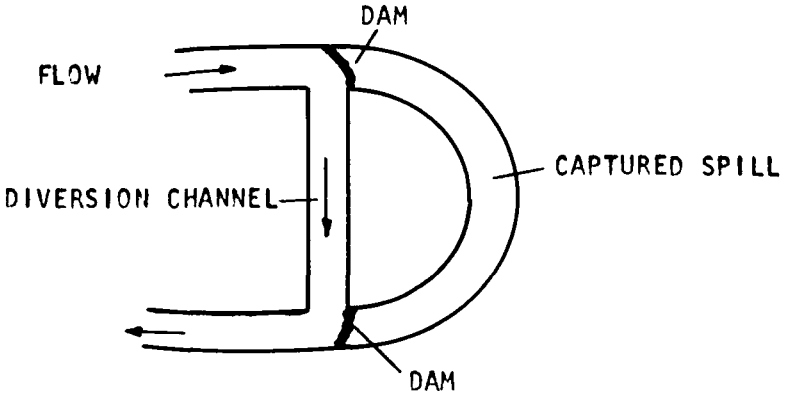
1. DIVERSIONS



1. The equipment and suitable land areas must be available for a large excavation upon short notice.

2. An effective method of backfilling the excavation must be available.

3. It is possible to use pumps for stream diversion.



1. Equipment and suitable land area must be available for a large excavation upon short notice.

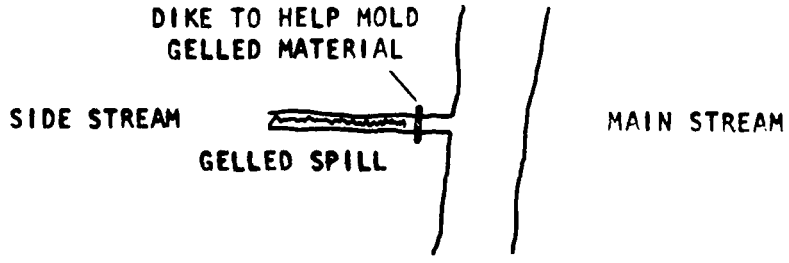
2. An effective method of enclosing the spill with dams must be available.

continued

Figure 28. Containment of an entire water mass

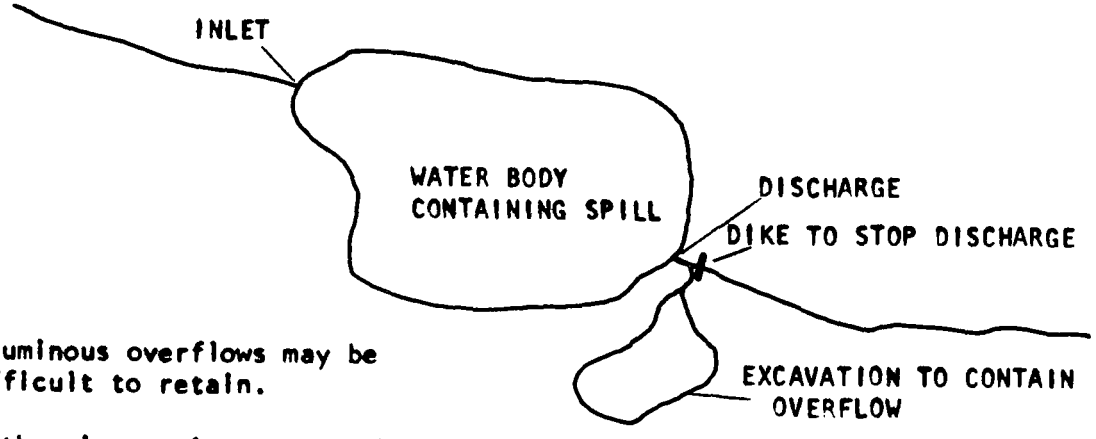
NWMAR116280

II. GELLING



1. Gelling is useful when a limited volume of waste is to be treated.
2. Treatment and/or disposal of the entire gelled mass is necessary.
3. Application of gelling agents must be implemented a short time after the spill occurs.
4. Trained personnel and specialized equipment must be available.

III. CONTAINING AN ENTIRE WATER BODY



1. Voluminous overflows may be difficult to retain.
2. Earthmoving equipment must be obtainable.
3. When more than one overflow originates from a waterbody, all overflows must be contained.

continued

Figure 28 (continued)

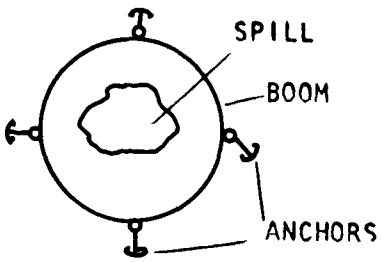
NWMAR116281

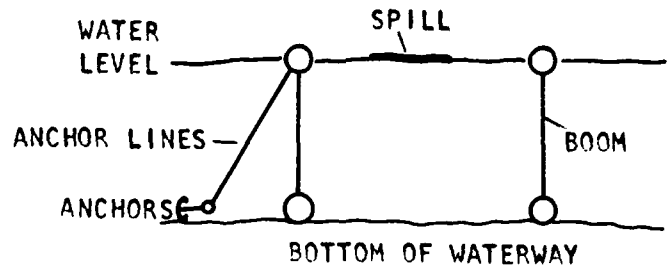
IV. SEALED BOOMS

TOP VIEWS

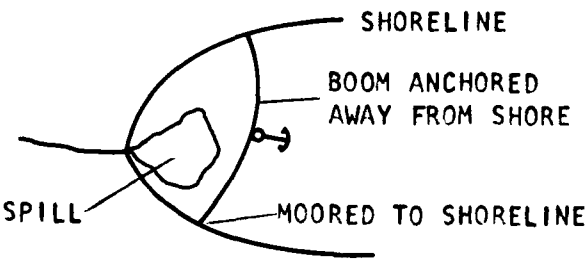
SIDE VIEWS

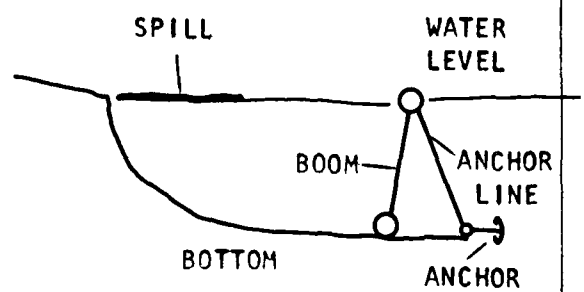
EXAMPLE 1





EXAMPLE 2



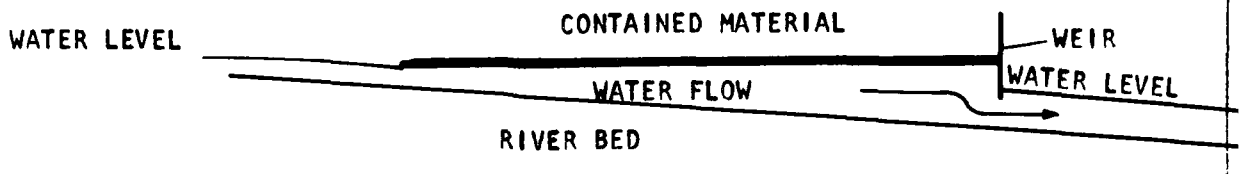


1. The spill must be of limited volume.
2. Wind or current may render this containment method ineffective.
3. Difficulties in obtaining a sealed boom system may be encountered.
4. This containment method is applicable in shallow water only due to bottom seal and anchoring difficulties.

Figure 28 (continued)

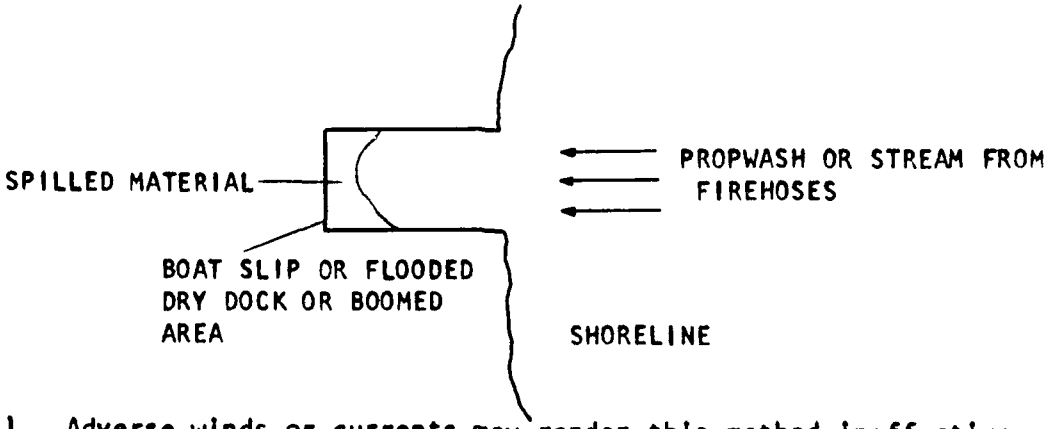
NWMAR116282

I. WEIRS



1. Weirs may be difficult to deploy properly.
2. Turbulence behind the weir may render this containment method ineffective.
3. To be effective the spilled material must be in the upper layer of water.

II. USING FIREHOSES OR PROPWASH TO DIRECT AND CONTAIN SPILLED MATERIALS



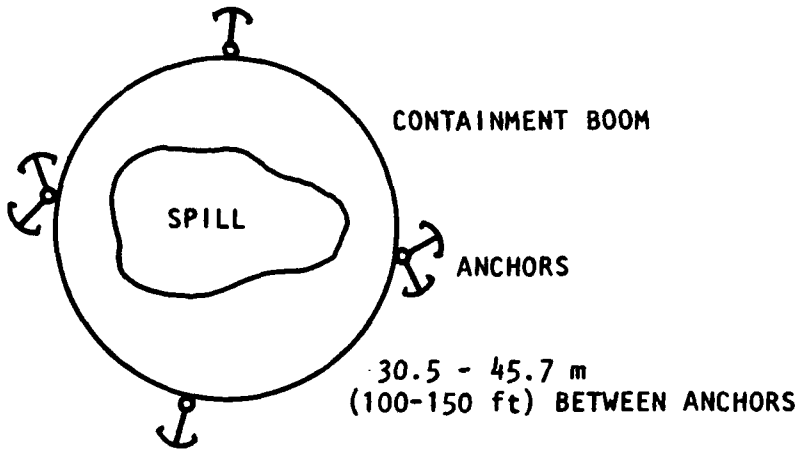
1. Adverse winds or currents may render this method ineffective.
2. Firehoses or ships must be obtainable, and have access to the spill site.
3. A suitable containment area must be available.
4. Winds and currents must be taken into account.
5. Impact water with fire stream at least 6.1-9.2 m (20-30 ft) away from spill.

continued

Figure 29. Containment of floating spills

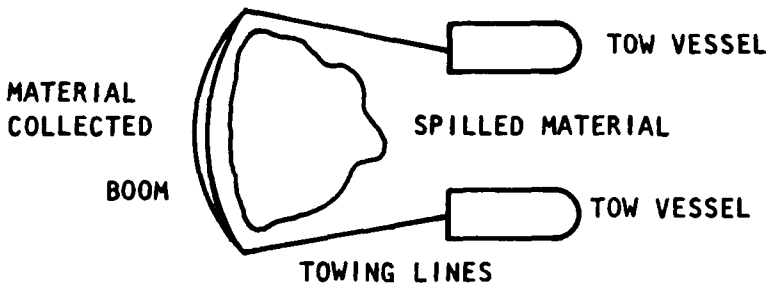
NWMAR116283

III. ENCIRCLING BOOM



1. Heavy seas may render containment with this method ineffective.
2. Wind or current shifts may render this containment method ineffective.
3. The proper booms and deployment systems may be difficult to obtain.

IV. COLLECTION AND TOWING OF A SPILLED MATERIAL WITH A BOOM

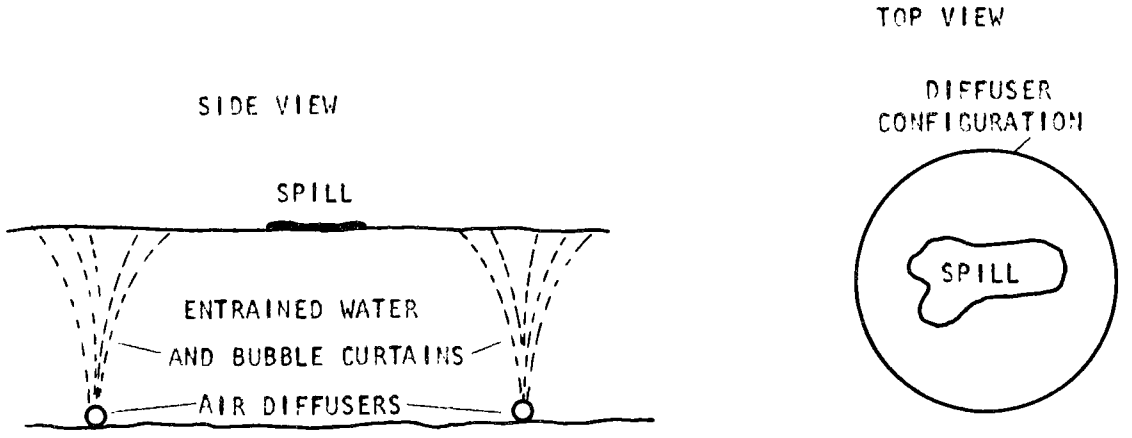


1. Heavy seas may render containment with this method ineffective.
2. Wind or current shifts may render this containment method ineffective.
3. The proper booms and deployment systems may be difficult to obtain.
4. Towing speed may be limited to 2.8 km/hr (1.5 knots) or less.

Figure 29 (continued).

NWMAR116284

V. PNEUMATIC BARRIERS



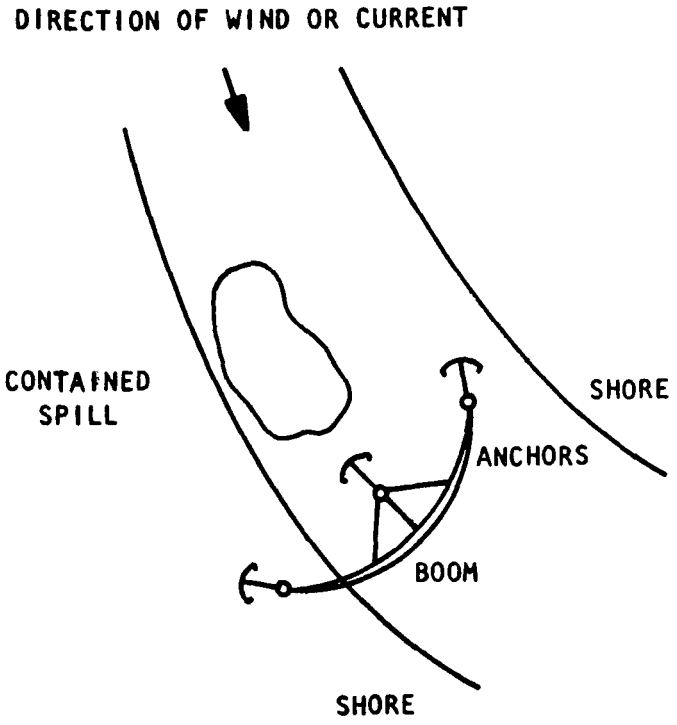
1. Wind or current may render this containment method ineffective.
2. Obtaining proper diffusers and compressors may be difficult.
3. Deep water requires suspension of diffusers in the water column to increase efficiency of unit.
4. Rarely used.

continued

Figure 29 (continued)

NWMAR116285

VI. DIVERSIONARY AND CONTAINMENT CONFIGURATION

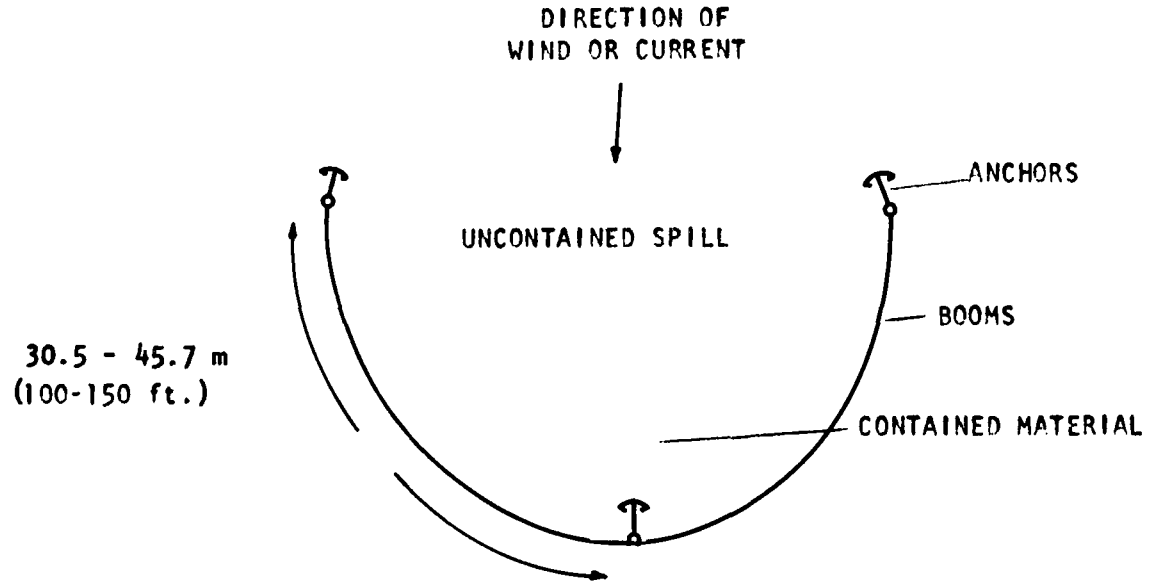


1. Whenever possible use with outside bend and sufficient clearance to reach site.
2. An intermediate tie is needed to keep "bucket" from forming.
3. Technique is limited to currents up to 2.4-3.1 mps (8-10 fps)
4. Proper booms and deployment systems may be difficult to obtain.

Figure 29 (continued).

NWMAR116286

VI. DIVERSIONARY AND CONTAINMENT CONFIGURATION

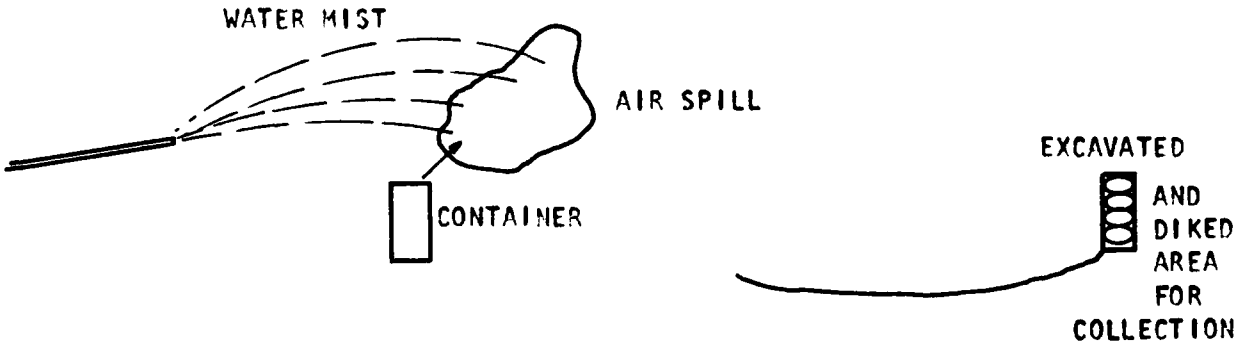


1. Heavy seas may render this containment method ineffective.
2. Wind or current shifts may render this containment method ineffective.
3. The proper booms and deployment devices may be difficult to obtain.
4. This technique is limited to currents up to 0.3-0.61 mps (1-2 fps).

Figure 29 (continued).

NWMAR116287

1. MISTING TO REMOVE CONTAMINANTS



1. Not all materials will be removed in this manner.
2. Water source must be available.
3. Require large area for containment of resulting water.

Figure 30. Suppression of air spills

NWMAR116288

location. Specific information on containment methods is presented in the tables which follow. (Tables 17-21).

Step 7 Evaluate Choice - Once a preliminary selection has been made, the choice is evaluated by answering the list of questions (Figures 31-35) which are designed to indicate problems with the containment method. It is important to consider each of the questions individually and determine if any aspect of containment by that method is limiting. One question which must be answered regards the hazard effect of containing the material in a small space rather than allowing natural dispersal processes to remove it. The specific nature of the material, the size and type of the area affected, and the mobility of the system will aid in answering this question.

Step 8 Contain Safely if Indicated - The questions answered in Step 7 will then indicate if the chosen containment technique is feasible. Then the MOS must proceed cautiously, taking adequate safety precautions to contain the spill. Referral to more specific references regarding containment is necessary (Table 16).

Steps 9 & 10 Evaluation of Other Alternatives — If evaluation by Step 7 indicates containment by the initial technique is not feasible, other alternatives can then be evaluated to determine the best method of containment, if any. Once it has been established if the material can or cannot be contained, then the decision must be made regarding the succeeding spill handling method.

4.3 COLLECTION OF SPILLED MATERIALS

After containment, the spill may require collection for containment removal, or treatment. Various methods are available including those listed. More detailed information is available in other references.

a. Suction Skimmers - Remove surface contaminants by drawing layers through an orifice. The angle of the orifice establishes the ratio of water and contaminant to be removed (16).

b. Vacuum Skimmers - Remove floating materials also using a vacuum tank to generate the drawing force. Useful mostly for small spills or places where flammable materials are to be removed.

c. Sorbents - Used to collect floating material by distributing absorbents and then collecting them from the surface of the water body.

d. Dredging - Used to remove insoluble chemicals that are heavier than water. Various methods are used, however, care must be taken not to disturb the bottom and create a more hazardous situation (17).

NWMAR116289

TABLE 17. SPILLS ON LAND

Type	Application or Construction Method	Use	Advantages	Disadvantages
Dikes				
Earthen	Create with bulldozer or earth-moving equipment to compact earth (height depends on earth type)	Flat or sloped surface	1. Material on site 2. Construct with common equipment 3. Construct quickly	1. Natural permeability of soil 2. Seepage through ground 3. Surface composition of soil not suitable in all cases
Foamed Polyurethane	Use trained personnel to construct	Hard, dry surfaces	1. Hold up to several feet of water (3)	1. Leaks on wet ground 2. Hard to obtain dispersion device
Foamed Concrete	Use trained personnel to construct	Flat ground Slow moving spill	1. Better adhesion to substrates (clay/shale/grass)	1. Hard to obtain foam and dispersion device 2. Must set for a time period Will not hold high hydraulic heads (15)
Excavation	Bulldozer or earth-moving equipment - line if possible	Soft ground Natural cavitation	1. Material on site 2. Construct with common equipment	1. Move large amounts of material 2. Natural permeability of soil 3. Surface of soil not suitable in all cases
Excavation & Dikes	Bulldozer or earth-moving equipment - line if possible	Soft ground	1. Need less space than separate 2. Material on site 3. Construct with common equipment	1. Move large amounts of material 2. Natural permeability of soil 3. Surface of soil not suitable in all cases

NWMAR116290

TABLE 18. SPILLS IN WATER - HEAVIER THAN WATER SPILLS

Technique	Application or construction method	Use	Advantages	Disadvantages
Natural Excavations & Dikes	none	Where a natural barrier exists	No construction needed	Can't control the area which contains the spill
Construction of excavations & dikes	Dredges: hydraulic or vacuum pumps Divers with pumps then place concrete or sand bags around to form dike if bottom material is not sufficient	If bottom can be moved	Material is on site	1. Hard to construct 2. Stirred up bottom may cause dispersion and increased turbidity.

NWMAR116291

TABLE 19. SPILLS IN WATER - SOLUBLE OR MISCIBLE SPILLS

Method	Application or Construction Materials	Use	Advantages	Disadvantages
Sealed Booms	Boom Device to anchor	Contain depth limited volumes leaking containers	Contain entire depth of water	1. Deployment difficult 2. Not used for large bodies 3. Difficult to get good seal (16)
Diversion of Uncontaminated Flow	Earthmoving Equipment	Special area where topography is right	1. Can put cleaned water into diverted stream 2. Used for flowing water	1. Difficult to move large amounts of earth 2. Clear area needed 3. Impermeability of ground
Diversion of Contaminated Flow	Block entrance with sandbags, sealed booms or dikes	Special area where topography is right	1. Can put clean water back into stream 2. Used for flowing water	1. Difficult to move large amounts of earth 2. Clear area needed 3. Impermeability of ground 4. Adverse environmental impact
Gelling Agent (40)	Gels, Dispersion Devices; use experienced personnel	If small volumes	1. Stop flowing contaminant 2. Stop permeation	1. Hard to obtain 2. Can't use in large area 3. Must haul to dispose
Containment of Entire Waterbody	Diking Materials Earthmoving Equipment Sandbags, etc. Lining	For entirely contaminated area	1. Can allow containment of a large waterbody 2. Materials on site 3. Easily constructed	1. Not all waterbodies have containable overflow 2. Permeability 3. May be an unstable condition

NWMAR116292

TABLE 20. SPILLS IN WATER - FLOATING SPILLS

Method	Application or construction materials	Use	Reference*	Advantages	Disadvantages
Booms	Varies; need deployment device	Not too much current	CG-446-4 (41) p. 6-10 to 6-25	Used on large area; Many varieties	1. Only in waves less 2-4 feet 2. Current speed less than 0.7 knots
Weirs	Weir & boat	Calm	CG-446-4 (41) p. 6-25	Not easily clogged; Collects & contains	Not used in rough water
Pneumatic Barriers	Air compressor diffuser deployment method	Only shallow water	CG-446-4 (41) p. 6-25 to 6-25	Do not create a physical barrier to vessels	1. Not in rough water 2. Only shallow water 3. Only thin layers or materials
Spill Herding Methods	Chemicals on water spray or prop. wash	To protect shore or other facilities	CG-446-4 (41) p. 6-31 to 6-35	Useful in rough water	1. Not easily obtainable 2. Not 100% effective

* Many references are applicable; see Table 16.

NWMAR116293

TABLE 21. SPILLS IN AIR

Technique	Method	Use	Advantages	Disadvantages
Mist Knock down	Spray fine mist into air	Water soluble or low lying vapors	Removes hazard from air	Create water pollution problem and must be contained in solution
Fans or blowers	Disperse air by directing blower toward it	Very calm and sheltered areas	Can direct air away from populated areas	1. Not at all effective if any wind 2. Need large capacity of blowers 3. Hard to control

NWMAR116294

1. Will any natural phenomenon such as rainfall, soil or subsoil render the containment ineffective?

2. Will man-made conditions such as wells or underground drain tile render the method of containment ineffective?

3. Is there a sufficient quantity of containment material, personnel and equipment?

4. Can the containment method be deployed safely and effectively?

5. Can the spill be contained quickly enough by the proposed containment method?

6. At what point is the containment equipment likely to leak and how can the leaks be minimized or prevented?

7. Would another containment method be better?

8. Would the repercussion of containment be more harmful than the natural dispersal and/or breakdown of the spill?

Figure 31. Establishing the feasibility of spill containment on land

1. Are there any natural phenomenon such as bottom composition, current, wave action, access or water depth that would render the containment method ineffective?

2. Would man-made conditions such as shipping, concrete channels, or discharge of dams render the containment method ineffective?

3. Can a sufficient amount of containment materials, equipment, and personnel be deployed to the site safely?

4. Can the spill be contained quickly enough?

5. Will the spill leak or seep out of the proposed containment device? If so, can it be prevented from doing so?

6. Would another containment method be getter suited to the spill?

7. Would the repercussions of containment be greater than those of natural dispersion and/or breakdown?

Figure 32. Establishing the feasibility of containment for heavier than water spills

NWMAR116295

1. Are there any natural phenomenon such as discharge volume, spill volume, soil structure, bottom composition or rainfall that would render this containment method ineffective?

2. Will any man-made conditions such as dams, concrete channels, or bypasses render the containment methods ineffective?

3. Can a sufficient quantity of containment material, equipment, and personnel be obtained and deployed safely?

4. Can the spill be contained quickly enough by the proposed containment method?

5. Will leakage and seepage be a problem? If so, how can it be ameliorated or prevented?

6. Would any other containment method be better?

7. Would the repercussion of containment be greater than those of natural dispersion and/or breakdown?

Figure 33. Establishing the feasibility of containment for soluble spills

1. Will natural phenomenon such as wind, waves, current or tidal action render the containment device ineffective?

2. Is there any man-made condition, such as, periodic discharge from dams, water intakes, or boat traffic that would render the containment device ineffective?

3. Can a sufficient quantity of the containment device be obtained?

4. Can the containment device be deployed safely and effectively?

5. Can the spill be contained quickly enough by the proposed method?

6. At what point is the containment equipment likely to leak and how can the leaks be minimized or prevented?

7. Would another containment method be better?

8. Would the repercussion of containment be more harmful than the natural dispersal and/or breakdown of the spill?

Figure 34. Establishing the feasibility of containment for lighter than water spills

NWMAR116296

1. Will natural phenomenon such as wind or air current disperse the containment before containment is possible?

2. Can a suitable water collection setup be established?

3. Can the spill be approached safely?

4. Is the material removable by reaction with a water mist?

5. Would the repercussions of containment, especially in creating a water pollution problem, be more harmful than natural dispersal, taking adequate safety precautions?

Figure 35. Establishing the feasibility of air spill suppression

NWMAR116297

4.4 DECISION ON SPILL HANDLING

4.4.1 General

The critical decision regarding handling of the spill is very difficult. Many variables affect the decision, and these variables must be considered by the user and altered to fit the specific situation. Only then can the final conclusion be reached. There are four ways the spill can be handled: (1) diluted and dispersed into the natural environment, (2) treated "in-situ" with makeshift processes, (3) hauled to another site for disposal or treatment, and (4) treated in an on-site, but offstream, treatment system. The following items are presented to guide the thought processes of the OSC and allow him to decide on the best course of action for his situation.

4.4.2 Use of the Thought Guide

The thought guide (Figure 36) is a graphical presentation of the thought processes required of the OSC when establishing the handling of a spill. The boxed questions presented are merely summaries of many considerations which are to be answered by the OSC in establishing the final answer to the main boxed question. Once an answer of yes or no has been established, the arrows are followed to the box with the next applicable question. It is assumed that the OSC is familiar with the manual and can refer to the following sections which elaborate on the questions, if necessary. The result of the following thought guide will be determination of a feasible handling method for the specific spill situation.

4.4.3 Variables to Consider

Determining which of the four methods of spill handling should be used in a spill situation involves consideration of a series of questions which affect the choice of handling methodology. The following questions are outlined in Figure 36. This guide is flexible and is intended to aid the OSC but not to make the decisions for him. The following paragraphs outline the considerations which are necessary when the questions are to be answered.

1. **Is the spill contained or containable? - This information can be obtained by reference to subsection 4.2. The size and type of area affected, mobility of the spill and availability of containment methods are prime factors in this decision.**

2. **Is a remote treatment or disposal site available? - The answer is dependent on a wide variety of factors and a series of subquestions can be asked.**

   a. **Can the remote disposal site or treatment plant handle this material?**

   b. **Is the volume of the area affected by the hazardous material compatible with the capacity of the remote site?**

NWMAR116298

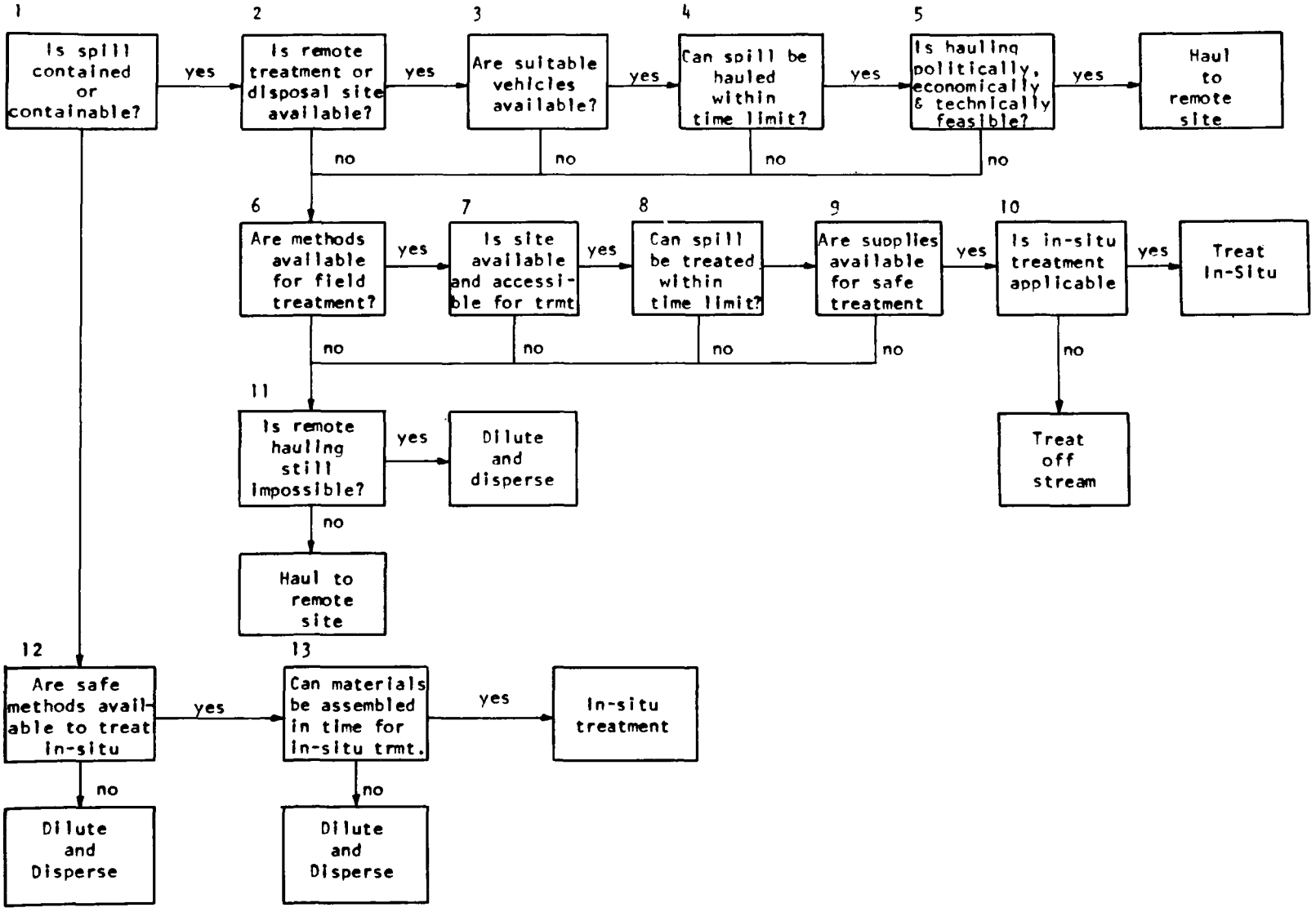


Figure 36. Spill handling thought guide.

NWMAR116299

c. Can permission be obtained to use the site for treatment or disposal of the hazardous material and the affected media?

3. Are suitable vehicles available to haul the affected material?

The type of vehicle required is established by the chemical and physical characteristics of both the hazardous material and the affected media. Included in the considerations should be the following:

a. State of the material - liquid or solid or percent of each.

b. Corrosiveness of the material.

c. Proximity of sewer lines to allow disposal to a nearby treatment plant.

d. Other handling properties of the material at the given concentration.

4. Can the spill be hauled within a reasonable time limit?

This consideration includes the establishment of a reasonable time limit. This limit can be established by comparison to the length of time to set up and operate a treatment system for on-site treatment or by other means. If hauling is more time consuming, other handling methods should be considered. To establish the time for hauling, the following questions must be answered:

a. Is an unstable weather or physical condition establishing a time limit?

b. How far away is the remote site?

c. What is the volume of the material affected?

d. What is the truck capacity?

e. How many vehicles are available to haul materials each day?

f. How many and what capacity pumps are available?

The answers to these questions will allow the calculations regarding the total time required for hauling.

Example of determining if a spill can be hauled in a reasonable time:

Answers to questions - 4a-f:

a. 1 week (before a large rainstorm is expected).

NWMAR116300

b. 161 km (100 miles) (the distance to a remote treatment plant).

c. 3.78×10^5 liters (100,000 gal.) - volume of affected waterway

d. 8325 liters (2200 gal.) - available volume of septic tank truck

e. 5 trucks are available (number of trucks).

f. pump on truck 378 liter/min (100 gpm).

Time to fill and empty the truck.

$$\text{Time} = \frac{8325 \text{ l } (2200 \text{ gal.})}{378 \text{ l/m } (100 \text{ gpm})} = 22 \text{ min}$$

Total = 22 + 22 = 44 min.

$$\text{Travel time} = \frac{161 \text{ km}}{80.5 \frac{\text{km}}{\text{hr}}} (50 \text{ mph}) = 2 \text{ hr } (120 \text{ min}) \text{ (one way)}$$

Total = 120 + 120 = 240 min.

Total time + break (10% extra)

284 + 29 = 314 min/trip = 5.3 hr/trip.

Total number of trips required for all trucks

$$\frac{3.78 \times 105 \text{ l}}{8325 \text{ l/truck}} = \frac{(10^5 \text{ gal})}{(2200 \text{ gal/truck})} = 45.4 \text{ trips} = 46 \text{ trips}$$

How many hours to haul entire amount with 5 trucks?

$$\frac{46 \text{ trips/1 truck}}{5 \text{ trucks}} = 9.2 \text{ trips}$$

9.2 trips x 5.3 hours/trip = 29 hours

Therefore, 1 week has 168 hours and hauling can be accomplished within this time period with a large safety factor.

5. Is hauling politically, economically and technically feasible?

This question combines many of the non-specific variables which must be evaluated by the OSC. Political opinions may affect the decision regarding hauling by insistence on a specific and/or immediate course of action. This position may force the OSC to concur without further evaluation. Another aspect of hauling is the cost potential. The economics of both treatment and hauling must be evaluated with the following considerations in mind:

NWMAR116301

a. Concentration of the contaminant - The more concentrated the contaminant, the more likely that hauling will be the most effective method since treatment by-products may be as voluminous as the material treated.

b. Amount of solids produced - The amount of solids or sludges produced by treatment must be considered when evaluating the alternatives.

c. Amount of treatment by-products produced - The amount of spent by-products, such as carbon, produced must be considered prior to hauling.

d. Solids concentration of the wastewater - The total solids concentration of the wastewater may dictate that the entire volume be hauled, since these solids will already require disposal.

e. Expense of materials required for treatment - The cost of the materials required for treatment must be added to the cost of removing any treatment by-products or sludge produced.

f. Specific gravity and solubility of the materials spilled - The specific gravity will indicate if dredging or skimming operations can be used to remove the material and the solubility will indicate the concentration of the materials in a water body. In general, mostly insoluble floating or sunken materials can be hauled because of their high concentration, while soluble materials will usually require on-site treatment.

g. Location of material spilled - Generally, both land and air spills cannot be easily treated on-site due to the nature of the contamination. Once an air spill has been contained, hauling it to a manufacturer or other suitable location is generally the most practical arrangement. Land spills will contain high concentrations of both the contaminant and other solids, so hauling of the affected earth can be the most practical approach. Any rinse water which is used can then be captured and the hauling feasibility for it evaluated separately.

h. Size of the water body affected - Water spills must be evaluated separately since the effect on the amount of water affected and the effective concentration of the contaminant must be considered jointly. Basically, the volume and concentration establish the applicability of various treatment steps, and the hauling economics. Large concentrated spills are most difficult to handle because large hauling volumes will be generated both with and without treatment.

The technical aspects of hauling must also be considered. If the hauling is transposing the problem to a place where more effective treatment or control is possible, then hauling is feasible. However, if hauling merely

NWMAR116302

transposes the problem without technical benefits, this approach may not be the best solution.

6. Are methods available for field treatment?

   This consideration is crucial when establishing the viability of treatment as an alternative handling method. There are treatment schemes presented in this document which establish methods for treating over 300 hazardous materials. OHMTADS, CHRIS, and other sources may include other treatment methods and should be consulted. If a treatment method cannot be found for a certain spilled material, the manufacturer can be contacted. If still no field applicable method is available, treatment on the scene is not an acceptable handling method.

7. Is the site available and/or accessible for treatment?

   There are certain size requirements that must be met when establishing a treatment site since an offstream plant requires at least 0.20 ha (0.25-0.5 acres) of area. In-situ treatment requires less area but accessibility to the spill location is important to allow delivery of necessary materials.

8. Can the spill be treated within a reasonable time limit?

   Treatment feasibility is also contingent upon the amount of time necessary to treat the wastewater. This time limit may be established by unstable weather conditions that would cause the spill to spread or by economic restraints caused by manpower costs. The following categories should be considered:

   a. Length of time to construct treatment process.

   b. Total flow through rate of operation.

   c. Total amount of material to be treated.

   d. Number of hours of operation per day.

   Example: a. 48 hours (to set up equipment).

   b. 189 l/min (50 gpm) (flow rate through plant).

   c. 3.78×10^6 l (10^6 gal.) (amount of water to treat)

   d. 16 hours/day (hours of daily operation)

$$\text{Total time} = \left[48 \text{ hrs} + \frac{3.78 \times 10^6 \text{ l}}{189 \text{ l/min} \times 60 \frac{\text{min}}{\text{hr}}}\right] \frac{1}{16 \text{ hr/day}} = 24 \text{ days}$$

NWMAR116303

9. Are supplies available for safe treatment?

Included in the considerations for this question are: The volume and cost of supplies; the length of time for delivery; and the materials necessary for safe handling of chemicals. If any of these considerations indicate proper materials are not available, the answer to the main question is considered negative.

10. Is in-situ treatment applicable?

At first inspection, in-situ treatment would seem to be the best method of treatment for the following reasons:

a. Handling of the hazardous material is minimized.

b. Construction time and land requirements are substantially reduced or eliminated.

c. Treatment can be done on the entire system at once.

In certain situations such as where efficient treatment is not necessary, when the time to treat is not critical, when the water volume is extremely great or when no significant amounts of byproducts are produced, in-situ treatment becomes more advantageous. However, it is necessary to evaluate the end products of the process and consider other aspects on in-situ treatment before it is implemented. Important considerations include:

a. Can in-situ treatment methods achieve the degree of treatment required?

b. Are significant amounts of sludge produced which may either harm the benthic population or require additional removal?

c. Can in-situ treatment accomplish the task in a reasonable amount of time or would an offstream process be faster?

d. Are dangerous by-products formed or is there a general change in the water chemistry which is harmful to existing fauna and flora?

e. Is the method safe for personnel employing it?

Once these factors have been considered, the choice of treatment type can be made.

11. Is remote hauling still impossible?

This question provides for re-evaluation of the hualing question. At this point, it is assumed that on-site treatment either in-situ or offstream is not possible due to negative answer to any one of

NWMAR116304

Questions 6-10. Therefore, the feasibility of hauling as indicated by Question 5 must be re-evaluated. It is best to reconsider all the questions (2-5) to determine the hauling feasibility. If this question still results in a negative answer, dilution and dispersal is the only alternative left.

12. Are safe methods available for "in-situ" treatment?

    This question initially assumes that the spill is not contained or containable. Then the methods for in-situ treatment must be considered. Both flow-through and "batch" methods and the effects of these procedures and their by-products must be established. Among the pertinent questions are:

    a. Is a reasonable in-situ method available? When in-situ treatment is not possible, dilution and dispersion is the only available handling technique.

    b. Is the treatment effective to achieve desirable removals?

    c. Are by-products produced which are harmful to the aquatic environment?

    d. Can the materials be assembled in time for in-situ treatment? This is a critical immediate concern for an uncontained spill. Both the specific chemicals or chemical products and the construction material must be obtained in a short time to determine if in-situ treatment is feasible. Where this is not possible, dilution and dispersal must be used.

4.5 HANDLING A SPILL BY HAULING

Once the decision has been made to haul a spill the following specific information must be gathered by the OSC:

1. Determine the hazard potential and corrosivity - the specific problems in handling are outlined in many handbooks and any special equipment must be obtained.

2. Calculate the total volume of material to be handled.

3. Obtain suitable hauling vehicles:

    Liquid spill: septic tank truck
    tank truck
    railroad tank car
    empty barge
    cargo ship

NWMAR116305

Solid spill: sealed dumpster (small volume)
lined and covered dump truck
lined and covered railroad cars

4. Obtain pumping or transfer equipment and estimate the rate of transfer of material.

5. Estimate the total time to haul the entire spill:

The calculations are summarized as follows:

$$\frac{\text{Total spill volume}}{\text{Volume of 1 truck}} = \text{Number of truck loads}$$

$$\frac{\text{Number of truck loads}}{\text{Number of trucks}} = \frac{\text{Number of loads}}{\text{1 truck}}$$

$$\frac{\text{Volume of 1 truck}}{\text{Loading Rate (pump etc.)}} \times 2 = \frac{\text{Number of loads}}{\text{1 truck}}$$

$$\frac{\text{Travel distance}}{\text{Highway speed}} \times 2 = \text{Travel Time}$$

1.1 (Travel time & fill and draw time) = Total Time/Load

Total time/load x Number of loads/truck = Total time/truck

$$\frac{\text{Total time}}{\text{truck}} + \text{Fill time} \times \text{Number of trucks} = \text{Total time to haul}$$
(assuming staggered fills)

4.6 HANDLING BY DILUTION AND DISPERSAL

Only after all other possible alternatives have been investigated and found not to be feasible is the method of handling by dilution and dispersal to be considered. This method must be used only as a last resort to minimize local hazards. Care must be taken to determine if this method is feasible in that mixing the hazardous chemical with water does not cause undesirable side reactions or by-products. Once it has been determined that dilution and dispersal is the only action available, then additional water sources must be brought to the spill site. Water should be added to the stream at a turbulent spot to allow complete mixing with the hazardous material. Care should be taken not to exceed the capacity of the water body and extend the hazard past its natural boundary. Dispersion can also be induced by creating mixing zones in the waterway and reducing the pockets of concentrated contaminant which may exist.

4.7 HANDLING BY TREATMENT ON SITE

NWMAR116306

4.7.1 General

Once it has been established that treatment of the spill on-site is the most feasible approach, then the method of treatment must be chosen. At the present time most in-situ treatment methods are experimental and therefore, have not been included as part of this review of state-of-the-art processes. The emphasis instead has been placed on construction of offstream processes and therefore leads directly into Chapter 5.

Unit processes have been chosen that have features applicable to jury-rigged construction. The possible processes were evaluated according to the following criteria:

1. They should be capable of being set up in one to two days, and therefore, must be constructed of readily available materials, and should be of simplified construction.

2. They should not require large amounts of power or other supplies.

3. They should be flexible and capable of operating under a wide variety of conditions.

Many types of wastewater treatment systems were considered and 5 were chosen: filtration, carbon adsorption, ion exchange, gravity separation and chemical reaction (oxidation/reduction, neutralization and precipitation).

The processes will be integrated into a parallel batch system which allows the flexibility and simplified operation of a batch process and yet almost continuous operation

4.7.2 Specific Treatment Schemes

Treatment schemes have been suggested for the 303 chemicals indicated on EPA's modified list of hazardous chemicals (18). It must be emphasized that the schemes have not been field tested and extreme care must be taken in their application. The information regarding the schemes indicated in this chapter was developed from several different references, common industrial waste treatment schemes and the experience of personnel familiar with chemical wastewater treatment. The schemes are intended to direct the people but may not be applicable in all situations. The following considerations were used in developing the treatment schemes:

1. The chemicals are assumed to be relatively pure and free of major chemical interferences during treatment.

2. All schemes are established to handle chemicals in an aqueous system and in water.

3. The dosages of treatment chemicals needed will be established by on-site

NWMAR116307

testing of a sample of contaminated water. These field tests will also aid in establishing problems which may occur during field treatment.

4. Gravity separation was included as a requirement or an option in all shcemes. This separation process should always be considered since it will reduce the chemical demand of the waste and allows a natural concentration of contaminants.

5. Filtration is included as an additional clarification step to allow carbon adsorption and ion exchange processes to operate more efficiently.

6. Filtration is also used to remove the fine suspended materials after certain precipitation reactions which require highly efficient removals (19,20).

7. Additional pretreatment requirements such as a presettler or filtration must be evaluated by the user.

8. The schemes indicate batch processes in series, however, sometimes more than one process can be done in the same tank. This is usually true when no sludge is produced in the reaction. However, if a sludge is produced, series tanks are necessary to avoid negating the effects of the previous operation.

The final consideration for all treatment schemes is determining if the treatment is complete and discharge is acceptable. The effluent quality achieved by a certain schematic is dependent upon many variables including strength of the waste, chemical interferences in the water body, etc., and cannot be predicted before a spill event. The discharge concentration level must be established depending upon the individual spill situation and the effluent must be tested prior to its release into the surrounding waters. Depending on the complexity of the analytical method required and the proximity of capable laboratories, it may be necessary to hold the effluent from the process for a certain time period. Therefore, extra tanks must be supplied to provide the necessary detention. These tanks must have a capacity which will equal the amount of flow that can be treated during the duration of analytical test, plus the amount treated during the time it takes to empty one of the tanks, plus the amount treated during the time it takes to fill one of the tanks. Obviously, a higher number of smaller volume tanks will result in less total tank volume required. The number of tanks can be calculated as follows:

$$\text{Number of tanks} = \frac{\text{Volume treated during analytical period}}{\text{Volume of tank being used}} + 2$$

The treatment schemes as shown in Table 22, convey specific information about the treatability of the 303 hazardous compounds. Each column in the table conveys specific information which is discussed below:

Column 1 - Name of Compound — One of the 303 hazardous materials.

NWMAR116308

Column 2 - Amenability to Treatment in a Municipal Treatment Plant -

This indicates whether the material can be discharged to a municipal treatment plant without creating major upset. The specific plant operator must be consulted before a final decision can be made.

Column 3 - Treatment Scheme -

This column indicates the applicable treatment scheme and options for each chemical. The symbols used are defined as follows:

- Batch Process

- Flow Through Process

- Optional Process

- Recommended Process

- Carbon Adsorption

F - Dual Media Filtration

- Ion Exchange

- General Chemical Reaction

- Reduction

- Oxidation

- Gravity Separation

- Precipitation

- Neutralization

- Dilution

The treatment chemicals are indicated by arrows into the specific unit processes and as indicated previously, more than one process may be done in one tank.

Column 4 - Treatment Specifications

The endpoints for determining chemical dosages are briefly indicated.

NWMAR116309

Column 5 - Comments

This gives additional information which may be helpful to the user. This may include specific hazards or methods to simplify treatment.

Column 6 - References

The reference column is intended to allow the user to have more information regarding treatment schemes or the bases of the schemes as presented. It must be recalled that the processes have not been field tested and care must be taken in their application. In some cases an asterisk (*) has been included which indicates that the process as described are theoretically possible but no reference was available which could verify the technique. Additional care must therefore be taken when performing bench scale tests and effluent analyses are critical.

Column 7 - Provisional Limit

The provisional limit defines acceptable levels of exposure of the working and general population and ecology (19). The levels are very conservative so the OSC must remember to take into account dilution by the natural water body which may allow the effluent level to be many times higher than that listed.

This limit is intended as a guideline, however, the best procedure is for the user to establish the acceptable discharge level for the specific material by consulting local authorities. This

NWMAR116310

number is not indicative of the effluent quality established by the treatment scheme.

Once the chemical has been located on the table, the user can then use the information to determine the amount of chemicals or materials needed for treatment. The treatment specifications and bench tests will allow the user to calculate the amount of chemicals to order.

The carbon amounts are indicated in weight of carbon per weight of soluble material. Therefore, to calculate the total amount of carbon, the solubility of the spilled chemical and the volume of water affected must be known. The carbon amounts ordered should be based on the highest number in the range presented. Then as the carbon is spent during treatment, the volumes should be checked to determine if more carbon is needed. The numbers given were divided into various ranges depending on many factors including adsorbability, toxicity and solubility. The following assumptions were made in establishing the values presented:

1. To reach low levels, much more carbon is needed even for strongly adsorbed materials.

2. All insoluble material will be removed by sedimentation and filtration prior to the carbon column.

3. Carbon demand by other organics is not great.

4. Compounds with low solubility and high toxicity will be treated to low contaminant levels and require high carbon doses.

5. Less toxic materials will not require low efficient concentrations so less carbon is needed.

It is very difficult to attain both effective contact time and control of carbon columns in the field, so a series operation is recommended. Samples can then be taken between the two columns to predict when breakthrough will occur. The columns should also be operated countercurrently to allow most effective removal of the contaminant.

To use Table **22** effectively, the following procedures should be followed:

1. Turn to the specific chemical name which is to be treated.

2. Establish the possible treatability through disposal to a sewage treatment plant.

3. If disposal to the sewer is not feasible, go on to determine the appropriate treatment scheme.

NWMAR116311

4. Note the treatment specifications and comments which apply to the spill situation.

5. Go to specific references to collect additional information if necessary.

6. Turn to individual sections on process descriptions and perform outlined bench scale tests.

7. Calculate and order amount of chemicals and other material needed as outlined.

8. Start process construction by reference to the system design, Chapter 5 & 6.

4.7.3 Treatment of Mixtures

The treatment schemes as presented in Table 22 deal with individual hazardous chemicals and to not specifically consider the numerous problems associated with treatment of mixtures. If a spill of mixed chemicals has occurred, extra care must be taken during all steps of identification, assessment, and treatment. The following procedures should be followed:

1. If the identity of one or more of the chemicals spilled is not known, do not approach the spill site.

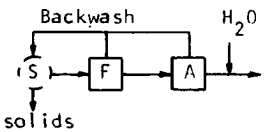
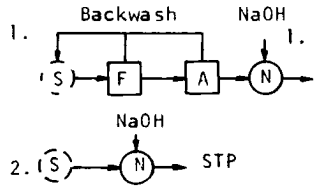
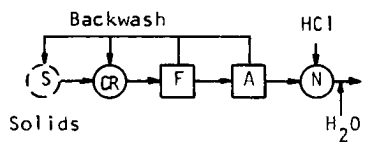
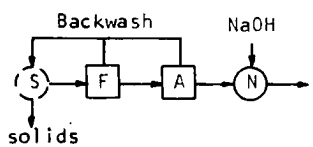
2. If the identity of the chemicals is known, determine the compatibility of the spilled compounds. To do this, make preliminary reference to the compatibility chart included in Table 10. Then contact the chemicals manufacturer or local University Chemistry department for more information.

3. Establish the identity and amount of reaction products from the above sources or reference to chemical handbooks.

4. Choose a possible treatment scheme to remove the reaction product or reactant. Removal of the product or reactant should force the equilibrium of the reaction in the desired direction. However, the treatment scheme chosen should be verified with the consulting chemical authority.

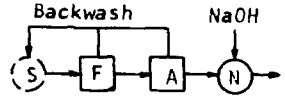
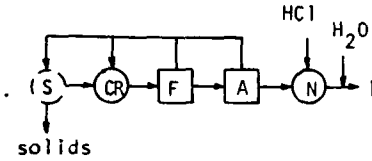
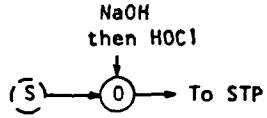
NWMAR116312

TABLE 22. SUGGESTED TREATMENT SCHEMES

Chemical	Amenable Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Acetaldehyde	When diluted		C:35-100 #/# Sol. Matl.	Dilute if necessary/ compound may volatilize	10,19 21,22	9.0
Acetic Acid	When neutralized and diluted		1. 10-35 #/# Sol. Matl. 2. Neutralize with NaOH to pH 7/send to STP.	Neutralize and send to STP if possible/otherwise treat with carbon/ion exchange may also be used	10,19 21,22	1.25
Acetic Anhydride	When neutralized and diluted	See Acetic Acid		Reacts with water to form Acetic acid	10,19	1.0
Acetone Cyanohydrin	May require acclimatization		Neutralize with NaOH to pH 8.5 Adsorb/neutralize to pH 7. C:10-100 #/# Sol. Matl.	Raise pH to suppress cyanide gas formation but not greater than pH 9	10,19	2.0
Acetyl Bromide	When diluted		After Adsorption add NaOH to pH 7. C:10-100 #/# Sol. Matl.	Dredge pump or vacuum undissolved from bottom. Decomposes to form Br_2 and HBr	10,19	0.05
Acetyl Chloride	When diluted	See Acetic Acid		Reacts with water to form acetic acid and HCl	19	0.05

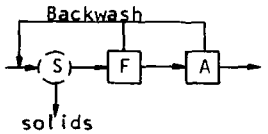
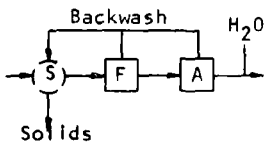
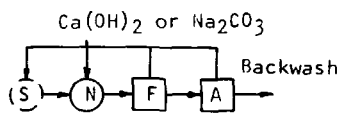
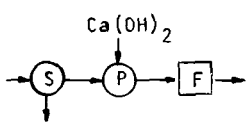
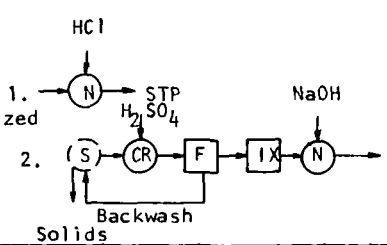
NWMAR116313

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Acrolein	When neutralized dilute/acclimated system desirable		C:10-100 #/# Sol. Matl. then NaOH or other base to pH 7.	Can oxidize and route to STP if possible (use air) - extremely poisonous and explosive	10, 19	0.01
Acrylonitrile	When diluted/ may need to be acclimated	1.  2. 	1. Add NaOH to pH 8.5/adsorb/ neutralize to pH 7 with HCl C: 10-100 #/# sol. matl. 2. Add NaOH to pH 10 then add HOCl to a residual react 30 min./ discharge to STP	Liquid is flammable and explosive - Careful to avoid HCN evolution or direct contact with NaOH. Option 2 produces cyanates which are less toxic	10, 19	2.0
Adipontrile	When diluted and acclimated	See Acrylonitrile			19	1.25

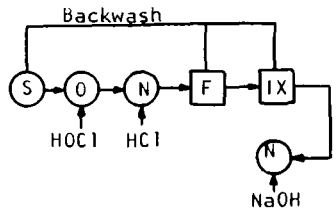
NWMAR116314

TABLE 22. (continued)

Chemical	Amenable Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Aldrin	No		C: 100-300 #/# sol. matl.	Vacuum dredge or pump undissolved portion from bottom (if wettable powder) skim if wettable oil	10, 19	0.012
Allyl Alcohol	When diluted		C: 35-100 #/# sol. matl.	Discharge to treatment plant if feasible; may require dilution after adsorption	10, 19	0.23
Allyl Chloride	When diluted and acclimated		Add $Ca(OH)_2$ to pH 6-7/ adsorb and discharge C:10-100 #/# sol. matl.	Highly flammable; hydrolyzes to allyl alcohol in aqueous solution; however, since slow to dissolve, use boom or sorbants if slick exists	10, 19, 23	0.15
Aluminum Sulfate	When diluted		Add $Ca(OH)_2$ to pH 6-7/filter and discharge	Hydrolyzes in water to reproduce aluminum hydroxide (white) precipitate/add polyelectrolyte if needed for settling	10, 19, 24	250 (as SO_4)
Ammonia (in water aqueous ammonia or ammonium hydroxide)	When diluted (and neutralized if necessary) 1. 2.		1. Neutralize to pH 7 with HCl 2. Add H_2SO_4 to pH 6-7/exchange/ neutralize to pH 7	Ammonium will exert oxygen demand on receiving body unless removed or oxidized. Adjusting pH to 6 insures formation of NH_4^+ if needed for resin.	10, 19, 25	0.01

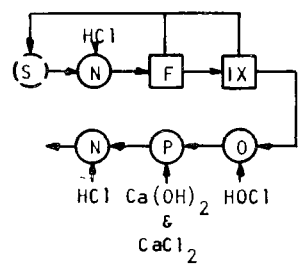
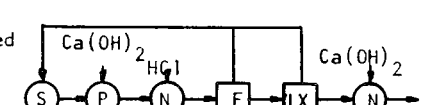
NWMAR116315

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Specifications	Comments	Reference	Prov. Limit mg/l
Ammonium Acetate	if neutralized	See Ammonia		Dilute discharge to reach acceptable acetate levels	10,19,25	0.01 (NH_3)
Ammonium Benzoate	if neutralized	See Ammonia		Dilute discharge to reach acceptable benzoate levels	10,19,25	0.01 (NH_3)
Ammonium Bicarbonate	if neutralized	See Ammonia			10,19,25	0.01 (NH_3)
Ammonium Bisulfite	if neutralized & oxidized		Add HOCl to a residual/ react 10 min/neutralize to pH 7 w HCl/filter/ place through ion exchange media/add NaOH to pH 7 if needed	Oxidation can occur before ammonium removal/ if STP available, discharge there	10,19,25	0.01 (NH_3)
Ammonium Bromide	if neutralized	See Ammonia		Dilute discharge to reach acceptable bromide level	10,19,25	0.01 (NH_3)
Ammonium Carbanate	if neutralized	See Ammonia		Dilute to reach acceptable carbonate level if necessary	10,19,25	0.01 (NH_3)
Ammonium Carbonate	if neutralized	See Ammonia		Dilute to reach acceptable carbonate levels	10,19,25	0.01 (NH_3)
Ammonium Chloride	if neutralized	See Ammonia		Dilute to reach chloride discharge levels if necessary	10,19,25	0.01 (NH_3) 250 (Cl^-)

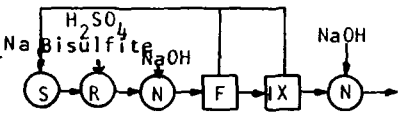
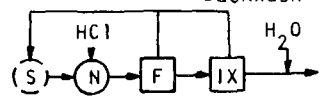
NWMAR116316

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Specifications	Comments	Reference	Prov. Limit mg/l
Ammonium, citrate-	if neutralized	See Ammonia		Dilute if necessary		
Ammonium Fluoroborate	unknown	No treatment scheme recommended at this time				
Ammonium Hydroxide	if neutralized	See Ammonia			10,19,25	0.01
Ammonium Hypophosphine	if neutralized & oxidized		Add HCl to pH 7/filter & exchange in weakly acidic media/oxidize to HOCl residual/add $Ca(OH)_2$ and some $CaCl_2$ to pH 11/neutralize to pH 7	Removal of phosphate should occur after exchange to avoid removing excess cations from solution/$CaCl_2$ will allow sludge volume to be reduced by adding $Ca(OH)_2$ if more ppt/continue until no ppt forms	10,19,25	0.01 as NH_3
Ammonium Iodide	if neutralized	See Ammonia		Dilute or reach acceptable iodide concentration	10,19,25	0.01 as NH_3
Ammonium Nitrate	if neutralized	See Ammonia		Dilute or remove with anionic exchange resin	10,19,25	0.01 as NH_3
Ammonium Oxalate	if neutralized		Add $Ca(OH)_2$ to pH 9/ ppt oxalate/neutralize w HCl to pH 7/filter exchange/neutralize with base to pH 7	Oxalate should be removed in the lime precipitation step	10,19,25	45 as NH_3

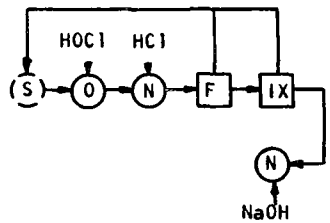
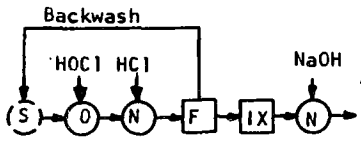
NWMAR116317

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Specifications	Comments	Reference	Prov. Limit mg/l
Ammonium Pentaborate	When neutralized and dilute	See Ammonia		Dilute to reach acceptable Pentaborate levels.	10,19,25	0.01 as NH_3
Ammonium Persulfate	When neutralized and dilute		Add H_2SO_4 to pH 3/ add bisulfite to large ORP change or indicator change/neutralize to pH 7/filter exchange neutralize to pH 7 with NaOH often.	Special indicator is Methylene Blue in 50% solution of Zinc Acetate - add 0.5ml to 1 drop of test solution/stays violet until persulfate is gone - when color is not violet reaction is done - test often.	26	0.01 as NH_3
Ammonium Silicofluoride	Unknown	No treatment scheme recommended at this time.				
Ammonium Tartrate	When neutralized and dilute		Add HCl to pH 7/ filter/exchange/ carbon can be used to remove tartrate	Dilute to meet tartrate standards on carbon	10,19,25	0.01 as NH_3
Ammonium Thiocyanate	When neutralized and dilute	See Ammonia		If desired, thiocyanate can be oxidized further with HOCl.	10,19,25	0.01 as NH_3
Ammonium Thiosulfate	When neutralized and dilute	See Ammonia		Dilute if necessary	10,19,25	0.01 as NH_3

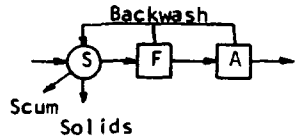
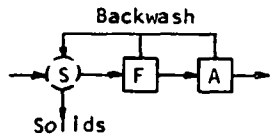
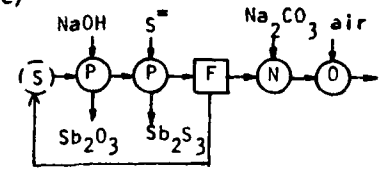
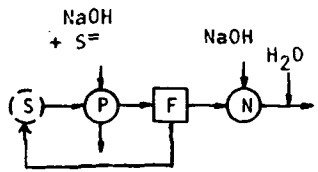
NWMAR116318

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Specifications	Comments	Reference	Prov. Limit mg/l
Ammonium Sulfamate	When dilute and neutralized		Chlorinate w HOCL to residual/react 5 min./ neutralize to pH 7 if needed/filter/exchange in weakly acidic resin neutralize to pH 7 with NaOH.	Sulfamate must be removed prior to ammonia trmt. since it converts to NH_3 and H_2SO_4 when oxidized.	10,19,25	0.01 as NH_3
Ammonium Sulfate	When neutralized	See Ammonia		Dilute if necessary to meet sulfate discharge levels	10,19,25	0.01 as NH_3 250 as SO_4
Ammonium Sulfide	When oxidized and neutralized		Add HOCl to residual react 5 min./neutralize to pH 7 with HCl/ filter/exchange on weakly acidic resin/ neutralize to pH 7 with NaOH.	Take care to avoid inhalation of H_2S- a self contained breathing apparatus is recommended.	10,19,25	0.75 as H_2S
Ammonium Sulfite	When oxidized and neutralized	See Ammonium Sulfide			10,19,25	0.01 as NH_3 0.10 as Sulfate

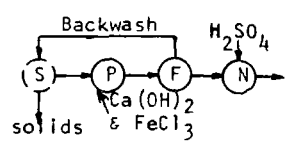
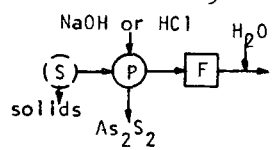
NWMAR116319

TABLE 22. (continued)

Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Amyl Acetate	When diluted		C: 10-100 #/# sol. matl.	Remove floating portion asap; soluble to 850 ppm. Dilution & discharge may be feasible	10,19	26.3
Aniline	When diluted with time for seed acclimation (activated sludge)		C: 1-10 #/# of sol. matl.	Slightly heavier than water so dredging may be necessary. Produces poisonous gas if heated	10,19,27	0.95
Antimony Pentachloride	Not unless treated first		Add NaOH to pH 7/ ppt oxide/then saturate w/$S^=$ to residual/settle/ filter/neutralize w/soda ash -pH 7/ aerate to remove excess $S^=$	Chlorine gas may be formed from this compound. Be careful not to add excess $S^=$ and produce H_2S toxic gas	1,10 *	0.05 (as Sb)
Antimony Pot. Tartrate	Not unless treated first		Add NaOH to pH 7/ ppt oxide/then saturate with Na_2S to residual/ settle/filter/neutralize to pH 7. Aerate if necessary.		9	0.05 as Sb

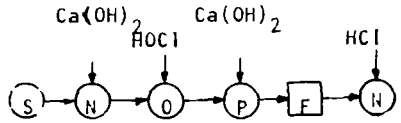
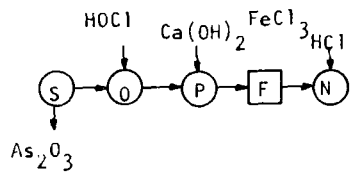
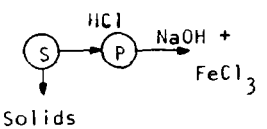
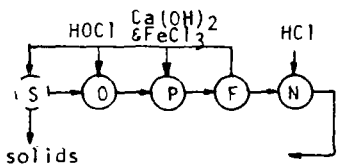
NWMAR116320

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Antimony Tribromide	no	See Antimony Pentachloride		Check to insure acceptable bromide level in discharge	10,19,20	0.05 as Sb
Antimony Trichloride	no	See Antimony Pentachloride		Check to insure acceptable chloride level in discharge	19,26	0.05 as Sb
Antimony Trifluoride	no	See Antimony Pentachloride		Check to insure acceptable fluoride level in discharge	19,20	0.05 as Sb
Antimony Trioxide	no	Same as Antimony Pentachloride			19,26	0.05
Arsenic Acid	no		Add lime to pH 10.5 then add $FeCl_3$ to form floc/settle & filter/neutralize.	Arsenic acid converts to Arsenate in water with O_2 present/will be caught with ferric hydroxide & removed	20*	0.05 as As
Arsenic Disulfide	no		Change pH to 6-7 and allow As_2S_2 to precipitate/filter & dilute if necessary	Dredging may be required since As_2S_2 is quite insoluble. Add $FeCl_3$ and alum to aid clarification	20,24	0.05 as As
Arsenic Pentaoxide	no	See Arsenic Acid		Dredge undissolved portion from bottom if necessary	20	0.05 as As

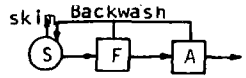
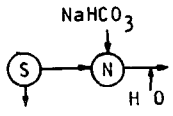
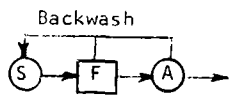
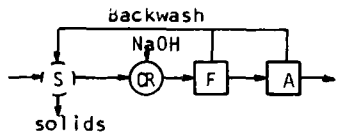
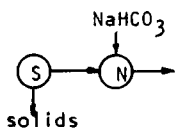
NWMAR116321

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Arsenic Trichloride	no		Neutralize to pH 7. Add HOCl to res./add more $Ca(OH)_2$ to pH 10.5 and $FeCl_3$ to floc/filter if needed neutralize.	Evolves HCl in water. Soda ash or bicarbonate can be used to suppress HCl evolution	19,20*	0.05
Arsenic Trioxide (As_2O_3)	no		Settle/add HOCL to residual. Add lime to pH 10.5 + $FeCl_3$ to floc/filter neutralize to pH 7.	Dredge pump or vacuum precipitate from bottom	10,19,20	0.05 as As
Arsenic Trisulfide	no		Change to pH 6-7 and then allow As_2S_3 to ppt/Add $FeCl_3$ to ppt.	--	10,19,20	0.05 as As
Calcium Arsenate	no	Same as Arsenic Acid			20	0.05 as As
Calcium Arsenite	no		Adjust pH to 5-9, oxidize w/HOCl to residual/add $Ca(OH)_2$ to pH 10.5/add $FeCl_3$ to floc/settle/ filter/ neutralize to pH 7/discharge.	The arsenite is oxidized to arsenate which is treated as before.	20	0.05 as As
Potassium Arsenate	no	See Arsenic Acid			20	0.05 as As

NWMAR116322

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Potassium Arsenite	no	See Calcium Arsenite			10,19,20	0.05 as As
Sodium Arsenate	no	See Arsenic Acid			20	0.05 as As
Benzene	When diluted		C:10-35 #/# sol. matl.	Skim off surface if possible.	10,29	3.5
Benzoic Acid	When diluted	1.  Solids insoluble acid 2. 	1. Add $NaHCO_3$ to pH 7 after sedimentation has removed most insolubles. 2. C:10-35 #/# sol. matl.	Dilute waste w/water to allow discharge into water body after neutralization. Carbon may be used to remove contaminant	19	1.25
Benzonitrile	no		C:35-100 #/# sol. matl. Adjust pH to 8.5 to suppress HCN formation	Overnight holding may be required to insure complete reaction.	28	0.01 As CN
Benzoyl Chloride	After with NaOH		Add bicarbonate to pH 7-8; Adsorb on carbon.	Send to STP if possible/if removal needed adsorb on carbon. C:10-100 #/# sol matl.	19,28	0.45

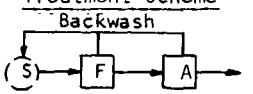
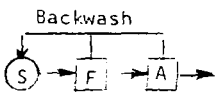
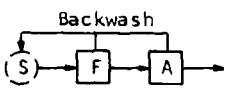
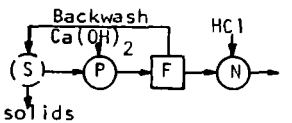
NWMAR116323

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Benzyl Chloride	Use NaOH to convert to alcohol; then biodegradable	1. Backwash: S → F → A 2. NaOH: S → N → to STP 3. CaO or Na_2CO_3: S → P → N (concentrated only)	1. C: 10-100 #/# sol. matl. 2. Neutralize to pH 7 & route to STP. 3. Conc. solutions only/add lime or soda ash to pH 7 dispose solids properly neutralize any effluent	Can form HCl-if concentrated haul to manufacturer if possible.	19,28	0.25
Beryllium Chloride	no	Backwash: S → P → F → N; $Ca(OH)_2$ at P; H_2SO_4 at N; solids from S	Add lime to pH 8.5-9 let react 15 min. settle (filter if needed)/neutralize to pH 7 w/H_2SO_4.	Be sure to dilute the Cl to an acceptable discharge concentration	10,19	1.0 as Be 250 as Cl-
Beryllium Fluoride	no	$Na_2CO_3/Ca(OH)_2$ at P; HCl at N'; H_2O	Add $Ca(OH)_2$ to pH 8.5-9/settle/decant /add lime to pH 11/ let stand 24 hr/filter if necessary/neut. to pH 7 with HCl.	Must remove Be and F in subsequent processes.	26	1.0 as Be
Beryllium Nitrate	no	See Beryllium Chloride		Dilute system so nitrate discharge is acceptable.	19,26	1.0 as Be
Brucine	no	Backwash: S → F → A	C: 10-100 #/# sol. matl.		30*	45 as NO_3
Butyl Acetate	When diluted	Backwash: S → F → A; Skim; Solids	Gravity separation tests should be done C: 1-10 #/# sol. matl.	Skim off quickly to reduce load on carbon column.	10,19	35.5

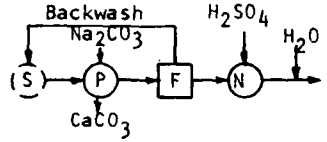
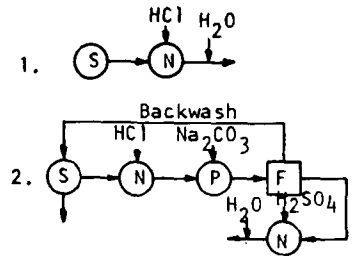
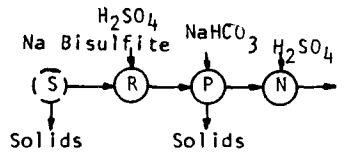
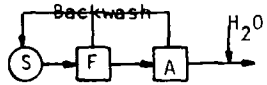
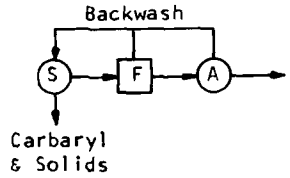
NWMAR116324

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Butylamine	When diluted		C: 10-35 #/# sol. matl.	Send to STP if possible.	19,31	0.75
Butyric Acid	Can be discharged after neutralized		C: 10-35 #/# sol. matl.	No treatment per se given; dilution to below toxic level is necessary if no STP.	28*	
Cadmium Acetate	no	1.  2. 	1. Add lime to pH 10/mix/flocculate & settle/add HCl to pH 7 2. C: 10-100 #/# sol. matl.	Cadmium cannot be removed if CN^- is present/prior CN^- removal is required/ iron addition may increase Cd removal/ dilute acetate if necessary.	19,20,24	0.01 as Cd
Cadmium Bromide	no	See Cadmium acetate		Dilute bromide to acceptable level.	19,20,24	0.01 as Cd
Cadmium Chloride	no	See Cadmium acetate		The precipitation reaction is recommended for removal at low concentrations. However, C adsorption is also effective/ dilute Cl^- to <250 mg/l if needed.	19,32	0.01 as Cd 250 as Cl

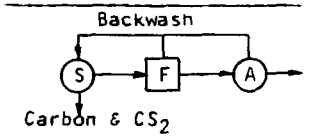
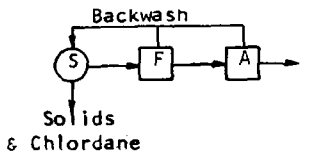
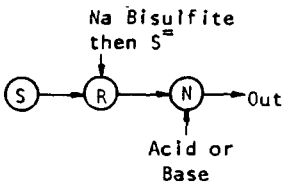
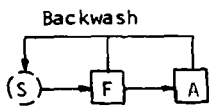
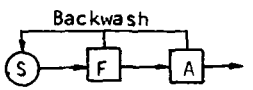
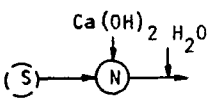
NWMAR116325

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Calcium Carbide	no		Add sodium bicarbonate to pH 9; allow to settle; neutralize to pH 7; dilute to reduce C_2H_2 concentration	Take car to avoid explosion from vapors (C_2H_2); discharge when conc. is acceptable	10,19	0.125
Calcium Hydroxide	after neutralization		1. Settle and neut. HCl; dilute; discharge 2. To remove calcium: add HCl to pH 7; then add Na_2CO_3 to pH 9; settle; filter; neut. with H_2SO_4	Dilute ultil CaCl by prod. conc. is at acceptable levels; Use 2. if Ca must be removed	10,19	0.25
Calcium Hypochlorite	no		Add acid to pH 3; then bisulfite until no chlorine residual; after 15 min. add $NaHCO_3$ to ppt calcium carbonate pH 9; neutralize; discharge	Other reducing agents: sodium thiosulfate, ferrous salt, etc. can be used	19,28	0.125
Calcium Oxide	when neutralized	See Calcium Hydroxide	Add acid to pH 7; then add Na_2CO_3 to pH 9; ppt $CaCO_3$; neutralize to pH 7	Possible dilution after reaction to form calcium chloride; should check w/local authorities	28	0.25
Captan	no		C: 100-300 #/# sol. matl.	--	30	--
Carbaryl (Sevin)	After reduction w/calcium hypochlorite for 24 hours		C: 100-300 #/# sol. matl. Carbaryl will be removed during sedimentation	A large amount will sink to bottom of water body so dredging may be required	10,19	--

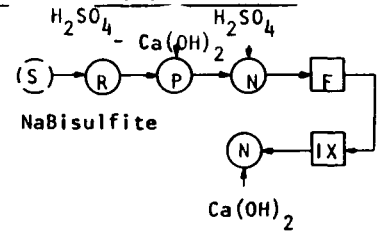
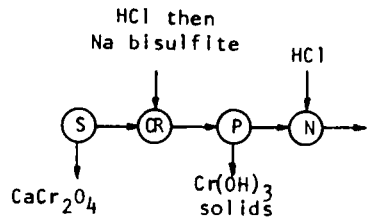
NWMAR116326

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STR	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Carbon Disulfide	no		C: 10-100 #/# sol. matl.	Dredging of the bottom of the water body may be needed	19,33	1.0
Chlordane	no		C: 100-300 #/# sol. matl.	Dredging of the bottom may be necessary	19	0.025
Chlorine	When reduced and diluted		Add H_2SO_4 to pH 2-3; add Na bisulfite until small or no chlorine residual; neutralize to pH 7	Carbon can be used for low concentration of Cl_2	19,34	0.15
Chloro-benzene	when diluted		C: 10-100 #/# sol. matl.	--	19,33	17.5
Chloroform	when diluted		C: 10-100 #/# sol. matl.	Sedimentation & dredging of water bottom may be necessary	10,19	6.0
Chlorosul-fonic acid	when neutralized		Add $Ca(OH)_2$ slowly to pH 7; dilute if necessary	Dissociates to H_2SO_4 & HCl in water and is explosive; dilute to meet Cl^- and $SO_4^=$ discharge levels	19	0.05 or 250 as SO_4 Cl

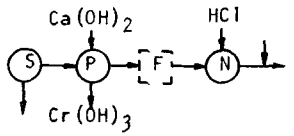
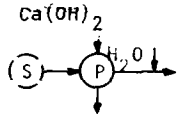
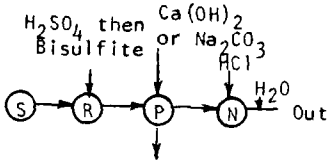
NWMAR116327

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Ammonium Bichromate	no		Add H_2SO_4 to pH 2-3/ add bisulfite to large ORP change or yellow to green color react 10 min/add $Ca(OH)_2$ to pH 8.5 settle/neutralize to pH 7/filter/IX in weekly acidic resin/ neutralize with lime to pH 7	Both chrome and ammonia must be removed/alum or polyelectrolyte may be necessary to aid settling of $Cr(OH)_3$	19	0.05 as Cr 0.01 as NH_3
Ammonium Chromate	no	See Ammonium Bichromate			19	0.05 as Cr 0.01 as NH_3
Calcium Chromate	no		Adjust pH to 2-3; add bisulfite until color changes to green or a large color change; add lime to pH 8-9/ allow to settle/ neutralize	Alum or polymer may be required to improve the settling/ filtration after precipitation may allow removal of fines & suspended $Cr(OH)_3$	10,19, 20,24, 13,23	0.05 as Cr

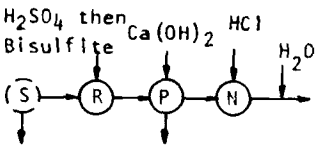
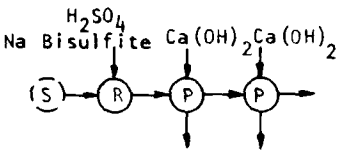
NWMAR116328

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Chromic Acetate	no		Adjust pH to 8-9 with slaked lime/ allow to settle/ filter if needed/ neutralize	Alum or poly-electrolyte may be required to improve the settling/filtration after precipitation may allow removal of fines & suspended $Cr(OH)_3$	19,20	0.05 as Cr
Chromic Acid	no	See Chromic Acetate	--	--	19,20	0.05 as Cr
Chromic Sulfate	no	See Chromic Acetate			19,20	0.05 as Cr
Chromous Chloride	no		Add $Ca(OH)_2$ to pH 8.5/settle	Chromous will oxidize to chromic so sludge will be mixture of chromous & chromic hydroxide/ use alum or poly-electrolyte to aid settling	19	0.05 as Cr
Chromyl Chloride	no		Add H_2SO_4 to pH 2-3; add bisulfite to large ORP change or color yellow to green; react 10 min/ add lime/soda ash to pH 8-9/settle/add HCl to pH 7	Dilution may be necessary to reduce Cl^- concentration	19,20	0.05 as Cr 250 as Cl

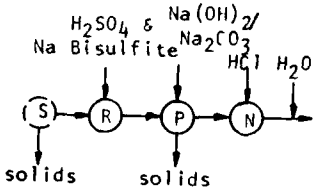
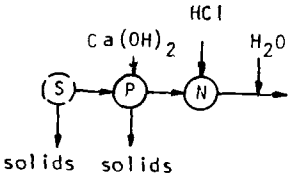
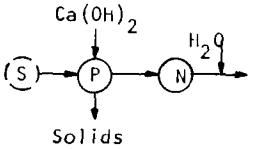
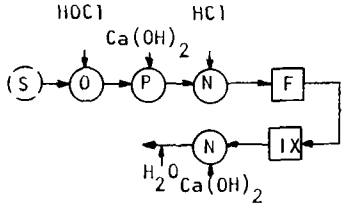
NWMAR116329

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	F.ov. Limit mg/l
Lithium Bichromate	no		Add H_2SO_4 to pH 2-3; add bisulfite to large ORP change or color yellow to green/react 10 mins/ add $Ca(OH)_2$ to pH 8-9/ settle neutralize with HCl to pH 7	Check acceptable lithium levels	19,24	0.05 as Cr
Lithium Chromate	no	See Lithium Bichromate		Check acceptable lithium levels	19,24	0.05 as Cr
Potassium Bichromate	no	See Chromyl Chloride			19,24	0.05 as Cr
Potassium Chromate	no	See Calcium Chromate			19,24	0.05 as Cr
Sodium Bichromate	no	See Calcium Chromate			19,24	0.05 as Cr
Sodium Chromate	no	See Chromyl Chlorate			19,24	0.05 as Cr
Strontium Chromate	no		Add H_2SO_4 to pH 2-3 add bisulfite until turns green or large ORP change/ add $Ca(OH)_2$ to pH 8.5/settle/add more lime to pH 10/ settle/discharge	Remove chromate sludge or decant supernatant before second lime addition check acceptable strontium levels	19,24,26	0.05 as Cr

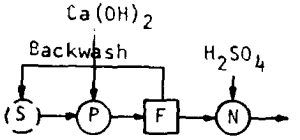
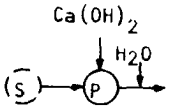
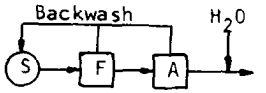
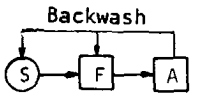
NWMAR116330

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Zinc Bichromate	no		Add H_2SO_4 to pH 2-3/ add bisulfite until color turns green or large ORP change/ add 50/50 lime/soda ash to pH 7.5-8.5 settle $Zn(OH)_2$ and chrome sludge	Alum may aid in settling floc	10,19,20	0.05 as Cr
Cobaltous Bromide	no		Add lime to pH 8-8.5/ settle/neutralize to pH 7 with HCl	Dilution may be needed to meet the bromide discharge requirements/Both cobaltic & cobaltous hydroxide are insoluble at pH 8-8.5	19,26	0.05 as Co
Cobaltous Fluoride	no		Add lime to pH 8-8.5/ settle/allow to react 24 hours/neutralize and discharge	A long holding time is needed to reduce F^- concentration	19,33	0.05 as Co
Cobaltous Formate	no	See Cobaltous Bromide		Dilute to meet acceptable formate concentrations	19,26	0.05 as Co
Cobaltous Sulfamate	no		Add HOCl to residual then add $Ca(OH)_2$ to pH 8.5/settle $CaSO_4$ add HCl to pH 7/filter/ IX on weakly acidic resin/neutralize to pH 7	Sulfamate is converted to sulfuric acid and ammonia when oxidized	19,24,26	0.05 as Co

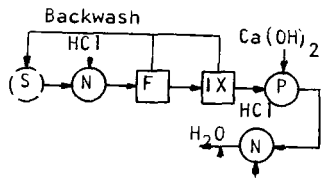
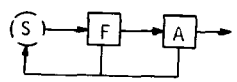
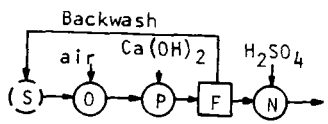
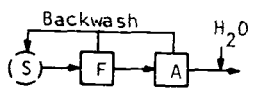
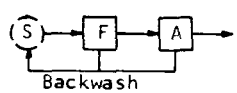
NWMAR116331

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Cupric Acetate	When dilute and neutralized		Add lime to pH 9.5 allow to settle/ filter for more solids removal/ neutralize to pH 7	Carbon may be beneficial in low ranges otherwise precipitation is effective/ ammonia must be removed prior to treatment	19,24,33	1.0 as Cu
Cupric Aceto-arsenite	no		Add $Ca(OH)_2$ to pH 8 and allow insoluble compound to precipitate	Dilute if necessary; initial material is insoluble in water so dredging may be necessary	19,24	0.05 as As
Cupric Chloride	When dilute and neutralized	See Cupric Acetate		Dilute to meet acceptable Cl- concen.	19,24,33	1.0 as Cu
Cupric Formate	When dilute and neutralized	See Cupric Acetate		Formate is degradeable in STP	19,24,33	1.0 as Cu
Cupric Glycinate	no		C: 10-100 #/# sol. material	Glycinate forms a complex which should be adsorbed/untested treatment scheme	19,24	1.0 as Cu
Cupric Lactate	When dilute and neutralized		C: 10-100 #/# sol. material	Lactate also complexes/untested treatment scheme	19,24,26	1.0 as Cu
Cupric Nitrate	When dilute and neutralized	Same as Cupric Acetate		Dilute nitrate to below acceptable discharge level	19,24,26	1.0 as Cu

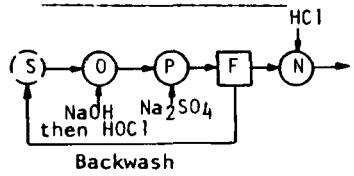
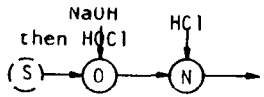
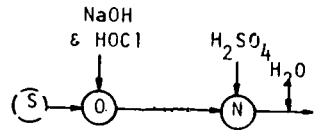
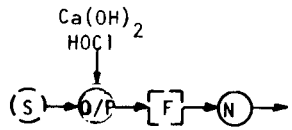
NWMAR116332

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Cupric Oxalate	When dilute and neutralized	See Cupric Glycinate		Forms complex/ untested treatment scheme	19,24,33	1.0 as Cu
Cupric Subacetate	When dilute and neutralized	See Copper Acetate			19,24,26	1.0 as Cu
Cupric Sulfate	When dilute and neutralized	See Copper Acetate			19,24,26	1.0 as Cu
Cupric Sulfate, Ammoniated	When dilute and neutralized		Add HCl to pH 7/ filter exchange/add $Ca(OH)_2$ to pH 9.5/ settle/neutralize/ dilute	Decomposes to NH_4^+ and $CuSO_4$	19,24,26	1.0 as Cu
Cupric Tartrate	When dilute and neutralized		C: 10-100 #/# sol. material	Forms complex/un-tested treatment scheme	28	1.0 as Cu
Cuprous Bromide	no		Add air 70% of max. residual/add lime to pH 9.5/filter neutralize to pH 7	Coagulant may be needed to increase settling rate	30	1.0 as Cu
Coumaphos	When diluted		C: 100-300 #/# sol. material			
Cresol	When diluted		C: 1-10 #/# sol. material		10,19	0.001

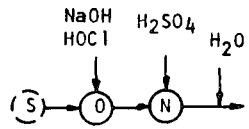
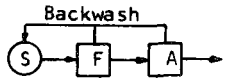
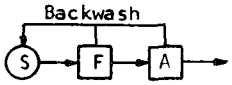
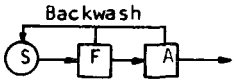
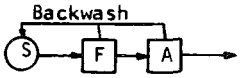
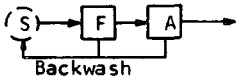
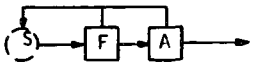
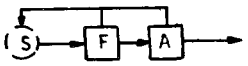
NWMAR116333

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Barium Cyanide	When acclimated (cyanate only)		Add NaOH to pH 8.5 and then HOCl to a residual/react 1 hr/ add Na_2SO_4 excess SO_4/settle/ filter/and neutralize to pH 7	Coagulant may be needed to increase settling rate use sulfate test to establish dosage for Na_2SO_4/shorter reaction-eg 10 min at pH of 10-11 will create cyanates (much less toxic)	19,20	0.01 as CN
Calcium Cyanide	If acclimated		Add NaOH to pH 8.5 then add HOCl to 10% excess/react 1 hr/ neutralize to pH 7	A shorter reaction time at pH of 10-11 dosage will allow reduction to cyanate for discharge to STP	10,19,20	0.01 as CN
Hydrogen Cyanide (Hydrocyanic Acid)	If acclimated		Add NaOH to pH 8-8.5 then add HOCl to a residual/add 10% XS HOCl/react 1 hr/neutralize w/H_2SO_4 prior to discharge	Do not allow pH to drop below neutral or NH_4 will be formed /add large excess NOCl to avoid the liberation of toxic cyanogen chloride	10,19,20	0.01 as CN
Potassium Cyanide	If acclimated	See Calcium Cyanide			10,19,20	0.01 as CN
Sodium Cyanide	If acclimated	See Calcium Cyanide			10,19,20	0.01 as CN
Zinc Cyanide	no		Add lime to pH 8.5and then add excess HOCl allow to react 1 hr/ settle/filter if nec. neutralize	The CN must be removed prior to zinc treatment/ also keep pH up until CN^- is removed to prevent HCN generation/filtration at end may help effluent quality	10,19,20 *	0.01 as CN

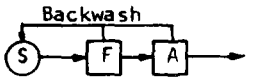
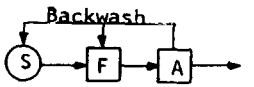
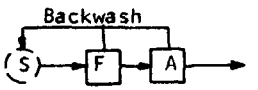
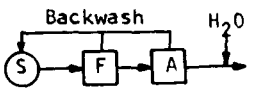
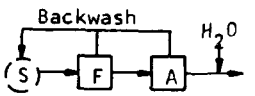
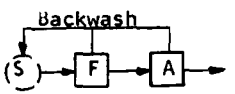
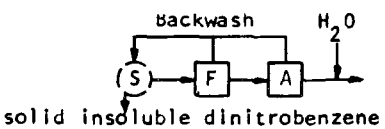
NWMAR116334

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Cyanogen Chloride	if acclimated		Add NaOH to pH 8-8.5 & 10% excess HOCl/allow to react 1 hr/neutralize/ dilute if necessary	Activated carbon may also be used if necessary	10,19, 20	0.01 as CN
Cyclohexane	When diluted		C: 10-100 #/# sol. matl.	Skim cyclohexane off surface and then adsorb remainder on carbon	10,19	52.5
2,4-D (acid)	no		C: 35-100 #/# sol. matl.	Dissolves slowly so dredge from bottom	10,19	0.5
2,4-D (ester)	no		C: 35-100 #/# sol. matl.	Dissolves slowly so dredge from the bottom	10,19	0.5
Dalapon	no		C: 100-300 #/# sol. matl.		19	
DDT	no		C: 100-300 #/# sol. matl.		10,19	0.05
Diazinon	no		C: 100-300 #/# sol. matl.	Dredge if possible then adsorb soluble portion on carbon	30	
Dicamba	no		C: 35-100 #/# sol. matl.		30	

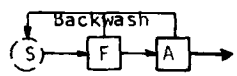
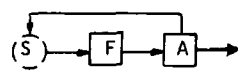
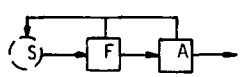
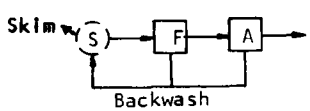
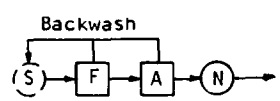
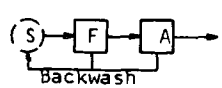
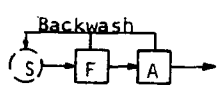
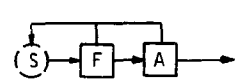
NWMAR116335

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Dichlobenil	no		C: 100-300 #/# sol. matl.	May not dissolve so dredging or skimming may be required	30	
Dichlone	no		C: 100-300 #/# sol. matl.		30	
Dichlorvox	no		C: 100-300 #/# sol. matl.		30	
Dieldrin	no		C: 100-300 #/# sol. matl.	Will sink so dredging of bottom is necessary with carbon adsorption of effluent-dilution may be required prior to discharge	10,19	0.012
Diethylamine	When diluted		C: 10-100 #/# sol. matl.	Also be neutralized w/acid or use cation exchange	10,19	3.75
Dimethylamine	When diluted		C: 10-100 #/# sol. matl.	Can be neutralized w/acid or use cation exchange	10,19	0.90
Dinitrobenzene	no		C: 10-35 #/# sol. matl.	Dredge bottom of water body also to remove insoluble material	10,19	0.05

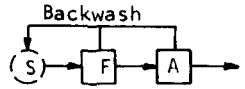
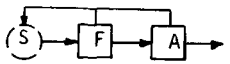
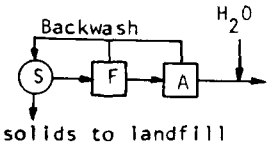
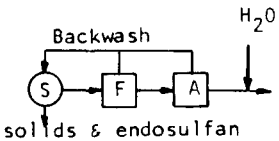
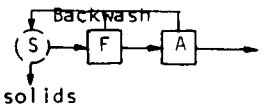
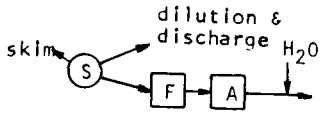
NWMAR116336

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Dinitrophenol	no		C: 10-35 #/# sol. matl.		19,30	0.010
Diquat	no		C: 100-300 #/# sol. matl.		19,30	
Disulfoton	no		C: 100-300 #/# sol. matl.		30	
Diuron	no		C: 100-300 #/# sol. matl.	Very little will dissolve unless a wetting agent is available so skimming or dredging may be necessary	10,30	
Dodecylbenzene-sulfonic acid	When diluted		Neutralization may be needed C: 10-35 #/# sol. matl.		23	
Dodecylbenzene-sulfonic acid, calcium salt	When diluted		C: 10-35 #/# sol. matl.	Dilute if needed or remove Ca separately	23	
Dodecylbenzene-sulfonic acid isopropanolamine salts	When diluted		C: 10-35 #/# sol. matl.		23	
Dodecylbenzene-sulfonic acid sodium salt	When diluted		C: 10-35 #/# sol. matl.		23	

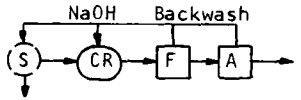
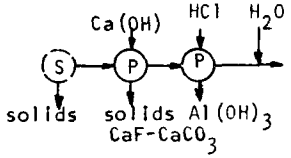
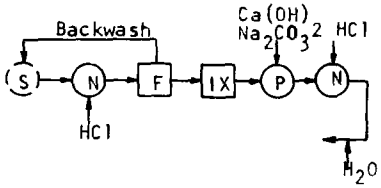
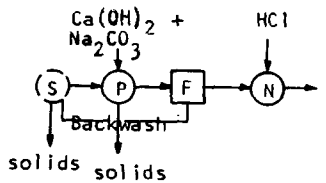
NWMAR116337

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Dodecylbenzene-sulfonic acid, triethanolamine salt	When diluted		C: 10-35 #/# sol. matl.		23	
Dursban	no		C: 100-300 #/# sol. matl.		30	
Endrin	no		C: 100-300 #/# sol. matl.	Dilution may be required prior to discharge-check to determine if skimming or dredging is needed.	10,19	0.005
Endosulfan	no		C: 100-300 #/# sol. matl.	sinks--so dredging may be needed--also dilute treated effluent if required.	10	
Ethion	no		C: 100-300 #/# sol. matl.		30	
Ethylbenzene	When dilute		C: 10-100 #/# sol. matl.	Skimming may be sufficient, however carbon will provide further polishing.	12,19	22

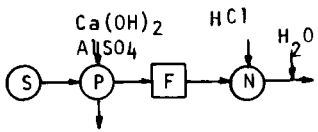
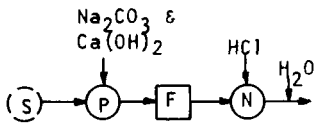
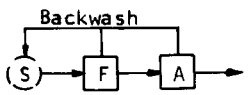
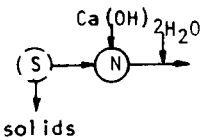
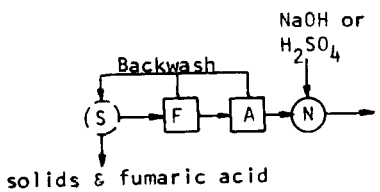
NWMAR116338

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Ethylene Diamine	When dilute		C: 35-100 #/# sol. matl. Add NaOH to make alkaline (pH 8-8.5). before adsorption		10	1.27
Aluminum Fluoride	--		Add lime to pH 11 let stand overnight (24 hrs) then add HCl to pH 7 settle to remove $Al(OH)_3$ discharge.	Complete fluoride removal requires 24 hours/add coagulant to aid settling of $Al(OH)_3$	10,19	0.6-1.7 as F
Ammonium Bifluoride	When neutralized and diluted		Add HCl to pH 7/ filter/ion exchange add 50/50 $Ca(OH)_2/Na_2CO_3$ to pH 11/react 24 hrs/ decant/neutralize to pH 7.	Fluoride requires 24 hrs. for ppt as $CaF\text{-}CaCO_3$	19,28	0.6-1.7 as F
Ammonium Fluoride	When neutralized and diluted	See Ammonium Bifluoride			10,19	0.6-1.7 as F
Hydrofluoric Acid	If diluted		Add 50/50 mixture of soda ash/lime until pH 11; allow to stand overnight/ filter/neutralize with HCl.	Fluoride requires 24 hrs. for ppt as $CaF\text{-}CaCO_3$	19,28	0.01

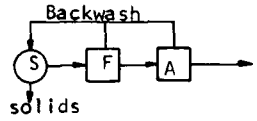
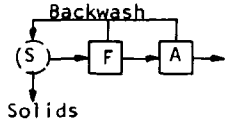
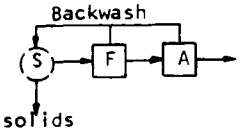
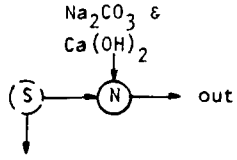
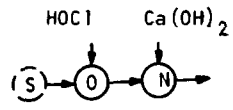
NWMAR116339

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Sodium Bifluoride	If diluted		Lime to pH 11/add alum to a good floc; allow to react for 24 hrs/filter/neutralize & dilute.	Fluoride requires 24 hr reaction time	19,28	0.6-1.7 as F
Sodium Fluoride	If diluted	Same as Sodium Bifluoride			19,28	0.6-1.7 as F
Stannus Fluoride	If diluted		Add 50/50 mixture of lime and soda ash to pH 11/allow to stand 24 hrs/ filter/neutralize and dilute.	Alum may be used to improve the settling rate.	19,28	0.6-1.7 as F
Formaldehyde	When dilute		C: 35-100 #/# sol. matl.		31	0.15
Formic Acid	When dilute		Add lime to pH 7.	Sodium bicarbonate can also be used.	31	0.45
Fumaric Acid	When dilute		C: 35-100 #/# sol. matl. Neutralize if necessary	Remove fumaric acid w/solids-bottom of water body may require dredging; Anion exchangers may also be used.	31	

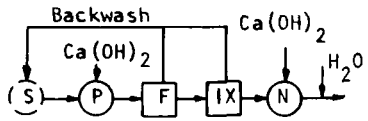
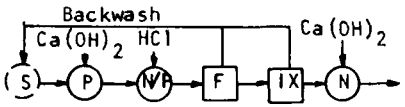
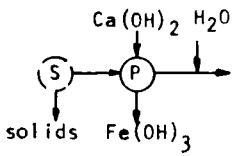
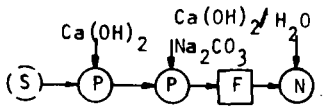
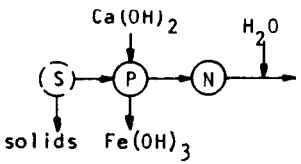
NWMAR116340

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Furfural	When dilute		C: 10-100 #/# sol. matl.	Dredge, pump or vacuum the undissolved portion from bottom.	10,19,20	1.0
Guthion	When dilute		C: 100-300 #/# sol. matl.	Dredge pump or vacuum undissolved portion from bottom-hydrolyzes in acid or cold alkali	10,19	0.01
Heptachlor	no		C: 100-300 #/# sol. matl.	Vacuum or pump undissolved portion from bottom/remove heptachlor w/solids; very little dissolves.	10,19,37	0.025
Hydrochloric Acid	When neutralized		Add 50/50 lime soda ash to pH 7	Stirring is needed; do not add NaOH because resulting reaction is quite violent/check to meet acceptable Cl^- levels	10,19	0.35 250 mg/P as Cl^-
Hydroxylamine	When dilute		Oxidize by slowly adding weak HOCl/ neutralize by adding $Ca(OH)_2$ to pH 7	Add only dilute HOCl to prevent violent reaction/forms HNO_3 to be neutralized	10	0.5 as HNO_3

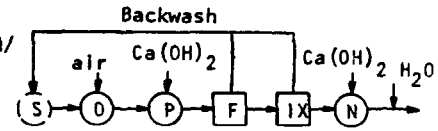
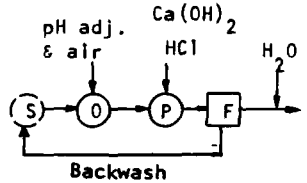
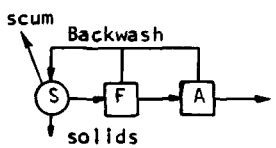
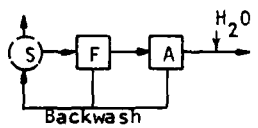
NWMAR116341

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Ferric Ammonium Citrate	When neutralized and dilute		Add $Ca(OH)_2$ to pH 6-7/ppt Fe/filter/ exchange neutralize to pH 7	Dilute may be needed for citrate	19*	0.03 as Fe
Ferric Ammonium Oxalate	When neutralized and dilute		Add $Ca(OH)_2$ to pH 9/ settle/reduce pH 6-7 w/HCl/ppt Fe/filter exchange/neutr to pH 7	The first ppt should remove oxalate	19*	0.03 as Fe
Ferric Chloride	When dilute		Add lime to about pH 7 and ppt $Fe(OH_3)$ neutralize if necessary	Ferric hydroxide is least soluble at pH 7 so this pH is recommended	10,19	0.03 as Fe
Ferric Fluoride	When dilute		Add lime to pH 7/ allow $Fe(OH)_3$ to settle/add more lime/ soda ash to pH 11/ settle 24 hrs/filter/ neutralize	Alum may improve settling after second lime addition/Fluoride require 24 hrs for removal	19,20,28	0.05 as Fe
Ferric Nitrate	When dilute		Add lime to pH 7 and ppt $Fe(OH)_3$/neutralize to pH 7 with HCl or lime if necessary	Dilute nitrate to acceptable level	10,19	0.03 as Fe
Ferric Sulfate	When dilute	See Ferric Chloride			10,19,24	0.03 as Fe

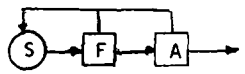
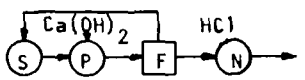
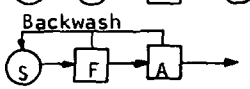
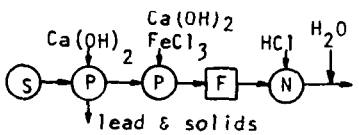
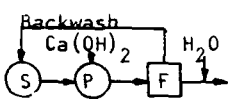
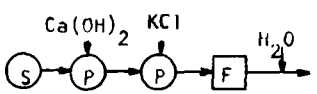
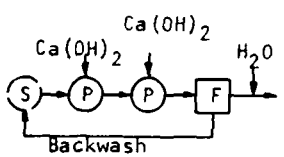
NWMAR116342

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Ferrous Ammonium Sulfate	When oxidized/ neutralized/ diluted		Aerate until no Fe^{+2} remained/add $Ca(OH)_2$ to pH 6-7/ settle/filter/ exchange/neutralize to pH 7	Oxidation changes ferrous to ferric/ should occur rapidly	19,24*	0.03 as Fe
Ferrous Chloride	When dilute		Adjust pH to 7.5 with lime or acid/ allow to aerate until no ferrous iron exists/ add lime and adjust pH to 7/react/settle/ filter/discharge	The lime should be added to achieve sufficient floccula-tion/polyelectrolyte may be needed	10,19,20	0.03 as Fe
Ferrous Sulfate	When dilute	See Ferrous Chloride		The sulfate ion may result in large amounts of calcium sulfate in the sludge	10,19,20	0.03 as Fe
Isoprene	When dilute		C: 10-100 #/# sol. matl.	Skim undissolved off top with booms and adsorbent	10,19	110
Kelthane	When dilute		C: 100-300 #/# sol. matl.	Dilution may be required prior to discharge, check bottom to see if dredging is required	10,30	

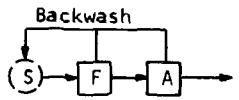
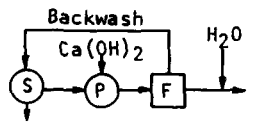
NWMAR116343

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Refence	Prov. Limit mg/l
Kepone	no		C: 100-300 #/# sol. matl.	Kepone is extremely toxic, dilution may be needed prior to discharge	-	-
Lead Acetate	no	1.  2. 	1. Add $Ca(OH)_2$ to pH 8-9/ppt filter/ neutralize to pH 7 if needed 2. C 10-100 #/# sol. matl.	Use Carbon as a polishing step/ Na_2CO_3 may also be used	19,20*	0.05 as Pb
Lead Arsenate	no		Add $Ca(OH)_2$ to pH 8.5/settle/add more $Ca(OH)_2$ to pH 10.5 and $FeCl_3$ to form floc/settle/filter/ neutralize if needed	Vacuum, dredge or pump off bottom. Both Arsenic & lead will be removed	10,19,20 *	0.05 as Pb 0.05 as As
Lead Chloride	no		Add $Ca(OH)_2$ to pH 8,5/ppt lead filter/ discharge. Use carbon as a polishing step	Dredge, vacuum or pump undissolved portion from bottom	10,19,20 *	0.05 as Pb
Lead Fluoraborate	no		Add $Ca(OH)_2$ to pH 8.5 ppt/decant/add KCl to ppt/filter/dis-charge	Can precipitate some fluoraborate with KCl untested scheme	19,24*	0.05 as Pb
Lead Fluoride	no		Add $Ca(OH)_2$ to pH 8.5/allow to settle/ decant & add lime to pH 11/settle 24 hrs/ filter/discharge	Dredge, vacuum or pump undissolved por-tion from the bottom. Fluoride requires 24 hrs to remove	19,20,28	0.05 as Pb

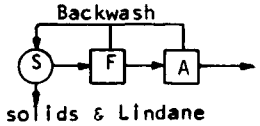
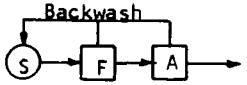
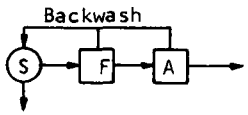
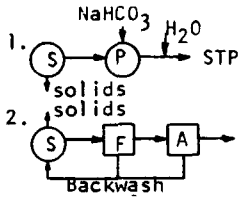
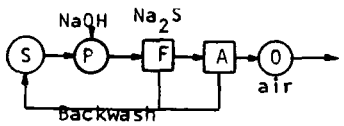
NWMAR116344

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Lead Iodide	no	See Lead Chloride			10,19,28	0.05 as Pb
Lead Nitrate	no	See Lead Chloride		Dilute so nitrate conc. reaches acceptable levels/dredge, pump, etc. undissolved portion from bottom	10,19,28	0.05 as Pb
Lead Stearate	no	See Lead Chloride			10,19,28	0.05 as Pb
Lead Sulfate	no	See Lead Chloride		Pump vacuum or dredge undissolved portion and solids *from bottom*	10,19,28	0.05 as Pb
Lead Tetraacetate	no		C: 10-100 #/# sol. mtl.	Dredge undissolved portion from bottom	31	0.05 as Pb
Lead Thiocyanate	no	See Lead Chloride		Dilute cyanate if needed	10,19,20	0.05 as Pb
Lead Thiosulfate	no	See Lead Chloride			10,19,20	0.05 as Pb
Lead Tungstate	no		Add lime to pH 7-8/ filter to remove fines/settling is necessary	Dredge, pump or vacuum undissolved portion or solids *from bottom*	26 *	0.05 as Pb

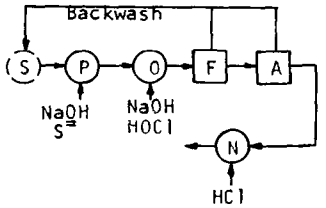
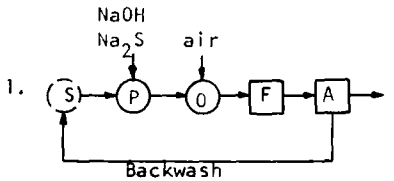
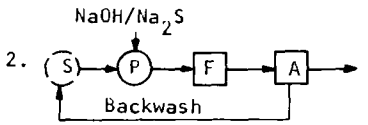
NWMAR116345

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Lindane	-		C: 100-300 #/# sol. mtl.	Dredge, pump or vacuum undissolved portion of solids from bottom	10	-
Malathion	-		C: 100-300 #/# sol. matl.	Dredge, pump or vacuum undissolved portion from bottom	10	-
Maleic Acid	After neutralization		C: 1-10 #/# sol. matl.	Dredge bottom as fast as possible	19*	0.05
Maleic Anhydride	After neutralization		1. Add $NaHCO_3$ to pH 7/ dilute; send to STP 2. C: 1-10 #/# sol. matl.	Either option is acceptable depending on available chemicals & discharge point	10,19	0.05
Mercuric Acetate	no		Raise pH to 7-8 with NaOH/add Na_2S to a $S^=$ residual/filter/ adsorb & aerate to 5 mg/l DO residual	Take care not to evolve H_2S at low pH	19,20,24	0.005 as Hg

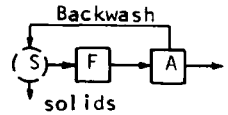
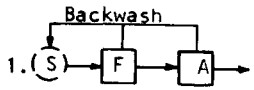
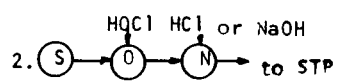
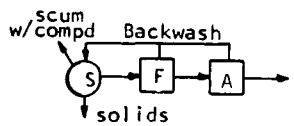
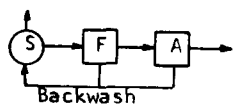
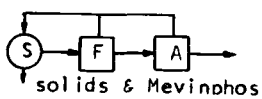
NWMAR116346

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Mercuric Cyanide	no		Raise pH to 8 with NaOH/add H_2S to $S^{=}$ residual/react 5 min/ settle, remove sludge/ adjust pH to 8.5 add HOCl to residual + 10% excess/react 1 hr./filter/adsorb/ neutralize. C: 1-10 #/# sol. matl.	CN- can be reacted to cyanates if pH is raised to 10-11/ reaction time is reduced to 10 min. Dilute cyanates if necessary.	19,20,24	0.005 as Hg
Mercuric Nitrate	no	See Mercuric Acetate			19,20,24	0.005 as Hg
Mercuric Sulfate	no	See Mercuric Acetate			19,20,24	0.005 as Hg
Mercuric Thiocyanate	no	See Mercuric Acetate (most will settle)		Sedimentation is required/can dilute if necessary	19,20,24	0.005 as Hg
Mercurous Nitrate	no	1. 	1. Add NaOH to pH 6-8/ add Na_2S to residual aerate to mercuric state/filter/adsorb. C; 1-10 #/# sol. matl.	If option 2 is used, mercury and mercuric sulfide will be present in sludge	19,24	0.005 as Hg
		2. 	2. Add NaOH to pH 7-8/ add Na_2S/let stand until no mercurous ion			

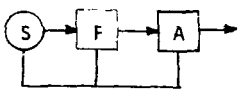
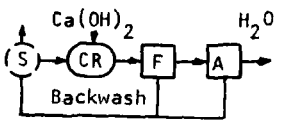
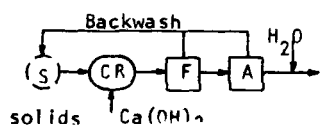
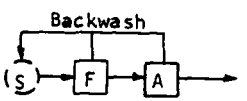
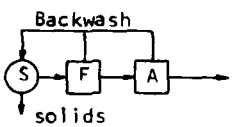
NWMAR116347

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Methoxychlor	no		C: 100-300 #/# sol. matl.	Dredge, pump or vacuum undissolved portion from bottom	10	-
Methyl mercaptan	After chlorine reduction (treatment scheme #2)		1. C: 35-100 #/# sol. matl.	Be sure to eliminate all ignition sources	10,19	-
			2. Add HOCl to Cl residual/then neutralize to pH 7 if necessary			
Methyl methacrylate	When dilute		C: 10-35 #/# sol. matl.	Skim the slick off surface of material	10,19	20.5
Methyl Parathion	When dilute into effective activated sludge system		C: 100-300 #/# sol. matl.	Vacuum, dredge or pump undissolved portion from bottom	10,19	0.001
Mevinphos (Phosdrin)	no		C: 100-300 #/# sol. matl.	Check bottom & remove any insoluble mat'l	n0	-

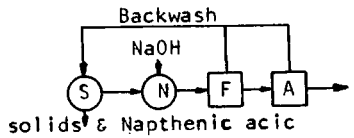
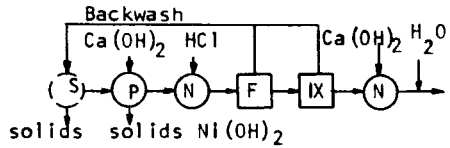
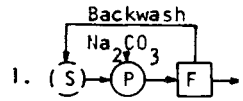
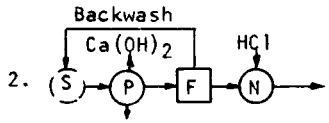
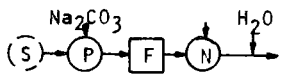
NWMAR116348

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Mirex	no		C: 100-300 #/# sol. mat'l	May require dilution prior to discharge	-	-
Monoethylamine	When dilute or reduced			May be able to skim some compounds from surface. Cation exchange can be used on acid or neutral solutions may require dilution	10,19	0.9
Monomethylamine	When dilute		Raise pH to 8 with lime/filter. C: 10-100 #/# sol. matl.	May also be used for exchange	10,19	0.9
Naled	no		C: 100-300 #/# sol. matl.		30	
Naphthalene	When dilute		C: 10-35 #/# sol. matl.	Dredge, vacuum or pump undissolved portion & solids from bottom	10,19	2.5

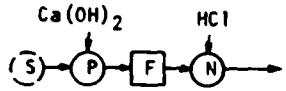
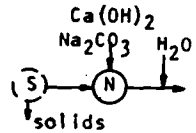
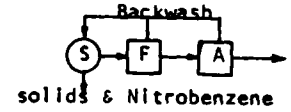
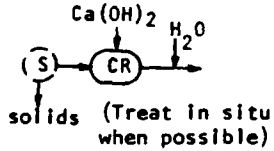
NWMAR116349

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Napthenic acid	When neutralized		Add NaOH to pH 7/ filter/adsorb on carbon. C: 10-35 #/# sol. matl.		19	-
Nickel Ammonium Sulfate	no		Add $Ca(OH)_2$ to pH 10/ppt Ni/add HCl to pH 7/filter/ neutralize to pH 7	May require dilution to reach SO_4 discharge levels. Make sure ammonia not present in high amounts/lime treatment should result in lower nickel levels	19,24 *	0.05 as Ni
Nickel Chloride	no	1.  2. 	1. Add Na_2CO_3 to pH 8-8.5/allow to settle/filter 2. Add lime to pH 10/allow to settle/ filter/neutralize		19,24 *	0.05 as Ni
Nickel Formate	no		Add soda ash to pH 8-8.5/allow to settle/ filter/neutralize to pH 7	Determine acceptable formate discharge level/ion exchange or carbon adsorption may be needed	19,24	0.05 as Ni

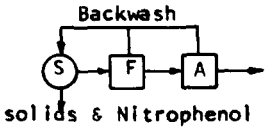
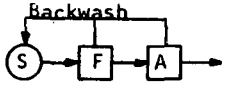
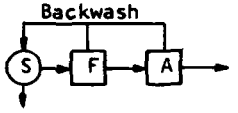
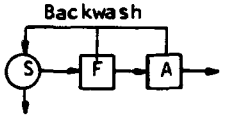
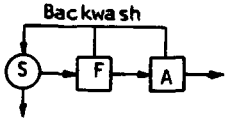
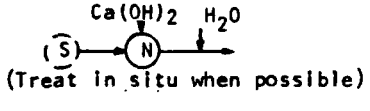
NWMAR116350

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Nickel Hydroxide	no		Add lime to pH 10/ allow to settle/ filter/neutralize with HCl	A coagulant may aid settling/neutralization with acid may be necessary first	19,20,24	0.05 as Ni
Nickel Nitrate	no	See Nickel Chloride			19,24	0.05 as Ni
Nickel Sulfate	no	See Nickel Chloride		Check discharge conc. for sulfates	19,24	0.05 as Ni
Nitric Acid	When neutralized		Add 50/50 soda ash to slaked lime until pH 7/dilute/discharge	Dilution to reduce nitrate concentration	10,19	0.25
Nitrobenzene	Not to all systems/only some		C: 10-100 #/# sol. matl.	Dredge, pump or vacuum insoluble portion from bottom	10,19 *	0.25
Nitrogen Dioxide	After neutralization and dilution		Add Ca(OH)2 to pH 7-8 dilute with water	Beware of flash fire Self-contained breathing apparatus mandatory/ lime addition forms nitrates and nitrates reqr. dilution	28 *	-

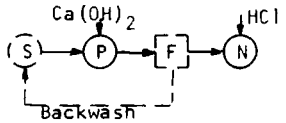
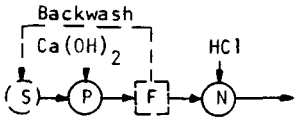
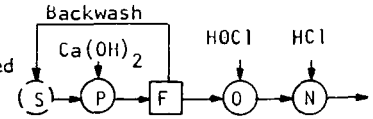
NWMAR116351

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Nitrophenol	no		C: 10-35 #/# sol. matl.	Dredge, pump or vacuum insoluble portion from bottom	18,19	0.01
Para-formaldehyde	When dilute		C: 10-35 #/# sol. matl.		10,19	0.15
Parathion	When dilute if activated sludge process is acclimated		C: 100-300 #/# sol. matl.	Dredge, pump or vacuum undissolved portion from bottom	10,19	0.005
Pentachloro-phenol	no		C: 100-300 #/# sol. matl.	Dredge, pump or vacuum undissolved portion from bottom/ Ion exchange may be used if available	10,19	0.25
Phenol	No unless very dilute		C: 1-10 #/# sol. matl.	Dredge undissolved portion from bottom	10,19	0.001
Phosgene	no	 (Treat in situ when possible)	Add $Ca(OH)_2$ to pH 7-8/ dilute with H_2O	Extreme caution needed/use self-contained breathing apparatus/toxic gas	*	0.02

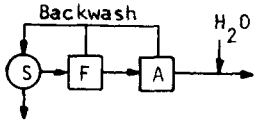
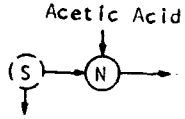
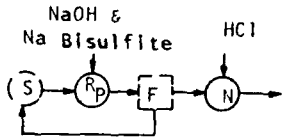
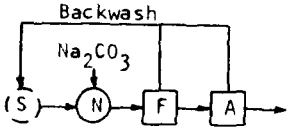
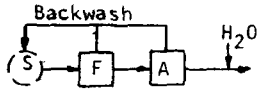
NWMAR116352

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Specifications	Comments	Reference	Prov. Limit mg/l
Phosphoric Acid	When neutralized		Add lime to pH 11/ allow to settle (an anionic polymer may help)/filter if needed/ neutralize to pH 7	The volume of sludge may be excessive so evaluation of this aspect from bench tests is required/ use $CaCl_2$ to reduce volume and air removal		—
Phosphorus	no	Place under water or wet sand and remove from scene to manufacturer		Will sink but caution must be taken to avoid contact with air or risk spontaneous ignition		0.005
Phosphorus Oxychloride	If neutralized & diluted		Add lime to pH 11/ (check to see if $CaCl_2$ removes more P)/settle/ (use anionic polymer if needed)/filter if necessary/neutralize to pH 7 with HCl	This compound decomposes to HCl and phosphoric acid/ large volumes of sludges may be produced so this factor must be considered-- use $CaCl_2$ with $Ca(OH)_2$ to reduce sludge volume and remove P	10,20, 32	0.35
Phosphorus Pentasulfide	If neutralized & diluted		Add lime to pH 11/ settle/filter if necessary/oxidize with HOCl until residual exists/neutralize with HCl	Decomposes to form H_2S and phosphoric acid so immediately raise the pH to avoid evolution of toxic H_2S	30 *	0.05
Phosphorus Trichloride	If neutralized & diluted	See Phosphorus Oxychloride				

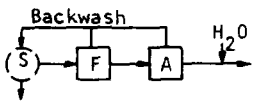
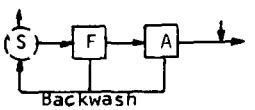
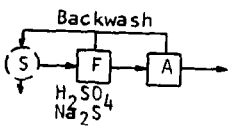
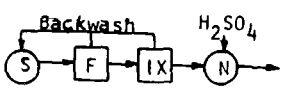
NWMAR116353

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Specifications	Comments	Reference	Prov. Limit mg/l
Polychlorinated Biphenyls	no		C : 100-300 #/# sol. matl.	Dredge, vacuum or pump undissolved portion and solids from bottom	10	0.025 to 0.05
Potassium Hydroxide	When neutralized and diluted		Add acetic acid to pH 7	Cation exchange may also be used. Care must be taken to avoid excessive heat buildup	10,19	0.10
Potassium Permanganate	When reduced & diluted		Adjust pH to 9-10 with NaOH and add bisulfite to large ORP change/ react 10 min/flocculate & settle/filter if needed/neutralize to pH 7	Natural reducing agent will most likely reduce the permanganate/ carbon may be used as reducer also	19,22	0.05 as Mn
Propionic acid	when dilute & neutralized		Add Na_2CO_3 to pH 7/ filter/adsorb C: 10-100 #/# sol. matl.	Not a problem in sea water because ppt with $CaCl_2$	10,19	1.25
Propionic Anhydride	When dilute & neutralized	See Propionic Acid	C: 10-100 #/# sol. matl.	Will not dissolve in salt water	10 *	1.25
Propyl Alcohol	When dilute		C: 10-100 #/# sol. matl.	Carbon may be ineffective so extensive dilution may be required	10,19	25

NWMAR116354

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Pyrethrins	no		C: 100-300 #/# sol. matl.		10,30	-
Quinoline	no		C: 10-35 #/# sol. matl.	Pump or vacuum undissolved portion from bottom/ will only dissolve slowly	10,30	-
Resorcinol	no		C: 1-10 #/# sol. matl.	Is very soluble so all water should be treated	10,30	-
Selenium Oxide	no	1. 2. 	1. Add acid to pH 6.5, add Na_2S until slight excess settle/ filter if needed/ oxidize to remove S 2. Filter/exchange for Se removal/neutralize	Take care to avoid evolution of H_2S/ Use ion exchange if media is available or if desired	19,20,24 *	0.01 as Se
Sodium Selenite	no	See Selenium oxide			19,20,24 *	0.01 as Se

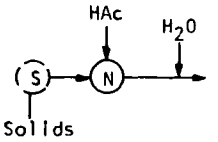
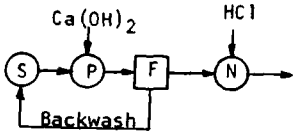
NWMAR116355

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Sodium	When neutralized	1. H_2O, HAC → (S) → (N) → ; solids 2. If on land, cover with oil and haul. Protect from contact with water or air.	Add acetic acid to pH 7/dredge	Dilute prior to neutralization/ is dissolved in water as NaOH	10,19	0.1 as NaOH
Sodium Bisulfite	After reduced with hypochlorite	Na_2CO_3, HOCl, HCl → (S) → (R) → (N) →	Add soda ash to pH 10/ then add HOCl to a chlorine residual/ react 2 hrs/neutralize with HCl and discharge	Be sure chlorine residual is low	10,19,28	
Sodium Hydrosulfide	When reduced	Na_2CO_3, air, H_2O → (S) → (N) → (O) →	Add Na_2CO_3 to pH 7-- air to 70% max. DO level	Remove any solids to land fill	10,19	
Sodium Hydroxide	When neutralized	acetic acid or dilute H_2SO_4 or HCl → (S) → (N) →	Add acid to pH 7/ discharge	Be careful not to create strong reaction	10,19,28	0.1 as NaOH
Sodium Hypochlorite	After reduction & neutralization	bisulfite & H_2SO_4, H_2O → (S) → (R) → (N) → ; Na_2CO_3	Add bisulfite and acidify with H_2SO_4 to pH 2-3/add soda ash to ppt Ca sulfate/ pH 10/neutralize with HCl		19,28	0.125

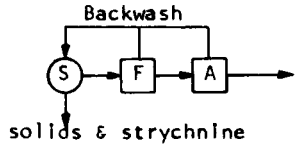
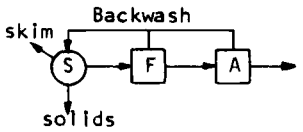
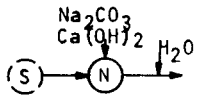
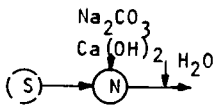
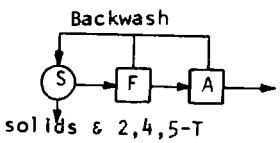
NWMAR116356

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Sodium methylate	If neutralized		Add acetic acid to pH 7 /dilute if needed	Whenever possible send to STP/otherwise dilute/can give off CH_4/also forms NaOH in water		0.1 as NaOH
Sodium Nitrite	If oxidized	See Sodium Bisulfite				-
Sodium Phosphate (dibasic)	If diluted		Add lime to pH 11/ allow to settle (use anionic polymer if needed)/filter if necessary/neutralize to pH 7		38	-
Sodium Phosphate (monobasic)	If diluted	See Dibasic Sodium Phosphate			38	-
Sodium Phosphate (tribasic)	If diluted	See Dibasic Sodium Phosphate			38	-
Sodium Sulfide	If oxidized	See Sodium Bisulfite			10,19,33	0.75 as H_2S

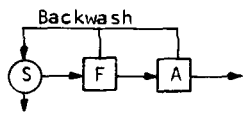
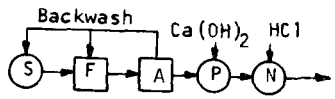
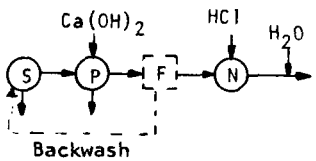
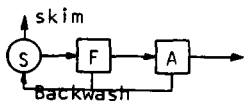
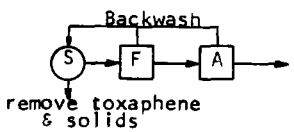
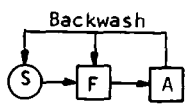
NWMAR116357

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Strychnine	no		C: 100-300 #/# sol. matl.	Dredge, pump, or vacuum undissolved portion from bottom	10	-
Styrene	If diluted		C: 10-100 #/# sol. matl.	Skim surface of water body	10,19	21
Sulfuric Acid	If neutralized		Add 50/50 mixture of lime and soda ash to pH 7/settle calcium sulfite sludge if needed/ discharge	Be careful not to create violent reaction by too fast base addition	10,19	0.05
Sulfur Monochloride	If neutralized		Add 50/50 mixture soda ash and lime to pH 7/ allow any sludge to settle	Will decompose in water to sulfuric acid/may fume to H_2S so take special precautions	10,19	-
2,4,5-T (acid)	No		C: 100-300 #/# sol. matl.	Dredge, pump or vacuum undissolved portion from bottom	30	-
2,4,5-T	No	See 2,4,5-T acid			30	-

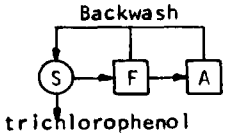
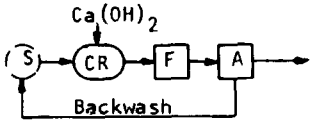
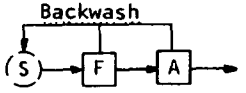
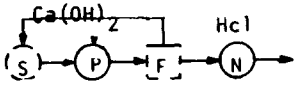
NWMAR116358

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
TDE (DDD)	no		C: 100-300 #/# sol. matl.	Dredge, pump or vacuum undissolved portion from bottom	10,19	0.05
Tetraethyl lead	no		Adsorb C: 10-35 #/# sol. matl. Add Ca $(OH)_2$ to pH 8.5/ppt lead neutralize to pH 7 if needed.	Dredge, pump or vacuum undissolved portion from bottom Carbon may be effective	10,19,33	0.05
Tetraethyl Pyrophosphate	no		Add $Ca(OH)_2$ to pH 11 settle/filter if necessary/neutralize to pH 7/dilute	Forms phosphates and methanol when hydrolyzed untested theoretical only	*	-
Toluene	When dilute		C: 10-100 #/# sol. matl.	Skim off surface of water body	10,19	18.75
Toxaphene	no		C: 10-100 #/# sol. matl.	Dredge, vacuum or pump undissolved portion from bottom	30	-
Trichlorfon	no		C: 100-300 #/# sol. matl.	Dredge or vacuum any undissolved portion from the bottom/usually will be dissolved	30	-

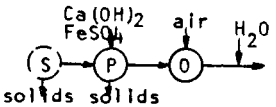
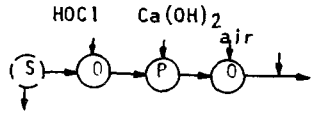
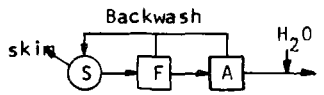
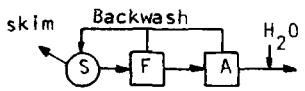
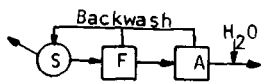
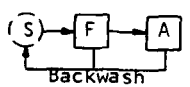
NWMAR116359

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Trichlorophenol	no		C: 10-100 #/# sol. matl.	Dredge, vacuum or pump undissolved portion from bottom	23	-
Triethylamine	When dilute		Add lime to pH 9, then run through filter. C: 35-100 #/# sol. matl.	Solubility is reduced at high temperatures	19	5.0
Trimethylamine	When dilute		C: 35-100 #/# sol. matl.	Add $Ca(OH)_2$ to pH 9/filter if necessary/neutralize to pH 7	10,19	5.0
Uranium Peroxide	no		C: 35-100 #/# sol. matl.	Uranium perioxide is a strong oxidizing agent/insoluble at pH 8/10	26*	-
Uranyl Acetate	no	See Uranium Peroxide		Uranyl acetate can also be precipitated as a phosphate	26*	-
Uranyl Nitrate	no	See Uranium Peroxide			26*	-
Uranyl Sulfate	no	See Uranium Peroxide			26*	-

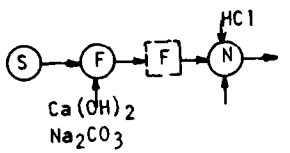
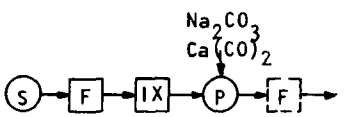
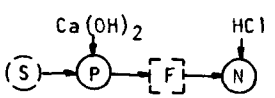
NWMAR116360

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Proy. Limit mg/l
Vandium Pentoxide	no		Add $Ca(OH)_2$ to pH 8.5/ Add 4:1 Fe:V weight ratio ppt/oxidize $Fe^{+2} \rightarrow Fe^{+3}$/ will ppt $Fe(OH)_3$		26,39*	-
Vanadyl Sulfate	no		Oxidize to HOCl residual add $Ca(OH)_2$ to pH 8.5/ Add 4:1 Fe:V weight ratio/ ppt/oxidize $Fe^{+2} \rightarrow Fe^{+3}$ with air/dilute		26,39*	-
Vinyl Acetate	When dilute		C: 10-35 #/# sol. matl.	Skim off from water body; light may cause polymerization to solid so dredging may be required	10,19	1.5
Xylene	When dilute		C: 10-35 #/# sol. matl.	Skim surface of water body	23	-
Xylenol	When dilute		C: 10-100 #/# sol. matl.	Skim surface of water body	10,19	0.001
Zectran			C: 100-300 #/# sol. matl.		30	-

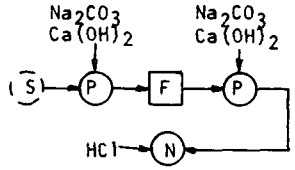
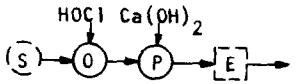
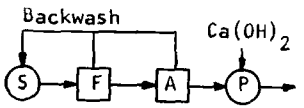
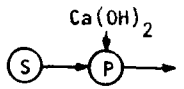
NWMAR116361

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Zinc Acetate	no		Add 50/50 mixture of soda ash and lime to pH 7.5-8.5; allow to settle/filter if needed/neutralize to pH 7	Check to assure discharge of acetate is acceptable	10,19,20, 24	5.0 as Zn
Zinc Ammonium Chloride	no		Settle/filter/exchange add 50/50 lime/soda ash to pH 7.5-8.5/settle filter if needed/neutralize if necessary	Ammonia must be removed first	24,26*	5.0 as Zn
Zinc Borate		See Zinc Acetate			10,19,20, 24,26	5.0 as Zn
Zinc Bromide		See Zinc Acetate			10,19,20 24,26	5.0 as Zn
Zinc Carbonate	no		Add lime to pH 7.5-8.5/settle/ filter is needed/ neutralize to pH 7		10,19,20, 24,26	5.0 as Zn
Zinc Chloride	no	See Zinc Acetate			10,19,20, 24,26	5.0 as Zn

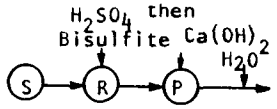
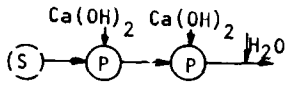
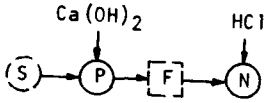
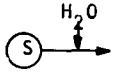
NWMAR116362

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Zinc Fluoride	no		Add soda ash to pH 7.5-8.5/settle/filter if needed/add additional soda ash/lime to pH 11/settle 24 hrs/ neutralize to pH 7	F^- requires 24 hrs for removal at high pH	10,20,24	5.0 as Zn
Zinc Formate	no	See Zinc Acetate			10,19,20, 24	5.0 as Zn
Zinc Hydrosulfite	no		Oxidize with HOCl to residual/add $Ca(OH)_2$ to pH 7.5-8.5/filter if needed	Oxidize to remove hydrosulfite	10,19,20, 24,26*	5.0 as Zn
Zinc Nitrate	no	See Zinc Acetate			10,19,20, 24	5.0 as Zn
Zinc Phenol-sulfamate	no		Adsorb C: 10-100 #/#, Add $Ca(OH)_2$ to pH 7.5-8.5	Precipitation will remove any excess Zn	19,24*	5.0 as Zn
Zinc Phosphide	no		Add $Ca(OH)_2$ to pH 7.5-8.5/settle	Do not lower pH or phosphine will be formed	19,24*	5.0 as Zn

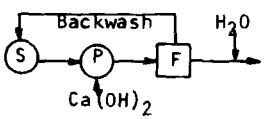
NWMAR116363

TABLE 22. (continued)

Hazardous Chemical	Amenable To Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Zinc Potassium Chromate	no		Settle to remove $ZnCrO_4$/ Add H_2SO_4 to pH 2-3, then bisulfite to large ORP or color change/add $Ca(OH)_2$ to pH 8/settle/discharge	Color changes from yellow to green Most $ZnCrO_4$ will be removed early	19,24*	5.0 as Zn
Zinc Silicofluoride	no		Add $Ca(OH)_2$ to pH 8.5/react	First lime dosage destroys silicofluoride complex test rxn carefully	19,24*	5.0 as Zn
Zinc Sulfate	no	See Zinc Acetate	Add additional lime to pH 11/settle 24 hours/dilute		10,19,24	5.0 as Zn
Zirconium Acetate	no		Add lime to pH 10/ allow to settle, filter if necessary, neutralize with HCl	Check discharge limit for Zirconium	26*	-
Zirconium Potassium Fluoride	no		Settle and dilute	A very stable complex/no other treatment recommended	26*	-
Zirconium Nitrate	no	See Zirconium Acetate			26*	-

NWMAR116364

TABLE 22. (continued)

Hazardous Chemical	Amenable to Biological Trmt. at Municipal STP	Treatment Scheme	Treatment Specifications	Comments	Reference	Prov. Limit mg/l
Zirconium Oxychloride	no		Add $Ca(OH)_2$ to pH 7/ settle/filter/dilute	May need polyelectrolyte to aid settling	26*	
Zirconium Sulfate	no	See Zirconium Acetate			26*	
Zirconium Tetrachloride	no	See Zirconium Oxychloride			26*	

NWMAR116365

5.0-CHAPTER 5 - SAFETY CONSIDERATIONS AND PROCESS DESIGN

5.1 GENERAL

5.1.1 Approach

The total section involving field implementation of treatment processes is very lengthy and for presentation in this Manual it has been divided into three sections. This first section presents sources of already constructed equipment for use in treating hazardous material spills, it also emphasizes the critical safety considerations evident in dealing with hazardous material spills and presents methods for developing the needed process design criteria. The next chapter (6) provides stepwise direction for individual design and construction of each of the five types of treatment processes. The final chapter (7) outlines needed information regarding process components such as tanks, pumps etc. and treatment chemicals. Step by step procedures are presented using cross references throughout the chapters to reduce repetition as much as possible.

Due to the complexity of treating hazardous spills and the need to make the manual as compact as possible, much desirable but not absolutely necessary information has been excluded. This procedure should not hamper the user but rather challenge him and his technical advisors to build from the basics presented here a system to suit the specific conditions and limitations with which he is faced.

5.1.2 Operation Design

It is essential that the OSC and other technical spill personnel be familiar with this Manual prior to use. Certain specific information sources have been left open and must be completed by the OSC prior to actual use of the manual. A good example is the location of local sources of materials, components, services, and supplies necessary to implement the field processes.

It is recommended that the duties at the site of the spill be divided into three distinct categories. A process engineer or director would be concerned with the process and the chemistry of the treatment. A maintenance engineer would oversee construction and then perform the necessary surveillance of the equipment to assure correct mechanical operation.

Finally, a separate safety director would be appointed whose only concern would be to attempt to provide safe working conditions in a hazardous situation. The people must work together closely to create a safe and effective working environment.

5.1.3 Format

These chapters have been structured to use various cross references in order

NWMAR116366

to minimize repetition. The general approach of the three chapters is shown in Figure 37. The various chapter references are shown with the action guiding scheme. The close association with Chapter 4 is apparent. Performance of bench tests is not always mandatory since some processes don't require this procedure. However, when needed, it must be done immediately.

The chapters are based on a two-fold philosophy. The first is scaleup of the bench test results (where applicable) to allow design of a full size unit. The second, and more critical aspect of the design, is a limiting factor approach to establishing a process flow rate. In order to correctly evaluate the systems calculations are made and then the entire system should be mapped out on paper. Once this paper treatment system is "constructed", it can be evaluated in terms of the limiting factors in the specific spill situation. The procedure for applying this approach is given in subsection 5.4 in terms of questions on limiting factors and examples. In order to save time and effort on a spill site, this procedure should be followed.

Once the system flow rate has been established, construction of the treatment system can begin. The following two chapters must be used to complete this effort. The first is Chapter 6 which addresses treatment process elements and the second is Chapter 7 which addresses component selection. Chapter 7 includes criteria for selecting various types of materials used in a treatment system such as tanks, pumps, hoses, mixers, etc. The selection of specific materials is based on mechanical factors as well as the corrosivity of process and treatment chemicals. Once selection of materials and components is complete, Chapter 6 directs the construction and operation of the system. In all phases of design, construction, and operation, concern should be given to safe operation, knowing that the treatment system is, to a certain extent, a reconcentrator of the spilled substance, and therefore a reconcentrator of the hazard. In addition, chemicals used to treat the spill are, many times, hazardous materials themselves. This chapter addresses some important safety requirements which must be considered at the outset of the cleanup effort.

The sections in Chapter 7 are auxilliary portions which give additional information to the OSC. The most critical of these involves the specific details on treatment chemicals and provides examples for converting volume, weight, concentrations, etc. It is important to understand the hazards involved in handling these materials and to work safely in their vicinity. The next section covering suppliers, gives direction to the OSC regarding where specific materials can be obtained, either locally or through national suppliers. The final section presents definitions and calculations aides to help the users of the manual.

Although this portion of this Manual does include extensive cross referencing, it is the most efficient way of presenting the material. However, it does confirm the necessity of users of this Manual being completely aware of its content before use.

NWMAR116367

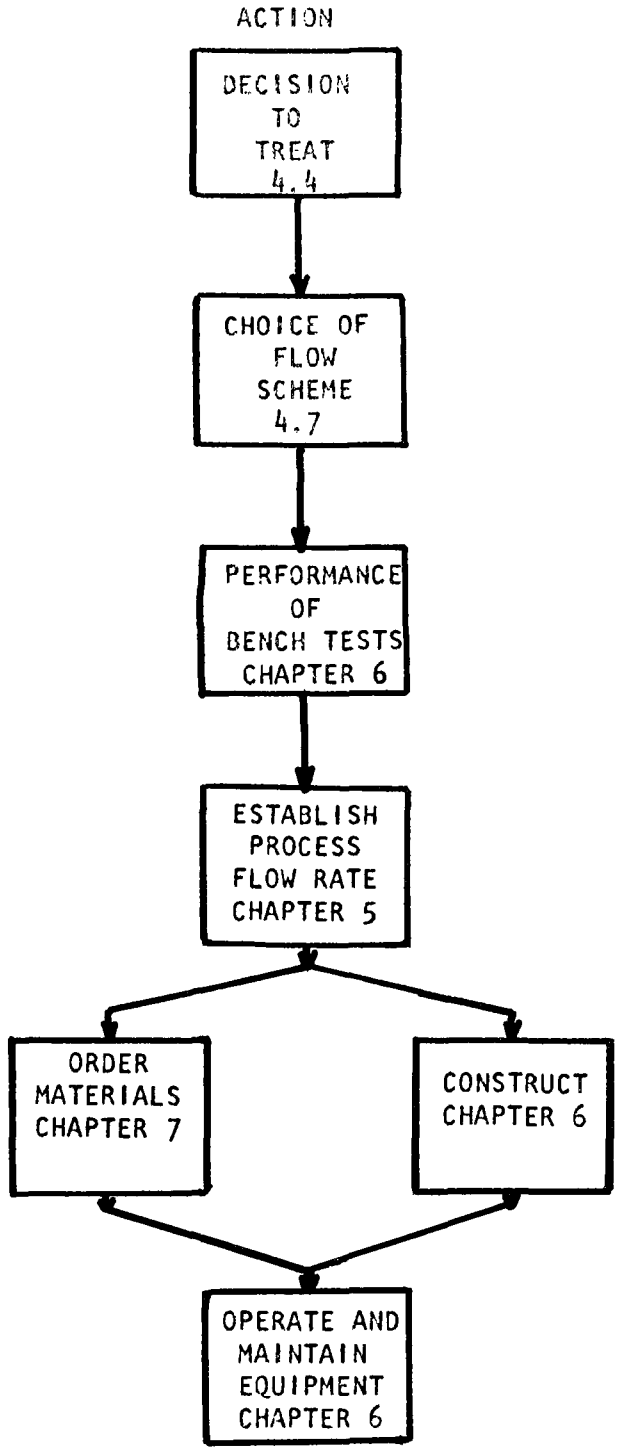


Figure 37. Stepwise use of chapters 4, 5, 6 and 7.

NWMAR116368

5.2 AVAILABLE EQUIPMENT SOURCES

Once it has been established that the spill must be treated using an on-site but off-stream system, it is necessary to construct the needed process units. Prior to following the instructions for improvising a treatment system as presented in Chapter 6, it is recommended that the spill coordinator investigate the possibility of using preconstructed system components. The OSC or other authorized personnel should determine the availability of equipment to be used in hazardous material spill cleanup. Table 23 presents a list of some of the available sources of equipment throughout the country. Prior to a spill situation, it would be desirable for the OSC to be familiar with these sources and other local suppliers so that upon the occurrence of a spill, the availability of preconstructed equipment can be determined rapidly.

5.3 SAFETY PRECAUTIONS

5.3.1 Approach

Safety procedures are critical when working with hazardous materials and even more so when operating an improvised treatment system. It is critical to judiciously guard the safety of those people on the treatment site to prevent creating a disaster out of the hazard. The operators must be alerted to possible dangers and potentially hazardous situations by a specific person at the scene. Since most people will be concerned with designing, constructing, or operating the system, it seems best to choose a separate individual whose only responsibility would be safety on the treatment site. This person, hereafter termed the Safety Director, would have direct responsibility for all aspects of safety.

Among the safety director's duties are obtainment of various safety equipment, the transfer of information regarding the hazard of the situation, the specification of the level and type of protective clothing needed for each position, operation and person, and policing of the area to insure that safety standards are followed. It is the safety director's duty to work directly with the process and maintenance engineers to incorporate safety considerations into the entire system. Therefore considerable diligence and tact are necessary to do an effective job.

5.3.2 General Duties

The safety director has many responsibilities for adapting a spill site into a safe working area. These are summarized in Figure 38. In the beginning of the set-up the safety director must approve the layout of the system and the chemical and fuel storage facilities. Special instructions for storage are available in many references and these should be consulted. The safety director should also restrict access to certain areas of the treatment system by roping them off. Specific restricted areas should include chemical feed systems and any inground tanks. Warning signs should also be placed in especially hazardous areas.

NWMAR116369

TABLE 23. PORTABLE TREATMENT EQUIPMENT SOURCES

(Used chemical process equipment suppliers)

San Francisco

Machinery and Equipment Corp.
P.O. Box 3132C
San Francisco, California 94119
Phone: 415-467-3400

Houston

Dynaquip, Inc.
1143 Brittmore
Houston, Texas 77043
Phone: 713-467-5500

Petro-Power, Inc.
6436 Rupley Circle
Houston, Texas 77087
Phone: 713-644-8271

Chicago

Aaron Equipment Co.
9301 W. Bernice Street
Schiller Park, Illinois 60176
Phone: 312-678-1500

A-1 Equipment & Chemical Co.
57 East 21st Street
Chicago, Illinois 60616
Phone: 312-842-2200

Indeck Power Equipment Co.
1075 Noel Avenue
Wheeling, Illinois 60090
Phone: 312-541-8300

Loeb Equipment Supply Co.
4131 South State Street
Chicago, Illinois 60609
Phone: 312-548-4131

Union Standard Equipment
163-167 N. May Street
Chicago, Illinois 60607
Phone: 312-421-1111

Cleveland

Arnold Equipment Co.
5055 Richmond Road
Cleveland, Ohio 44146
Phone: 216-831-8485

Cleveland (Continued)

C.P.R. Machinery & Equipment Co.
5061 Richmond Road
Cleveland, Ohio 44146
Phone: 216-464-8590

Federal Equipment Co.
8200 Bessemer Avenue
Cleveland, Ohio 44127
Phone: 216-271-3500

International Power Machinery Co.
834CE Terminal Tower
Cleveland, Ohio 44113
Phone: 216-621-9514

Process Equipment Trading Co.
1250 St. George Street
East Liverpool, Ohio 43920
Phone: 216-385-2400

New York

Brill Equipment Co.
35-63 Iabez Street
Newark, New Jersey 07105
Phone: 201-589-7420

George Equipment Co.
27 Haynes Avenue
Newark, New Jersey 07114
Phone: 201-242-9000

H&P Equipment Co., Inc.
14 Skyline Drive, Box 368
Montville, New Jersey 07045
Phone: 201-335-9770

Keith Machinery Co.
34 Gear Avenue
Lindenhurst, New York 11757
Phone: 516-884-1200

Perry Equipment Co., Inc.
Box C
Hainesport, New Jersey 08036
Phone: 609-267-1600

NWMAR116370

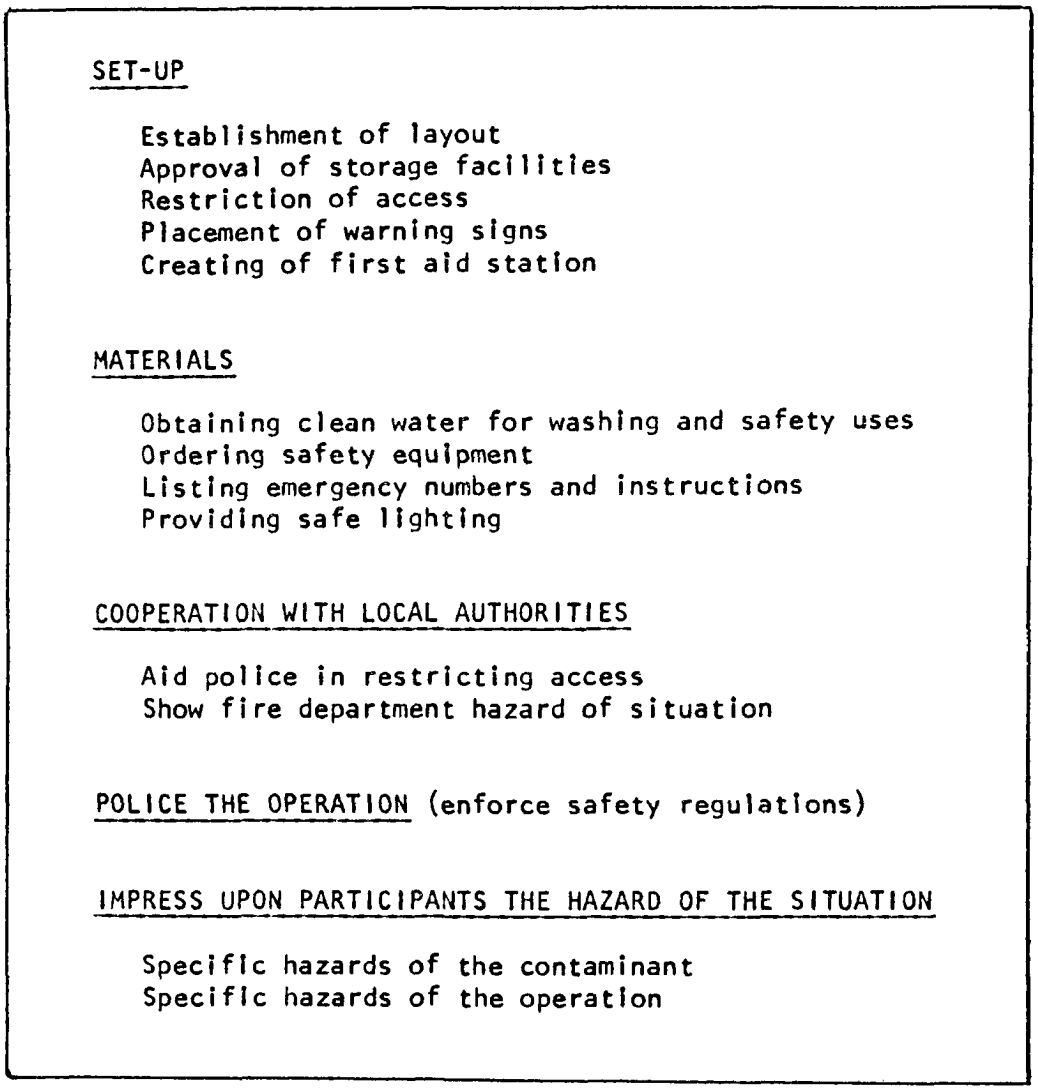


Figure 38. Summary of a safety director's responsibilities.

NWMAR116371

While chemicals and media are being ordered, the safety director should obtain the necessary safety equipment and clothing. These materials are available from various suppliers. A discussion of these devices is included at the end of this chapter. The safety director should also obtain a source of clean water for use in washing and for emergency shower and eyewash systems. It must be stressed that all workers are dealing with a hazardous substance and should wash thoroughly prior to eating or touching anything. Finally, it is critical that the safety director instruct each person performing a specific operation with regard to its hazards and the level and type of protective clothing needed for the task.

In addition to these duties, the safety director must set up a protected safety or first aid station with a cot, blanket and first aid kit. Emergency numbers, the location of hospitals and telephone numbers of doctors in the area should also be obtained. In addition, lighting should be provided on the site if nighttime operation is expected.

The safety director should also work with local authorities--police, civil defense and fire department--to establish procedures for both emergency and normal operating situations. Police may be able to restrict access of unauthorized persons to the site, while both civil defense and fire department officers should inspect the system prior to the development of any emergency situation. The safety director should be familiar with the hazards of the specific contaminant being treated. He must have knowledge of antidotes or special safety procedures to insure that adequate precautions are taken. This information must then be conveyed both to local emergency authorities and to the people working at the site.

Once the system is operating, the safety director must inspect the area regularly, and check to make sure the system and the people are working safely. All treatment equipment should be inspected as should the protective clothing worn by operators.

However, it is more important for the safety director to impress upon the operators of the equipment the importance of system safety. The various situations which present specific hazards should be explained and the possible affects made known to the workers. If this is done effectively, safety will be a concern of all people on the spill site and accidents can be avoided or minimized.

5.3.3 Specific Operating and Maintenance Hazards

There are many inherent safety problems which arise when a jury-rigged system is operated. The following sections indicate some of the situations which require special attention. Once on the scene, a safety director should be able to notice many more. It is necessary to warn the person performing the task of the specific hazards involved and help him to minimize them.

5.3.3.1 Desludging - The desludging operation involves transfer of a con-

NWMAR116372

centrated and highly contaminated sludge. In general, the job is messy and difficult. All personnel involved in this task should wear protective clothing and eye protection as specified by the safety director and avoid unnecessary contact with the sludge.

5.3.3.2 Hose Repositioning - Moving hoses may be a necessary task and it may be difficult to do without showering the area (and people) with contaminated liquid since hoses can easily get loose. When hoses are to be moved, the pump feeding them should be shut off and for extra safety the person moving the hose should wear protective clothing and eye protection, specified by the Safety director.

5.3.3.3 Tank Patching - When tanks require repair, this must usually be done from the inside of the tank and therefore may involve direct contact with the contaminant. Two people should be involved in the operation and both should be equipped with specified protective clothing and goggles. One person must enter the drawn-down tank while the other can stay outside to assist in any manner necessary. However, extreme caution is needed to avoid falling since the tank bottom liner may be quite slippery.

5.3.3.4 Pump Handling - Pumps must be watched at all times, so flow can be shut off immediately to avoid downstream problems. When hoses on pumps are removed, it is necessary to fully relieve the pressure which builds up at the pump to avoid blow back of the wastewater. The pump operator should be equipped with protective clothing and eye protection to avoid injury from this situation. The raw flow pump is also very difficult to set up and handle, so operators should be protected and take special precautions.

5.3.3.5 Hoses and Fittings - Another problem involves slippage between hoses and fittings which occurs during operation. To minimize the problem a maintenance director can check these systems throughout the day and retighten them as necessary. Anyone in the vicinity should be protected to avoid contact with the contaminant in case the hose breaks loose.

5.3.3.6 Chemical Feed System - The handling of treatment chemicals and the chemical feed system is a very dangerous operation in a jury-rigged system. Specific cautions and problems are indicated in Chapter 7, however certain general rules should be followed. The chemicals should not be touched under any circumstances and a respirator should be used if dust is present. Eye protection, gloves and rubber aprons or specified protective clothing are necessary for anyone operating the feed pump or mixing chemicals. As stated previously, the area should be restricted and access granted only to those wearing proper safety equipment. The hoses for chemical systems must be well supported so that they don't loosen and spray chemicals on unprotected individuals. In addition, hoses, fittings and pumps should be inspected frequently and any leak fixed immediately. These chemicals can present a personal hazard equal to or greater than exposure to the contaminated liquid because of the high concentrations involved. Therefore, the safety director must stress this fact to all people concerned with treatment and strictly enforce the safety regulations.

NWMAR116373

5.3.4 Commercially Available Safety Equipment

5.3.4.1 General - The safety equipment previously referred to will be described in this section. This equipment is commercially available and a number of vendors are given at the end of this discussion. The needed safety materials should be ordered and kept on hand by the OSC, by responsible agencies such as police and fire departments, and by contractors involved in hazardous material spills cleanup.

5.3.4.2 Testing Equipment - Testing of the air is often advisable at the scene of the spill to determine if a combustible, toxic or oxygen deficient atmosphere exists. While there are varying degrees of sophistication, portable instruments which would be of the most use include:

1. Universal tester - tests for a wide range of toxic gases.
2. Combustible gas indicator - measures combustible gases or vapors.
3. Oxygen indicator - tests for concentration of oxygen.

5.3.4.3 Protective Clothing - Protective clothing available includes respiratory devices, suits, gloves, hoods, shoes and boots. A comprehensive inventory of much of this equipment is available in the U.S. GPO Publication "A Survey of Personnel Protective Equipment and Respiratory Apparata for Use by Coast Guard Personnel in Response to Discharges of Hazardous Chemicals" (NTIS ADA - 010-110)(42). In addition to listing of available safety equipment, a prototype of the Coast Guard fully protective suit is included. This document should be obtained for use by the safety director at the spill site. Respiratory devices include atmosphere supplying breathing apparatus, gas masks and other types of respirators (dust, mist or paint spray, etc.). Breathing apparatus have their own source of air or oxygen rather than attempting to purify and use the ambient, contaminated air. Breathing apparatus are the safest and recommended type of respiratory protection and should be used unless it is confirmed that the contaminant can be removed by a filter or canister. A breathing apparatus provides general protection against toxic gases and oxygen deficiency. The most commonly used breathing apparatus is the self-contained air mask. A cylinder of air is carried on the back of the user and is supplied on demand. Exhaled air is exhausted to the surrounding atmosphere.

Gas masks provide protection against a specific hazard when equipped with the appropriate chemical-sorbent canister. Canisters are available to protect against low concentrations of acid gases, organic vapors, carbon monoxide, ammonia, and chlorine. In no case should a canister gas mask be used if there is a chance that the concentrations may exceed the sorbent limit or that an oxygen deficiency may exist.

The protective suits (thought of as completely enclosing the wearer) provide the maximum protection against a hazardous environment. There is no suit commercially available which is resistant to all hazardous chemicals. The Coast Guard is developing a butyl rubber maximum protection suit and the U.S. EPA is developing a lightweight butyl rubber suit. Once the hazard is known, however, appropriate clothing usually can be selected from what

NWMAR116374

is commercially available. In most cases this will be acid resistant clothing, i.e., fabric coated with vinyl, butyl, or neoprene rubber. A typical commercially available suit consists of a neck-to-toe, one piece coverall and a separate hood. Air is supplied to the suit from an outside source. Less restrictive garments are also available but provide less protection.

Coated gloves are available to protect against various chemicals. Hard hats should be worn if there is a danger of falling objects or low-clearance bump hazards. Hard toe boots and shoes should be standard items. However, it must be stressed that protective clothing is only effective when the identity of the spill is known and when the clothing is properly used. If the specific hazard is not known, a fully protective suit may not provide long term protection for working in the spill vicinity. The hazard associated with improper use of protective clothing is obvious.

5.3.4.4 Eye Protection - Eye protection in the form of safety glasses or goggles should be required of everyone on the site of a spill clean-up. Unlike some street glasses, safety glasses have lenses that are impact and shock resistant. Side-shields or goggles are recommended if corrosive chemicals are to be handled or pumped.

5.3.4.5 Skin Protection - Skin creams are available for protection against specific types of irritants. These irritants include acids, alkalies, tar, and cooling and cutting oils.

5.3.4.6 First Aid Equipment - A first aid kit should be kept at the site of the spill cleanup. A portable resuscitator may also be in order depending on the hazards involved.

5.3.4.7 Vendors - Safety equipment is available from the following vendors (among others):

Mine Safety Appliances Company
400 Penn Center Boulevard
Pittsburgh, Pa. 15235
412-241-5900

Environmental Tectonics Corp.
4 James Way
County Line Industrial Park
Southampton, Pa. 18966
215-355-9100

Additional equipment may be found locally by checking the Yellow Pages under Safety Equipment and Clothing.

NWMAR116375

5.4 SYSTEM DESIGN CRITERIA

5.4.1 General

Once it has been established that the spill must be treated on site in an offstream treatment system, many considerations must follow. The first design step is to establish the process flow rate of liquid through the treatment system before further design can be started. Various factors affect the flow rate including time, site considerations, material availability, manpower requirements and the characteristics of the contaminated liquid itself. It is best to consider each spill situation individually and evaluate which factors limit flow in that spill occurrence. This section presents the various factors and then applies examples to indicate how the site and material problems can be solved using the built-in flexibility of a parallel batch system. However the section does not attempt to judge a situation, but rather to present circumstances which may occur to make the OSC aware of these limiting factors.

5.4.2 Limiting Factors in System Design

Many factors are used to establish the maximum possible flow rate through a specific treatment system. Some of the variables are outlined in Figure 39. They have been divided into six general headings and each of these will be discussed in the following sections.

5.4.2.1 Time - For many spill situations, time is a critical factor for various reasons. In some circumstances there is immediate danger or a change in weather conditions will create a more severe problem by spreading the spill, so treatment must be completed before the next precipitation event. Possibly, the men on site are only available for a limited amount of time or the local authorities insist the spill must be cleaned by a certain time. In any event, once a time is established, and the volume of spill is known, then a process flow rate can be calculated.

5.4.2.2 Site Considerations - A new set of factors is introduced when the site is being considered. If the spilled material is extremely hazardous, a treatment site near the spill may be dangerous and the available pumping capacity may be insufficient to convey the contaminated liquid to a treatment system located a far distance from the spill itself. Another consideration is accessibility to the spill site by vehicular traffic (i.e. trucks) to allow equipment, supplies and manpower to reach the site. Other important considerations involve the amount of firm, flat and clear area available for construction of tanks and other large area requiring equipment. Modifications of the site with earth moving equipment or fill may be needed to allow a sufficient area to provide the required capacity of the treatment system.

Other problems involved in site considerations are the proximity to residences and roads. Residential interference may create problems when

NWMAR116376

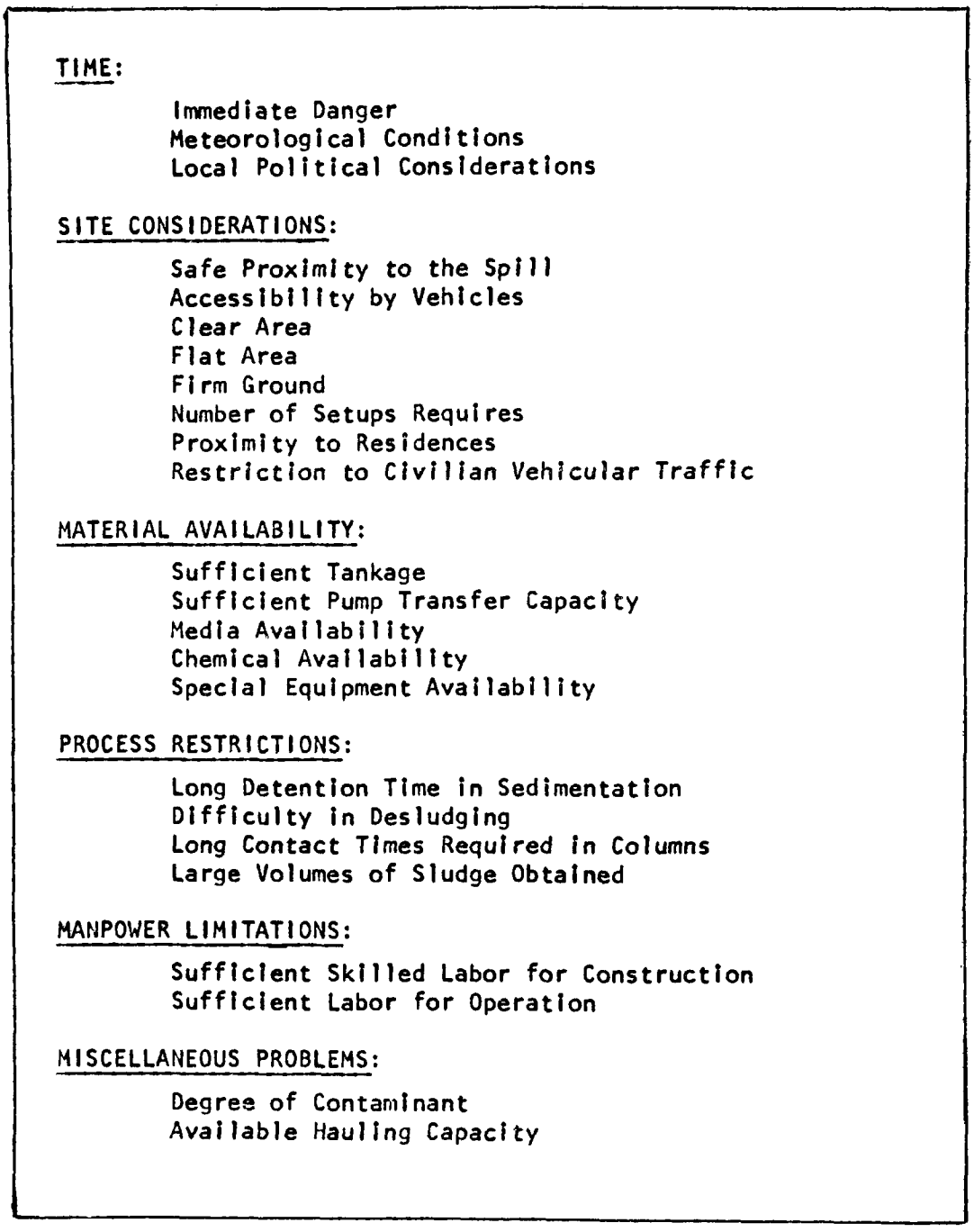


Figure 39. Limiting factors in system design.

NWMAR116377

24 hour per day operation is desirable or nearby roads may require special police or DOT provisions. Finally if the spill extends over a long distance, the number of times the treatment system must be set up has to be considered. A central but relatively remote location may be absolutely necessary to avoid reconstructing the treatment system at another site.

5.4.2.3 Material Availability - Once a flow rate has been estimated, the amount of construction materials and chemicals needed to meet this goal can be calculated. At this point, various parts of a treatment scheme may completely limit the flow through rate. These requirements are also directly related to the contaminated liquid treatment characteristics. In general, the most common limiting factor will be the availability of sufficient tankage to handle the spill. This required tank volume will also directly affect the area needed for treatment as discussed previously. Another consideration is the availability of sufficient pump capacity for transfer from the liquid source through the treatment processes and back to a receiving body of water together with the requirements of the chemical feed system and desludging operations.

In some situations, special equipment is needed to allow the safe handling of corrosive material and this special supply may be limiting. Finally, the availability of treatment chemicals and column media may affect the overall flow rate. However, it must be remembered that partial orders can be shipped before the complete order to reduce this problem.

5.4.2.4 Process Restrictions - The treatability of the contaminated liquid will also affect the design of the treatment system. A slow settling liquid will require more tankage. Also a sludge which is bulky or difficult to remove or pump from the tank will increase the number of needed tanks. The specific hazardous material being removed may need longer column contact time (especially for carbon) or may require removal to a higher degree. Finally, the characteristics of the contaminated liquid may result in a large volume of bulky sludge to be removed daily.

5.4.2.5 Manpower Limitations - There are two types of general labor required, although both functions can be filled by the same people. The first is the labor required for construction of the treatment plant within a short period of time. Local contractors can generally provide assistance in this area. The other manpower requirement is for the actual operation of the treatment system. Table 24 summarizes the approximate manpower needed for each operation on a per shift basis. However, prudent scheduling or a reduced working day may reduce the number needed. In general, based on 8-10 hr./day of work, each pump requires at least one person to operate it and column operation may need more manpower. Supervisory manpower must also be included and should include at least 3 people: process director, maintenance director and safety director plus some personnel to aid in process control functions.

NWMAR116378

Table 24. MANPOWER REQUIREMENTS FOR VARIOUS UNIT PROCESSES PER SHIFT

	Manpower	Job Description
1. Sedimentation	1	Fill tanks
	1	Empty tank
	1	Change hoses
	1	Desludging
	4	
2. Filtration	1	Run influent pump
	1	Watch columns for loading
	1	Backwash
	3	
3. Ion Exchange	1	Run influent pump
	1	Watch columns for loading
	2	
4. Carbon Column	2	Run influent pump
	2	Watch columns for loading (1 bank each)
	4	
5. Chemical Reaction	1-2	Chemical feed
Oxidation	1	Mixer
Reduction	1	Run influent pump
Sedimentation	1	Run effluent pump
Neutralization	1	Run flocculating unit
	1	Test endpoint
	1	Desludge (opt.)
	7-8	

NWMAR116379

5.4.2.6 Miscellaneous Problems - Other problems can also affect the flow rate. If the containment is not complete, the total overflow from the spill must be treated or held for treatment. Another consideration is the availability of hauling vehicles for sludge removal and the availability of the disposal site. If the proposed sludge volume per day is too voluminous, the flow rate must be reduced.

5.4.3 Parallel/Batch System Use

The use of the parallel batch operation does add flexibility to the system. If the scale-up of the process changes from that which is expected or if maintenance problems occur, the addition of tanks in parallel can compensate for these problems. The systems are set up in banks of tanks and filters served by pumps fitted with flow splitters and then equalization tanks between processes. If more capacity is needed, more tanks can be added to the operation without changing much of the basic design criteria. The examples which follow indicate how these systems can be modified with various limiting factors.

5.4.4 System Flow Scheme Construction

5.4.4.1 General - Once the flow scheme has been chosen, there are some construction steps which are not apparent from the original schematic. Additional tanks for equalization between processes and specific process logistics are necessary for efficient operation of a treatment system. Therefore various procedures have been recommended and are discussed in the following sections.

5.4.4.2 Equalization Tanks - Addition of equalization tanks between processes will simplify the operation of a batch and continuous flow integrated system. It also provides a safety factor and extra storage in a malfunctioning process. These tanks are not necessarily large, but they should hold a sufficient amount of liquid between the units to smooth out the flow rates. In general, an equalization tank is placed before and after each unit process. For column operation, the calibrated equalization tanks can be used to regulate the loading rates.

5.4.4.3 Carbon Column Series Operation - Design of efficient carbon column operation is established by two criteria of equal importance. One criteria is the loading rate to a column and this variable is a function of the surface area of the column itself. The other variable is the contact time between the carbon and the contaminated liquid and this factor is a function of the depth of carbon in the column and the loading rate. It is necessary to provide a minimum contact time of thirty minutes for removal of contaminants, however, the loading rate of 81.41/min/sq. m or (2gpm/ft^2) will only allow a fifteen minute contact time when the carbon depth is limited to 1.22m (48") (See Section 6.3.2.) Therefore,

NWMAR116380

to increase the contact time a second column can be used in series with the first column and this can be visualized as a tall column split into two shorter columns for easier operation. However, the surface area of the second column is not to be considered in the calculation of the required surface area. Another way to increase the contact time is to decrease the loading rate to 40.71/min/m^2, however, use of series operation at 81.41/min/sq. m or (2gpm/ft^2) has several advantages. These are: 1) additional contact time to 60 minutes can be obtained by reducing the loading rate if necessary and more importantly, 2) the exhaustion of carbon can be monitored at the effluent from the first column to establish the actual breakthrough time and still provide removal through the second column.

A schematic of the carbon column operation as recommended is shown in Figure 40.

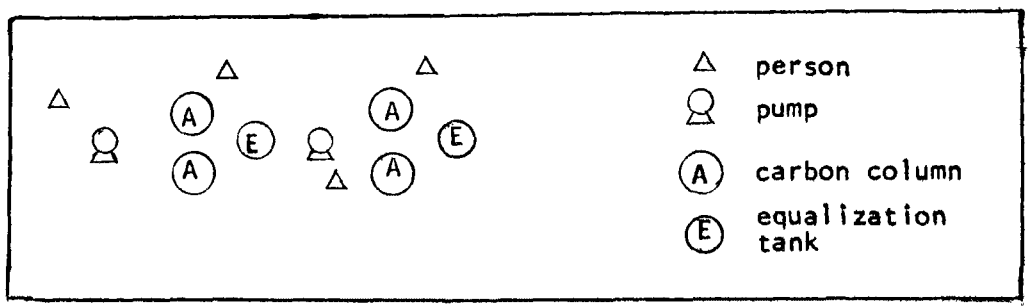


Figure 40. Schematic of carbon column operation.

In this operation, however, there are requirements for additional manpower, number of pumps and equalization tanks.

5.4.4.4 Pump Requirements - Transfer of the contaminated liquid from the water body to the treatment system, through the process and then back to the environment is done using pumps. Specific details on pump choices are given in Chapter 7; Figure 41, however, the number of pumps needed and the required capacity are established in this system design section. Using pumps in a batch system requires a single pump which is operated at a flow equal to or higher (if possible) than the system's design flow rate. Tanks are filled, then hoses are switched to another tank to keep the operation as continuous as possible, therefore, one influent and one effluent pump are used for any number of tanks. Column operations are also fed by one pump which operates at the system's design flow rate, however, a flow splitting device is used to divide the flow and allow correct loading rates. Miscellaneous pumps necessary include individual chemical feed pump for each chemical added, mixing pumps, desludging or solids handling pumps, and a final pump to return the effluent to the water body. The pump requirements and schematics are shown in Figure 41.

5.4.5 Examples of System Design

NWMAR116381

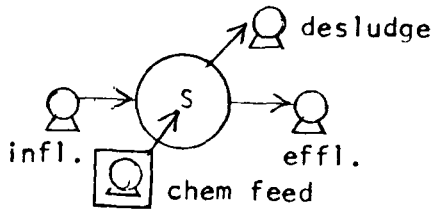
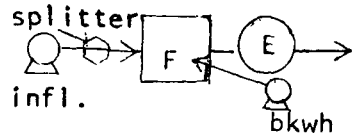
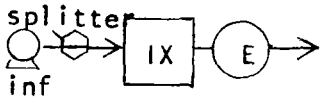
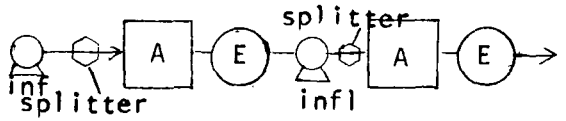
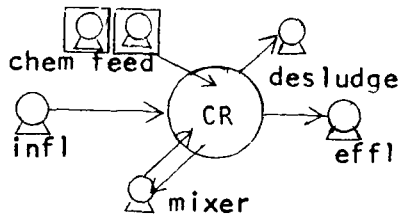
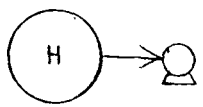
Process	No. Pumps	Approximate Configuration
Sedimentation	1 - Influent 1 - Effluent 1 - Solids Handling 1-2 - Opt. Chem. Feed	
Filtration	1 - Influent 1 - Backwash	
Ion Exchange	1 - Influent	
Carbon Column	2 - Influent	
Chemical Reaction	1-2 - Chemical Feed 1 - Influent 1 - Effluent 1 - Mixer 1 - Desludge	
Holding Tank	1 - Effluent	

Figure 41. Pump requirements for unit processes.

NWMAR116382

5.4.5.1 General - The following examples show a general approach to system design. After bench scale tests have been performed on the contaminated liquid, and a flow scheme chosen, a detailed schematic is developed. A summary of the equipment requirements for the various unit processes is shown in Figure 42. The user must keep in mind these requirements and the information presented in Section 5.4.4 when developing the preliminary schematic.

Once the schematic is established, then calculations are begun to establish the design flow rate. An initial approach is to choose an approximate time which is to be considered limiting (if one does not already exist) to provide a starting point for calculations. Once the design has been completed at that flow rate, then the various limiting factors should be considered. These were discussed in Section 5.4.2 and are presented in Figure 43 as questions to be considered by the user after a design has been completed. Answering these questions will force the OSC to evaluate the entire system prior to construction and allow a decision to be made as to whether the initial design flow rate can be attained or not. This procedure is outlined in the examples which follow.

5.4.5.2 Example: Endrin Spill -

Note: All calculations are in English units, the following conversions are appropriate.

lbs x 0.454 = kg
ft x 0.305 = m
gal. x 3.785/1000 = cum
ft^2 x 0.093 = m^2
gpm x 3.785 = lpm

SECTION REFERENCE

Scene: A train car has derailed and spilled ten 45 gallon drums of Endrin into a pond. The spill has been contained within the pond, however a long range weather forecast indicates storms are expected in 7 - 10 days. It has been decided to treat the water column and dredge the bottom separately but the local suppliers have only six 5' diameter tanks available for use in treatment construction. Calculate the design flow rate and system logistics to treat the water column.

1. Choose Appropriate Flow Scheme — Table 22

Carbon 100-300 #/#

NWMAR116383

Gravity Separation

1. Tanks - equalization, process, chemical storage
2. Desludging/Skimming Equipment
3. Chemical Feed System (opt.)
4. Mixing Equipment (opt.)
5. Flocculation Device (opt.)
6. Chemicals (opt.)
7. Pumps - raw flow pumps, solids handling
8. Sludge or Scum Tanks
9. Sampling Equipment

Column Operation

(Filtration, carbon, adsorption, ion exchange)

1. Tanks - equalization, process
2. Pumps - influent, solids handling
3. Flow Splitter
4. Media
5. Sampling Equipment
6. Fines Skimming Device
7. Underdrain system - bricks, grating, gravel, sand
8. Equalization Tank (after)

Chemical Treatment

General

1. Tanks - equalization, process, chemical feed
2. Chemical Feed System
3. Pumps - solids, raw flow, chemical feed
4. Mixing System
5. Flocculation System (opt.)
6. Chemicals
7. Chemical Testing Kit

Neutralization

1. pH Meter

Precipitation

1. Desludging System
2. pH Meter
3. Sludge Tanks

Oxidation/Reduction

1. ORP Meter (if possible)
2. Chlorine Testing Kit (opt.)
3. Spot Plate Chemicals (opt.)

Figure 42. Equipment requirements by process element.

NWMAR116384

1. Is time limiting?

   a. Is there an immediate danger or limiting period of time before a hazard exists?
   b. Do meteorological conditions impose a time limit?
   c. Do local political situations impose a time limit?
   d. Do other circumstances impose a time limit?

2. Is the site limiting?

   a. Can the treatment site be located close enough for pumping?
   b. Is the site accessible by truck?
   c. Is sufficient clear area available?
   d. Is sufficient flat area available?
   e. Is the ground firm enough to hold the treatment system?
   f. Are too many set ups needed?
   g. Is the site close to residences which impose various other restrictions?
   h. Does the site impede vehicular traffic?

3. Materials available?

   a. Is sufficient tankage available (volume, number, type)?
   b. Can pump transfer capability be obtained?
   c. Is column media available?
   d. Are chemicals available?
   e. Is special equipment necessary and available?

4. Process Restrictions?

   a. Is an extra long time needed in sedimentation?
   b. Is the sludge difficult to remove?
   c. Are longer contact times required in the columns (especially carbon)?
   d. Are large volumes of sludge generated?

5. Is manpower limiting?

   a. Is there sufficient skilled labor for construction?
   b. Is there sufficient labor for operation?

6. Are other problems apparent?

   a. Is the degree of containment sufficient to allow a chosen flow rate?
   b. Is there sufficient hauling capacity available for sludge?

Figure 43. Questions to establish limiting factors.

NWMAR116385

SECTION REFERENCE

II. Do Bench Scale Tests

Only settling tests were performed on the water column which contained algae with entrained endrin. This material must be removed prior to carbon column adsorption since it exerts a large carbon demand. The results are as follows:

Flocculation time = 5 min.
Settling rate = 0.5 fpm
Sludge volume = 1.3% of influent flow
Sludge height = 0.5 cm.
Cylinder height = 36.5 cm.
Polyelectrolyte dose = 2.0 mg/l

III. Develop an Appropriate Schematic

1. Establish number of pumps

Figure 41

Explanation: Each process (or bank of tanks) requires an influent pump. Since carbon adsorption is done in series, it requires two influent pumps. An effluent pump is used after the final holding tank.

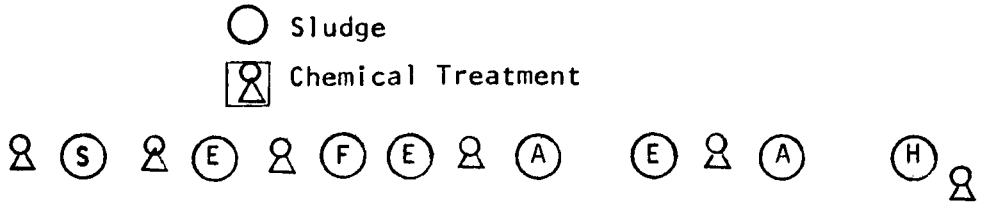
2. Place equalization tanks, denoted E , between the unit processes

Explanation: These additional tanks will simplify the operation.

3. Use dashed lines to indicate possible process tanks.

4. Place a holding tank at end of the system for effluent storage

5. Draw diagram:



NWMAR116386

IV. Calculate Desirable Flow Rate.

SECTION REFERENCE

Assumptions: a. 7 day time limit
b. 1,000,000 gal. to treat

$$\text{Flow rate} = \frac{V_{spill}}{\text{time to treat}}$$

$$= \frac{1{,}000{,}000 \text{ gal.}}{7 \text{ day} \times 16 \text{ hr/day} \times 60 \text{ min/hr}}$$

$$= 148.8 \text{ gpm} \sim 150 \text{ gpm}$$

Explanation: Assume a design day of 16 hours for treatment although actual operation may be longer to treat backwash. Experience has indicated that a jury-rigged system will require large amounts of maintenance and that backwashing and desludging is more easily accomplished during down time.

V. Establish Number of Sedimentation Tanks Required 6.5.4

1. Apply data from settling test to establish detention time

$$\text{det. time} = \frac{\text{process height}}{\text{settling rate}} \times 3 \text{ (safety factor)}$$

assumption: Hp = 3 feet
settling rate = 0.5 fpm

$$\text{det time} = \frac{3 \text{ ft.} \times 3}{0.5 \text{ fpm}}$$

$$= 18 \text{ min:}$$

flocculation time = 5 min.
total detention time = 23 min.

2. Calculate fill and draw time

Assumption: Pumping rate into and out of tank 150 gpm
tank type - 20 ft. diameter pool
effective diameter = 19 ft.
process height = 3 ft.

NWMAR116387

SECTION REFERENCE

$$\text{Tank volume, } Vn = \frac{\pi D^2}{4} \times Hp \times 7.48 \frac{gal}{ft^3}$$

$$= \frac{3.14 \times (19)^2 \text{ ft}^2 \times 3 \text{ ft} \times 7.48 \frac{gal}{ft^3}}{4}$$

$$Vn = 6360 \text{ gal.}$$

$$t_{fill} = t_{draw} = \frac{Vn}{\text{Pumprate}} = \frac{6360}{150} = 42.5 \text{ min.}$$

T_T = total time = 23 min + 2 (42.5) = 108 min.

Explanation: Although a filling and drawing rate of 150 gpm is necessary when working through the design steps, it is recommended that higher rate pumps actually be used for shorter durations, allowing time in between batches to move hoses, pumps, do maintenance, etc.

3. Establish frequency of desludging

$$\text{time between desludging} = \frac{0.25 \times Hp \times T_T}{\frac{\text{accumulation of sludge}}{\text{batch}}}$$

$$\frac{\text{accumulation of sludge}}{\text{batch}} = \frac{0.5 \text{ cm}}{36.5 \text{ cm}} \times 3 \text{ ft.} = .014 \times 3 \text{ ft.}$$

$$= 0.041 \text{ ft.}$$

$$\text{time between desludging} = \frac{0.25 \times 3 \text{ ft.} \times 108 \text{ min.}}{.041 \text{ ft} \times 60 \text{ min/hour}}$$

$$= 33 \text{ hours}$$

However desludging can be performed after the 16 hour operating period (i.e. during the 8 hour down time).

4. Calculate reduction in tank volume caused by sludge accumulation.

$$\text{Amount of sludge accumulated between desludgings} = \frac{\text{amount of sludge}}{\text{batch}} \times \frac{\text{batches}}{\text{before desludging}}$$

NWMAR116388

SECTION REFERENCE

amt. of sludge accumulated $= 0.041 \frac{ft}{batch} \times \frac{16 \text{ hr/between desludging}}{108 \text{ min/batch}} \times 60 \text{ min/hour}$

$= 0.37$ ft./between desludging $\sim$ 0.4 ft.

Effective process heights =

Hp - amount of sludge accumulated between desludgings
= 3 ft - 0.4 ft = 2.6
and the corrected tank volume (V_{peff}) is therefore:

$$\frac{(19)^2 ft^2 \times 3.14 \times 2.6 \text{ ft} \times 7.48 \frac{gal}{ft^3}}{4}$$

$V_{(peff)} = 5500$ gal.

Explanation: This height is then equal to the actual effective process height after reducing for accumulated sludge over the time period. The total sludge will not accumulate to this height until the end of the day so the average is 0.5 times the total accumulation. However drawoff can only be done to a level approximately twice as high as the sludge layer. Therefore the effective reduction is the following:

2 x (0.5 x height of sludge for drawoff) = height of sludge.

5. Calculate process volume required

$Vp = Qp\ (T_t)$

Vp = 150 gpm x 180 minutes = 16,200 gal.

6. Calculate number of tanks needed

$n = Vp/Ve$

$= \frac{16200 \text{ gal.}}{5500 \text{ gal/tank}}$

≈ 3 tanks

VI. Calculate the Number of Filters Needed. 6.2.2

Assumption: loading rate = 4 gpm/ft^2
diameter of filter = 5'

NWMAR116389

1. Calculate surface area of 1 filter

SECTION REFERENCE

$$\text{surface area} = \frac{\pi D^2}{4}$$

$$= \frac{3.14 \times (5)^2 ft^2}{4}$$

$$= 19.6\ ft^2/filter$$

2. Calculate surface area needed based on flow rate

$$\text{surface area} = \frac{Qp}{4 gpm/ft^2}$$

$$\text{Surface area} = \frac{150\ gpm}{4\ gpm/ft^2} = 37.5\ ft^2$$

3. Calculate the number of filters needed

$$\text{number of filters} = \frac{\text{surface area}}{\text{surface area/filter}}$$

$$= \frac{37.5\ ft^2}{19.6\ ft^2/filter}$$

$$= 1.9$$

$$= 2\ filters$$

VII. Calculate the Number of Carbon Columns Needed 6.3.2

Assumptions: diameter = 5' surface area = 19.6 ft^2

surface loading = 2 gpm/ft^2

a. calculate surface area needed: $\frac{Qp}{2 gpm/ft^2}$

$$\frac{150\ gpm}{2\ gpm/ft^2} = 75\ ft^2$$

b. calculate the number of columns

$$\frac{75\ ft^2}{19.6\ ft^2/column} = 3.8$$

$$= 4\ columns$$

c. Total number = 2 x 4 columns = 8 columns

NWMAR116390

Explanation: Carbon columns are used in series to provide the required contact time so the second column is not included in the surface area calculation.

SECTION REFERENCE

VIII. Design the Holding Tank

Assumptions: Hold about 30 min. flow, pump into and from tank at 150 gpm.
Use 20' diameter tank
Use 19' feet effective diameter
Hp = 3 ft

$$\text{Volume}_n = \frac{(19)^2 \text{ft}^2 \times 3.14 \times 3 \text{ ft} \times 7.48 \text{ gal}}{4 \qquad \text{ft}^3}$$

$$= 6360 \text{ gal.}$$

$$\text{Time to fill and draw} = \left(\frac{V_n}{\text{pumping rate}}\right)$$

$$= \frac{6{,}360 \text{ gal.} \times 2}{150 \text{ gpm}}$$

$$= 85 \text{ minutes}$$

$T_T = 85 + 30 = 115$ minutes
Vp = 115 minutes x 150 gpm

$$= 17{,}250 \text{ gal.}$$

$$\text{Number of tanks} = \frac{Vp}{Vn} = \frac{17{,}250}{6{,}360} = 2.7$$

Use 3 tanks

Explanation: If possible the OSC should determine if 2 tanks and a shorter holding time is sufficient.

IX. Design Sludge Holding Tank 6.5.4.

Calculate sludge volume for one day of operation.

Assume the volume to be stored is twice the actual volume of sludge produced since it is recommended that drawdown only go down to twice the actual sludge depth.

depth of sludge for storage = 2 x 0.40 ft. = 0.8 ft.

NWMAR116391

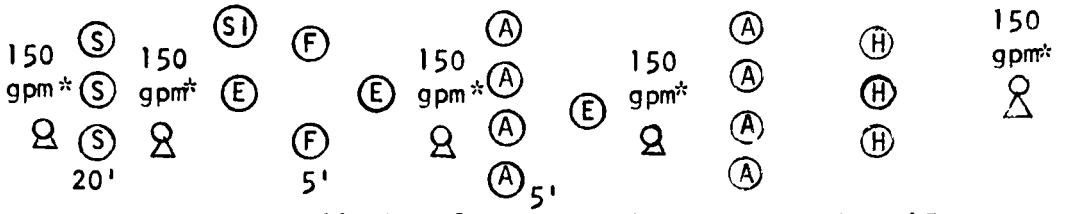
volume of sludge for storage from 3 sedimentation tanks = $\frac{(19)\ ft^2 \times 0.8\ ft \times 3.14 \times 7.48\ gal. \times 3\ tanks}{4 \qquad\qquad ft^3}$

SECTION REFERENCE

= 5087 gal. required

one 20' diamter tank holds 6360 gal. so 1 tank is sufficient

X. Revise the Schematic:



* These pumps can actually be of any capacity greater than 150 gpm; the greater the capacity the shorter the duration of their operation.

XI. Evaluate the Limiting Questions

Figure 43

1. Time limits - No problem since the flow rate was established based on this criteria.

2. Site considerations

   a. Safe proximity?
   Answer: Yes, it is safe to approach and treat.

   b. Accessible by truck?
   Answer: Yes.

   c. Is area clear/flat/firm and available?
   Answer: The amount of area required can be estimated be assuming 5' between large tanks and 2' between small tanks and then adding the distances from the schematic. In this case an area 105 ft. x 85 ft is needed and is available.

   d. Are residences or roads near by which would restrict operation or operating hours?
   Answer: No.

   e. How often must the treatment system be set up and can the site be centrally located:
   Answer: The site can be centrally located and set up only once.

NWMAR116392

3. Material availability

SECTION REFERENCE

a. Are enough tanks available?

number needed			number available 1-25' diameter
20'	9	(sedimentation/sludge/ 1 equalization/holding tank)	0
5'	10	(columns)	6
10'	3	(2 equalization/carbon storage)	2 1-18' diameter

b. Are sufficent numbers of pumps available? 7.2

Number	see references Rates to be pumped	Available number pump size
3	≥ 150 gpm	3 - 400 gpm
3	- 150 gpm	3 - 150 gpm
1	- 25 gpm backwash	1 - 50 gpm
1	50 gpm solids pump	1 - 100 gpm

c. Is media available? 6.3.2

Amount needed = 100-300 #/# of soluble material.

Solubility of endrin = 0.19 mg/ℓ in water

Volume of spill = 1,000,000 gal.

lbs of Endrin = volume (MG) x 8.34 $\frac{\text{lb}}{\text{MG-mg/l}}$ x solubility in mg/ℓ.

= 1 MG x 8.34 $\frac{\text{lb}}{\text{MG-mg/l}}$ x 0.19 mg/l

= 1.58 lbs of Endrin is soluble, the remainder is entrained or sunk.

Amount of carbon to order =

1.58# x 300#/# of soluble Endrin = 475 lbs.

Answer: Yes. Carbon is available.

d. Are chemicals for flocculation available?

Amount of chemicals needed;

NWMAR116393

polymer added; $\frac{2.0 \text{ mg/}\ell \times 3.784 \ \ell\text{/gal.} \times 10^6 \text{ gal.}}{453.6 \text{ gr/\#} \times 2000 \text{ mg/gr}}$

lbs of polymer = 17 lbs needed

Answer: Yes. Chemicals are available.

e. Does spill require special equipment?
Answer: No.

4. Process restrictions

a. Is the detention time too long?
Answer: A 23 min. detention time is not too long.

b. Are problems involved with desludging?
Answer: No apparent problems for water column treatment.

c. Long contact time needed in column?
Answer: No. Endrin will adsorb well.

d. Are large volumes of sludge obtained?
Answer: No. Only 1.3% of influent volume is estimated to become sludge.

5. Manpower limitations

a. Construction: 10 people are available - enough people.

b. Operation: See Table 24. The number of people needed per shift of operation is as follows:

sedimentation - 3	carbon - 4
filters - 2	effluent pump - 1

Add 3 people for safety, process and maintenance directors.

13/shift and 2 shifts/day for operation

c. Downtime crew

This crew should equal the number of people on the operating crew during one shift. In this case 10 people.

d. Total manpower in operation = 26 + 10 = 36 people

NWMAR116394

SECTION REFERENCE

6. Miscellaneous

a. Is the spill sufficiently contained to be stable for 7-10 days?
Answer: Yes.

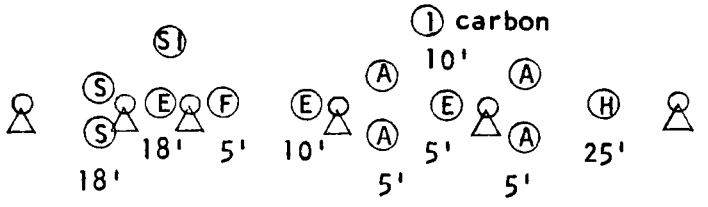
b. Is their sufficient hauling capacity for 5050 gal. of sludge/day?
Answer: Yes.

Evaluation indicates that the sufficient tankage is not avaialble to handle the flow rate. The system must be modified.

XII. Draw an Appropriate Schematic Utilizing the Available Tanks.

Criteria - tanks - 6-5' diameter tanks
4-18' diameter tanks
1-25' diameter tank
2-10' diameter tanks

An 18 foot tank has an effective diameter of 17.5 feet, pumpage ≈ the same



Establish flow through each unit process:
choose the smallest as limiting process flow.

a. sedimentation: $\frac{\text{volume available}}{T_T}$

T_T = fill & draw time + settling time

$$Vn = \frac{(17.5)^2 ft^2 \times 3.14 \times 7.48 \text{ gal.} \times 3 \text{ ft}}{4 \qquad\qquad ft^3}$$

$$= 5394.7 \text{ gal.}$$

$$T_{fill} = T_{draw} = \frac{5394.7 \text{ gal}}{150 \text{ gpm}} = 36 \text{ min.}$$

NWMAR116395

T_T = 2(36 min) + 23 min.

= 95 min.

SECTION REFERENCE

Volume available = 2 x V_n

$$gpm = \frac{2(5394.7)\ gal}{95\ min.}$$

= 114 gpm

b. Number of columns (same as filter & carbon).

for filters: surface area = $\frac{3.14 \times 5^2 ft^2}{4}$

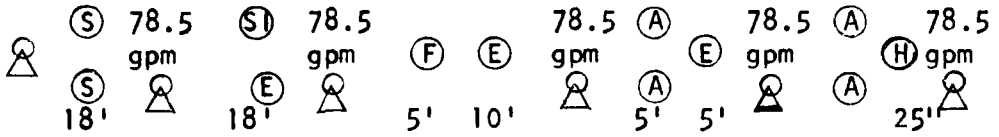
= 19.6 ft^2

design = 4gpm/ft^2

$$flow = \frac{4gpm}{ft^2} \times 19.6\ ft^2$$

= 78.5 gpm

Therefore the operating flow must not exceed 78.5 gpm.



XIII. Compare the Systems

		Optimum System	Actual System
a.	Time to treat	7 days	14 days
b.	Area needed	105' x 85'	82' x 41'
c.	Tanks needed	10-5'D.	6-5'D tanks
		5-20'D.	4-18'D
		3-25'D	1-25'D
		3-10'D	2-10'D
D.	Pumps needed	3 $\geq$ 150 gpm	3 $\geq$ 78.5 gpm
		3 - 150 gpm	3 - 78.5 gpm
		1 - 25 gpm	1 - 25 gpm
		1 - 50 gpm	1 - 50 gpm

All other elements are the same.

NWMAR116396

The responsibility is now up to the OSC to determine if the time factor is more critical to the cleanup operation than the tank shortage. If so, tanks must be made available from any source. If not, the OSC can use available tankage for construction.

SECTION REFERENCE

5.4.5.3 Example: Sodium Cyanide Spill -

Note: All calculations are in English units, the following conversions are appropriate:

$$lb \times 0.454 = kg$$

$$ft \times 0.305 = m$$

$$gal. \times 3.785 \times 10^{-3} = cum$$

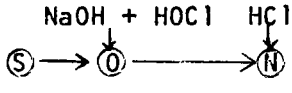
$$ft^2 \times 0.093 = m^2$$

$$gpm \times 3.784 = lpm$$

Scene: A truck carrying five 200 lb. drums of 30% sodium cyanide has spilled into a slowly flowing river. A dam has been placed downstream and the upstream water is diverted around the contaminated portion of the stream. Approximately 1,900,000 gallons of water has been contaminated and the bottom of the stream is also affected. It has been decided to dredge the top layer of the bottom and treat the river water in one operation. A presettler and sedimentation are necessary. It is desired to treat the entire spill within 5 days, however only an area 105' x 75' is available for treatment. Establish the most feasible flow system for this situation.

I. Choose Appropriate Flow Scheme

Table 22



Add Na(OH) to pH 8.5 then add HOCl/10% excess/react 1 hour/ neutralize to pH 7 if needed.

II. Do Bench Scale Tests

a. Settling tests: settling tests were done and it was found a presettler was needed. Polyelectrolyte was added at 5 mg/l with a flocculation time of 5 minutes. The settling rate was 0.4 fpm.

b. Oxidation tests indicated that 5 ml of 1N NaOH were needed to raise the pH to 8.5 and 10 ml of 0.05%

NWMAR116397

hypochlorite solution were added per liter of sample. The mixture reacted one hour to degrade cyanide to cyanate and carbon dioxide and nitrogen.

SECTION REFERENCE

c. Neutralization required only 2 ml of 1N HCl to return the pH to 7.

d. Since no sludge was formed it was established the oxidation and neutralization could occur in the same tank.

e. Sludge volume from the presettler was approximately 4% of the wastewater influent and the height of sludge after sedimentation was 2.0% of the total height.

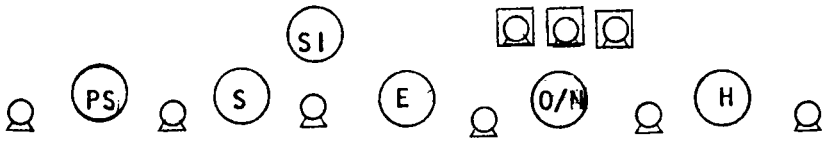
f. Summary of bench test results.

1) presettling - 4% volume of wastewater is sludge.

2) sedimentation - polyelectrolyte dose - 5 mg/ℓ
settling rate - 0.4fpm
sludge volume - 2.0%
5 minute flocculation time

3) chemical treatment - NaOH - 5ml 1N/ℓ
HOCl - 10 ml of 0.05%/ℓ
HCl - 2ml 1N/ℓ

III. Develop an Appropriate Schematic. Figure 41



IV. Calculate Desirable Flow Rate.

$$Q_p = \frac{V_{spill}}{\text{Time to treat}} = \frac{1.9 \times 10^6 \text{ gal.}}{5 \text{ day} \times 16 \frac{\text{hr}}{\text{day}} \times 60 \frac{\text{min}}{\text{hr}}} = 400 \text{ gpm}$$

Explanation: Assume 16 hour per day operation. Use other 8 hours for maintenance, desludging, chemical mixing, etc.

V. Calculate Number of Sedimentation Tanks Required. 6.5.4

NWMAR116398

1. Apply data from settling tests to estimate detention time.

SECTION REFERENCE

$$\text{detention time} = \frac{\text{process height}}{\text{settling rate}} \times 3(\text{safety factor})$$

parameters: settling rate = 0.4fpm
process height, Hp = 3 feet
flocculation time = 5 min.

6,5,4

$$\text{detention time} = \frac{3 \text{ ft.}}{0.4\text{fpm}} \times 3 = 22.5 \text{ min.}$$

Total detention time = 22.5 min + 5 min. = 27.5 min.

2. Calculate fill and draw time.

6,5,4

Assumption: Pumping rate = 400 gpm (in & out)
tank type = 25' diameter
24' effective dia.
3' process height

$$\text{tank volume} = V_n = \frac{\pi D^2}{4} \text{Hp} \times 7.48 \frac{\text{gal.}}{\text{ft}^3}$$

$$= \frac{(3.14) \times (24)^2 \text{ft}^2}{4} \times 3 \text{ ft} \times 7.48 \frac{\text{gal.}}{\text{ft}^3}$$

$$= 10{,}146 \text{ gal.}$$

$$T_{fill} = T_{draw} = \frac{V_n}{\text{pump rate}} = \frac{10{,}146 \text{ gal.}}{400 \text{ gpm}} = 25.4 \text{ min.}$$

$$T_T = \text{total time} = 2(25.4) \text{ min.} + 28 \text{ min.} = 78.8 \text{ min.}$$

$$= 79 \text{ min.}$$

3. Establish frequency of desludging.

$$\text{Time between desludging} = \frac{0.25 \times \text{Hp} \times T_T}{\frac{\text{accumulation of sludge}}{\text{batch}}}$$

$$\frac{\text{Accumulation of sludge}}{\text{batch}} = 0.02 \times 3 \text{ ft} = 0.06 \frac{\text{ft}}{\text{batch}}$$

$$\text{Time between desludging} = \frac{0.25 \times 3 \text{ ft} \times 79 \text{ min.}}{0.06 \text{ ft/batch}} =$$

$$= 988 \text{ min.}$$

$$= 16.5 \text{ hours}$$

NWMAR116399

Therefore desludging can occur after operation 16.5 hours.

SECTION REFERENCE

4. Calculate reduction in tank volume caused by sludge accumulation.

$$\text{Amount of sludge accumulated between desludings} = \frac{\text{amount of sludge}}{\text{batch}} \times \frac{\text{batches}}{\text{before desludging}}$$

Amount of sludge accumulated =

$$0.06 \frac{\text{ft}}{\text{batch}} \times \frac{16 \text{ hr/between desludging}}{79 \text{ min./batch}} \times 60 \text{ min./hour}$$

$$= 0.73 \text{ ft between desludging}$$

Effective process height = Hp - height of sludge accumulated between desludgings.

$$3 \text{ ft} - 0.73 \text{ ft} = H_p \text{ (eff)} = 2.27 \text{ ft}$$

$$V_n \text{ (eff)} = \frac{(24)^2 \text{ft}^2 \times 3.14 \times 2.27 \times 7.48 \text{ gal.}}{4 \text{ ft}^3}$$

$$V_{n(\text{eff})} = 7.677 \text{ gal.}$$

5. Calculate process volume required

$$Vp = Qp\ (T_T)$$

$$= 400 \text{ gpm } (79) \times \text{minutes}$$

$$= 31600 \text{ gal.}$$

6. Calculate the number of tanks needed

$$\frac{Vp}{V_{neff}} = \frac{31600 \text{ gal.}}{7677 \text{ gal/tank}} = 4.1 \text{ tanks}$$

$$= 5 \text{ tanks}$$

VI. Calculate the Number of Oxidation/Neutralization Tanks.

1. Calculate fill and draw time. 6.6.9

Assumptions: pump capacity - 400 gpm
tank diameter - 25'
effective tank diameter - 24'

NWMAR116400

process height - 3'
tank volume - 10146 gal.

SECTION REFERENCE

2. Fill time = draw time $= \frac{Vn}{\text{pump capacity}} = \frac{10146 \text{ gal}}{400 \text{ gpm}} = 25.4$ minutes

3. Calculate total detention time

$T_T = (25.4 \text{ min}) \times 2 + 60$ min for total reaction = 110.8 min.

= 111 min.

Explanation: Reaction time is very short for neutralization so the oxidation is the most time consuming.

4. Establish tank volume needed

$Vp = Qp \ (T_T)$

= 400 gpm x 111 min.

= 44,400 gal.

5. *Calculate number of tanks needed*

$N = \frac{Vp}{Vn}$

$= \frac{44,400}{10146}$

= 4.4 tanks

= 5 tanks

Explanation: No sludge accumulates in this process so entire volume is available.

VII. Calculate Number of Sludge Tanks 6.5.4

$\frac{\text{Volume of sludge}}{\text{day}} = Vp \times 0.04 \times \frac{\text{hour of operation}}{\text{day}}$

$= 400 \text{ gpm} \times 0.04 \frac{\text{gal. sludge}}{\text{gal. influent}} \times 16 \text{ hr/day} \times \frac{}{60 \text{ min./hr.}}$

= 15,360 gal./day

NWMAR116401

SECTION REFERENCE

Assumptions: 25' diameter tank
3' process height
Vn = 10146 gal.

Number of tanks - $\frac{\text{volume sludge/day}}{\text{volume/tank}} = \frac{15,300}{10,146}$

= 1.5 tanks

= 2 tanks

Explanation: Sludge is removed once per day.

VIII. Estimate Number of Presettling and Equalization Tanks.

1 - presettler - 3000 gal tank is good
1 - equalization - 25' pool, 3' Hp

IX. Calculate Number of Holding Tanks Needed.

Assumption: holding 15 min. of flow
pump into tanks at - 400 gpm
tank volume - 10146 gal.

T_T = Total time = 2 $\underbrace{\left(\frac{10146 \text{ gal}}{400 \text{ gpm}}\right)}_{\text{fill \& draw time}}$ + 15 min. = 65.7 min.

$Vp = Q_p \times T_T$

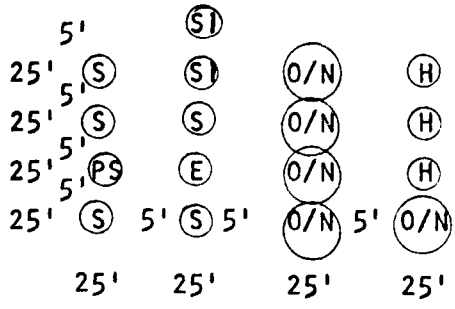
= 400 gpm x 65.7 min.

= 26280 gal.

$n = \frac{Vp}{Vn} = \frac{26280 \text{ gal}}{10146} = 2.6 \text{ gal./tank}$

n = 3 tanks

X. Revise the Schematic



NWMAR116402

SECTION REFERENCE

XI. Evaluate the System.

Figure 43

The 1st limiting factor to consider is the space requirement: The system @ 400 gpm requires 115' x 140' and only 105 x 70' is available.

Therefore more consideration is necessary.

XII. Modify the system to comply to limiting factors of the Space Requirement.

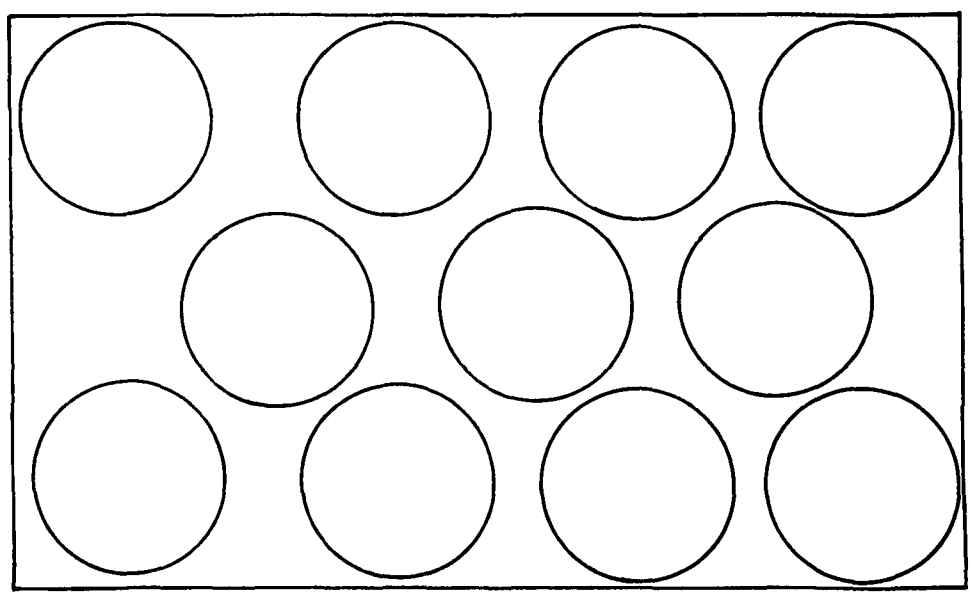
1. Establish available tanks.

   3 types are available

D (feet)	calculation	Volume (gal)
18'	(17) $^2ft^2$ x 3.14 x 3 ft 7.48/4	5090
20'	(19) $^2ft^2$ x 3.14 x 3 ft 7.48/4	6360
25	(24) $^2ft^2$ x 3.14 x 3 x 7.48/4	10146

2. See how many tanks fit one area approximately 60 x 100 (accounting for spaces between the tanks).

Trial 1



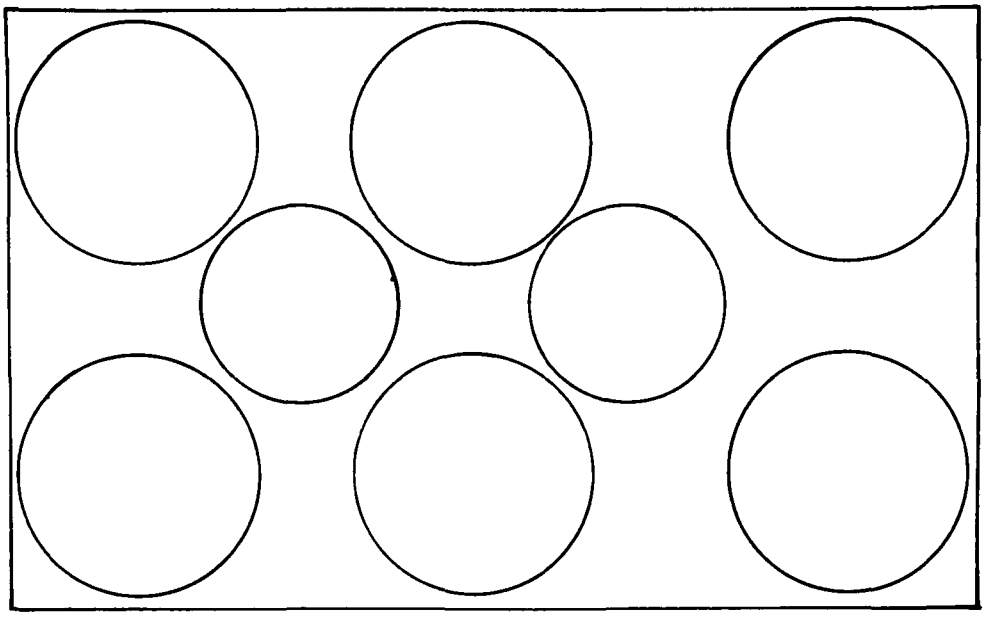
NWMAR116403

Trial 1 20' D tanks - 11 tanks or 69960 gal.

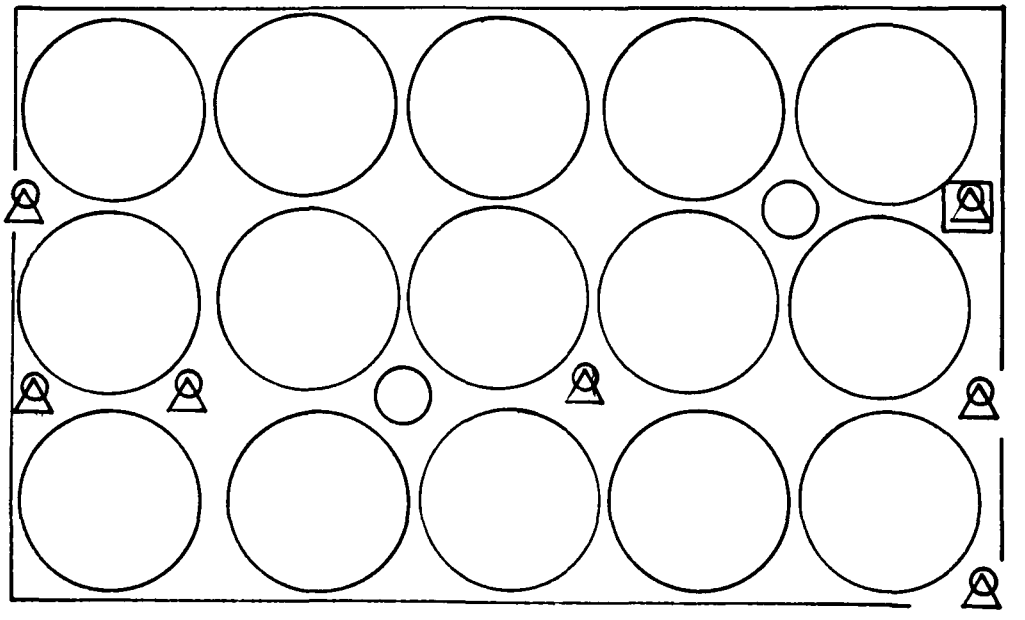
Trial 2 25' D tanks - 6 tanks + 2 20' D = 60876 + 12720 = 73596 gal.

Trial 3 18' D tanks - 15 tanks or 76350 gal.

Trial 2



Trial 3



NWMAR116404

The usage of tanks could then be calculated based on the following system.

SECTION REFERENCE

3. Estimate the best allocation of tanks to processes.

4. Develop a new flow rate based on a comparison of the two tank total volumes:

   System 1 - 17 25' D or 10,146 gal. tanks - 172,482

   System 2 - 15 18' D or 5,090 gal. tanks = 76,350

   Assume that 5 of the tanks will be used for the O/N step and 4 for sedimentation.

5. Calculate the fill and draw times.

   In this case we already know the number of tanks available, therefore it is necessary to first calculate the effective tank volume taking into consideration the accumulated sludge as follows:

$$\frac{(17)\ ^2ft^2 \times 3.14 \times 2.27\ ft \times 7.48\ gal}{4 \qquad\qquad ft^3} = 3852\ gal.$$

   Since the process flow rate is unknown, the fill and draw times are as follows:

$$T_T \text{ sedimentation} = 28\ min + 2\ \left(\frac{3852\ gal}{Qp}\right)$$

$$T_T\ O/N = 60\ min + 2\ \left(\frac{5090\ gal}{Qp}\right)$$

6. Knowing the allowable process volumes, solve for the process flow rate, Qp using:

$$V_p = Qp \times T_T$$

   For sedimentation:

$$V_p = 4(3852\ gal) = Qp \times \left(28\ min + 2\ \frac{3852\ gal}{Qp}\right)$$

$$= 15{,}408 = Qp(28) + 7704$$
$$7704 = 28\ Qp$$
$$275 = Qp$$
$$Qp = 275\ gpm$$

NWMAR116405

For O/N:

$$Vp = 5\ (5090\ gal.) = Qp \times (60\ min + 2 \times \frac{5090\ gal.}{Qp})$$

$$= 25450 = Qp \times 60 + 10180$$

$$15270 = 60\ Qp$$

$$254 = Qp$$

$$Qp = 254\ gpm$$

Therefore the design processes flow rate is the lower of the two, or 254 gpm.

7. The resulting tank utilization would then be:

Number	Type
1	presettler
2	sludge tank
4	sedimentation tank
1	equilization tank
5	oxidation reduction tank
2	holding tanks

XIII. Compare the Two Systems.

Now evaluations of the limiting factors is necessary for both situations.

		Initial Design	Alternate Design
Time limits:		5 days	8 days
Site limits:	location close	yes	yes
	accessible	yes	yes
	clean area	no; need 115' x 140'	yes; 105' x 70'
	flat area	no	yes
	firm area	yes	yes
	setups	OK	OK
	residences	no	no
	vehicular traffic	no	no
Materials:	tanks	17-25' D yes	15-18' D; yes
	pumps	1-20 gpm (solids) 2-10 gpm chem feed	yes; same

NWMAR116406

	media	not needed	not needed
	chemicals	yes	yes
	spec. equipment	not needed	not needed
Process Restrictions:	settling rate	no problem	no problem
	desludging	no problem	no problem
	contact time	N/A	N/A
	sludge volume	same	same
Manpower Limits:	construction	no	no
	operation	no	no
Miscellaneous:	contaminant	no problem	no problem
	hauling capacity	OK	OK

The choice is then left to the OSC to establish if the time restriction is more critical than the space problem. Possibly more flat area could be cleared for use but the expense and possible time lost may negate the benefits. Each situation must then be evaluated on its own merits.

SECTION REFERENCE

5.4.5.4 Example: Ammonium Persulfate Spill -

Note: All calculations are in English units, the following conversions are appropriate:

lb x 0.454 = kg

ft x 0.305 = m

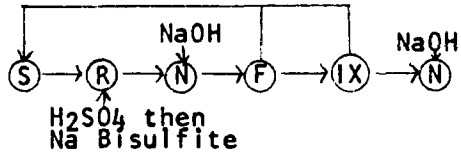
gal. x 3.785×10^{-3} = cum

$ft^2 \times 0.093 = m^2$

gpm x 3.784 = lpm

Scene: A truck carrying six 50 pound packages of ammonium persulfate has spilled into a swamp. The spill is contained but needs treatment within 3 days. The total spill volume is 500,000 gallons of silty swamp water which requires long periods of clarification. However, a limited number of swimming pools and area are available for use. Therefore the OSC must evaluate the situation and choose the best alternative.

1. Choose Appropriate Flow Scheme



Add H_2SO_4 to pH 3/add bisulfite to large ORP change or indicator change/neutralize to pH 7 with NaOH/filter/exchange/neutralize to pH 7 with NaOH

Table 22

NWMAR116407

SECTION REFERENCE

II. Do Bench Scale Tests — 6.5.2

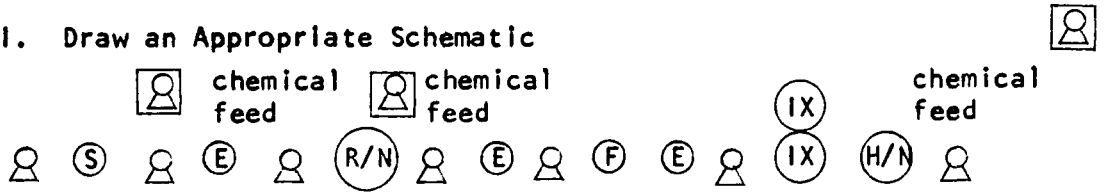
1. Settling tests: A polymer was added in dosages of 25 mg/l and the material was allowed to settle. The settling rate was 0.1 fpm. Flocculation required was 10 min. Sludge accumulation was 1.1 cm.

2. Reduction and neutralization test: 15 ml of 1N H_2SO_4 was added per liter of sample to reach pH of 2 with addition of 10 ml of 100 mg/l sodium bisulfite to the indicator change. (Needs 10 min for reaction.) An additional 10 ml of 1N NaOH returned to pH 7 — 6.6.7

3. Extra NaOH was ordered to allow readjustment of the pH after ion exchange.

4. Cation analyses were performed to establish need for ion exchange media. — Figure 41

III. Draw an Appropriate Schematic



The initial neutralization can be done after reduction is complete in the same tank and the final neutralization can be done in the holding tank.

IV. Calculate Desirable Flow Rate

Assumption: 3 days to clean 500,000 gal. spill

$$\text{flow rate} = \frac{500{,}000 \text{ gal.}}{3 \text{ day} \times 16 \text{ hr/day} \times 60 \text{ hr/min}} = 175 \text{ gpm}$$

Explanation: Use 16 hr/day operation to allow time for maintenance of the system.

V. Establish Number of Sedimentation Tanks Required — 6.5.4

1. Apply data from settling test to establish detention time:

NWMAR116408

$$\text{detention time} = \frac{\text{process height}}{\text{settling rate}} \times 3 \text{ (safety factor)}$$

Assumption: Hp = 3
settling rate = 0.1 fpm

$$\text{Detention time, } t_d = \frac{3 \text{ ft} \times 3}{0.1} = 90 \text{ min}$$

Flocculation time = 10 min

Total detention time = 90 min + 10 min = 100 min.

2. Calculate fill and draw time

Assumption: pumping rate into tank: 175 gpm

tank - 25' dia.
24' effective diameter
3' process height

$$\text{Tank volume } V_n = \frac{3.14 \times (24)^2 \text{ ft}^2 \times 3 \text{ ft} \times 7.48 \text{ gal.}}{4 \qquad \text{ft}^3}$$

$$= 10{,}146$$

$$\text{fill time - draw time} = \frac{V_n}{\text{pumping rate}}$$

$$= \frac{10{,}146 \text{ gal.}}{174 \text{ gpm}} = 58.3 \text{ min}$$

Total time $(T_T) = 2(58.3)$ min + 100 min = 216.6 min.

3. Establish Frequency of Desludging

$$\text{Time between desludging} = \frac{0.25 \times \text{Hp}}{\text{accumulation of sludge/batch}} \times T_T$$

Process height = 3 feet

$$\frac{\text{accumulation of sludge}}{\text{batch}} = \frac{1.1 \text{ cm}}{36.6 \text{ cm}} \times 3 \text{ ft} = 0.090 \text{ ft/batch}$$

$$\text{Time between desludging} = \frac{0.25 \times 3 \text{ ft} \times 216.6 \text{ min}}{0.09 \text{ ft}}$$

NWMAR116409

= 1,805 min

= 30.0 hours/between desludging

However, the desludging can be performed after the 16 hours operating period.

4. Calculate reduction in tank volume caused by sludge accumulation

amount of sludge accumulated between desludging =

$$\frac{\text{amt of sludge}}{\text{batch}} \times \frac{\text{batches}}{\text{before desludging}} =$$

$$\frac{0.09 \text{ ft}}{\text{batch}} \times \frac{16 \text{ hours/desludge} \times 60 \text{ min/hr}}{216.6 \text{ min/batch}}$$

$$= 0.398$$

approx. 0.4 ft

5. Calculate effective process volume

Hp - height of sludge accumulated = effective process height between desludging

3 ft - 0.4 ft = 2.6 ft

$$\text{Volume tank} = \frac{(3.14)\ (24)^2 \text{ ft}^2 \times 2.6/\text{ft} \times 7.48 \text{ gal.}}{4 \qquad \text{ft}^3}$$

= 8,793.6 gal.

6. Calculate process volume required

$$V_p = Q_p\ (T_T)$$

= 174 gpm (216.6 min)

= 37,689 gal.

NWMAR116410

SECTION REFERENCE

7. Calculate number of tanks needed

$$n = \frac{V_p}{V_e}$$

$$= \frac{37,689 \text{ gal.}}{8794 \text{ gal/tank}}$$

$$= 4.3 \text{ tanks}$$

$$n = 5 \text{ tanks}$$

VI. Calculate number of chemical reaction tanks 6.6.9

1. Apply data from bench tests to establish a detention time.

a.	Neutralization	10 minutes
b.	Reduction	15 minutes
c.	Safety factor	5 minutes
		30 minutes

2. Calculate fill and draw rates

Assumption: 174 gpm influent rate

Tank specs: 20' diam.
19' diam.
3' process height
6366 gal. process volume

$$\text{fill and draw time} = \frac{V_n}{\text{pump rate}} = \frac{6366 \text{ gal.}}{174 \text{ gpm}} = 36.6 \text{ min.}$$

$$T_T = (36.6)\ 2 \text{ min} + 30 = 103.2 \text{ min.}$$

3. Is desludging necessary? No

Explanation: The tank is mixed continuously and no sludge is formed. Solids entering the process have been removed in the sedimentation tank.

4. Calculate Required Process Volume

$$V_p = Q_p\ (T_T)$$

NWMAR116411

SECTION REFERENCE

$$V_p = 174 \text{ gpm } (103.2) \text{ min.}$$

$$= 17{,}957 \text{ gal.}$$

5. Calculate Number of Reaction Tanks Needed

$$N = \frac{V_p}{V_n}$$

$$= \frac{17{,}957 \text{ gal.}}{6366 \text{ gal./tank}}$$

$$= 2.8$$

$$= 3 \text{ tanks}$$

VII. Calculate Number of Filters Needed 6.2.2

Assumptions: 174 gpm flow rate
Loading rate = 4 gpm/ft^2
4' diameter filters

1. Calculate Surface Area of One Filter

$$\text{surface area} = \frac{\pi D^2}{4}$$

$$= \frac{3.14 \times (4)^2 \text{ft}^2}{4}$$

$$= 12.56 \text{ ft}^2$$

2. Calculate Surface Area Needed Based on Flow Rate

$$\text{surface area} = \frac{Q_p}{4 \text{ gpm/ft}^2}$$

$$= \frac{174 \text{ gpm}}{4 \text{ gpm/ft}^2}$$

$$= 43.5 \text{ ft}^2$$

3. Calculate Number of Filters Needed

$$\text{number of filters} = \frac{\text{surface area}}{\text{surface area/filter}}$$

NWMAR116412

SECTION REFERENCE

$$= \frac{43.5 \text{ ft}^2}{12.56 \text{ ft}^2/\text{filter}}$$

$$= 3.46 \text{ filters}$$

$$= 4 \text{ filters}$$

VIII. Calculate Number of Ion Exchange Columns Needed 6.4.2

Assumptions: 174 gpm flow rate
Loading rate - 2 gpm/ft^2
5' diameter columns

1. Calculate Surface Area of One Column

$$\frac{\text{surface area}}{\text{column}} = \frac{\pi D^2}{4}$$

$$= 19.6 \text{ ft}^2/\text{column}$$

2. Calculate Surface Area Needed Based on Flow Rate

$$\text{surface area needed} = \frac{Q_p}{2 \text{ gpm/ft}^2}$$

$$= \frac{174 \text{ gpm}}{2 \text{ gpm/ft}^2}$$

$$= 87 \text{ ft}^2$$

3. Calculate Number of Columns Needed

$$n = \frac{\text{surface area}}{\text{surface area/column}}$$

$$= \frac{87 \text{ ft}^2}{19.6 \text{ ft}^2/\text{column}}$$

$$= 4.4 \text{ columns}$$

$$= 5 \text{ columns}$$

NWMAR116413

SECTION
REFERENCE

IX. Design the Holding Tanks

Assumption: 1 hour's flow at 174 gpm (60 min)
24' pool
24' effective diameter
3' process height
10,146 gal. process volume

1. Calculate Fill and Draw Time

$$\text{fill time} = \text{draw time} = \frac{V_n}{\text{flow rate}}$$

$$= \frac{10146 \text{ gal.}}{174 \text{ gpm}}$$

$$= 58.3 \text{ min.}$$

$$T_T = 2(58.3) \text{ min} + 60 \text{ min} = 177 \text{ min}$$

2. Calculate Process Volume

$$V_p = Q_p(T_T)$$

$$= 174 \text{ gpm} \times 177 \text{ min}$$

$$= 30{,}798 \text{ gal.}$$

3. Calculate Number of Tanks

$$n = \frac{V_p}{V_n}$$

$$= \frac{30{,}798 \text{ gal.}}{10{,}146 \text{ gal./tank}}$$

$$= 3 \text{ tanks}$$

X. Design Sludge Holding Tank 6.5.4

Calculate sludge volume for one day of accumulation. The volume to be stored is calculated based on twice

NWMAR116414

the sludge depth due to ineffective draw off techniques

Volume of sludge for storage from 5 sedimentation tanks =

$$\frac{(24)\text{ft}^2 \times 0.8\text{ ft} \times 3.14 \times 7.48\text{ gal.} \times 5\text{ tanks}}{4 \qquad\qquad \text{ft}^3}$$

$$= 13{,}529\text{ gal.}$$

Assumption: 20' diameter tanks
19' effective diameter
3' process height

$$V_n = \frac{(19)^2\text{ft} \times 3.14 \times 3\text{ ft} \times 7.48\text{ gal.}}{4 \qquad\qquad \text{ft}^3}$$

$$= 6360\text{ gal./tank}$$

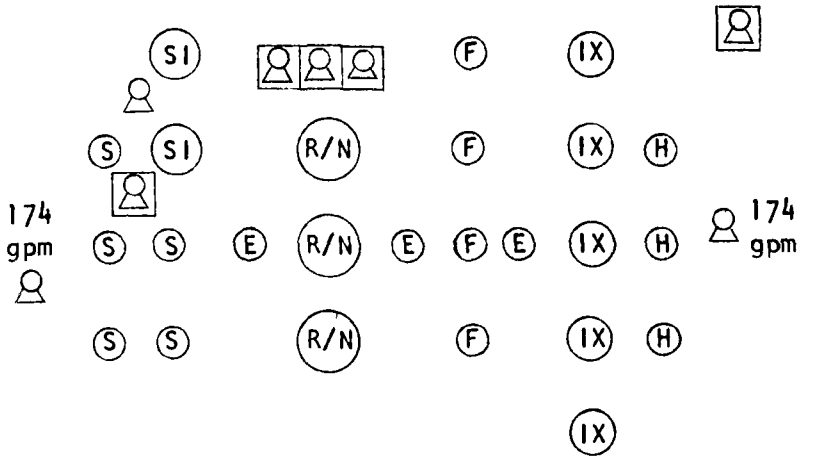
$$\text{number of tanks} = \frac{V_{sludge}}{V_n} = \frac{13529}{6360}$$

$$= 2.1\text{ tanks}$$

use = 2 tanks

Explanation: Store excess sludge in reaction tank after final batch.

XI. Revise the Schematic



NWMAR116415

SECTION REFERENCE

XII. Evaluate the System — Figure 43

1. Time Limit - The flow is based on time.

2. Site considerations:

   a. Safe proximity?
   Answer: Yes, it is safe to approach and treat.

   b. Accessible?
   Answer: Yes.

   c. Is area clear/flat/firm and available?
   Answer: The area available is not optimal to handle 8-25' dia. pools and 5-20' diameter pools, so a reduction in this area would be desirable.

   d. Proximity to residence?
   Answer: No.

   e. Number of setups required:
   Answer: 1

3. Material Availability

   a. Are enough tanks available?
   Answer: No.

No. Needed	No. Available	Type
8	2	25' diam.
5	3	20' diam.
0	3	18' diam.
3	3	10' diam.
5	5	5' diam.
4	4	4' daim.

   b. Are sufficient pumps available?
   Answer: Yes.

Number	Rates to pump	Available pumps
7	>174 gpm	8 - 250 gpm
1	solids handling	1 - 50 gpm
4	5 gpm chem. feed	4 - 6 gpm chem. feed

NWMAR116416

c. Is media available?

1) Ion exchange?
Answer: Yes.

2) Chemicals?
Answer: Yes.

3) Special equipment?
Answer: No.

4. Process restrictions?
Answer: None

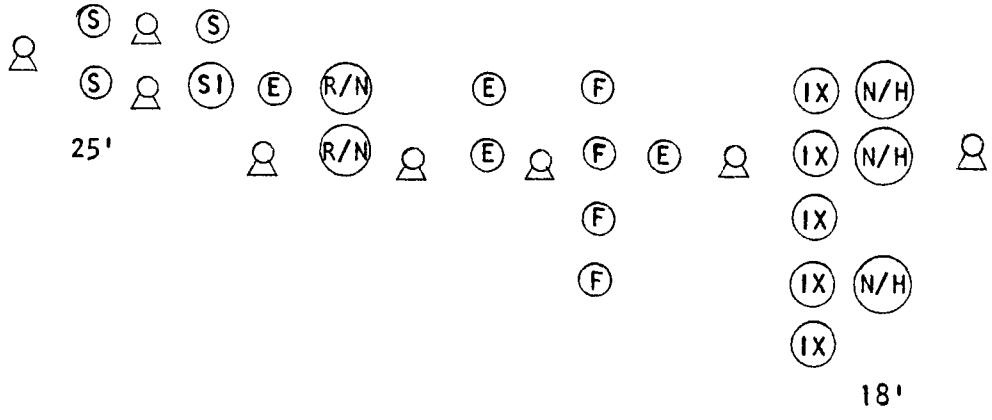
5. Manpower limits?

a. Construction - 10 people available
b. Operation - 25 people available
c. Direction - 3 people available

Therefore, manpower is not critical.

6. Miscellaneous?
Answer: No limits.

XIII. Draw Appropriate Schematic Utilizing Available Tanks and a Smaller Area



XIV. Calculate a New Flow Rate

The effective volume of the sedimentation tanks must be considered first. The sludge accumulates to 0.4 ft

$$V_{eff} = 8794 \text{ gal.}$$

NWMAR116417

Since the process flow rate is unknown, the total times are calculated as follows.

$$T_T \text{ sedimentation} = 100 + 2\left(\frac{8794}{Q_p}\right)$$

$$T_T \text{ R/N} = 30 + 2\left(\frac{6366}{Q_p}\right)$$

$$T_T \text{ N/G} = 10 + 2\left(\frac{5090}{Q_p}\right)$$

Next the process flow rate is solved for, using the known volume of tankage for sedimentation.

$$V_p = 3\ (8794) = Q_p\ (100 + 2\left(\frac{8794}{Q_p}\right)$$

$$26{,}382 = 100\ Q_p + 17{,}588$$

$$100\ Q_p = 8{,}794$$

$$Q_p = 87.9 \text{ gpm}$$

For R/N:

$$V_p = 3(6366) = Q_p\ (30 + 2\left(\frac{6366}{Q_p}\right))$$

$$19{,}098 = 30\ Q_p + 12{,}732$$

$$30\ Q_p = 6366$$

$$Q_p = 212 \text{ gpm}$$

For H/N:

$$V_p = 3\ (5090) = Q_p\ (10 + 2\ \frac{5090}{Q_p})$$

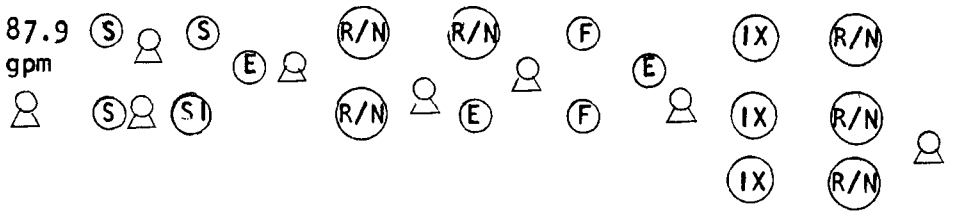
$$15{,}272 = 10\ Q_p + 10{,}180$$

$$10\ Q_p = 5092$$

$$Q_p = 509 \text{ gpm}$$

NWMAR116418

Note: The limiting 87.9 gpm flow rate is to be evaluated by the OSC. If it is acceptable, the following schematic results are as predicted.



NWMAR116419

6.0 CHAPTER 6 PROCESS CONSTRUCTION AND OPERATION

6.1 GENERAL

The following subsections detail the information needed for both the design and construction of the various components used in the treatment scheme. This chapter is broken down into 5 parts: filtration, carbon adsorption, ion exchange, gravity separation and chemical reaction. Each of these parts is further subdivided into a process description, bench testing procedures, design considerations, construction details, operation and maintenance and troubleshooting.

It is critical that the user of the Manual be familiar with the format and the content of this subsection. The process description is intended to provide background information to the user and some clarification for assumptions used in the design. Bench testing procedures are outlined for gravity separation and chemical reaction treatment schemes and should be performed on site or at a nearby laboratory on an actual sample of the wastewater to be treated. It will be necessary for the user to be familiar with the techniques and the chemicals presented, prior to actual field operation. The same need occurs with the design and construction section. The directions are indicated as steps with indented cautions, explanations and examples. It is intended that the steps alone can guide the user with reference to the other columns only when necessary. However, previous familiarity to these comments will aid the user in the field.

To use this part of the manual effectively, the user will refer to the portion just following the process description. For column operations, this is entitled: Design of Columns, and for chemical reaction or gravity separation: Bench Testing Procedures. The remainder of the instructions will then follow based on the results obtained.

6.2 FILTRATION

6.2.1 Process Description

Filtration is designed to remove particulate matter by passing contaminated water through a layer of porous media. The applications for this treatment vary from a pretreatment step to provide clarified water to a carbon column or ion exchange system to a polishing step for removal of fine particulates after a precipitation reaction.

Various types of media and modes of operation are used in filtration. However, a simplified mode is needed for field application and therefore a gravity flow dual media column filter has been chosen. The effectiveness of this type of filtration is a function of:

a. The concentration and characteristics of the solids in suspension.

b. The characteristics of the filter media and the mode of operation

NWMAR116420

(media sizes and depths, filtration rate, and terminal head loss).

The filter design presented in this section can provide adequate filtration under a wide variety of solids loading conditions.

Off stream dual media filtration is operated in a column as a gravity downflow process. During a filter run, the process head loss will gradually increase due to accumulation of solids within the filter media. When this head reaches the limit set by the hydraulic conditions of the design, the filter run must be stopped and the filter backwashed. A common fault with filters, especially single media filters, is surface blinding which can shorten the filter run. Dual media filters, utilizing coal above sand, act to give better depth filtration. Backwash involves passing clean process effluent through the filter in a reverse direction and at a rate several times greater than forward flow rate. For downflow gravity filters, the terminal head loss before backwash depends primarily on the available freeboard above the filter media, which is limited by the available tank height. In addition, the effluent quality requirement may control termination of filter runs because effluent quality decreases as the process head loss increases. It is desirable in filter design that acceptable effluent quality be produced within the entire head loss range. Acceptable effluent quality may be dictated by the necessity to efficiently remove contaminated solids from the water stream, or to provide a pretreatment for subsequent processes which would be fouled by solids, such as carbon adsorption or ion exchange.

Filters are usually backwashed with stored filter effluent and backwash wastes are usually retreated and refiltered. Therefore, the total volume treated per filter cycle equals the forward flow volume minus the backwash volume. Generally the higher the solids loading the shorter the filter run and thus the lower the net process flow rate. It is usually easier in the field to set up and operate gravity separation tanks than it is to construct and operate filters. Filter backwash is time consuming, varying from one-half to one hour per filter, and may be manually complicated in systems which must be constructed without the availability of valves or separate backwash pumping systems. In some cases, the filter pump will have to double as a backwash pump, and switch-over from forward to reverse flow will require that hoses be relocated. Personal safety dictates that the number of hose relocations be minimized. Another benefit of extended filter runs is the flexibility it affords in scheduling backwash during process shutdowns or other convenient times.

The filter is a rather difficult process to construct in the field. Thus the mode of dual media filtration outlined in the subsequent design section was scrutinized to simplify field construction and operation as far as is practicable.

NWMAR116421

6.2.2 Design of Dual Media Filters (43, 44)

1. Determine the required filter area from the process flow rate using Figure 44.

   Explanation: Required filter area is based on a design filtration rate of -

   $$163 \frac{l/min.}{m^2} \quad (4 \text{ gpm/ft}^2)$$

   Operational ranges may vary from 80-240 $\frac{l/min.}{m^2}$ (2-6 gpm/ft^2)

   Example: (from Figure 44) At 212 l/min, a filter area of 1.31 m^2 will be required.

2. Select a filter tank from Section 7.3 with the following limitations:

   a. A tank with vertical sides (Types A, F, G, H).

   b. An above-ground tank.

   c. A minimum height of 2.7 m (105 in.).

   d. A diameter in the range of 0.61-1.2 m (24-60 in.).

      Explanation: In tanks over 1.2 m (60 in.) in diameter, a single outlet will probably not be sufficient to permit uniform flow distribution necessary for adequate backwashing. Multiple outlets would be required for these filters or the construction of a header lateral system (not covered in these instructions).

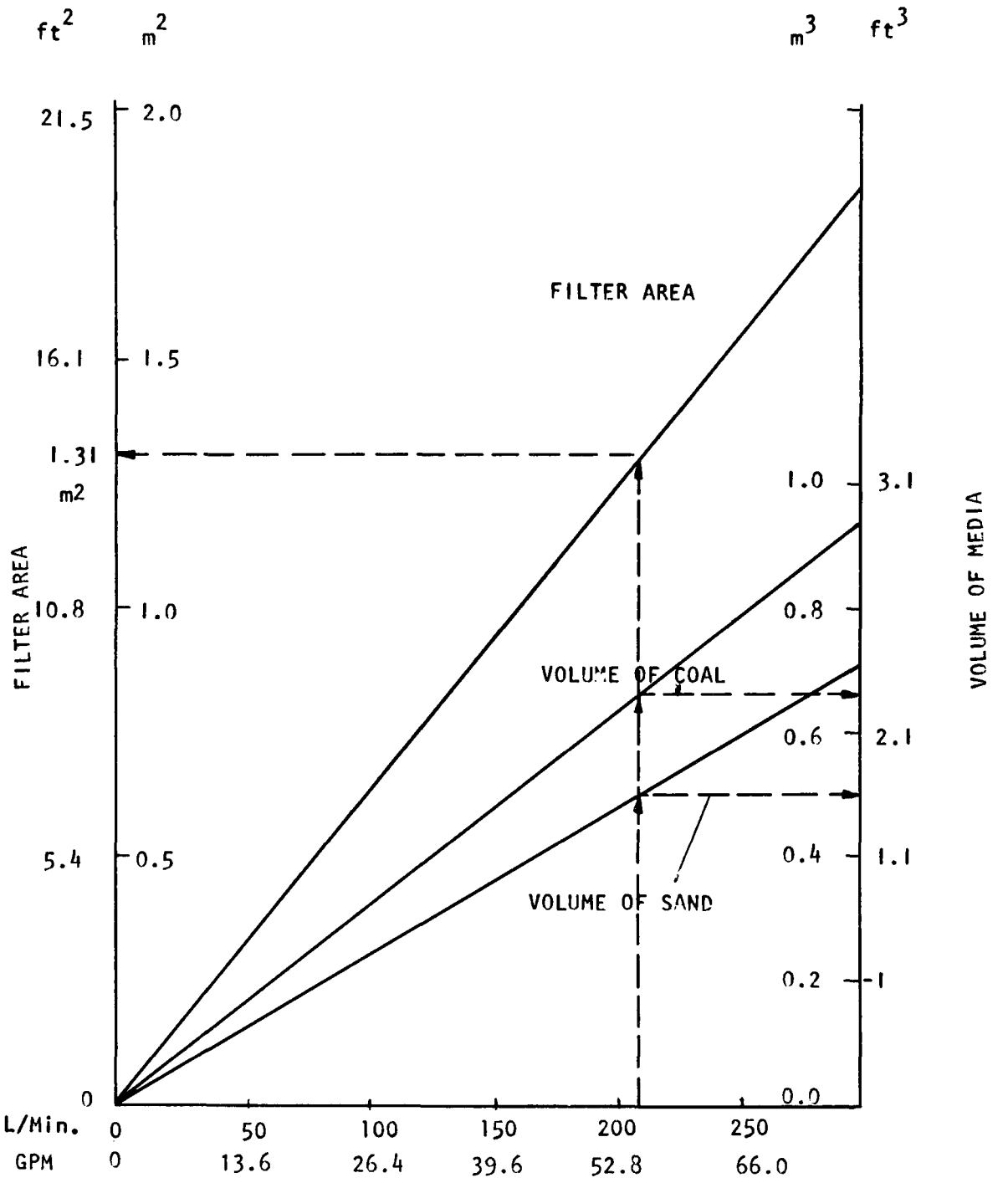
   e. A flat bottom which can be uniformly supported, e.g., laying flat on the ground.

   f. Tank wall construction into which a hole may be machined for an outlet.

3. Order filtration media using the following specification and media volumes from Figure 44. Suppliers are listed in Section 7.9

	Silica Sand	Anthracite Coal
Effective size (mm)	0.59-0.60	1.00-1.20
Uniformity Coefficient	1.35-1.70	1.25-1.80

NWMAR116422



ASSUMPTIONS

1. FILTER AREAS BASED ON HYDRAULIC LOADING OF 163 l/min/sq m (4 gpm/sq ft).
2. 20% EXCESS MEDIA SPECIFIED TO ALLOW FOR SAFETY FACTOR AND SKIMMING.

Figure 44. Filter area and media requirements.

NWMAR116423

Explanation: The effective size range of anthracite coal listed above is a minimum requirement. If a lower effective size is used, skimming of fines will be required per Section 6.2.4. The lower the uniformity coefficient, the better.

Example: (from Figure 44) For the flow rate of 212 $\frac{l/min.}{m^2}$, 0.5 m^3 of sand and 0.66 m^3 of coal will be required.

4. Order gravel for media underdrains from a local sand and gravel yard using amounts from Figure 45. Order equal amounts of pea gravel, and #1 and #2 gravels, and one-half that amount of torpedo sand.

Explanation: Pea gravel is about 0.31 cm (0.23 in.) in diameter; #1 gravel ranges in size from 1.25-1.9 cm (0.5-0.75 in.); #2 gravel ranges in size from 2.50-2.90 cm (1.0-1.5 in.).

Example: (From Figure 45) For the flow rate of 212 l/min., and an underdrain area of 1.31 order the following quantities:

Torpedo Sand - 0.75 m^3,

Pea Gravel, #1 and #2 gravels - 0.55 m^3.

6.2.3 Construction Options for Filters

Preferred option - gravity outlet (Figure 46)

Fully gravitational flow, with a free discharge leading to an equalization tank or a combination equalization and backwash storage tank.

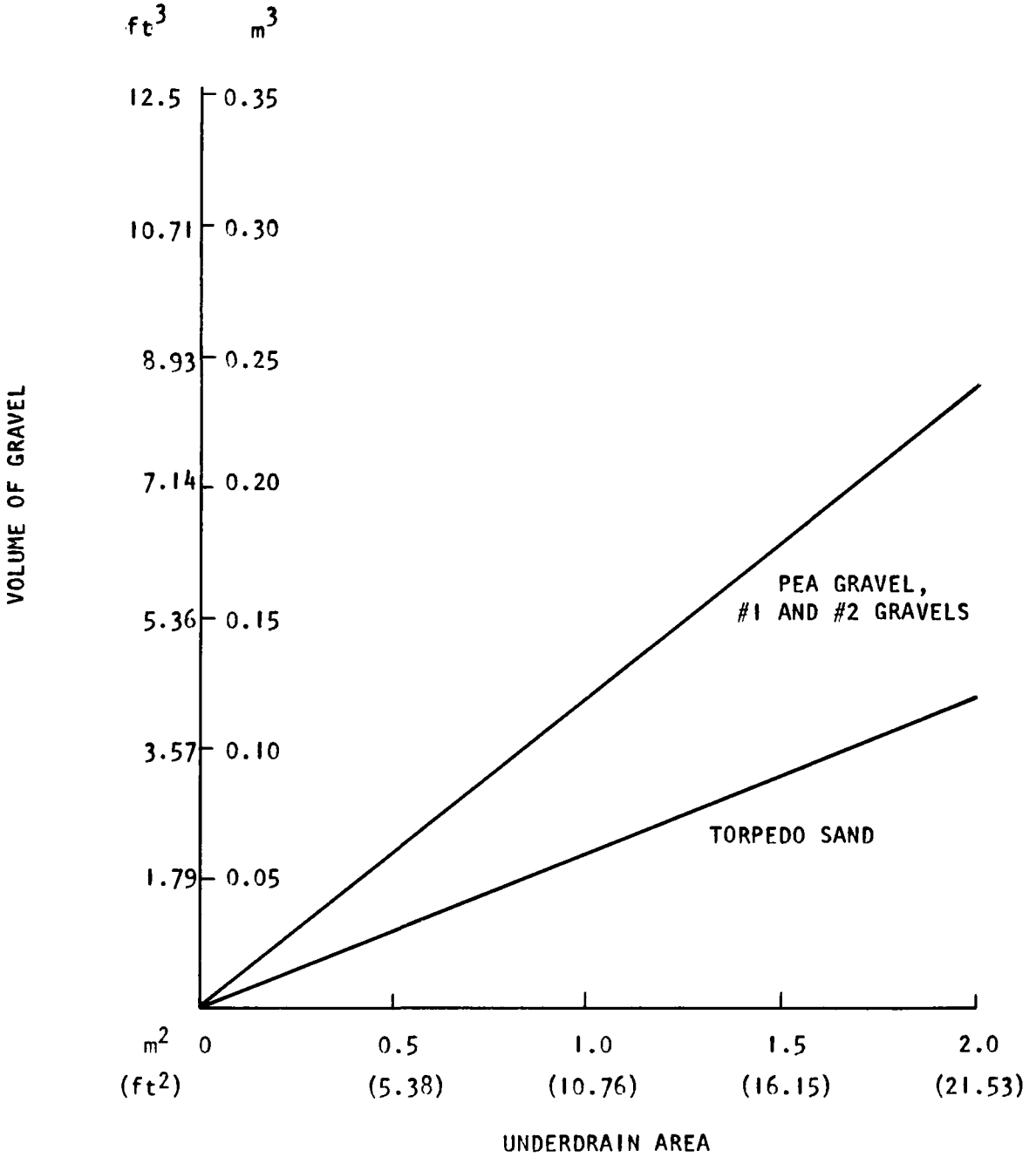
Explanation: Gravity discharge rather than suction from a pump is desirable to prevent air blinding of the bed.

Advantages: Easy to operate and monitor effluent quality. Outlet location permits bed to remain submerged after batch runs, a desirable feature. Can be hydraulically connected with hoses and a total of six hose fittings, eliminating the necessity of piping and valves.

CAUTION: In cases where hazard to personnel would exist from contact with fluid, piping and valves could be installed to eliminate the necessity to transfer hoses when shifting from the forward flow to backwash mode.

Two pumps may be used handling both forward flow and backwash, providing the

NWMAR116424



ASSUMPTIONS

1. 20% EXCESS SPECIFIED FOR SAFETY FACTOR.

Figure 45. Amounts of underdrain material required for column systems.

NWMAR116425

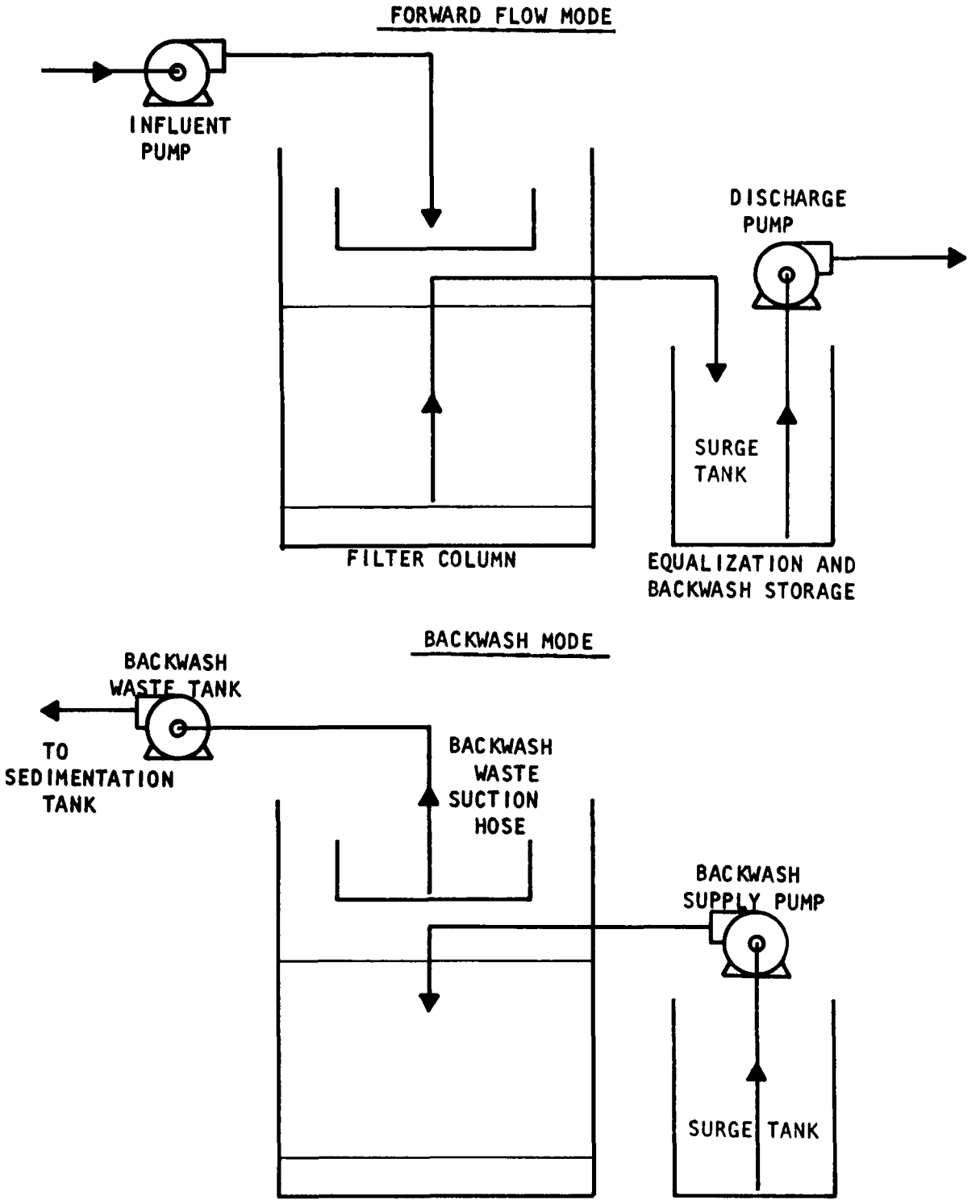


Figure 46. Preferred option and operating modes - filtration

NWMAR116426

pump capacities are determined from backwash requirements and that they can be throttled to accommodate forward flow and backwash flow conditions. This option is well-suited to a parallel-flow arrangement utilizing multiple filters and a single equalization tank.

Explanation: The benefit derives from the fact that backwash flow rate is four times forward flow rate. Thus, in a single filter system, both pumps operate in the forward mode at 25% capacity. On the other hand, if two filters are used, the same pumps could operate at 50% capacity in forward flow, with the stipulation that the filters be backwashed individually. With three and four filters the pumps would operate at 75% and 100% of capacity respectively in the forward flow mode.

Any type tank may be used for equalization, in-ground or above ground, provided that the wall height be lower than the filter discharge height.

6.2.4 Construction Steps for Filters

Preferred Option - gravity outlet (Figure 47)

1. Construct tank shell and bottom as instructed in Section 7.3.3.

2. Install brick supports for an expanded metal grating underdrain support. Note that all bricks are to be oriented radially with the center of the filter, except the bricks on the periphery which are oriented tangentially. For a one piece grating use about 12 bricks per square meter.

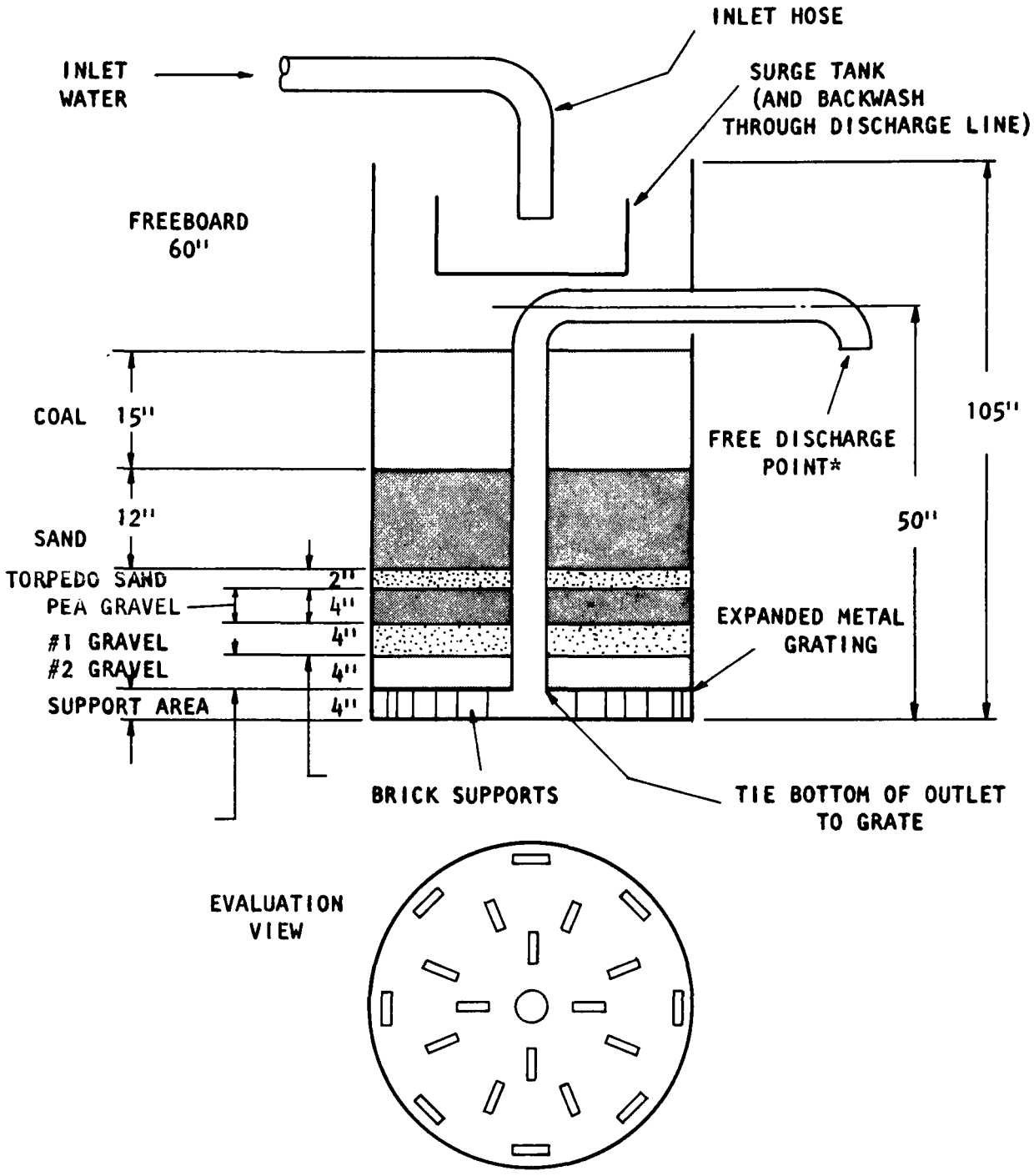
   Explanation: During backwash the distribution of water in the underdrain area is critical. Symmetrical, radial orientation of bricks assists in backwash flow distribution.

3. Install an expanded metal grating covering the complete filter area. The maximum opening in the grating should not pass a 2.5 cm (1 in.) sphere. Standard 3.0 lb, 4.0 lb, or 5.0 lb expanded metal grating will meet this requirement. Construct from one piece if possible. If installed in multiple pieces, be sure the free edges are supported sufficiently (almost continuous support of free edge). Fit grating so that no gaps over 2.5 cm (1 in.) in diameter exist anywhere.

4. Install the discharge line as shown, tied on one end to the grating and extending through the tank wall at 1.27 m (50 in.) above the base of the filter. Discharge line size is given in Table 25.

5. Install the three layers of gravel and 33 cm (13 in.) of filter sand. Backwash the filter (Section 6.2.5) at this point to remove fines; drain down the filter and skim off the top 2.5 cm (1 in.) of fines. A makeshift fines scoop is shown in Figure 48. Install the coal,

NWMAR116427



PLAN FOR PLACEMENT OF BRICKS

* DO NOT LET THE FREE DISCHARGE POINT EXTEND BELOW THE TOP OF THE BED

INCHES x 2.54 = cm

Figure 47. Construction details for filters.

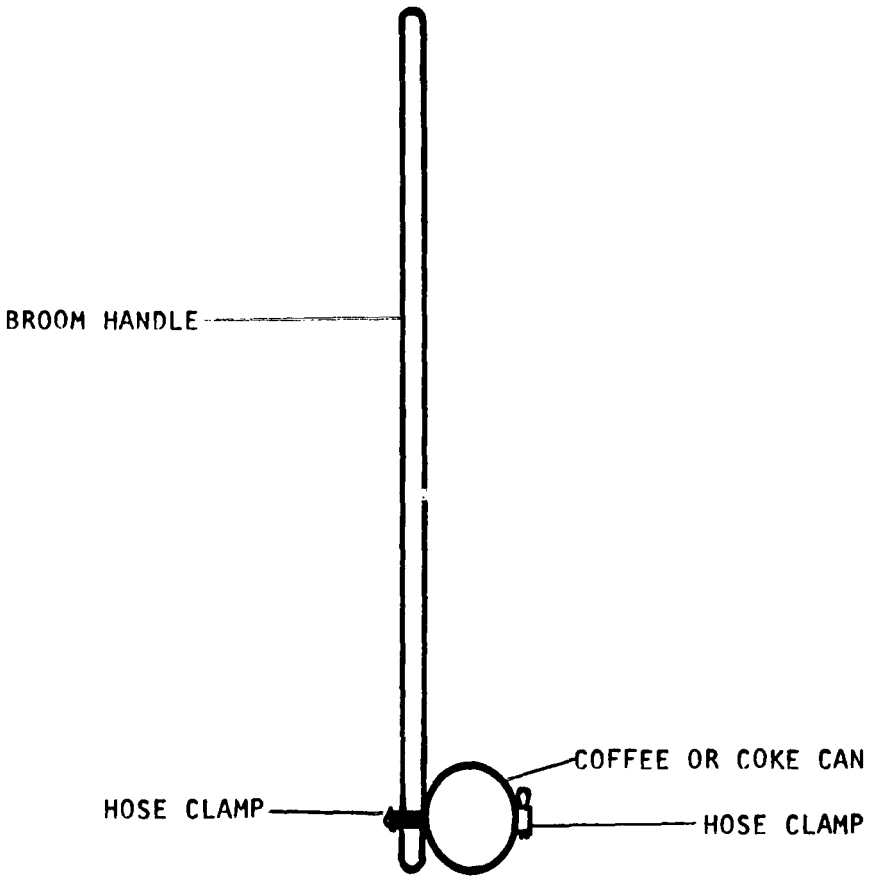
NWMAR116428

Table 25. COLUMN OPERATION
DISCHARGE LINE SIZING [1]

Maximum Flow		Line Size	
l/min.	GPM	cm	in.
11.36	3	2.54	1
37.85	10	3.81	1.5
83.27	22	5.08	2
189.25	50	7.62	3
340.65	90	10.16	4

[1] Based on maximum total length of discharge of 10 feet and head loss of 2 inches.

NWMAR116429



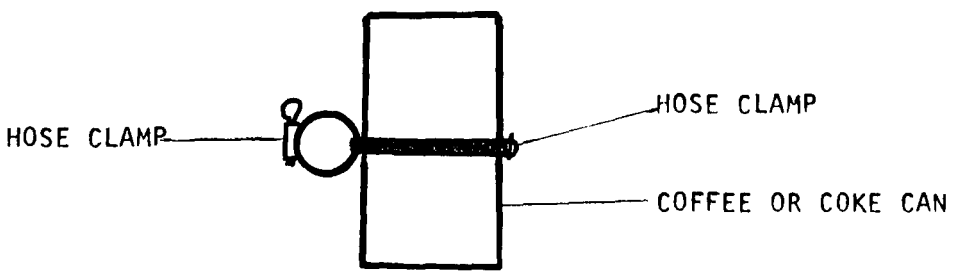


Figure 48. Fines scoop.

NWMAR116430

backwash again, and remove 2.5 cm (1 in.) of coal fines.

6. Construct a surge tank to dissipate the inlet velocity head and act as a backwash trough. A good size would be 1/4-1/3 the filter diameter and about 0.3 m (1 ft) in height. The surge tank may be supported by cables suspended from the top of the filter. Locate the bottom of the surge tank 0.6 m (24 in.) above the top of the filter bed as shown on Figure 47. If a surge tank cannot be constructed, place the inlet hose in a horizontal, tangential position to cause velocity dissipation through swirl. This technique will help minimize the boring out effect on the bed, which causes channeling of flow with resulting poor filtration.

7. Install an equalization tank, any type, with the restriction that the top of the vertical wall be lower than the filter discharge. If the equalization tank is to double as a backwash storage tank, the process volume should be at least 8.0 m^3 per m^2 of filter bed (200 gal./ft^2) to accommodate one backwash for a single filter. Calibrate the volume of this tank, by calculations, and put a scale on the inside wall showing 0.4 m^3 or 100 gal. increments. This calibration will permit proper flow during forward flow and backwash modes.

6.2.5 Operational and Maintenance Steps

Forward Flow-

1. Set up the system in the forward flow mode as shown in Figure 46.

2. If backwashing of fines was not performed, leaving the media in submerged condition, care must be taken during filling, e.g., reduced flow rate so that the media is not bored out by the flow.

3. Throttle the inlet flow as necessary to achieve the desired filtration rate (163 $\frac{l/min.}{sq\ m}$ (4 gpm/ft^2) is design rate). When flowing at design rate, the water level should stabilize. Mark this level on the tank wall as the clean bed head. If the water level is more than 0.3 m (1 ft) above the bed at design flow during the first filter run, there is probably some blinding from fines taking place and the fines removing procedure should be repeated. If, after backwash, the clear bed head does not come back close to the clean bed head, consult the troubleshooting section.

4. When the head rises to within 15 cm (6 in.) from the top of the tank, either the flow rate must be reduced or the filter must be backwashed.

NWMAR116431

Backwash Mode (44)-

1. Set up the system for the backwash mode as shown in Figure 49. Restrain the backwash waste suction hose so that it will not be possible for it to become attached to the bottom of the surge tank. This would starve the backwash waste pump and require that it be shut off momentarily to release the hose.

   Explanation: Backwashing of filters is intended to:

   a. Remove undesirable fines during filter preparation.
   b. Remove collected suspended materials.
   c. Stratify the bed.
   d. Remove air bubbles and pockets.

2. It is desired to backwash for a total of about ten to fifteen minutes at: 4.1 $\frac{m^3/min}{m^2 \text{ of filter}}$ (10 gpm/ft^2), or a volume of about 41-61.5 m^3/m^2 (100-150 gal./$ft.^2$). The required volume and flow rate are given in Figure 49. Flow setting may be easier by noting the drop in level of the equalization tank.

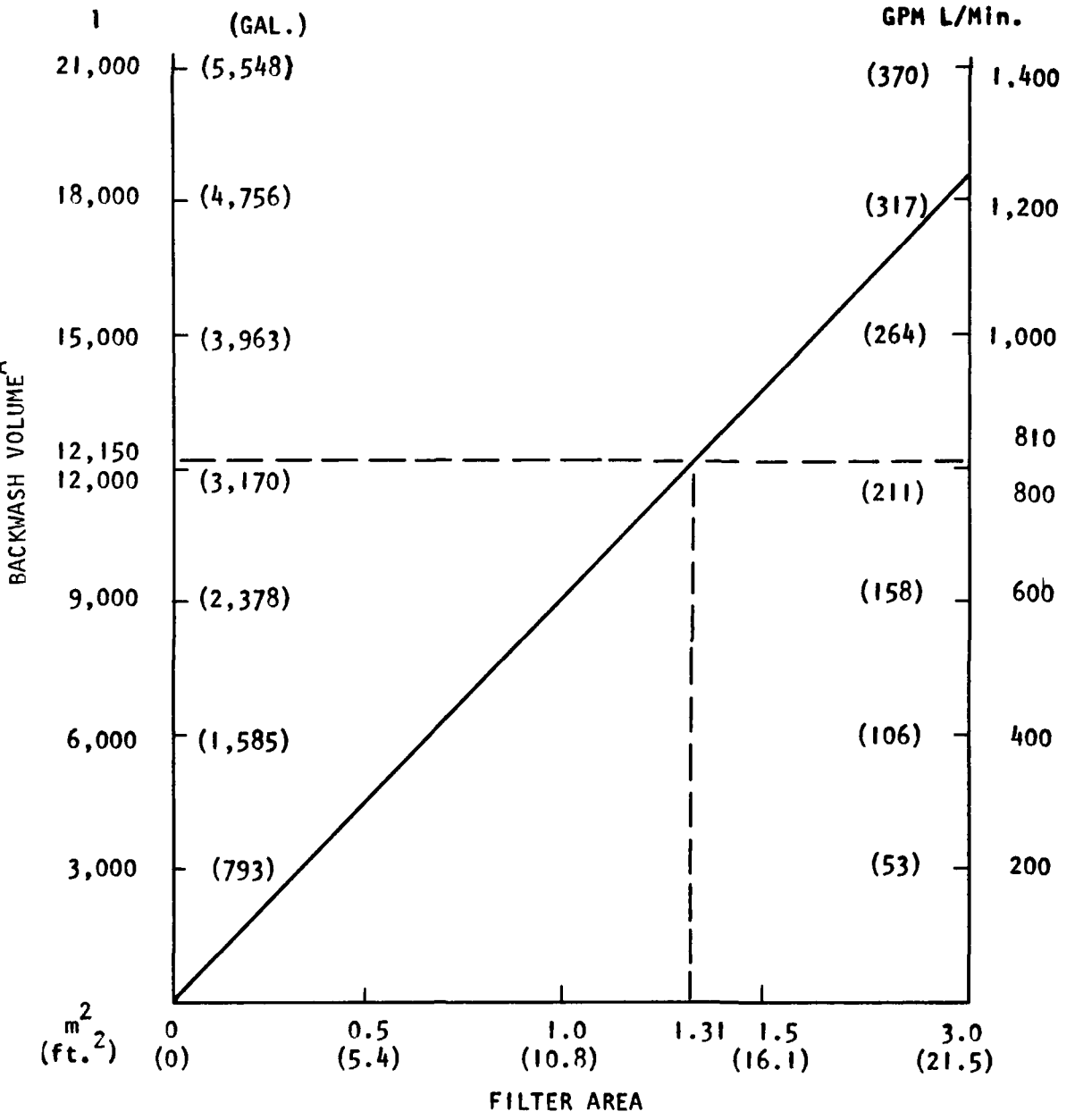
   Explanation: Efficient backwash requires that a certain flow rate, termed the minimum fluidization velocity, be passed upward through the bed causing all of the media particles to separate.

   Note whether the total bed is in agitation (desirable). Channeling is caused by poor backwash water distribution. Extended backwash period may help to effect better removal in this situation.

   CAUTION: Do not allow an excessive flow rate to cause the media to be washed into the effluent trough. If you are in doubt as to whether this is happening or not, take a sample near the effluent trough with a glass jar and visually inspect for media carry-over.

3. After the backwash is completed the water above the bed should appear to be clear and not murky. After the pump is turned off, a short duration must be allowed for the water to syphon backward through the backwash pump thus permitting the hose connection at the filter discharge to be separated without having a back pressure behind it.

NWMAR116432



[A] VOLUME BASED ON 15 MIN. BACKWASH

[B] FLOW RATE BASED ON 611 $\frac{l/min.}{m^2}$

Figure 49. Backwash volumes for column processes.

NWMAR116433

6.2.6 Filter Troubleshooting

1. Mudballing - In cases where a silty water is being filtered or oils or greases are present, mud balls may form and gradually pass downward through the bed during backwash. They tend to accumulate at the media support and act to restrict flow. Mudballing may be alleviated by air lancing. An air compressor of 0.28cu m/min. (10 cfm) capacity is connected to a straight 1.2 cm (0.5") tube. A valve is necessary to meter the flow of air through the tube. The tube should be inserted into the bed no further than the torpedo sand layer 68.5 cm (27"). The bed must be covered with water during air lancing but the backwash pump must be left off. The tube is moved around to cover the entire bed area. The air discharge should cause significant local turbulence. After the air lancing procedure is completed, the bed must be backwashed before being put back in operation.

2. Excessive Clean Bed Head - If backwashing and/or air lancing does not permit return to the clean bed head, 2-5 cm (1-2 in.) of coal may be removed and replaced. This procedure will be especially effective if surface blinding is occurring.

3. Poor Effluent Quality - Suggests:

    a. Too high a flow rate.

    b. Poor filterability of the process flow.

    c. Channeling of the bed (uneven distribution of flow)

    d. Excessive intermixing of the media.

6.3 CARBON ADSORPTION

6.3.1 Process Description

Activated carbon adsorption is a physical phenomenon which removes organic and some inorganic chemicals from water. These chemicals are physically adsorbed on the large surface area of the carbon (typically 500-1000 m^2/gr). The activated carbon can be produced from various cellulosic materials including wood, coal, peat, lignin, etc. These are prepared using dehydration and carbonization, followed by activation to enlarge the pore openings, which increases the surface area and therefore increases the adsorptive capacity.

The adsorption process is dependent on the nature of the material being adsorbed, the solution and the carbon used for adsorption. Critical factors include molecular size and polarity, type of carbon, pH of the solution, carbon contact time and solubility of the contaminant. The adsorption rate increases with increasing temperature and decreasing concentrations. In general, concentrations greater than 1000 mg/l of soluble contaminant require excessive detention times and produce large amounts of spent carbon.

NWMAR116434

The amount of carbon needed to adsorb a certain chemical must be established by actual testing. Various tests can be used, but these should be done on the contaminant in its natural environment since constituents of the medium may also exert a carbon "demand". One test which can be run is a carbon isotherm. This test indicates the amount of contaminant adsorbed per weight of carbon at equilibrium conditions. However, since equilibrium conditions are not met in the actual application, scale-up factors are required. Other shorter tests compare adsorption of molecules on different types of carbon. The Molasses number indicates a carbon's affinity for large molecules and a Iodine number the affinity for small molecules (45). More information on these tests is available in other sources (46).

Once the capacity of the carbon has been reached, the carbon must be replaced and the spent carbon disposed of or regenerated for reuse. Regeneration can be done using various physical and chemical techniques. However, thermal regeneration is the most common method. This process requires high temperatures and a controlled atmosphere and is therefore unsuited for field implementation unless a preconstructed mobile system is available. Instead, carbon should be removed and hauled to an established site for regeneration or incineration.

Offstream treatment is typically done using either powdered or granular carbon. Usually offstream treatment is performed in column tanks which provide efficient use of the carbon in the system. Carbon columns are similar to filters in many ways:

1. Efficiency of the bed is dependent on good flow distribution which will provide uniform contact time for the entire fluid stream.

2. An underdrain system is necessary to prevent the carbon from exiting with the effluent water and to distribute backwash water.

3. Initial backwash is required to remove fines and air pockets, as well as to stratify the bed.

In other ways, carbon columns are distinct from filter operations:

1. Termination of the cycle is established by "breakthrough" which indicates that the adsorptive capacity of the bed has been reached. Once spent, the carbon must be transported out of the bed and replaced with fresh media.

2. For efficient adsorption, the carbon must be "wetted" prior to use. This process may require up to 24 hours at room temperature with the carbon submerged in clean water (or less time at higher temperatures). Therefore, a source of clean water must be available on site for use in wetting the carbon prior to startup of the system.

3. Use of the carbon column as a filter causes inefficient use of the adsorption capabilities. Therefore, clarification processes including dual media filtration are necessary pretreatment steps prior to carbon adsorption.

NWMAR116435

4. Carbon columns possess more versatility than filters and can be operated in either downflow or upflow modes. Suspended solids are not removed during upflow operation due to bed expansion and extra contact time is generally necessary for this operation because of the expanded bed condition.

When a carbon adsorption process is constructed in the field, the first, priority is the ordering of carbon which may require a 24 to 48 hour lead time and an additional 24 hours to wet prior to use. The amount of carbon required is determined by the treatment specifications in Table 22. A range of weight of carbon per weight of soluble contaminant is given to aid in ordering the carbon. The following calculation should be done to determine the amount of carbon needed.

Example A.

1. Spill of Parathion: 10^5 gal. of water
   The solubility of Parathion is 24 mg/l
   Pounds of soluble Parathion = $\frac{24 \times 8.34 \times 10^5}{10^6}$ = 20.0 lbs
   (lbs x .454 = kg)
   (gal. x 3.785 = l)
   Then, the range of carbon needed to remove parathion is 100-300 #/# of soluble material. Therefore, the maximum number of pounds of carbon is 20.0 lbs. of parathion x 300 = 6,000 lbs. of carbon. This amount should be ordered.

Once the carbon is placed in the column, then the actual carbon requirement of the system must be tested. Since it is recommended that the carbon columns be run in series with an equalization tank between, samples can be taken periodically from the effluent lines of the columns, composited, and sent the laboratory for analysis. These analyses will indicate when the first carbon column has broken through and future carbon changes can be based on that time period or additional sampling. The second column will allow the operation to safely continue in the interim until the samples can be analyzed.

When using powdered carbon during offstream operation, carbon can be injected into a tank, mixed via hydraulic, air or mechanical means and then collected prior to discharge of the wastewater. However, the carbon is not used as efficiently with this method, but the same weight of carbon should be initially ordered. As the carbon is spent, the data can be extrapolated and the additional amount ordered.

6.3.2 Design of Activated Carbon Columns (46, 47)

1. Order the activated carbon using the formula presented in the process description to determine the total amount of activated carbon required to treat the spill.

   CAUTION: Due to the long times required to get the activated carbon on site, it is essential that it be ordered

NWMAR116436

immediately! If the total amount can not be obtained at once, have the available weight shipped immediately.

2. Wet the activated carbon.

   Explanation: The activated carbon should be deposited in holding tanks and sufficient water should be added to cover the carbon with 6" or more of water.

   CAUTION : This step is essential for good removal rates during operation of the activated carbon column.

3. Determine the required activated carbon bed surface area from the process flow rate using Figure 50.

   Explanation: Required carbon bed surface area is based on a design bed flow rate of

   $$81.4 \frac{l/min}{m^2} = 2.0 \text{ gpm/ft}^2$$

   Operational ranges may vary from

   $$40.7\text{-}81.4 \frac{l/min}{m^2} \quad (1\text{-}2 \text{ gpm/ft}^2)$$

   Example: (From Figure 50) At 212 l/min, a bed area of 2.60 m^2 will be required.

4. Select a carbon column tank from Section 7.3 with the following:

   a. A tank with vertical sides (Types A, F, G).

   b. An above-ground tank.

   c. A minimum height of 2.7 m (105 in).

   d. A diameter in the range of .6-1.2 m (24-60 in).

      Explanation: Over 1.2 m (60 in.) in diameter, a single outlet will probably not be sufficient to permit uniform flow distribution necessary for adequate backwashing. Multiple outlets would be required for these larger sizes or the construction of a header lateral system (not covered in these instructions).

   e. A flat bottom which can be uniformly supported, e.g., laying flat on the ground.

   f. Tank wall construction which a hole may be machined for an outlet.

NWMAR116437

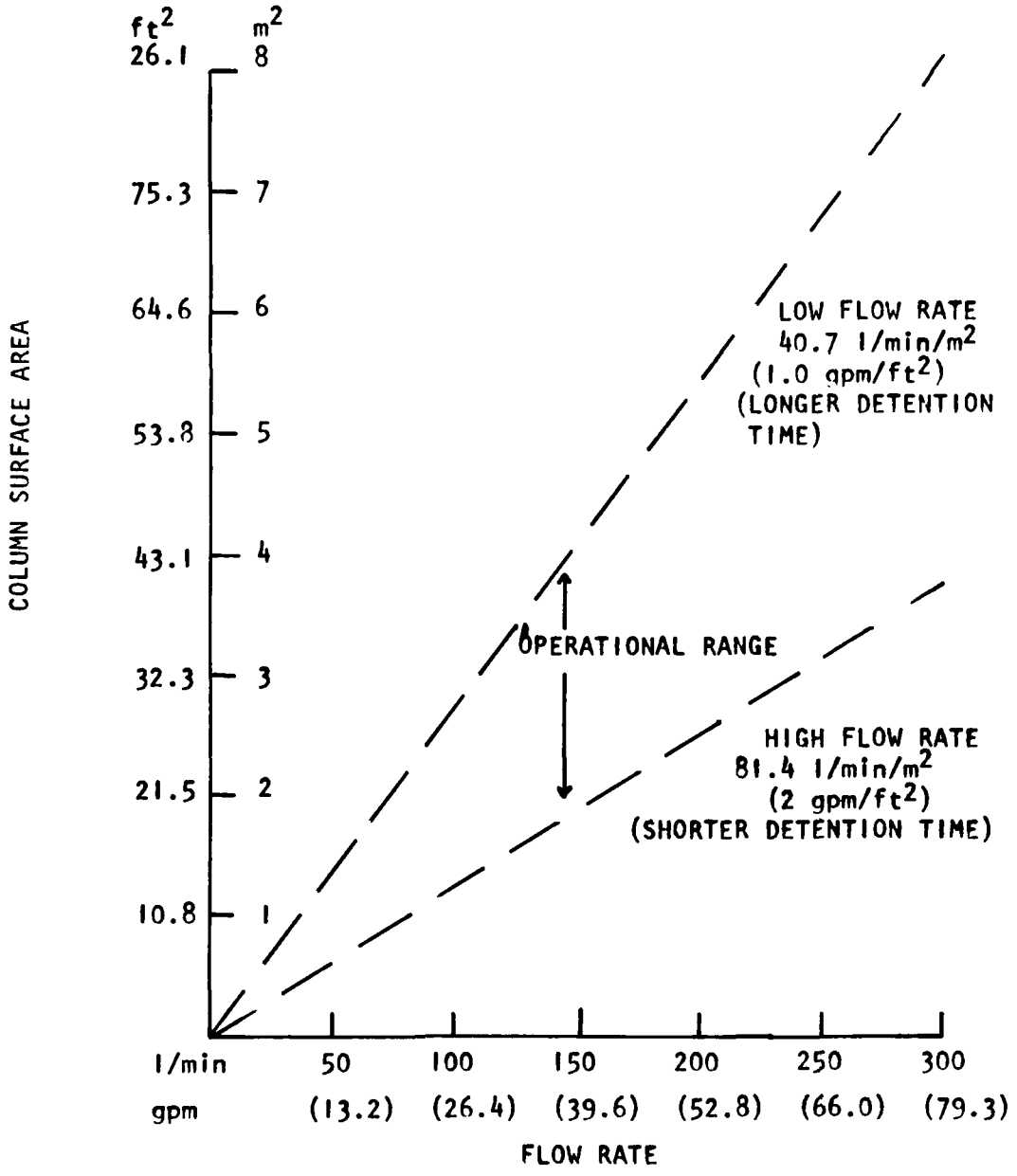


Figure 50. Required surface area for carbon columns.

NWMAR116438

5. Order gravel for media underdrains from a local sand and gravel yard using amounts from Figure 45. Order equal amounts of pea gravel, and #1 and #2 gravels, and one-half that amount of torpedo sand.

Explanation: Pea gravel is about .31 cm (0.23 in.) in diameter; #1 gravel ranges in size from 1.25-1 cm (0.5-0.75 in.); #2 gravel ranges in size from 2.50-2.90 cm (1.0-1.5 in.).

Example: (From Figure 45). For the flow rate of 212 l/min, order the following quantities;

Torpedo Sand - 0.065 m^3

Pea Gravel, #1 and #2 gravels - 0.132 m^3,

6.3.3 Construction Options for Activated Carbon Columns - Preferred option Gravity Outlet (Figure 51) Full gravitational flow, with a free discharge leading to an equalization and backwash storage tank.

Explanation: Gravity flow rather than suction from a pump is desirable to prevent air blinding of the bed.

Advantages: Easy to operate and monitor effluent quality. Outlet location permits bed to remain submerged after batch runs, a desirable feature. Can be hydraulically connected with hoses and a total of six hose fittings; eliminating the necessity of piping and valves.

CAUTION: In cases where hazard to personnel would exist from contact with fluid, this option has a drawback in the necessity to manually transfer hoses when shifting the forward flow to backwash mode.

Two pumps may be used for handling both forward flow and backwash, providing the pump capacities are determined from backwash requirements and that they can be throttled to accommodate forward flow and backwash flow conditions. This option is well-suited to a parallel flow arrangement utilizing multiple activated carbon columns and a single equalization tank.

Explanation: The benefit derives from the fact that backwash flow rate is four times forward flow rate. Thus, in a single activated carbon column system both pumps operate in the forward mode at 25% capacity. On the other hand, if say two activated carbon columns are used, the pump could operate at 50% capacity in forward flow, with the stipulation that the activated carbon columns be backwashed individually.

Any type tank may be used for equalization, in-ground or out, provided that the wall height be lower than the activated carbon column outlet fitting height.

NWMAR116439

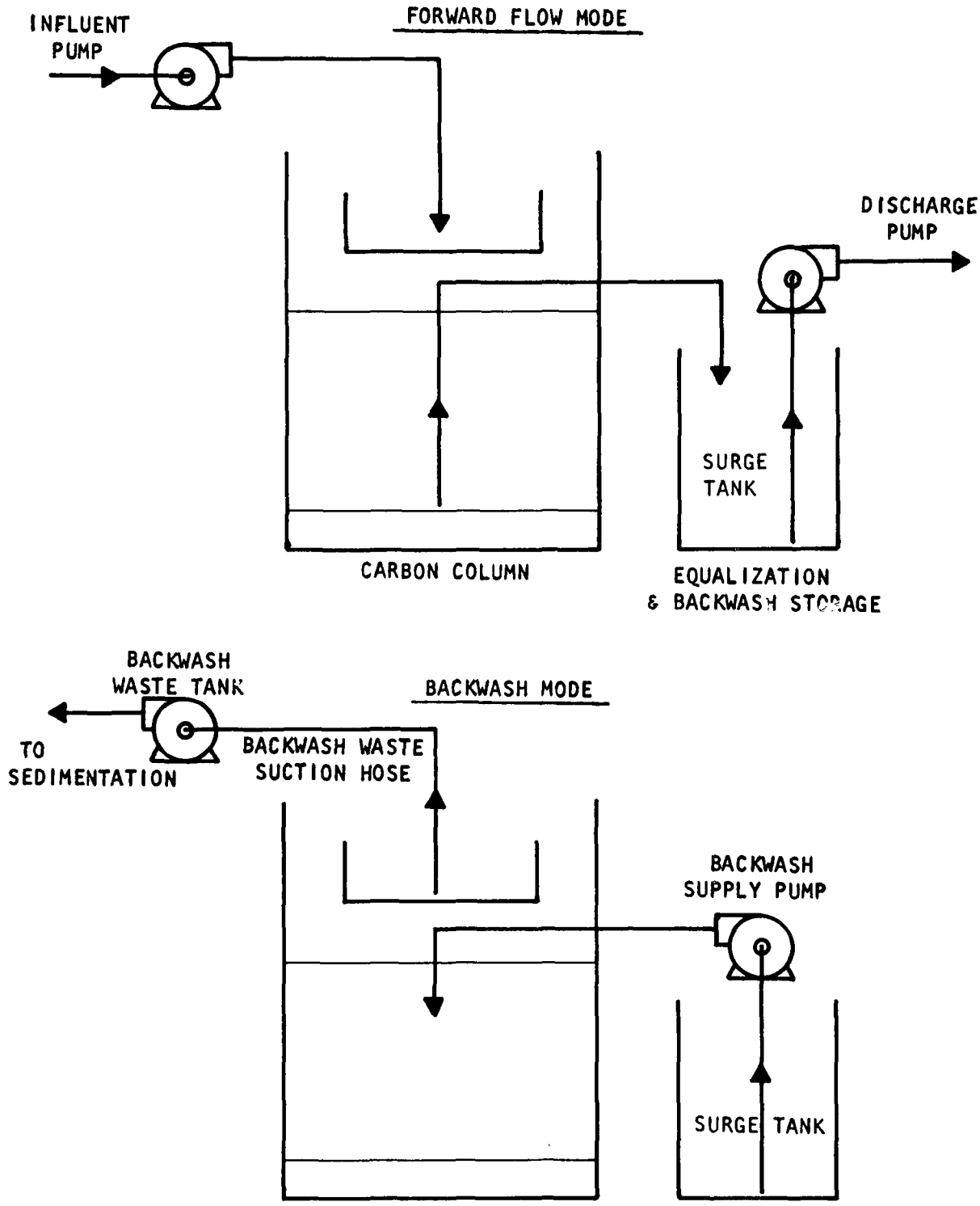


Figure 51. Preferred option and operating modes - carbon adsorption

NWMAR116440

6.3.4 Construction Steps for Activated Carbon Columns

Preferred Option - Gravity Outlet (Figure 52).

1. Construct tank shell and bottom as instructed in Section 7.3.3.

2. Install brick supports for an expanded metal grating underdrain support. Note that all bricks are to be oriented radically with the center of the column, except the bricks on the periphery. For a one piece grating use about 12 bricks per square meter.

3. Install an expanded metal grating covering the complete column area. The maximum opening in the grating shall not pass a 2.5 cm (1 in) sphere. Standard 3.0 lb., 4.0 lb., or 5.0 lb., expanded metal grating will meet this requirement. Construct from one piece, if possible. If installed in multiple pieces, be sure the free edges are supported sufficiently (almost continuous support). Fit grating so that no holes over 2.5 cm (1 in.) in diameter are created.

4. Install the discharge line as shown, tied on one end to the grating and extending through the tank wall at 1.27 m (50 in.) above the base of the column. Discharge line size is given in Table 25.

5. Install the gravel and sand underdrain layers.

6. Install 1.2 m (48") of activated carbon which has been wetted for 48 hrs (see Preferred Option Figure 51). Backwash the filter to remove fines (see Section 2.5 for proper backwash method for removal of fines). A makeshift fines scoop is shown in Figure 48.

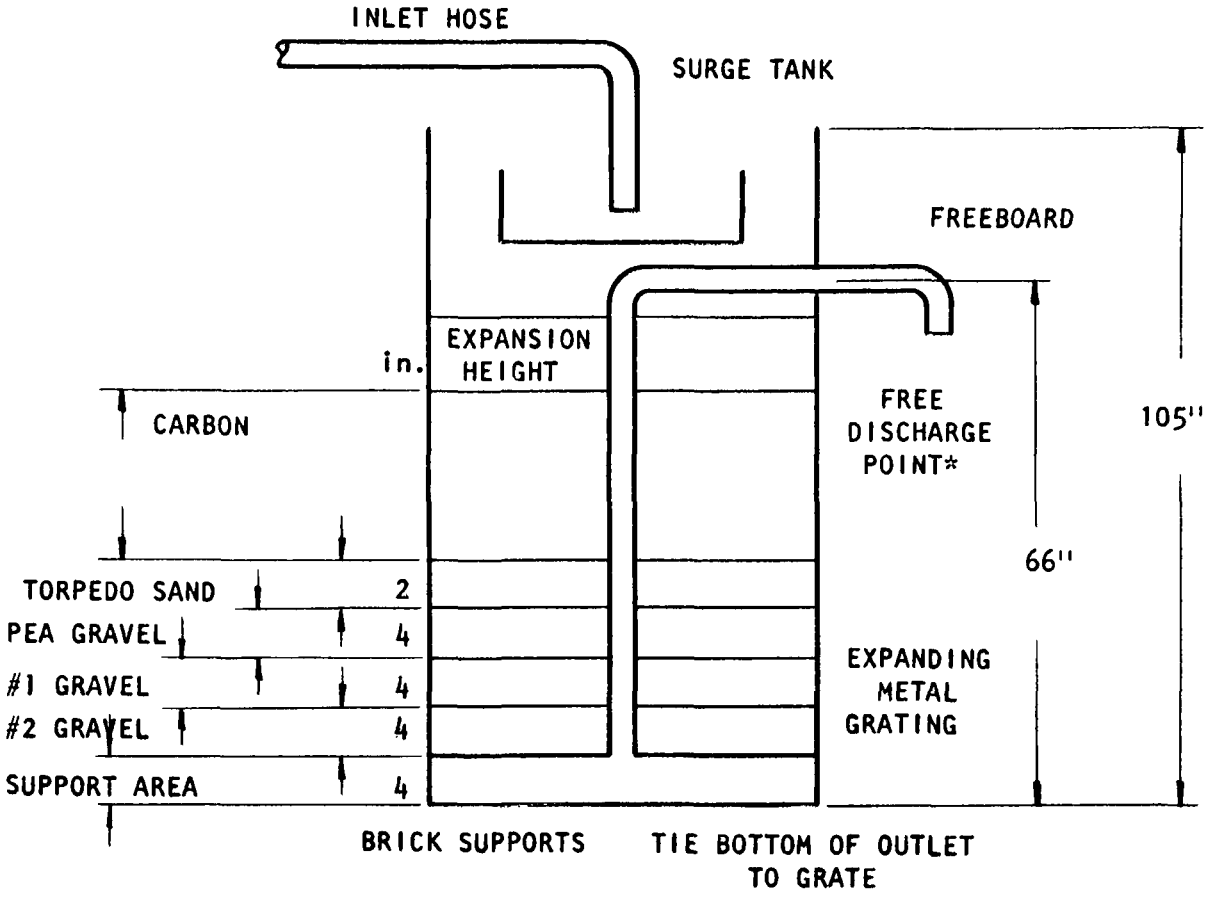
   Explanation: The carbon column should have 1.2 m (4 ft.) of standing water before introduction of the carbon. As this water is displaced by carbon it should be collected in the equalization basin. A mark 1.2 m (48") above the torpedo sand will insure the proper bed depth is obtained.

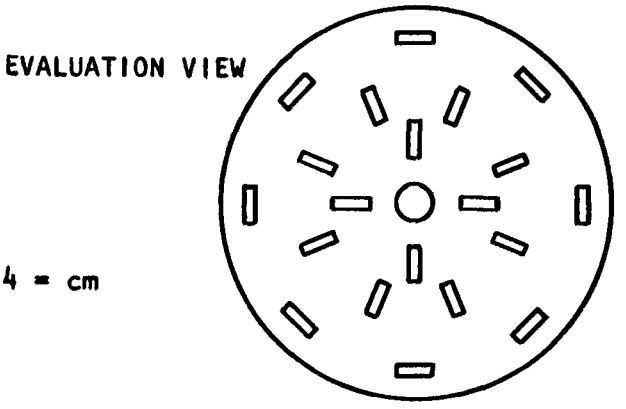
   CAUTION: All lines in which activated carbon is to be pumped must be at least 5cm (2 in.) in diameter. The lines must be kept as short as possible, i.e., the suction line is not to exceed 6m (20 ft.) and the discharge line will be no longer than necessary.

   Wetted activated carbon can also be installed by hand using buckets and shovels, etc.

7. Construct a surge tank to dissipate the inlet velocity head and act as a backwash trough. A good size would be 1/4 - 1/3 the column diameter. The surge tank may be supported by three cables suspended from the top of the column. Locate the bottom of the

NWMAR116441





inches x 2.54 = cm

PLAN VIEW FOR BRICK PLACEMENT

* DO NOT LET FREE DISCHARGE POINT EXTEND BELOW THE TOP OF THE BED.

Figure 52. Carbon column construction details.

NWMAR116442

surge tank .6 m (24 in.) above the top of the column bed as shown on Figure 52. If a surge tank cannot be constructed, place the inlet hose in a horizontal, tangential position to cause velocity dissipation through swirl. This technique will help minimize the boring out effect on the bed, which causes channeling of flow.

8. Install an equalization tank, any type, with the restriction that the top of the vertical wall be lower than the column discharge. The process volume should be at least 8.0 m^3 per m^2 of column (200 gal./ft^2) to accommodate one backwash for a single column. Calibrate the volume of this tank, by calculations, and put a scale on the inside wall showing 0.5 m^3 or 100 gal. increments.

   Explanation: This calibration will assist in flow setting.

6.3.5 Operational and Maintenance Steps for Activated Carbon Column Forward Flow

1. Set up the system in the forward flow mode as shown in Figure 51.

2. If backwashing of fines was not performed during or after column construction, care must be taken during filling, e.g., reduce flow rate so that the media is not bored out by the flow.

3. Throttle the inlet flow as necessary to achieve the desired flow rate.

   $$81.4 \frac{l/min.}{m^2} \quad (2\ gpm/ft^2)$$

   When flowing at design rate, the water level should stabilize. Mark this level on the tank wall as the clean bed head. If the water level is more than .3 m (1 ft.) above the bed at design flow during the first column run, there is probably some blinding from fines taking place and the fines removing procedure should be repeated. If, after backwash, the clear bed head does not come back close to the original level, consult the troubleshooting section.

4. Sample frequently at the effluent from each column or in the equalization tank. Have analysis done to establish effective loading possible for that carbon. When carbon has broken through, replace it immediately.

5. Activated carbon columns should never become fouled. If they do, the processes prior to the activated carbon column should be inspected and steps should be implemented to improve the product water of the processes. If the head rises to within 15 cm (6 in.) from the top of the tank, the column must be backwashed. However, backwashing is undesirable, because stratification of the carbon bed will occur, and should not be done unless absolutely necessary.

NWMAR116443

Backwash Mode

1. Set up the system for the backwash mode as shown in Figure 51. Restrain the backwash waste suction hose so that it will not be possible for it to become attached to the bottom of the surge tank. This would starve the pump and require that it be shut off momentarily to release the hose.

   Explanation: Backwashing the carbon column is intended to:

   a. Remove undesirable fines during filter preparation;

   b. Remove air bubbles and pockets during filter preparation;

   c. Remove collected suspended material.

2. Backwashing during carbon column preparation or for removal of fines and air bubbles and pockets: It is desirable to backwash for a total of 15 minutes at

   $$30 \frac{\text{l/min.}}{\text{m}^2 \text{ of Filter}} \quad (0.74 \text{ gpm/ft.}^2)$$

   The accepted operational range for carbon column preparation backwashing is

   $$20.4 \text{ to } 40.7 \frac{\text{l/min.}}{\text{m}^2 \text{ of Filter}} \quad (0.5\text{-}1.0 \text{ gpm/ft.}^2)$$

   The required volumes and flow rates or carbon column preparation are given in Figure 53. Flow setting may be easier by noting the drop in level of the equalization tank.

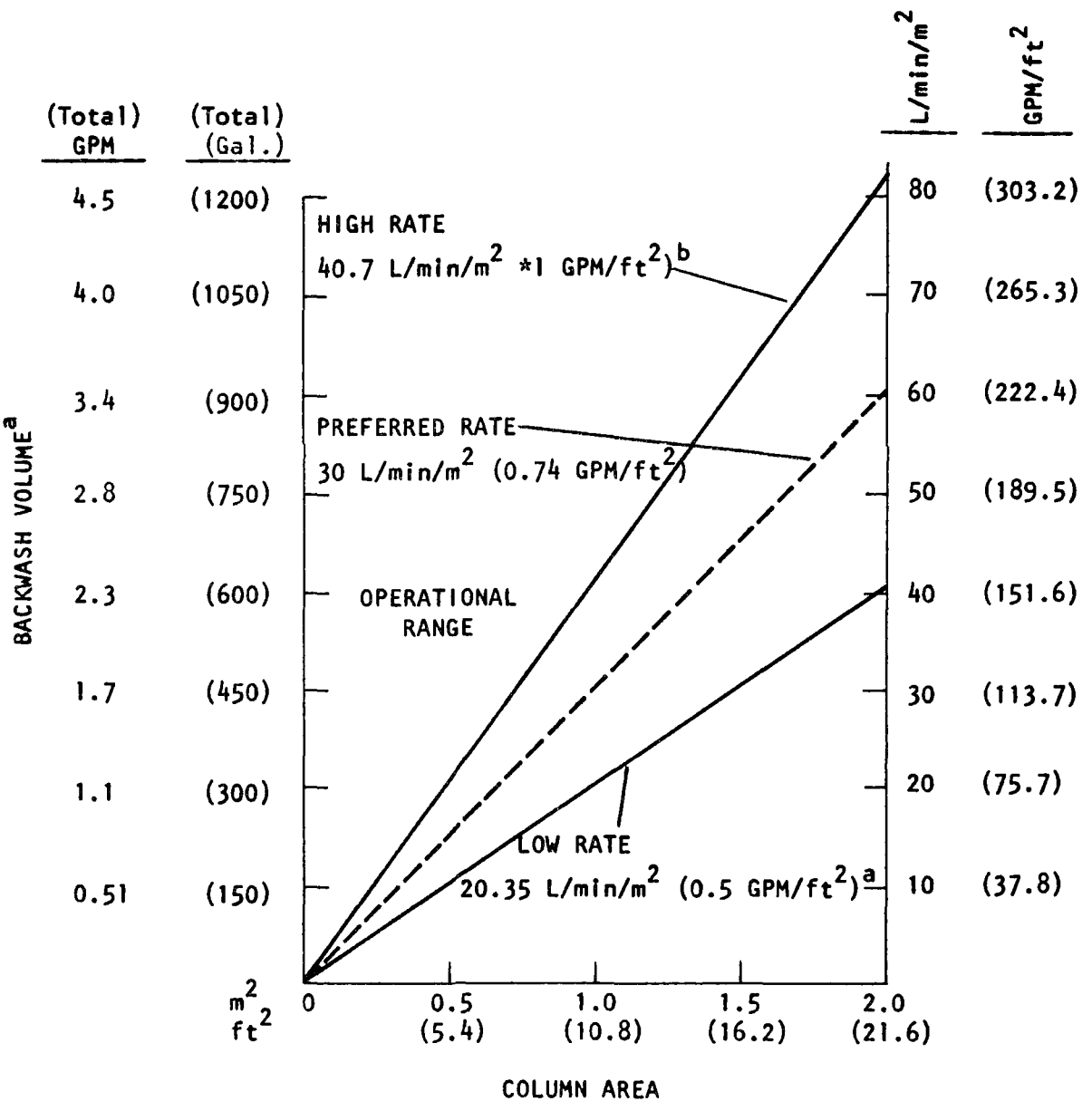
   CAUTION: Flow rates in excess of 40.7 l/min./m^2 may cause the activated carbon to stratify thus decreasing its ability to adsorb contaminants.

3. Backwashing for removal of suspended materials from the carbon column: It is necessary to backwash for about 10 - 15 minutes at

   $$6.1 \frac{\text{m}^3/\text{min.}}{\text{m}^2 \text{ of Filter}} \quad (150 \text{ gpm/ft.}^2)$$

   The required volume and flow rates are given in Figure 53. Flow setting may be easier by noting the drop in level of the equalization tank.

NWMAR116444



[a] VOLUME IS BASED ON A 15 MINUTE BACKWASH

[b] RECOMMENDED BACKWASH RATES ARE FROM 40.7 L/min/m^2 to 20.35 L/min/m^2

Figure 53. Carbon bed preparation by backwashing for fines removal.

NWMAR116445

Explanation: Efficient backwash requires that a certain flow rate termed the minimum fluidization velocity be passed upward through the bed causing all of the media particles to separate.

CAUTION: Do not allow an excessive flow rate to cause the activated carbon to be washed into the effluent trough. If you are in doubt as to whether this is happening or not, take a sample near the effluent trough with a glass jar and inspect for activated carbon carry-over.

Note whether the total bed is in agitation (desirable) or if the flow is being channeled (undesirable). Channeling is caused by poor backwash water distribution. Extended backwash period may help to effect better removal in this situation.

If backwashing does not effectively remove the suspended material or if extreme stratification occurs, the carbon must be replaced prior to further column use.

CAUTION: If backwashing at high rates above

$$\frac{40.7 \text{ l/min}}{\text{m}^2 \text{ of Filter}} \quad (2.0 \text{gpm/ft}^2)$$

is performed, removal rates of the hazardous material may be significantly lowered.

4. After the backwash is completed the water above the carbon bed should be clarified and not murky. After the pump is turned off, a short duration must be allowed for the water to syphon backward through the backwash pump thus permitting the hose connection at the filter discharge to be separated without having a pressure behind it.

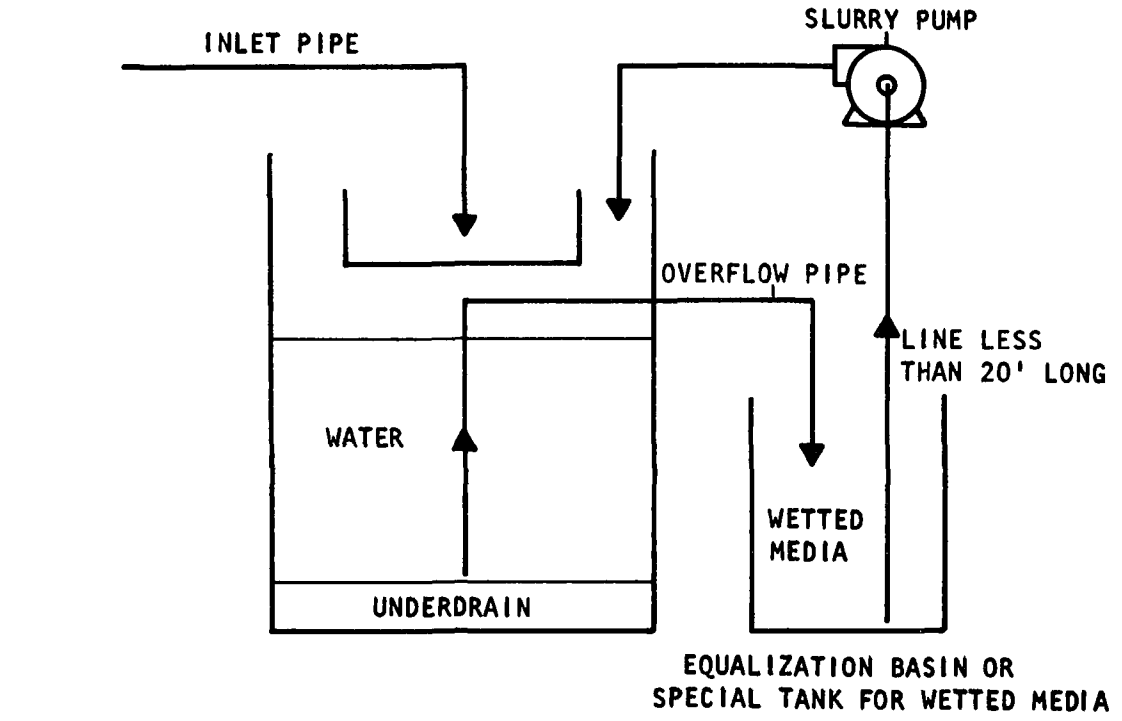
   Any fines should then be skimmed from the bed.

5. Removal of the exhausted activated carbon: The preferred removal method for the spent activated carbon is shown in Figure 54. The carbon should be submerged prior to and during removal.

   Explanation: Because activated carbon will dewater freely, it is necessary to pump water into column to keep the activated carbon slurried. The water can be replaced by intermittent operation of the backwash system or auxiliary pumps can be used to pump product water into the top of the column.

   CAUTION: Do not remove too much carbon or the underdrain

NWMAR116446



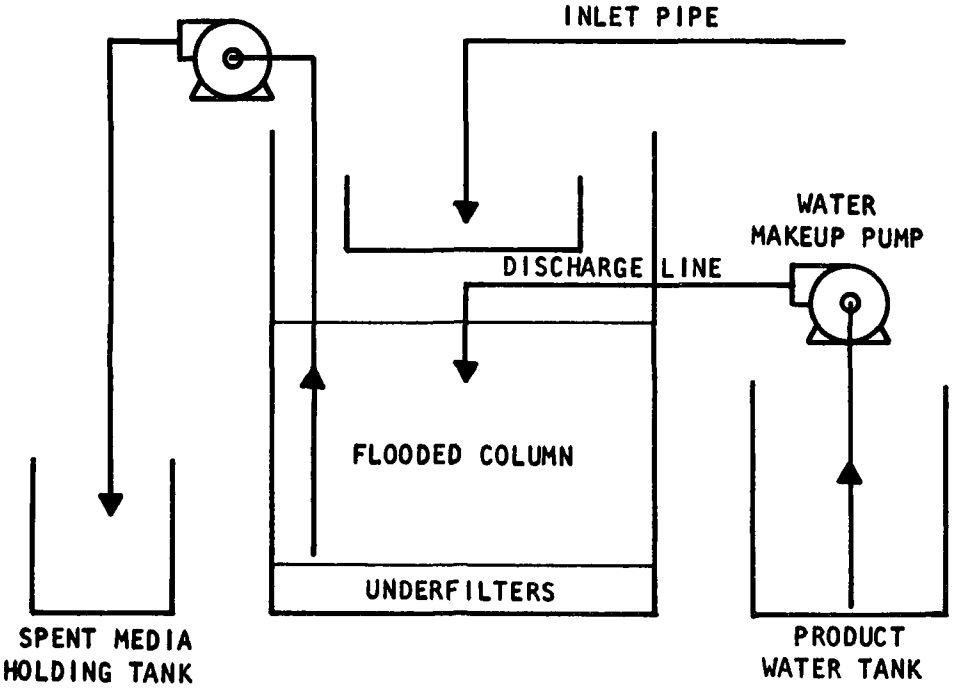


Figure 54. Operating modes for carbon transfer

NWMAR116447

will be disturbed. To avoid this, it is preferred to leave an inch or two of carbon above the torpedo sand layer.

6.3.6 Activated Carbon Column Troubleshooting

1. Excessive Clean Bed Head - If backwashing does not permit return to the clean bed head, surface blinding may be occurring which can be alleviated by removing and replacing the top 5-12 cm (2-5 in.) of carbon from the bed. If suspended material is clogging the column, steps should be implemented to improve the feed water quality.

2. Poor effluent quality suggests:

    a. Too high a flow rate;

    b. Channeling of the bed (uneven distribution of flow);

    c. Excessive mixing of media;

    d. Exhausted activated carbon.

6.4 ION EXCHANGE

6.4.1 Process Description

Ion exchange is a process in which ions held by electrostatic forces to functional groups on the surface of a solid are exchanged for ions of a different species in solution (48). This process takes place on a resin which is usually made of a synthetic material. The resin contains a variable number of functional groups which establish both the capacity of the resin and the type of group removed. Various kinds of resins are available including weakly and strongly acidic cationic exchangers and weakly and strongly basic anion exchangers. The ions are exchanged until the resin is exhausted and then the resin is regenerated with a concentrated solution of ions flowing in a reverse direction. Various specific reactions occur but generally the reaction is as follows:

$$RI_x + I_c \longleftrightarrow RI_c + I_x$$

R = resin

I_x = exchangeable ion

I_c = contaminating ion

The ion exchange process is dependent on the type of resin involved, the specificity of the resin and the general ion content of the wastewater. Capacities of resins also vary with the manufacturer of the resin, the distribution of flow and concentration of contaminant.

NWMAR116448

The amount of resin required must be established by chemical tests done on wastewater for ion content. The best type of resin to use is established mainly by the specific contaminant to be removed, the amount of wastewater involved and the other ionic demand on the resin. A resin manufacturer must be contacted by the OSC to allow the correct resin to be chosen. The following information must be given to the manufacturer.

1. Name of compound to be removed,
2. Concentration of contaminant,
3. Amount of wastewater to be treated,
4. Chemical analysis of ions.

Cation removal ($e.g.$ Metals/NH_4) +	Anion removal
a. Hardness	a. Chloride
b. Sodium	b. Sulfate
c. Other cations	c. Nitrates
	d. Other significant anions

The resin manufacturer can then specify the amount and type of resin required to remove the entire contaminant from the waterway. Unless absolutely necessary, the resin will not be regenerated on site; once the capacity is depleted, the resin will be replaced, hauled away for regeneration and either returned for reuse on site or sent to storage.

Two types of off-stream treatment are available, 1) column exchange and 2) distribution of uncontained media into a tank. Column treatment is more common and more efficient. There are many similarities between ion exchange and carbon columns and some similarities to filters. The three systems have the following features in common:

1. Efficiency of the bed is dependent on good flow distribution which will provide uniform contact time for the entire fluid stream.

2. An underdrain system is necessary to prevent the media from exiting with the effluent water and to distribute backwash water.

3. Initial backwash is required to remove fines and air pockets, as well as to stratify the bed.

The carbon and ion exchange systems are similar in the following ways:

1. Termination of the cycle is established by "breakthrough" which indicates that the exchange capacity of the bed has been spent. This procedure is indicated by an increase in the concentration of the contaminant to be removed or by a change in pH (when strongly anionic or cationic resins are involved).

NWMAR116449

2. Use of the column as a filter causes inefficient use of the exchange capabilities. Therefore clarification processes including dual media filtration are necessary pretreatment steps.

3. Backwashing of these systems can be done, however, it is not recommended and the necessity of frequent backwashing indicates the malfunction of upstream processes.

However, ion exchange does have a high potential for fouling since the size of the resin particles is approximately the same as that of filter sand.

The amount of resin and the type required are established by the manufacturer. However, the design of the columns presented in this manual is based on two resins. Amberlite IRC-84 and IR-120. The OSC must compare the critical design data and then make appropriate changes in the design. (See Table 26).

TABLE 26. DESIGN PARAMETERS USED FOR ION EXCHANGE (49)

Parameter	Design criteria	
	metric	English
Loading rate	81.4 $\frac{l/min}{m^2}$	2 gpm/ft^2
Loading range	40.7 - 203.5 $\frac{l/min}{m^2}$	1-5 gpm/ft^2
Minimum bed depth	61 cm	24"
Expanded height	43.2 cm 65%	17"
Head loss (total head loss based on exp. height)	$\frac{0.07\ kg/cm^2}{m}$	$\frac{0.69\ ft\ of\ H_2O}{ft}$
Backwash rate	$\frac{244.2\ l/min}{m^2}$	6 gpm/ft^2
Backwash rate (range)	$\frac{162.8\text{-}488.4\ l/min}{m^2}$	4-12 gpm/ft^2
Backwash time	15 min.	15 min.
Backwash expansion	58.4 cm, about 50%	23", about 50%

NWMAR116450

6.4.2 Design for Ion Exchange Columns

1. Order the ion exchange media by contacting a manufacturer and giving him the wastewater characteristics indicated in the process description. See Section 7.4 for supplier.

   Explanation: Due to long lead times to receive the resin on site, it is essential to order the resin immediately. It is assumed that the resin will not be regenerated in the column or on site due to other hazards. Therefore, the amount of resin ordered must have capacity to handle the entire spill without regeneration.

2. Determine the required surface area from the process flow rate using Figure 55.

   Explanation: Required surface area is based on a design flow rate of 81.4 $l/min/m^2$ (2.0 gpm/ft^2)

   Operational ranges may vary from 40.7-203.5 $\frac{l/min.}{m^2}$ (1-5 gpm/ft^2) (49).

   Example: (From Figure 55). At 212 l/min., a bed area of 2.6 m^2 will be required if the ion exchange column is to be run at 81.4 $\frac{l/min.}{m^2}$

3. Select a tank from Section 7.3 with the following:

   a. A tank with vertical sides (Types A, F, B).

   b. An above-ground tank.

   c. A minimum height of 3.2 m (127 in.).

   d. A diameter in the range of 0.6-1.2 m (24-60 in.).

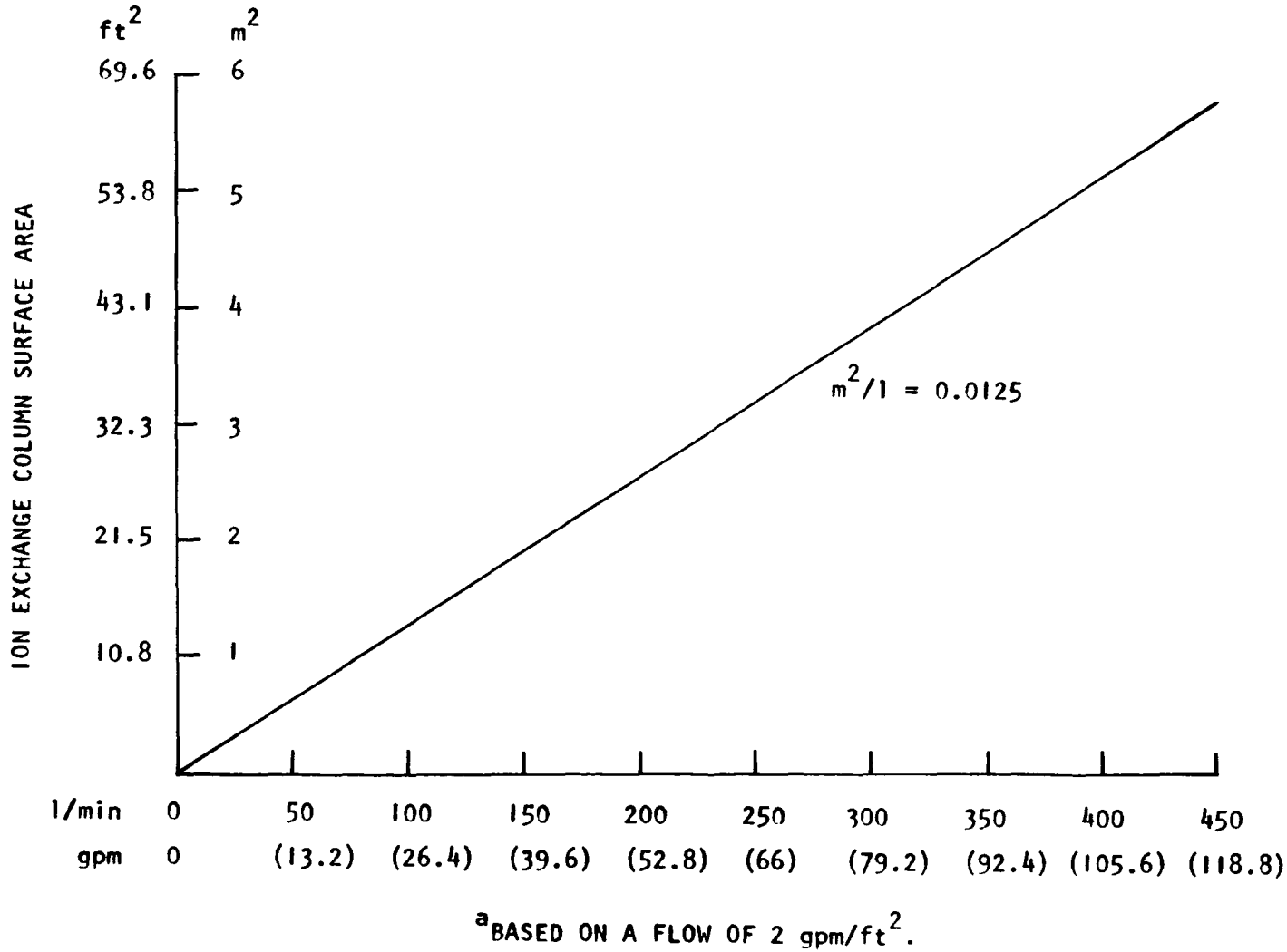
      Explanation: Over 1.2 m (60 in.) in diameter, a single outlet will probably not be sufficient to permit uniform flow distribution necessary for adequate backwashing.

   e. A flat bottom which can be uniformly supported, e.g., laying flat on the ground.

   f. Tank wall construction in which a hole may be machined for an outlet.

4. Order gravel for media underdrains from a local sand and gravel

NWMAR116451



[a]BASED ON A FLOW OF 2 gpm/ft^2.

Figure 55. Required surface area for ion exchange columns.

NWMAR116452

yard using amounts from Figure 45. Order equal amounts of pea gravel, and #1 and #2 gravels, and one-half that amount of torpedo sand.

Explanation: Pea gravel is about .31 cm (0.23 in.) in diameter; #1 gravel ranges in size from 1.25-1.9 cm (0.5-0.75 in.); #2 gravel ranges in size from 2.50-3.90 cm (1.0-1.5 in.).

Example: (From Figure 45). For the flow rate of 212 l/min., and the area requirement of 2.6 m^2 order the following quantities:

Torpedo Sand - 0.15 m^3

Pea Gravel, #1 and #2 gravels - 0.31 m^3.

6.4.3 Construction Options for Ion Exchange Columns

Preferred Option - Gravity Outlet (Figure 56)
Fully gravitational flow, with a free discharge leading to an equalization and backwash storage tank.

Explanation: Gravity flow rather than suction from a pump is desirable to prevent air blinding of the bed.

Advantages: Easy to operate and monitor effluent quality. Outlet location permits bed to remain submerged after batch runs, a desirable feature. Can be hydraulically connected with hoses and a total of six hose fittings; eliminating the necessity of piping and valves.

CAUTION: In cases where hazard to personnel would exist from contact with fluid, this option has a drawback in the necessity to manually transfer hoses when shifting from the forward flow to backwash mode.

Two pumps may be used handling both forward flow and backwash, providing the pump capacities are determined from backwash requirements and that they can be throttled to accommodate forward flow and backwash flow conditions. This option is well-suited to a parallel - flow arrangement utilizing multiple ion exchange resin columns and a single equalization tank.

Explanation: The benefit derives from the fact that backwash flow rate is four times the forward flow rate. Thus, in a single ion exchange column system, both pumps operate in the forward mode at 25% capacity. On the other hand, if say two ion exchange columns are used, the pump could operate at 50% capacity in forward flow, with the stipulation that ion exchange columns be backwashed individually.

NWMAR116453

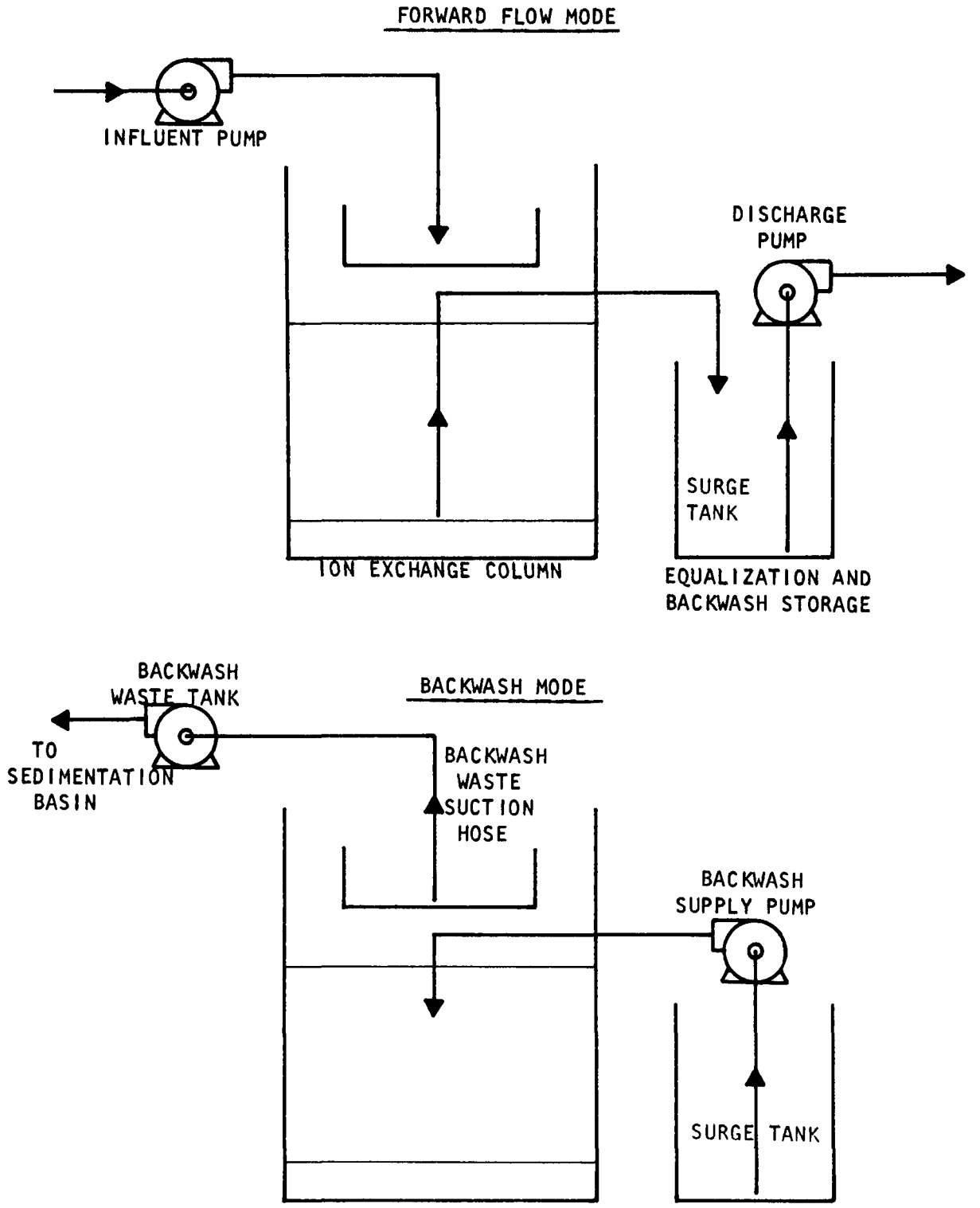


Figure 56. Preferred option and operating modes - ion exchange

NWMAR116454

Any type tank may be used for equalization, in-ground or out, provided that the wall height be lower than the ion exchange column outlet fitting height.

6.4.4 Construction Steps for Ion Exchange

Preferred Option - Gravity Outlet (Figure 57).

1. Construct tank shell and bottom as instructed in Section 7.3.3.

2. Install brick supports for an expanded metal grating underdrain support. Note that all bricks are to be oriented radially with the center of the column, except the bricks on the periphery. For a one piece grating use about 12 bricks per square meter.

   Explanation: During backwash the distribution of water in the underdrain area is critical. Symmetrical orientation of bricks assists in backwash flow distribution.

3. Install an expanded metal grating covering the complete column area. The maximum opening in the grating shall not pass a 2.5 cm (1 in.) sphere. Standard 3.0 lb., 4.0 lb., or 5.0 lb., expanded metal grating will meet this requirement. Construct from one piece if possible. If installed in multiple pieces, be sure the free edges are supported sufficiently (almost continuous support). Fit grating so that no holes over 2.5 cm (1 in.) in diameter are created.

4. Install the discharge line as shown, tied on one end to the grating and extending through the tank wall at 1.83 m (72") above the base of the column. Discharge line size is given in Table 25.

5. Install the gravel underdrain layers.

6. Install 61 cm (24 in.) of ion exchange resin (see preferred option Figure 57). Backwash the column to remove fines (see section 6.2.5 for proper backwash method for removal of fines).

   Explanation: The ion exchange column should have 0.6 m (2 ft.) of standing water before introduction of the resin, as this water is displaced by the resin it should be collected in the equalization basin. A mark 61 cm (24 in.) above the torpedo sand will insure the proper bed depth is obtained.

   CAUTION: All lines in which ion exchange resin is to be pumped must be at least 5 cm (2 in.) in diameter. The lines must be kept as short as possible, i.e., the suction line is not to exceed 6 m (20 ft.) and the discharge line will be no longer than necessary.

NWMAR116455

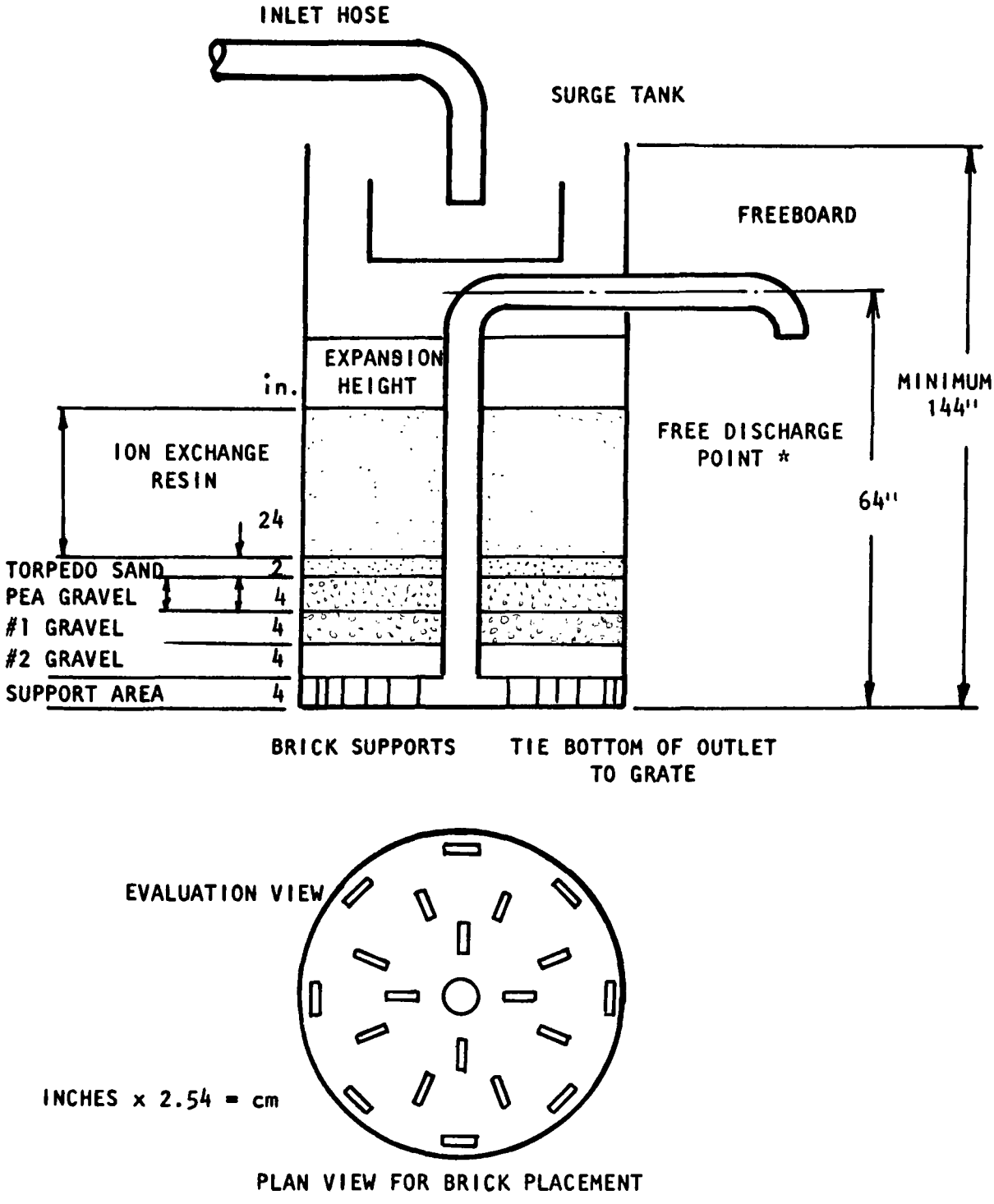


Figure 57. Ion exchange column construction details.

NWMAR116456

ion exchange resin can also be installed by hand using buckets and shovels, etc.

7. Construct a surge tank to dissipate the inlet velocity head and act as a backwash trough. A good size would be 1/4 - 1/3 the column diameter. The surge tank may be supported by three cables suspended from the top of the column. Locate the bottom of the surge tank .6 m (24 in.) above the top of the column bed (as shown in Figure 57). If a surge tank cannot be constructed, place the inlet hose in a horizontal, tangential position to cause velocity dissipation through swirl. This technique will help minimize the boring out effect on the bed, which causes channeling of flow.

8. Install an equalization tank, any type, with the restriction that the top of the vertical wall be lower than the column discharge. The process volume should be at least 3.7 m^3 per m^2 of column (291 gal/ft^2) to accommodate one backwash for a single column. Calibrate the volume of this tank, by calculation, and put a scale on the inside wall showing 0.5 m^3 or 100 gal. increments.

   Explanation: This calibration will assist in flow setting.

6.4.5 Operational and Maintenance Steps for Ion Exchange

Forward Flow

1. Set up the system in the forward flow mode as shown in Figure 56.

2. If backwashing of fines was not performed during or after column construction, care must be taken during filling, e.g., reduced flow rate so that the media is not bored out by the flow.

3. Throttle the inlet flow as necessary to achieve the desired flow rate (81.4 $\frac{l/min.}{m^2}$ (2 gpm/ft^2) is design rate). When flowing at design rate, the water level should stabilize. Mark this level on the tank wall as the clean bed head. If the water level is more than .3m (1 ft.) above the bed at design flow during the first column run, there is probably some blinding from fines taking place and the fines removing procedure should be repeated. If, after backwash, the clear bed head does not come back close to the original level, consult the troubleshooting section.

4. Monitor the pH of the effluent which flows either into or from the gravity equalization tank. When the pH changes drastically from the normal operating value the resin is exhausted and flow must then be stopped and the resin replaced.

NWMAR116457

5. Ion exchange columns should never be allowed to become fouled. If they do, the processes prior to the ion exchange column should be inspected and steps should be implemented to improve the product water of these processes. If the head rises to within 15 cm (6 in.) from the top of the tank, it is time to backwash, which is undesirable.

Backwash Mode

1. Set up the system for the backwash mode as shown in Figure 56. Restrain the backwash waste suction hose so that it will not be possible for it to become attached to the bottom of the surge tank. This would starve the pump and require that it be shut off momentarily to release the hose.

   Explanation: Backwashing the ion exchange column is intended to:

   a. Remove undesirable fines during filter preparation;

   b. Remove air bubbles and pockets during filter preparation;

   c. Remove collected suspended material.

2. For ion exchange column preparation, removal of fines, air bubbles and pockets and suspended material removal, it is desirable to backwash for a total of 15 minutes at 244.2 $\frac{l/min.}{m^2 \text{ of filter}}$ (6.0 gpm/ft^2). The accepted operational range for ion exchange column preparation backwashing is 162.8 to 488.4 $\frac{l/min.}{m^2 \text{ of area}}$ (4.0 - 12 gpm/ft^2). The required volumes and flow rates for ion exchange column preparation are given in Figure 58. Flow setting may be easier by noting the drop in level of the equalization tank.

   Explanation: Efficient backwash requires that a certain flow rate termed the minimum fluidization velocity be passed upward through the bed causing all of the media particles to separate. Note whether the total bed is in agitation (desirable) or if the flow is being channeled (undesirable). Channeling is caused by poor backwash water distribution. Extended backwash period may help to effect better removal in this situation.

   CAUTION: Do not allow an excessive flow rate to cause the ion exchange resin to be washed into the effluent trough. If you are in doubt as to whether this is happening or not, take a

NWMAR116458

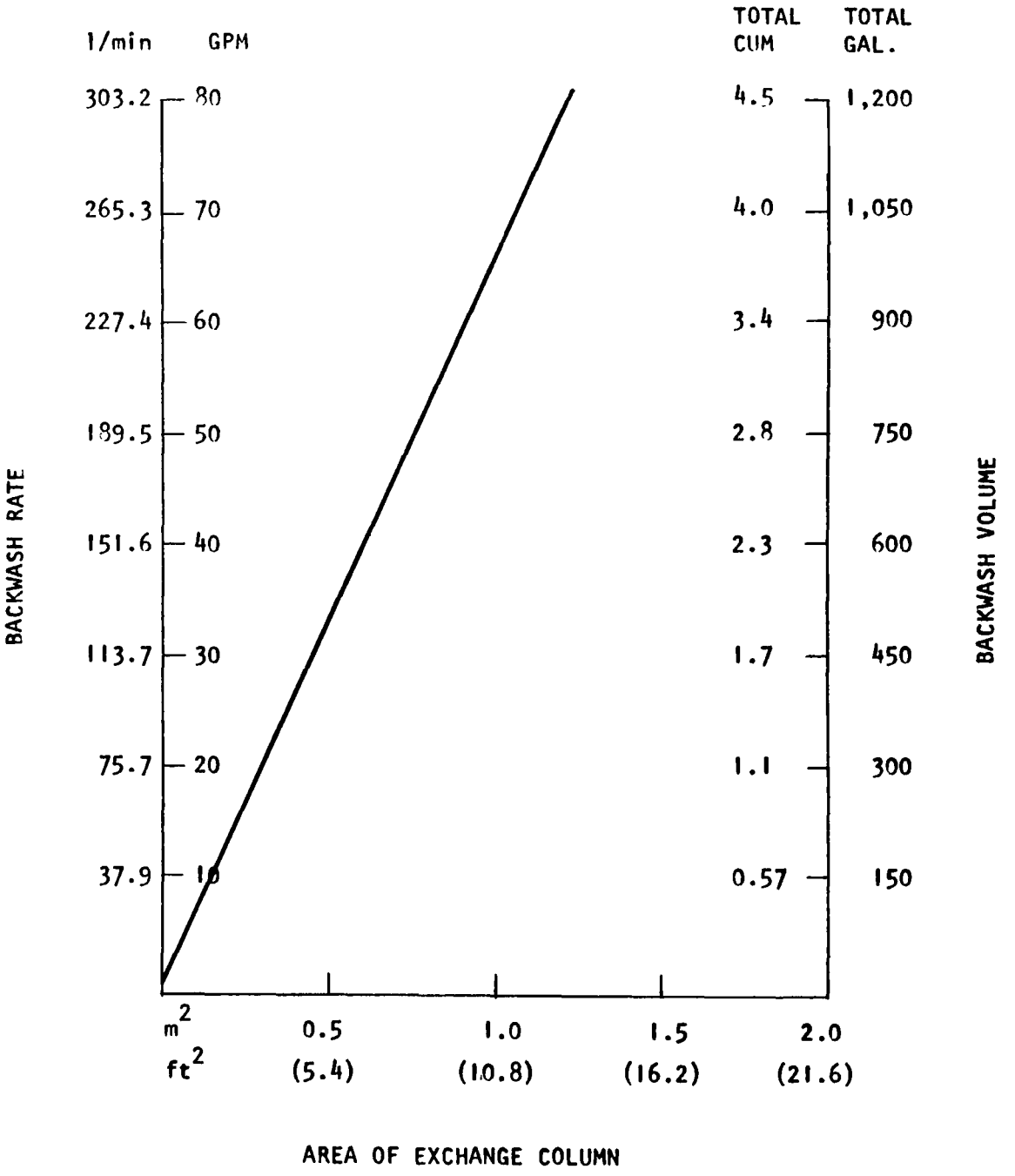


Figure 58. Backwash volume for ion exchange.

NWMAR116459

sample near the effluent trough with a glass jar and inspect for ion exchange resin carry-over.

As an alternative to backwashing, the ion exchange bed may be replaced. This would be desirable if the exchange capacity is almost exhausted.

3. After the backwash is completed the water above the bed should be clarified and not murky. After the pump is turned off, a short duration must be allowed for the water to syphon backward through the backwash pump thus permitting the hose connection at the filter discharge to be separated without having a pressure behind it. Any fines should then be skimmed from the bed, and make-up resin should be pumped into the bed to replace the resin that was removed.

4. Removal of the exhausted ion exchange resin: The preferred removal method for the spent resin is shown in Figure 59. The resin should be submerged prior to and during removal.

   Explanation: Because ion exchange resin will dewater freely, it is necessary to pump water into the column to keep the resin slurried. The water can be replaced by intermittent operation of the backwash system or auxiliary pumps can be used to pump product water into the top of the column.

   CAUTION: Do not remove too much ion exchange resin or the underdrain will be disturbed. To avoid this it is preferred to leave an inch or two of resin above the torpedo sand layer.

6.4.6 Ion Exchange Column Trouble Shooting

1. Excessive clean bed head - If backwashing does not permit return to clean bed head, 5-12 cm (2-5 in.) media may be removed and replaced. This procedure will only be necessary if feed water quality is high in suspended material which is causing surface blinding. If suspended material is clogging the column, steps should be implemented to improve the feed water quality.

2. Poor effluent quality - suggests:

   a. too high a flow rate (insufficient detention time);

   b. channeling of the bed;

   c. exhausted ion exchange resin;

   d. improper choice of resin - wrong type of anion/cation removal.

NWMAR116460

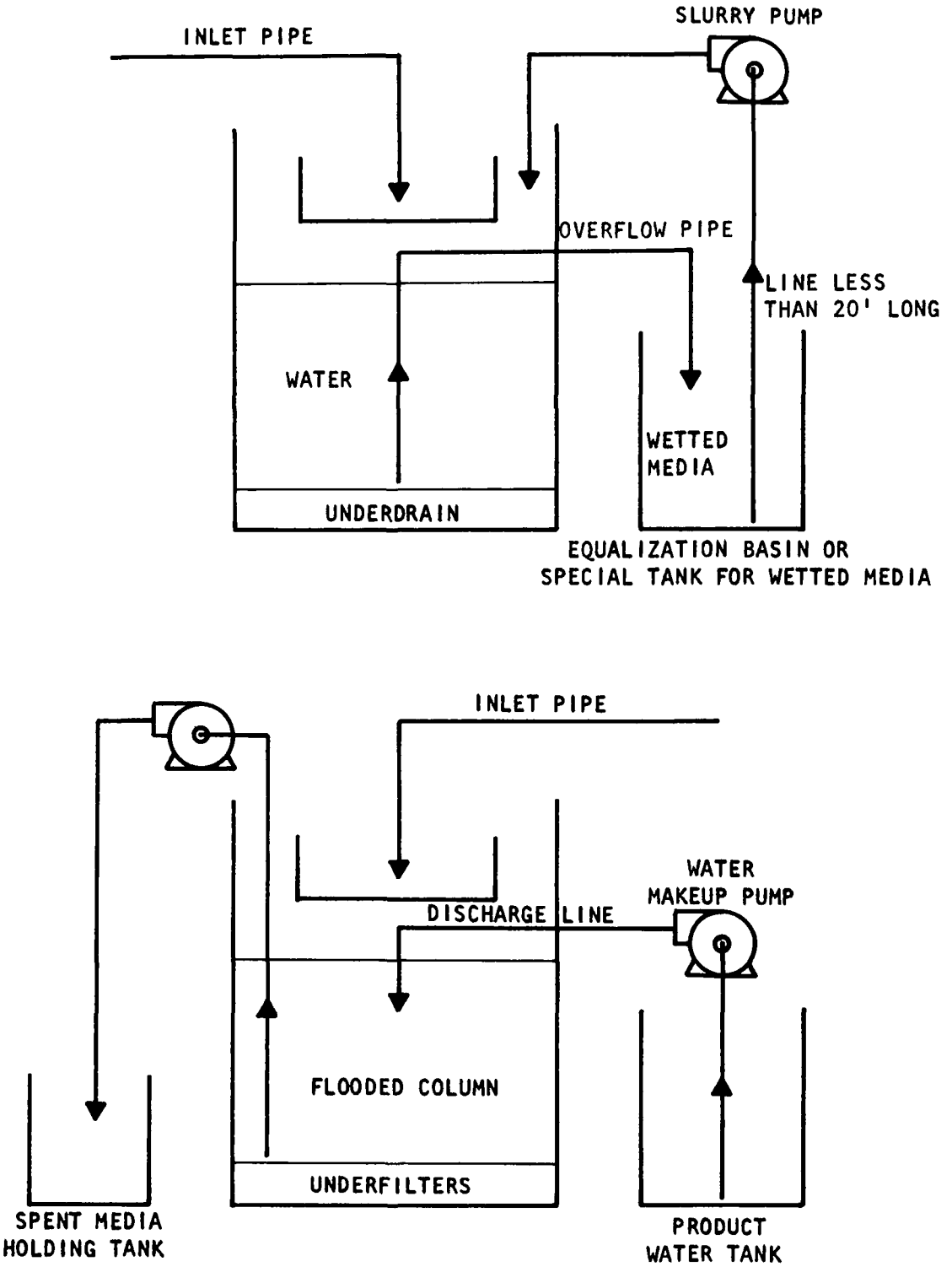


Figure 59. Operating modes for ion exchange resin transfer

NWMAR116461

6.5 GRAVITY SEPARATION

6.5.1 Process Description

Gravity separation involves the removal from the water column of materials with a different specific gravity than water. Both flotation and sedimentation processes are included as an off-stream treatment system. In situ treatment is generally not applicable since dredging and absorbant processes have been covered in Section 4.3.

Sedimentation: Sedimentation is the removal of solid particles from a suspension through gravity settling (50). The process is used as a pretreatment and concentration step to reduce the load on downstream processes and utilize the natural concentrating procedure. Various factors affect the rate of settling including particle size and shape, density and viscosity of the water and other materials in the water column. The rate of settling can be predicted using theoretical equations, however, a field testing procedure is faster and more accurate.

Gravity separation has been included either as a necessary or optional process in all of the treatment schemes. The requirement for sedimentation preceeding the system is determined by the nature of the spill situation. A large amount of suspended solids in the influent, a strongly insoluble contaminant or sensitive downstream processes may lead to the use of a sedimentation system. Each situation must be evaluated on its own merits. Criteria are listed in Section 6.5.3.

Several problems are inherent when using sedimentation processes. The first difficulty is that the batch nature of the process requires a bank of parallel tanks to produce a continuous flow system. The number of tanks is dependent on the fill and draw rate, the detention time of settling and the amount of desludging required.

The desludging operation is tedious, time consuming, can be dangerous to personnel, and should be done as infrequently as possible. To reduce the amount of desludging, a presettler can be used which is set up for continuous desludging. The frequency of desludging is dependent on the nature of the sludge produced, the removal device and the type of tank used.

The tank operation is accomplished by:

1. Filling the tank up to the freeboard level by pumping fluid into the influent well. The well dissipates the velocity head and allows the fluid to overflow into the tank without disrupting the sludge blanket.

2. Allowing sufficient detention time for settling after filling operation is completed.

3. Drawing off supernatent by manually controlled suction hose which draws off the clear supernatent to the point where there

NWMAR116462

is danger of sludge entering the suction hose. After drawoff, tank refilling or desludging may proceed.

4. Removing sludge when a blanket has formed which has reduced the batch size substantially. Desludging is performed with a solids handling pump and special suction fitting.

There is an experimental settling test which can be used to establish flow rates and number of tanks for sedimentation. It is mandatory that a mixed sample of the wastewater be used to evaluate the settling capabilities. The sample is placed in a cylinder and the position of the interface with time is recorded. This data is then translated into a settling rate and evaluated. If the settling rate is less than .031 mpm (0.1 fpm) then chemicals may be added to increase the settling rate. The chemicals are added, mixed and flocculated, then the clumped solids are allowed to settle. There are several commonly used chemicals including ferric chloride, alum, and polyelectrolytes. The following paragraphs describe these chemicals and their use.

Ferric chloride: This compound is effective in clarifying both organic and inorganic suspensions. The final pH should be above 6 for best results so lime or caustic soda may be needed to control pH. Dilute suspensions require dosages of approximately 50-500 mg/l although larger dosages may be needed for concentrated or highly alkaline suspensions. If the wastewater is low in alkalinity, lime or caustic may be needed to raise the pH to 6 or higher. Excessive doses of ferric chloride will result in a brown colored effluent and should be avoided.

Alum: Aluminum sulfate is effective in clarifying both organic and inorganic suspensions. The pH should usually be controlled in the range of 6.5 to 7.5 pH and this control is generally crucial for good alum use. If a dilute suspension is to be treated, alum dosages of 100-1000 mg/l should be effective. Huge dosages may be needed for concentrated or highly alkaline suspensions. As with ferric chloride, suspensions low in alkalinity may require an addition of lime or caustic to produce the final pH range of 6.5 to 7.5

Organic Polyelectrolytes: Polyelectrolytes are available in anionic, cationic or nonionic form and may be effective alone when flocculating suspensions of inorganic materials (clay, soils, colloidals, metal salts etc). These polyelectrolytes are usually not effective alone when flocculating organic suspensions, but can be used with alum or ferric chloride for treating organic suspensions. Polyelectrolyte dosages vary with both the type of charge on the polymer and the type of suspension to be treated. Cationic polyelectrolytes are generally added in higher dosages, 1-10 mg/l in dilute situations (less than 100 mg/l suspended solids) and anionic or nonionic polymers are added at approximately 0.5 to 5 mg/l. When the solution is concentrated and the suspended solids concentration is greater than 1,000 mg/l add 1-300 mg/l of a catonic polyelectrolyte or 1-100 mg/l of an anionic or nonionic compound.

NWMAR116463

These chemicals are also used in combinations and various types of mixtures should be evaluated prior to establishing the treatment mechanism. When the chemicals are added, mixed and flocculated, the resulting solution and solids should be examined for the following:

a. A relatively clear internatant (i.e., the liquid between the particles). A cloudy internatant may indicate the need for more chemicals.

b. A medium to large but well defined floc. This is a good sign of correct chemical dosages.

c. Initial settling of the floc - the faster the floc drops out the better.

d. A relatively small sludge volume (3-5%) - even in a 100 ml graduate an approximate idea of sludge volume can be obtained. Excessive volumes of sludge from chemicals indicate future problems - a different chemical or smaller dosage may be desirable.

The following paragraphs describe the uses of the treatment chemicals to aid sedimentation. The total flocculation times are for full scale use. Laboratory times for mixing are 15-30 sec. and for flocculation are 30 sec. to 2 minutes.

Polyelectrolytes: Slowly add polyelectrolyte solutions to the waste while vigorously mixing the wastewater. Mix rapidly for 1 to 2 minutes to ensure dispersal. Then agitate the material at a speed just sufficient to keep the floc from settling and continue for 5 to 10 minutes. If more time is needed, increase the polymer dosage.

Alum Treatment: The order of addition of alum and then lime or NaOH may be critical. However either alum addition first or last may be the best for a given situation. Generally, alum addition followed by lime or NaOH addition will give satisfactory results and allows simple pH control. Alum should be added, mixed 1 to 2 minutes and then the lime or caustic can be added to achieve the proper pH. Again flocculation speed is established at the rate to keep the floc in suspension. The flocculation time should range from 5-15 minutes and if longer times are required, increase the alum dosage. If the floc is easily broken, add a polyelectrolyte to increase the strength.

Alum and polyelectrolytes: The use of polyelectrolyte will allow a stronger floc and a faster settling rate. Add the alum and lime or caustic as described previously. Flocculate from 2 to 5 minutes to allow creation of the desired alum floc. Then add polyelectrolyte in concentrations from 1 to 10 mg/l. Increase the rate of agitation during polymer addition to prevent settling and mix about 1 minute. Flocculate for 5-10 minutes or increase dosage of polyelectrolyte.

NWMAR116464

Ferric Chloride: (lime or caustic may be needed for pH control). Add ferric chloride and then mix for 2 to 5 minutes vigorously. Then add lime or caustic to raise pH to the desired level, mix an additional 2 to 5 minutes and then reduce mixing speed to allow flocculation. Flocculate at a sufficient speed to keep floc from settling for 5 to 15 minutes. If additional time is necessary, increase dosages or add polyelectrolyte.

Ferric chloride and polyelectrolyte: Use the same procedure as ferric chloride addition. After the second 5 minutes mix and add the polyelectrolye (1-10 mg/l). Mix at a higher rate to prevent settling and continue to mix approximately one minute. Then flocculate 5 to 10 minutes.

Once the chemicals and dosages have been determined, the system can be operated. To establish the efficiency of the unit, sampling should be done at both the influent and effluent of the batch and if the system is not operating properly, further bench tests may be needed.

Flotation: Flotation is used to separate materials with a specific gravity less than water. The contaminant rises to the top and is skimmed off periodically. This skimming process should be done during each batch, so the influent and effluent flows remain constant and do not disturb the downstream processes.

The flotation process operation has the same basic steps as are used in sedimentation except that skimming of floating substances is performed during each batch. A settled sludge blanket would probably accumulate but typically in far less proportions than in the sedimentation tank.

Flotation rates can be either calculated methematically or measured in the field. The equation for rise rate is dependent upon the specific gravity and viscosity of the water, the specific gravity of the particle, and the estimated diameter of the globule. It is commonly assumed that the diameter is equal to 0.015. The rise rate is then equal to:

$$v_t = 0.0241 \quad \frac{(Sw - S_c)}{\mu}$$

v_t = m/sec
Sw = sp.gr. of water
S_c = sp.gr. of contaminant
μ = viscosity of water

The other method is measuring the rising position of the interface with time, in the same manner as a solids settling test. Once the rate is determined, the detention time is calculated:

$$\text{Detention time} = \frac{\text{height of tank}}{\text{rise rate}} \quad 2^* \qquad \text{(2 is a safety factor)}$$

Once the detention time is calculated, the test can be re-done for that

NWMAR116465

length of time and the scum volume estimated. The same chemicals and dosages used for settling tests can be used for gravity flotation.

6.5.2 Bench Testing Procedure - Gravity Separation

The following tests should be performed on the sample to establish the requirements for gravity separation. The procedure is as follows and an example appears in Figure 60.

Equipment Required:

1. 1 liter or similar graduated cylinder.
2. Raw wastewater.
3. Stop watch or wrist watch with second hand.
4. Ruler.
5. Chemicals
6. Pipette.
7. Pipette Bulb.
8. 100 ml graduated cylinders.

Procedure for Separation Tests:

1. Place graduate on a level surface.
2. Fill with 1,000 mls of sample.
3. Record position of the solids/liquid interface (POI) with time (see example data).

Calculations for Separation Tests:

1. Plot the interface versus time.
2. Establish the settling (or rise) rate from straight line portion of graph.
3. If settling rate (or rise rate) (from 2) is less than .031-0.153 mpm(0.1 to 0.5 fpm)do chemical addition prior to settling

Procedure for Chemical Settling Tests:

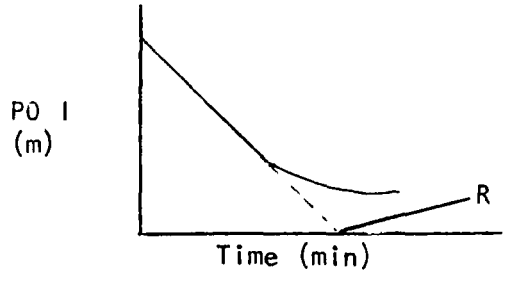
1. Place wastewater in 100 ml graduated cylinders.

NWMAR116466

Time (min)	Volume of Solids Phase (ml)	POI (m)
0	1000	0.349
1	950	0.332
2	900	0.314
3	850	0.299
5	750	0.264
8	600	0.212
10	500	0.178
12	400	0.143
15	200	0.073
20	175	0.065
25	175	0.065
30	175	0.065

Plot the data using time as the X-coordinate and POI as the y-coordinate.

The slope of the straight line portion of the curve represents the settling rate of the solids in meters per minute



$$R = \frac{\text{Height of Cylinder}}{\text{Intersection of Straight Line with Abscissa}}$$

Figure 60. Example of settling test graphs.

NWMAR116467

2. Choose appropriate chemicals from Table 27.

3. Add in dosages at the endpoints of the range and various intervals.

4. Mix by covering the cylinder and inverting 3-4 times.

5. Flocculate by holding cylinder at the top and rotating for 1-2 minutes.

6. Observe floc formation and noticable settling.

   Explanation: Large floc or small floc which settles well is desirable/the clarity of the liquid portion around the floc is also indicative of the effectiveness. If dosage increases do not aid or improve settling, another chemical or a combination of chemicals should be utilized.

7. Choose chemical and proper dosage/ scale up to 1,000 ml graduate size.

8. Repeat settling test but add chemicals/mix and flocculate and then record settling rate (steps 3-6).

Calculations for Chemical Settling Tests:

1. Calculate the amount of chemical required per gallon of wastewater (see Section 7.8)

2. Determine settling or rise rate as for non-chemical settling rate (i.e., graph + slope method).

NWMAR116468

Evaluation of Data from Settling Tests:

1. Calculate detention time as follows:

   detention time =

   $$\frac{\text{process ht. of tank}}{\text{settling (or rise) rate}} \times (2 \text{ to } 3)$$

2. Place new sample in 1,000 ml graduate, treat with established chemical dosage (if any) settle for calculated detention time, measure sludge height (as compared to height of cylinder between 0 ml - 1,000 ml) and sludge volume.

6.5.3 Evaluating Needed Pretreatment Schemes

There are various options available for pretreating the raw process flow. When the sedimentation tank is considered optional in the flow schemes listed in Table 22, or even when it is required, the pretreatment system must be evaluated. The following possible systems are described and numerically coded below for specification in the following criteria evaluations.

0. No Pretreatment - Pumpage directly from the water.

1. Equalization tank only - This tank is used to simplify pumping from the source to the next unit process and is needed so syncronization or smooth operation of pumps is not required.

2. Gravity Separation tank only - This tank is used to provide floating or settling solids removal. A bank of systems is necessary to provide flow through the process even during an hour's detention time.

3. Presettler and Sedimentation Tank - This system provides continuous solids removal in the presettler followed by sedimentation, often chemically treated.

Various methods can be used to establish the type of pretreatment required. When answering the following questions, the final choice of pretreatment is based on the highest number indicated by the criteria:

Criteria 1: Type of pumping system: a. centrifugal 0

b. reciprocating 1

NWMAR116469

Criteria 2:	Type of operation:	a. suction point in water column only.	0
		b. total dewatering of area.	2
		c. surface skimming	2
		d. bottom skimming, dredging	3
Criteria 3:	Next process in Sequence:	a. filtration	2
		b. precipitation	2
		c. neutralization	1
		d. oxidation/reduction	1
Criteria 4:	Settling Rates (from Bench Tests)	a. greater than 1.53 mpm (5 fpm)	3
		b. 0.153-1.53 mpm (0.5-5 fpm)	2
		c. less than 0.153 mpm (0.5 fpm)	0
Criteria 5:	Sludge Volume	a. 3% or more	3
		b. 0.5 - 3%	2
		c. 0.5%	1
Criteria 6:	Flow patterns in System:	a. steady flow/continuous	0
		b. steady flow/intermittent	1
		c. fluctuating flow/continuous.	1
		d. fluctuating flow/ intermittent	1

In summary the following criteria justify the use of a presettler:

1. The raw flow is the product of a dredging operation. The high surface area of sedimentation tanks makes them difficult to desludge.

NWMAR116470

2. A reciprocating pump, such as a diaphragm pump, will transport raw flow to the sedimentation tank (especially tanks made from commercial swimming pools with thin plastic liners).

3. The raw flow pattern is intermittent or sporadic in nature.

4. The settling rate is greater than 1.53 mpm (5 fpm) or the sludge volume is greater than 3% of the influent volume.

A sedimentation tank is needed when:

1. It is to precede a filtration process - since sedimentation will allow removal of solids prior to filtration and permit an acceptable forward flow duration before backwash is necessary.

2. A settling rate of 0.153-1.53 mpm (0.5-5 fpm) and a sludge volume of less than 3% of the influent is available.

Explanation: As a pretreatment device for dual media filtration, the sedimentation tank plays a crucial part in establishing a reasonably long interval between backflushes (a maximum of one backflush per day is desirable).

6.5.4 Design Considerations

If gravity separation is to be accomplished without chemical precipitation, proceed with the following design considerations under either;

A. Sedimentation, or
B. Flotation

If chemical precipitation is required turn to Section 6.6.9.

A. Design Considerations for Sedimentation

1. Apply data from settling tests to establish a detention time.

$$\text{Detention time} = \frac{\text{process height}}{\text{settling rate}} \times 3 \text{ (safety factor)} + \text{floc} + \text{mix time.}$$

Example:

Assume: process height = 0.91 m (3 ft.)
settling rate = 0.061 mpm (2 fpm)
floc time = 10 min.
mix time = 2 min.

NWMAR116471

Total Det. Time = 45 + 10 + 2

= 57 min.

Explanation: The minimum process height is 3 feet and the large safety factor overcomes scaleup problem. If flocculation and mixing times are needed as shown in Table 27, add these to the detention time.

2. Choose a tank type (Section 7.3) using the following criteria:

   a. The shallower the tank, the shorter the detention time required for sedimentation. The minimum process depth should be 0.9 m (3 feet) and the minimum freeboard about 15 cm (6 in.). However, shallower tanks must be desludged more often.

   b. Choose a suitable desludging technique before finalizing tank selection:

      Flat bottom tanks - Tanks up to about 8 m (26 ft) in diameter can usually be desludged with a swimming pool cleaner with its flexible hose connected to a solids handling pump. The swimming pool cleaner incorporates a suction fitting mounted on rollers to allow movement along the tank bottom without tearing liners. Technique is limited to silty muds and other loosely packed sediments. Exclusions are gravel, fibrous debris, leaves, twigs, and grass which would justify the use of a presettler and/or screen chamber. A swimming pool cleaning device is also well suited for removing floating material.

      Slopesided tanks - In ground tanks can be excavated to provide sloped sides leading to a single low point. A hose suction can be located at the low point and used as a stationary desludging point. Long-handled push devices can be used to move the sediment toward the suction point. Screening can be fitted around the hose outlet for protection from fouling where necessary.

NWMAR116472

TABLE 27. TREATMENT CHEMICAL INFORMATION

Chemical	Use	Strength	Common dosage, mg/l	Field mix time[a]	Field floc time
Ferric Chloride	organic inorganic	25-100 mg/mℓ solution	∿1000 mg/ℓ, 50-500 mg/ℓ + lime to pH 6 or or greater	complete dispersal of chemical (approx. 2-5 min).	5-15 min
Alum	organic inorganic	25-50 mg/mℓ solution	1000 mg/ℓ, SS 100-1000 mg/ℓ + CaO or NaOH to pH 6.5 to 7.5	Complete dispersal of chemical (approx. 2-5 min).	5-15 min
Polyelectrolytes	inorganic	0.5-1% solutions:		complete dispersal of chemical: (approx 1-2 min).	5-10 min
Cationic			SS <1000 mg/ℓ 1-10 mg/ℓ SS >1000 " 1-300 "		
Anionic			SS <1000 " 0.5-5 " SS >1000 " 1-100 "		
Nonanionic			SS <1000 " 0.5-5 " SS >1000 " 1-100 "		
Alum & Poly	inorganic/ organics to increase strength of floc	--	Alum 100-1000 mg/ℓ Poly 1-10 mg/ℓ	complete dispersal of chemical (approx 1-2 min) then poly & mix about 1 min.	2-5 min 5-10 min
Ferric chloride & Poly	inorganic/ organics to increase clarity	--	Ferric 50-500 mg/ℓ Poly 1-10 mg/ℓ	Complete dispersal of ferric (approx 1-2 min) then add poly & mix about 1 min.	2-5 min 5-10 min

a. If required flocculation time exceeds the maximum time, try a higher chemical dosage.

NWMAR116473

c. Calculate the tank volume, V_n according to the formulae presented in Figure 73.

Example: Tank 6.1 m (20') diameter pool (Tank type A)
5.8 m (19') effective diameter
0.9 m (3') process height

$$V_n = .78\ D^2 \times Hp = .78\ (5.8m)^2 \times 0.9m = 23.6m^3$$

or, expressed in English units

$$V_n = 0.78\ (19ft)^2 \times 3 = 842.5ft^3 \times \frac{7.48\ gal}{ft^3} = 6360\ gal.$$

3. Calculate Fill and Draw Times

$$t_{fill} = t_{draw} = \frac{V_n}{\text{pump rate}} = \frac{V_n}{p}$$

Example:
Assume: $Q_p = 0.66cum/min$ (175 gpm)

Explanation: The process flow rate has been established by evaluating limiting factors (See section 5.4).

4. Calculate total time of tank use per batch.

T_T = total time = $2t_{(fill)} + t_d$ (detention time)

Example: $T_T = 2\ (35.7)\ min + 57\ min$

$$t_{fill} = t_{draw} = \frac{30.3cum}{0.66cum/min} = 45.9$$
$$= 128.4\ min$$
$$= 130\ min$$

Explanation: The total time needed for operation is the fill time plus draw time plus detention time. As the tank fills with sludge, the total time will decrease, however, this calculation provides a safety factor. Higher pump rates for fill and draw will also provide a safety factor.

5. Establish frequency of desludging.

$$\text{Time between desludging} = \frac{0.25 \times Hp \times T_T}{\frac{\text{accumulation of sludge}}{\text{batch}}}$$

NWMAR116474

Explanation: Sludge can accumulate to 1/4 of the process height before desludging so the difficult desludging operation is less frequent.

$$\frac{\text{Accumulation of sludge}}{\text{batch}} = \frac{\text{height of sludge in test}}{\text{height of liquid in test}} \times \text{process height}$$

Example
Assume: 1.1 cm of sludge in test
36.4 cm of liquid in test
0.91m (3 ft) process height

$$\frac{\text{accumulation of sludge}}{\text{batch}} = \frac{1.1}{36.4} \times (0.910)_m$$

$$= 0.028\text{m/batch}$$

$$\text{time between desludging} = \frac{0.25 \times .91\text{m} \times 130 \text{ min/batch}}{0.028\text{m/batch}}$$

$$= 1056 \text{ min.}$$

$$= 18 \text{ hours}$$

Therefore desludging can occur once per day or once every 16 hours because the operations have a scheduled down time then.

6. Calculate the reduction in tank volume caused by sludge accumulation.

$$\text{amount of sludge accumulation between desludgings} = \frac{\text{amount of sludge}}{\text{batch}} \times \frac{\text{batches}}{\text{before desludging}}$$

$$\text{batches before desludging} = \frac{\text{time between desludging}}{\text{time per batch}}$$

Example:

$$\text{amount of sludge} = \frac{.028\text{m}}{\text{batch}} \times \frac{16 \text{ hr/between desludging} \times 60 \text{ min/hour}}{130 \text{ min/batch}}$$

Calculate new effective depth

Effective depth = process height - amount of sludge accumulated between desludgings.

Example:
Assume: process height = 0.91m
height of sludge = 0.207m
effective depth = 0.91m - 0.207m = 0.703m

NWMAR116475

Explanation: Based on the assumption that sludge is accumulating at a uniform rate during the cycle, the average amount of sludge in the tank throughout the cycle would be one-half of the total amount of sludge collected, making the above calculated effective depth too low by one-half of the final sludge height. However, the inefficiency of the drawoff operation only allows the tank to be drawn down to twice the height of the sludge blanket which substantiates the above equation.

Explanation: The effective volume can then be used in future calculating.

New effective volume:

$$V_n \text{ eff} = \frac{\pi D^2}{4} \times \text{eff depth}$$

Example:
Assume: 5.8m - Tank diameter
eff depth = 0.703m
V_n eff = 18.6 cum

7. Calculate Process Volume Required

$$V_p = Q_p (T_T)$$

Example:
Assume: Q_p = 0.66 cum/min
T_T = 130 min.
V_p = 0.66 cum/min x 130 min.
= 85.8 cum

Explanation: Q_p is set by systems approach. T_T is calculated in Step 4.

8. Calculate number of tanks needed.

$$n = \frac{V_p}{V_n \text{ eff}}$$

Example:

$$\frac{V_p}{V_n \text{ eff.}} = \frac{85.8 \text{ cum}}{18.4 \text{ cum/tank}}$$

n = 4.66 tanks

n ≐ 5 tanks

NWMAR116476

9. Calculate the sludge volume accumulated per day: sludge volume/day =

$$= \text{height of sludge} \times 2 \times \frac{\text{number of desludges}}{\text{day}} \times \frac{\pi D^2}{4}$$

$$= 0.20\text{m} \times 2 \times 1 \times \frac{3.14 \times (5.8)^2\text{m}}{4}$$

$$= 10.9 \frac{\text{cum}}{\text{day}}$$

10. Calculate number of sludge tanks needed:

$$n_{sl} = \frac{\text{sludge volume/day}}{\text{volume of 1 tank}}$$

Example: volume of 1 tank = 23.6 cum

$$n_{sl} = \frac{10.9 \text{ cum/day}}{23.6 \text{ cum/tank}} = 0.5 \text{ : need one tank}$$

B. Design Considerations for Flotation

1. Apply data from the batch tests to establish a detention time.

$$\text{Detention time} = \frac{\text{process height}}{\text{rise rate}} \times 3 \text{ (safety factor)} + \text{floc time} + \text{mix-time}$$

Example: process height = 1.22m (4 ft)
rise rate = 0.061 mpm
no chemicals added

$$\text{Detention time} = \frac{1.22\text{m}}{0.061\text{mpm}} \times 3 = 60 \text{ min}$$

2. Choose a tank type (Section 7.3)

Remember: The system must be skimmed between each operation so the tank geometry should be chosen to simplify this process (Tank diameter should be 7.63m (25') maximum).

Example: 5.49 (18') diameter pool
5.19 (17') effective diameter
1.22 (4') process height

$$V_n = 0.78 \times D^2 \times h_p = 0.78\ (5.19\text{m})^2 \times 1.22\text{m} = 25.63 \text{ cum}$$

$$V_n \text{ (gal)} = 0.78 \times (17\text{ft})^2 \times 4(\times 7.48 \frac{\text{gal}}{\text{ft}^3})$$

$$= 674 \text{ gal.}$$

NWMAR116477

3. Calculate the fill and draw time.

$$t_{fill} = t_{draw} = \frac{Vn}{\text{pump rate}} = \frac{Vn}{Q_p}$$

Example: 0.568 cum/min
Assume: Q_p (150 gpm)

$$t_{fill} = t_{draw} = \frac{25.63}{0.568 \text{ cum/min}}$$

$$= 45 \text{ min.}$$

4. Assume a time needed for skimming the tank.

Example:
Surface area $= 0.78D^2$
$= 21 m^2$ or $225 ft^2$
Time $= 1.07 \text{ min}/m^2 \times 21 m^2$
$= 22.5$ min

Explanation: Assume a skim time of $\frac{1.07 \text{ min}}{m^2}$ of surface area. However, some skimming can be done during the operation (i.e., detention time) and the draw time and this will reduce the time.

5. Calculate total time of tank use per batch.

T_T = total time $= 2(t_{fill}) + t_d$ (detention time) $+ t_s$ (skim time)

Example: $T = 60 + (45)2 + 23$
$= 173$ min.

Explanation: The maximum time for these operations is shown. However, the total time may be reduced if some of the skimming could be done at the same time the tank is drawn down.

6. Calculate the reduction in tank volume caused by settled sludge accumulation.

a. Calculate amount of sludge accumulated per batch.

Assume: from settling tests the sludge = 0.3% of total height

$$\text{sludge accumulation} = \frac{\text{sludge accumulation} \times H_p}{100}$$

NWMAR116478

Example: $= \frac{0.3 \times .22m}{100} \neq 0.0037m/batch$

b. Amount of sludge accumulated per day

Assume: 16 hours of operation

$$\frac{\text{amount of sludge}}{\text{day}} = \frac{\text{amount of sludge}}{\text{batch}} \times \frac{\text{batches}}{\text{day}}$$

$$\text{batches per day} = \frac{\text{time of operation per day}}{T_T}$$

Example:

$$\frac{\text{amount of sludge}}{\text{day}} = \frac{0.0037m/batch}{} \times \frac{16 \text{ hour/day} \times 60 \text{ min/hr}}{173 \text{ min/batch}} = 0.021m$$

c. New effective depth

$$H_p - \frac{\text{sludge accumulated}}{\text{day}} = \text{effective depth}$$

d. New effective volume

$V_n = 0.78 \times (5.19m)^2 \times 1.199m$

$= 25.19$ cum

V_n (gal) $= 0.78\ (17)^2\ ft^2 \times 3.93\ ft \times .48\ gal/ft^3 = 6627$ ga.

Explanation: The skimming volume is not included since the tank is skimmed each time and the volume is not affected.

7. Calculate the process volume required.

$V_p = Q_p\ (T_T)$

Example: $= 0.568$ cum/min $\times$ 173 min

$= 98.3$ cum

8. Calculate the number of tanks needed:

$$n = \frac{V_p}{Vn\ eff}$$

Example: $n = \frac{98.3 \text{ cum}}{25.19 \text{ cum/tank}} = \frac{25950 \text{ gal}}{6627 \text{ gal/tank}}$

$n = 3.9 = 4$ tanks

NWMAR116479

9. Calculate sludge volume and tank requirements as shown in steps A-9 and A-10.

6.5.5 Construction of Gravity Separation Tanks and Presettlers

If gravity separation is to be accomplished without chemical precipitation, proceed with the following construction steps under either;

A. Sedimentation, or
B. Flotation

If chemical precipitation is required turn to Section 6.6.9. Presettlers are described under C in this section.

A. Construction of Sedimentation Tanks - Tank sizing has already occurred as part of the design process in Section 6.5.4. The remaining construction steps involve tank installation, inlet velocity head dissipation and supernatant drawoff (see Figure 61).

1. Tank installation - Small areas where the tank bottom is flat are required at the inlet and outlet. This is no problem when using a flat bottomed tank but must be considered during excavation for sloped side, in ground tanks. The tank liner at those spots should be protected with a rubber sheet.

2. Obtain or construct an inlet well according to the following guidelines:

   a. The configuration of the tank is not important provided that it be sturdy and have a level top edge.

   b. Height: 3/4 process water height.

   c. Total length of top edge = 0.336 cm/lpm (1/2 in. per gpm) (if 55 gallon drums are used, Figure 0.378 cum/min (1,000 gpm) per drum. Multiple drums can be used with a flow splitter. See Section 7.4.2.2.

   d. Whenever possible, employ a non-removable section of inlet hose which can be adequately supported. Extend the hose about a quarter of the way down into the tank.

   e. Ballast the tank with at least 45.5 kg (100 lbs) if possible.

      Explantion: When the inlet pump is shut off, the well will syphon back to the level of the hose end. The buoyancy force

NWMAR116480

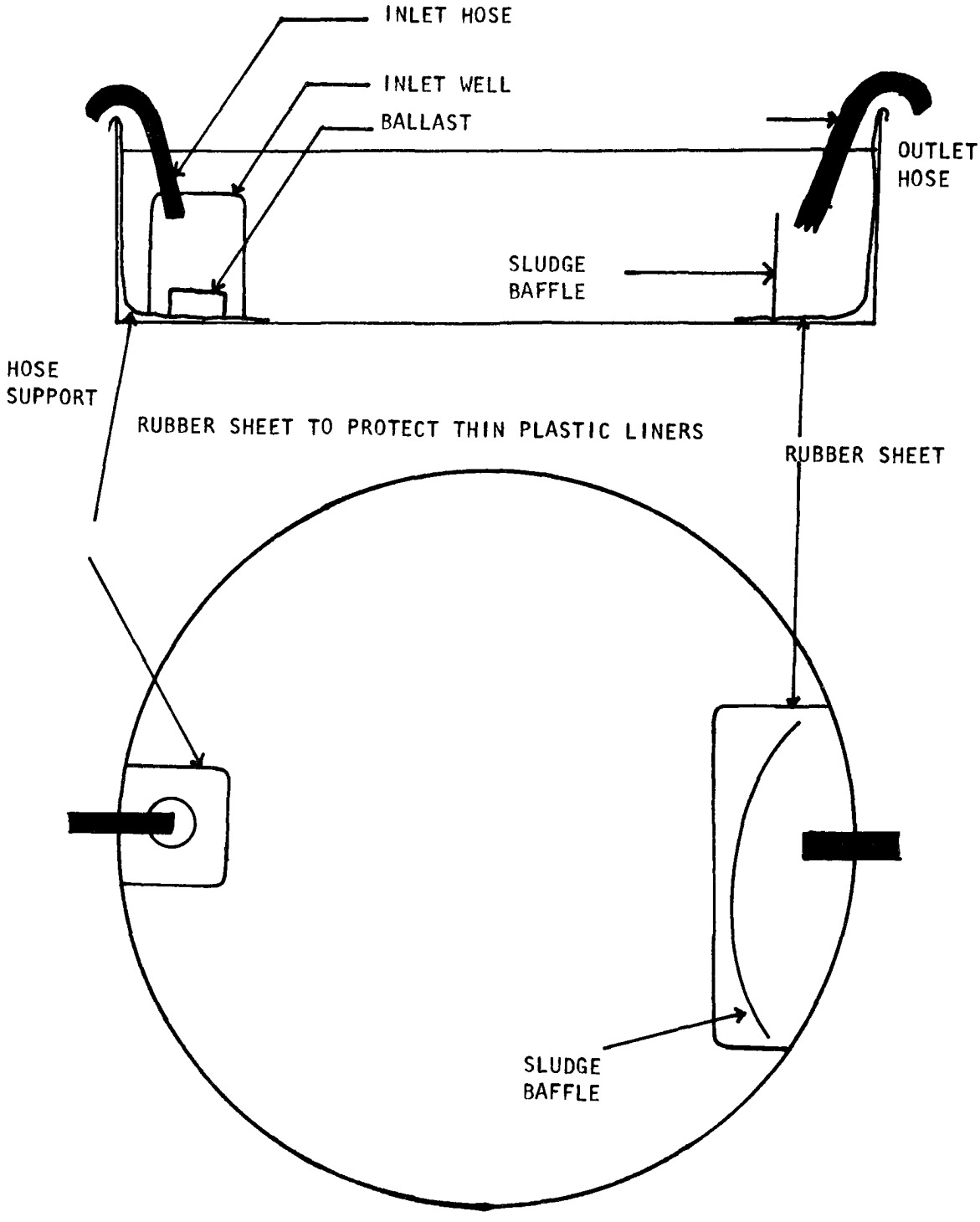


Figure 61. Batch sedimentation tank schematic

NWMAR116481

could cause the well to tip over. Remedies are to shorten the well or not extend the hose down as far.

3. Construct a sludge baffle according to the following guidelines (see Figure 61).

   a. Materials heavier than water or ballasted.

   b. Height - approx. 1/2 process height.

   c. Length to form a semicircle around the drawoff point, 180° from the inlet.

      CAUTION: The baffle should not be constructed as a dam and therefore suitable gaps should be present to allow the supernatant to flow easily around the baffle during drawoff.

4. Serrate the end of the outlet hose as shown below (Figure 62).

   Explanation: A square edge hose will attach itself solidly to the tank by virtue of the suction and require that the drawdown pump be turned off to release it.

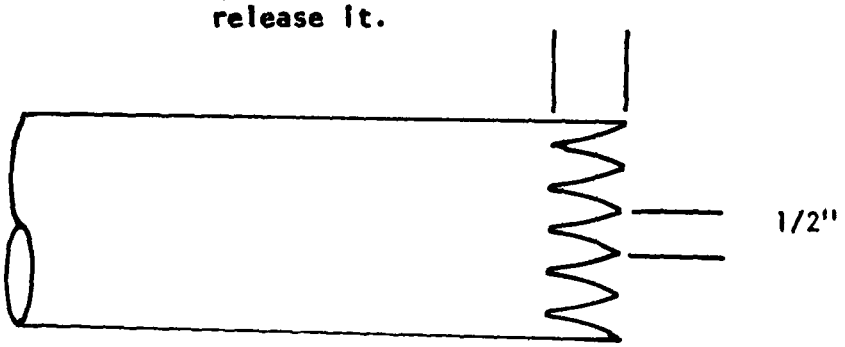


Figure 62. Serrated outlet hose.

B. Construction of Flotation Tanks - Because sludge will accumulate in a flotation tank the basic construction is identical to the sedimentation tank. The only exception is the use of a floating barrier around the outlet to prevent any uncollected floating materials to be drawn into the influent.

C. Presettlers - These devices do not attempt to produce quiescent conditions but rather to allow separation of gravel, sand, fibrous debris, leaves, grass etc., as well as to act as equalization tanks and pulse deadener for reciprocating pumps before transferring the fluid by centrifugal pump to the sedimentation tank. There are a wide variety of ways a presettler could be constructed. Only one technique is being shown here to illustrate possible ways in which the desired separation can be accomodated.

NWMAR116482

Option I - Features: Continuously Operated Swirl Tank (Figure 63).

1. Velocity is dissipated through a horizontal flow pattern which causes the tank contents to swirl.

2. The incoming fluid travels around the complete periphery of the tank before being discharged.

3. Sequential screens from coarse to fine can separate suspended and floating materials from the swirling fluid.

4. Desludging and skimming can be performed continuously.

6.5.6 Operational and Maintenance Steps

A. Sedimentation

1. Fill the tank to the desired freeboard height.

2. Allow the contents to settle for a specified detention time.

3. Draw off the supernatant to the point where solids are at the point of flowing around the outlet baffle.

Desludging

1. Following the last supernatant drawoff operation draw down the entire contents of the tank Keep the suction fitting or hose end submerged at all times in the mud.

Explanation: A certain minimum amount of water is necessary to effectively pump solids. Keeping the suction head in the mud will retain the necessary water in the tank. Water can be replenished to facilitate solids removal as necessary.

2. Reconcentration of Settled Sludges - Further solids separation will occur in the sludge storage tank and so supernatent drawoff can again be performed. Chemical precipitation as described in Section 6.6.9 can also be used to increase the separation process.

B. Flotation

1. Fill the tank to the desired freeboard height.

2. Allow the suspended material to float to the surface for a specified detention time. Draw off the underflow, taking precautions not to draw in settled sludges. Draw down can probably be started during the latter stages of skimming.

NWMAR116483

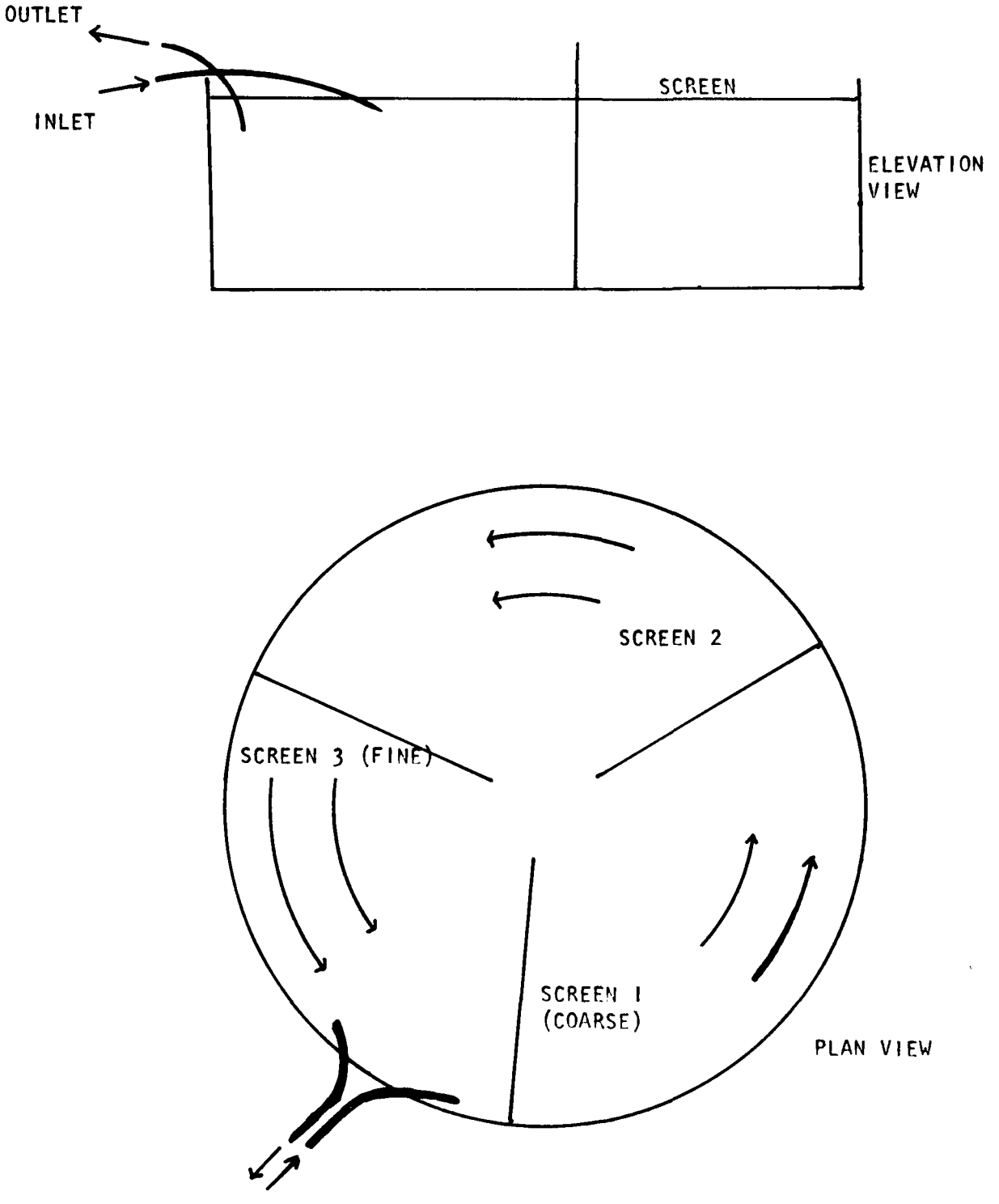


Figure 63. Continuous operated swirl tank presettler.

NWMAR116484

Desludging

1. Desludge the tank during shutdown times as required.

2. Reconcentration of flotated and settled wastes can be performed provided the wastes are kept separated.

3. Skim tank carefully taking care to remove as little water as possible.

6.5.7 Troubleshooting

A. Sedimentation

No settling or poor settling	1. Increase settling time.
	2. Repeat bench testing and revise system to include chemical addition if necessary.
Too much sludge	1. Add necessary presettlers.

B. Flotation

No effective flotation	1. Increase detention time.
	2. Repeat bench testing and revise system to include chemical addition if necessary.

6.6 CHEMICAL REACTIONS

6.6.1 General

There are three types of chemical reactions being considered in this chapter. Each of these are used to treat various chemicals as specified in Chapter 4. In general, the wastewater is pumped into a tank, the treatment chemical or chemicals added to a predetermined endpoint, the system allowed to react and then the treated water is removed. The three types of reactions considered are neutralization, precipitation and oxidation/reduction.

To determine the amount of chemicals needed, bench testing operations are necessary. These involve small scale chemical addition to a sample of the actual wastewater. The volume of chemical needed to treat the entire spill and other operating parameters can then be established. After the chemical requirements are established, the process tankage required is calculated using procedures similar to those for gravity sedimentation. However, neutralization and oxidation/reduction reactions do not produce significant amounts of sludge and therefore, are easier to handle.

NWMAR116485

This section has been split into sub-sections to deal separately with the different types of chemical reactions up to and including the sub-section on design considerations. However, the construction details and operation and maintenance procedures have been combined because of the similarities in all of the chemical reaction procedures. Information on chemical injection, mixing and flocculation procedures have also been presented there.

6.6.2 Process Description: Neutralization

Neutralization is a process in which hydroxyl or hydrogen ions are added to a solution to produce an approximately equal concentration or a pH of 7. This process is used to reduce the acidic character of a spilled chemical by addition of caustic soda (NaOH), lime (CaO) or slaked lime ($Ca(OH)_2$) or soda ash (Na_2CO_3). Alkaline wastewaters (pH>9) are neutralized by the addition of hydrochloric acid (HCl), sulfuric acid (H_2SO_4) and acetic acid (HCH_3COOH).

The specific reagents to be added are indicated on the actual flow scheme in Chapter 4. Strongly basic, NaOH, or strongly acidic, H_2SO_4 and HCl, chemicals must be added very carefully to avoid creating a violent reaction. Complete mixing of the contents is especially important to avoid pockets of strong chemicals in the tank. The other reagents are considered weaker acids (acetic) and bases, (lime and sodium carbonate (soda ash)). In some schemes, acids used may be interchangeable with others and the choice is established by acceptable anion concentrations in the discharge. Any discharge restrictions for chloride, sulfate, or acetate ions should be established before the reagents are used. In general, strong reagents react faster than others. Lime has a relatively slow reaction rate and should be slaked with water before use. Even after slaking, the reaction time should be extended.

To establish the amount of neutralizing chemical needed, a bench scale test is performed. The endpoint of the reaction is a change in the pH to the desired or required level, generally pH 6-9. The diluted chemicals are added to a sample of the actual wastewater and then the required amounts are scaled up to allow both ordering of chemicals and treatment of the individual batches.

Generally, a 10 minute complete mix has been found to be satisfactory in field operation, however, addition of lime may require 15-30 minutes to stabilize and this extra time must be allowed.

6.6.3 Bench Testing Procedure - Neutralization

Equipment needed:

1. Beaker (preferable 500-1,000 ml).
2. Burette or graduated pipette.
3. Burette stand or pipette bulb.
4. pH meter or pH paper.
5. Mixing apparatus.
6. Graduated cylinder = 1/2 volume beaker.

NWMAR116486

Chemicals needed:

1. Acidic wastewater

   a. slaked lime slurry - 100 mg/ml as CaO
   b. 100 mg/ml NaOH (sodium hydroxide).
   c. 100 mg/ml Na_2CO_3 (sodium carbonate)

2. Alkaline wastewater

   a. 100 mg/ml HCl
   b. 50 mg/ml H_2SO_4
   c. 100 mg/ml HCH_3COOH

Procedure:

1. Place known volume of wastewater into a beaker two times its size.

2. Mix and record initial pH.

3. Add neutralizing chemical in increments and record volume added and pH after equilibrium has been reqched (lime requires a longer time to reach equilibrium).

4. Continue adding neutralizing chemicals to reach pH 4 or pH 10.

5. Plot neutralization curve, pH versus amount of chemical/liter of wastewater.

6. Choose desired pH, (usually 7) and corresponding dosage.

7. Repeat steps 1 and 2 and then add the amount of chemical required to achieve desired pH (usually 7).

8. Record time required to achieve final pH, note volume of any accumulated sludge.

Calculations for Neutralization Test:

1. Calculate the amount of chemical required per gallon of wastewater (see Section 7.8) and for entire spill.

2. Estimate the amount of time required per batch (see Table 28).

3. Calculate volumes of sludge produced per gallon of wastewater (if any).

$$\text{Volume of sludge} = \frac{\text{volume sludge}}{\text{volume test sample}} \times \text{volume of wastewater to be treated.}$$

NWMAR116487

TABLE 28. CHEMICAL REACTION OPERATING PARAMETERS

Process	Mixing		Endpoint	Chemicals
	Type	Time		
Chemical Sedimentation	Rapid Flocculation None	1-5 min 5-15 min 30-60 min depends on rate and process height	Clarified water and good settling	Ferric Chloride Aluminum Sulfate Polyelectrolytes
Neutralization	Rapid	10-30 min Use 30 min for lime addition	Add to pH 7, use pH paper or meter to check	Calcium Hydroxide, Calcium Oxide, Sodium Hydroxide, Sodium Carbonate, Sulfuric Acid, Acetic Acid, Hydrochloric Acid
Precipitation	Rapid Flocculation None	1-5 min 5-10 min 30-60 min depends on rate and process height	Varies to a pH or until residual of reactant or until clarified	Calcium Hydroxide, Sodium Hydroxide, Sodium Carbonate, Sodium Biocarbonate, Sodium Sulfate, Sodium Sulfide, Potassium Chloride
Oxidation Chlorination	Rapid	10-30 min	To a HOCl residual of 1 mg/l	Sodium Hypochlorite
Aeration	Air mix	depends on test	D.O. measure to 70% of saturation or other	Air
Reduction	Rapid	10-30 min	Large ORP change/ Cr^{+6} -- Cr^{+3} is yellow to green HOCl reduction, no Chlorine residual	Sodium Bisulfite, Sodium Sulfide

NWMAR116488

6.6.4 Process Description: Precipitation

Precipitation is a process which removes pollutants by reacting these materials to form an insoluble product (51). This process results in a reaction rather than physical adsorption and is therefore different from coagulation and sedimentation, however, treatment construction is similar. There are a series of steps to allow effective precipitation: 1. chemical addition; 2. rapid mix; 3. addition of coagulant; 4. flocculation; 5. sedimentation; and 6. filtration. However, each precipitation reaction may not require all of these processes and secondly all of these steps except filtration can be performed in one tank.

Precipitation is used to remove many types of metal cations and some anions such as fluorides and sulfides. The reagents involved in the precipitation reactions include calcium and sodium hydroxide and sodium carbonate, bicarbonate, sulfate and sulfide. These chemicals are added to reach certain pH or in some cases to a small residual of the reagent. Sulfide amount and addition can be checked using an electrode or by reacting with zinc acetate. The sulfide residual is present when a white precipitate appears or if zinc acetate indicating paper changes color. However, excessive sulfide addition must be avoided because of the strong reducing ability of this material. The other precipitation chemicals (e.g., lime, soda ash) are added to a specific pH, allowed to mix and then to settle. If no definitive test is available, the addition of a reactant to a distinct floc, and then analysis of the supernatant for the contaminant is necessary. However, the metallic hydroxides are difficult to remove so coagulation and flocculation using alum, ferric chloride or polymers (or a combination) may be helpful. The procedure to establish chemical dosages of the coagulant is the same as that outlined in the gravity sedimentation section.

The amounts of chemicals required to precipitate the entire reactant are determined by running a bench scale test. This test is similar to the procedures outlined earlier in Section 6.5. A known volume of wastewater sample is reacted to the endpoints specified in the treatment specifications from section 6.5.2. The chemicals are mixed, reacted and then settled. If necessary a coagulant is added to improve the settling. Once the test is completed, the data is scaled up to determine the amount of chemical required. In general, 25% excess chemical should be ordered.

When operating a field unit, the tank contents should be mixed completely for 5-10 minutes (or 15-30 minutes if lime is added). If flocculation is required, a 10-15 minute flocculation at a speed just fast enough to keep the solids suspended is required: the settling time will be equal to

$$\left[\frac{\text{height of tank m}}{\text{settling rate m/min}}\right] \times (2\text{-}3)$$

The 2-3 is the scaleup factor for most settling operations.

NWMAR116489

6.6.5 Bench Testing Procedure: Precipitation

Equipment needed:

1. Beaker (preferable 500-1500 ml).
2. Graduated cylinder (1/2 volume of beaker).
3. Burette or graduated pipette (pipette is better for lime addition).
4. Burette stand or pipette bulb.
5. pH meter, or pH paper, or chemical testing kit, or zinc acetate paper, or zinc acetate
6. Mixing apparatus.
7. 1,000 ml graduated cylinder.
8. Stop watch or watch with second hand.

Chemicals needed:

1. lime (calcium hydroxide) $Ca(OH)_2$.
2. Sodium hydroxide NaOH.
3. Sodium carbonate Na_2CO_3.
4. Sodium bicarbonate $NaHCO_3$.
5. Sodium sulfate Na_2SO_4.
6. Sodium sulfide Na_2S.
7. Coagulants
   a. ferric chloride.
   b. aluminum sulfate.
   c. polyelectrolytes.
8. Sulfuric acid (H_2SO_4) may be needed.

Procedure:

1. Place known volume of wastewater into beaker two times its size.
2. Mix/record initial pH.
3. Add acid to adjust pH if necessary.

NWMAR116490

4. Add reagents (as indicated) in increments and record pH until the desired pH level is reached while mixing for 2 minutes. If pH is not the controlling factor as for sulfate:

   Take samples at increments after mixing and analyze for sulfate concentration using Hach kit or spectrophotometer.

   For sulfide:

   Take samples at increments after mixing and analyze for sulfide concentration using a $S^{=}$ probe or precipitation with zinc acetate (paper or chemical).

   For others:

   Add chemical until a good floc is formed.

5. Allow to settle and note the rate of settling using a stopwatch and increments on the beaker.

6. Take sample of supernatant for analysis of contaminant.

7. Plot pH versus volume of reagent added/liter of waste, sulfate/sulfide residual versus volume of reagent added/liter of waste or concentration of contaminant versus volume of reagent added.

8. Choose point on curve to establish amount of reactant needed.

9. Place another wastewater sample into 1 liter and add chemical while mixing.

10. Check to insure endpoint has been reached.

11. If the settling is poor, add coagulants in the amounts indicated in the previous section and establish a new settling rate (section 6.5.2).

NWMAR116491

12. Note sludge volume and height in the cylinder.

Calculations from Data:

1. Scale up the results to establish the amount of chemical required per volume of wastewater to be treated.

2. Calculate amount of sludge expected per volume of wastewater.

3. Calculate the amount of time needed for entire reaction (see Table 28).

6.6.6 Process Description: Oxidation/Reduction

Oxidation/reduction involve the transfer of electrons from one species to anogher. Oxidation involves the loss of electrons and reduction, the gain of electrons. In some instances these reactions can be used to change hazardous species into less harmful forms.

Reduction: In this manual, reduction reactions are only applicable to a small number of compounds. Sodium bisulfite has been recommended as the reducing agent, however, other chemicals including sodium sulfite and sodium metabisulfite can also be used. Reduction is used as a pretreatment for chromate or chromyl compounds to change them to the chromic state for precipitation. This reaction must occur at low pH, so adjustment to pH 2-3 with acid is recommended. The endpoint is best determined by either a large oxidation reduction potential (ORP) change, as measured by a platinum electrode, or removal of the chromate (e.g. Cr^{+6}) as measured by a chemical test. A visual indication is the color change from yellow to green and it can be used as a confirming indicator. Reduction is also used when either sodium or calcium hypochlorite are to be removed. The pH is reduced to three and the reducing agent can be added until an acceptable chlorine residual is measured. Excess reducing agent can be removed by addition of more wastewater or aeration.

To determine the amount of sodium bisulfite, or its equivalent, to order, a small scale bench testing procedure is used. A known volume of wastewater is placed in a beaker and the reagents are added to the endpoints indicated in the treatment specifications. The reaction time and any sludge volume should be noted by the OSC.

Once the amount of chemical required has been established, the chemicals should be ordered from suppliers. In operating a large scale reduction process, the acid should be added (75%, then in increments) and mixed approximately one to two minutes and the pH should be determined. Then the bisulfite can be added to the pre-established endpoint, in the same manner, e.g., add 75% of the total and then increments until the endpoint is reached. The tank should then be mixed for ten minutes to insure complete reaction and then the residual rechecked for discharge.

NWMAR116492

Oxidation: Oxidation reactions are more common than reduction and more reagents can be used. Chlorination and aeration are two ways to oxidize materials. Chlorination is discussed here and aeration is addressed in a later section.

Chlorination reactions are most commonly used to oxidize cyanide to the less toxic cyanate and then to carbon dioxide and nitrogen. These reactions are most effective at alkaline pH so soduim hydroxide is often added with hypochlorite. The chlorine is most safely added in the form of liquid hypochlorite in concentrations of 5%-6% (household bleach). On a bench scale the concentration is diluted tenfold or more. Chlorine doses are determined by doing a bench scale test until a slight residual of chlorine remains as measured by a test kit. Once operating in the field, both NaOH and hypochlorite should be added at 75% of the expected volume and then in increments to the desired endpoint. The system should then be mixed and additional 15 minutes and the residual chlorine tested before discharge to be certain it meets acceptable limits.

6.6.7 Bench Test Procedure - Reduction

Equipment needed:

1. Beaker (500-1500 ml).
2. Graduated cylinder (1/2 volume of beaker).
3. Burette or graduated pipette.
4. Burette stand or pipette bulb.
5. pH paper or meter.
6. ORP meter, chemical test kit or swimming pool test kit.
7. Mixing apparatus.

Chemicals needed:

1. Sulfuric acid H_2SO_4.
2. Sodium bisulfite.

Procedure:

1. Place known volume of wastewater into beaker two times its size.
2. Mix/record initial pH.
3. Add acid to pH 2-3.
4. Add sodium bisulfite to
   a. large ORP change
   b. removal of chromate (CR^{+6})

NWMAR116493

5. React ten minutes.

6. Scale up to establish amounts of reagents needed.

6.6.8 Bench Test Procedure: Chlorination

Equipment Required:

1. Beaker (500-1500 ml).
2. Graduated cylinder (1/2 volume of beaker).
3. Burette or graduated pipette.
4. Burette stand or pipette bulb.
5. pH meter or pH paper.
6. Chlorine test kit (Hach, swimming pool).
7. Mixing apparatus.

Chemicals needed:

1. Sodium hydroxide-NaOH.
2. Hypochlorite solution.

Procedure:

1. Place known volume of wastewater into beaker two times its volume.
2. Mix/record initial pH.
3. Add NaOH to desired pH.
4. Add chlorine in increments mix and check residual.
5. Stop adding chlorine when residual appears.
6. Allow to mix five minutes, check residual.
7. Add more chlorine if necessary to reach a persistent residual.
8. Note any sludge produced.
9. Scale up to the amount of hypochlorite required to treat entire spill.

NWMAR116494

6.6.9 Design of Chemical Reaction Processes

1. Calculate amounts and order chemicals from the manufacturer (see Section 7.9 for information).

   Explanation: Chemicals will require long delivery times and should be ordered immediately. If the total amount of chemical is not available immediately, have a partial order shipped first.

2. Design the volume of chemical tanks needed to hold one day's supply of chemicals.

   a. Calculate volume of chemicals needed per day:

$$\frac{\text{volume of feed solution}}{\text{day}} = \frac{\text{volume of feed solution}}{\text{volume of wastewater}} \times \frac{\text{volume of wastewater}}{\text{day}}$$

   b. Calculate size of tanks needed per day:

$$\text{volume of tank} = \frac{1.2 \times \text{volume of feed solution chemicals}}{\text{day}}$$

   c. Determine if single or multiple feed tanks are needed.

      Explanation: If large volume of chemicals are needed daily, a smaller feed tank can be used with a separate mixing tank. Chemicals can be mixed in batches throughout the day to provide a supply for the feed tank.

   d. Repeat steps (a-c) for each chemical.

3. Apply data from bench tests to establish a detention time.

   Explanation: Refer to Table 28 for general reaction times. Follow calculations when settling is necessary

$$\text{Detention time} = \frac{\text{process height}}{\text{settling rate}} \times 3$$

   Example: Refer to section 6.5.4 for an example of the calculations.

4. Choose a tank type using the following criteria (Section 7.3):

   a. The shallower the tank the shorter the total time needed

NWMAR116495

for settling, when necessary. Also, mixing gradients may be more effective. All depths should be greater than 0.91m (3 ft) with at least 0.305m (12") of freeboard.

b. Choose a desludging technique if precipitation or chemically treated sedimentation is used. Refer to section 6.5.4 for information on desludging techniques.

5. Calculate the process volume per tank according to the formulae presented in Figure 73.

6. Calculate fill and draw times.

$$t_{fill} = t_{draw} = \frac{Vn}{\text{pump rate}} = \frac{Vn}{Qn}$$

Explanation: Process flow rate has been previously established using limiting factors design (see Section 5.4).

7. Calculate total time of tank use per batch.

T_T = total time = 2 (t_{fill}) + t_d (detention time)

Explanation: t_{fill} is calculated from Step 6.

8. Establish the frequency of desludging.

$$\text{time between desludging} = \frac{0.25 \times Hp \times TT}{\frac{\text{accumulation of sludge}}{\text{batch}}}$$

Explanation: Desludging must be done when the sludge accumulates to 1/4 of the available process height. Sludge will accumulate considerably in the precipitation reactions or chemically treated sedimentation. Oxidation/reduction and neutralization reactions should not generate much, if any, sludge. Therefore, if sludge accumulation is negligible, Steps 8-9 can be eliminated.

$$\frac{\text{Accumulation of sludge}}{\text{batch}} = \frac{\text{height of sludge in test}}{\text{height of liquid in test}} \times \text{process height}$$

9. Calculate the effective tank volume. (Volume is reduced by sludge accumulation).

$$\frac{\text{amount of sludge accumulation}}{\text{between desludging}} = \frac{\text{amount of sludge}}{\text{batch}} \times \frac{\text{batches}}{\text{before desludging}}$$

$$\text{batches between desludging} = \frac{\text{time between desludging}}{\text{time per batch}}$$

NWMAR116496

Calculate new effective volume

V_n eff = $\frac{\pi D^2}{4}$ x effective depth = 0.78 D^2 x effective depth.

10. Calculate process volume required.

$V_p = Q_p\ (T_T)$

Explanation: Q_p or system flow rate is already established.

11. Calculate number of tanks needed.

$$n = \frac{V_p}{V_n \text{ eff}}$$

Explanation: Always round n to the higher round number.

12. Calculate the sludge volume accumulated per day.

$$\frac{\text{sludge volume}}{\text{day}} =$$

$$\left(\frac{\text{height of sludge}}{\text{per batch}} \times \frac{2 \times \text{number of batches}}{\text{day}} \times 0.78\ D^2\right)$$

Explanation: It is assumed that the sludge is disposed of once per day and the tanks are cleaned for the following day.

13. Calculate the number of sludge tanks needed.

$$n_{sl} = \frac{\text{sludge volume/day}}{\text{volume of 1 tank}}$$

Explanation: It is assumed that the sludge disposed of once per day and the tanks are cleaned for the following day.

14. Calculate the capacity required for each rapid mix tank.

$V_{RM} = 5 \times Q_p \xrightarrow{\text{to}} 10 \times Q_p$

Q_p = process flow rate from Section 5.4

Explanation: The rapid mix tank will be designed on a continuous flowthrough basis with a detention time from 5-10 minutes. One tank will be necessary for each process tank.

NWMAR116497

15. Choose rapid mix tank type from Section 7.3 following these guidelines.

    1. Sturdy construction.
    2. Compatible materials for chemicals being added.
    3. Height to diameter ratio 0.5-1.5 if possible.

6.6.10 Construction of Chemical Reaction Processes

Two separate systems are described here to accomplish the various chemical reaction requirements; aeration processes are discussed separately.

A. Chemical addition and mixing.
B. Chemical addition, mixing and flocculation.

A. Chemical Addition and Mixing - This option is used for the addition and mixing of one or more chemicals in a continuous flow rapid mixing tank followed by chemical reaction to a predetermined endpoint in a batch operated tank. A schematic diagram of the system is shown in Figure 64. Construction details follow.

1. Install rapid mix tank as instructed in Section 7.3.

    a. Construction of submerged jet (Figure 65) for the process flow transfer pump (52).

        Explanation: Recommended for most mixing conditions, although the faster mixing chemicals will be properly mixed from the normal transfer hose discharge velocities.

        Principle of operation - When a submerged jet is introduced into a tank, the jet stream traverses a significant distance through the water before the jet stream velocity dissipates. The jet tends to entrain fluid, producing significant mixing and the creation of a turbulent zone.

        1) A nozzle can be constructed by installing a combination nipple into the hose end of transfer pumps 1 and 2 and bushing it down to the desired jet diameter, D_j (see Figure 65).

            Explanation: Commercially available tank eductors may also be used; they have a shroud around the nozzle to increase entrainment and intensity of the turbulence.

            Jet diameter will depend on tank configuration and detention time

NWMAR116498

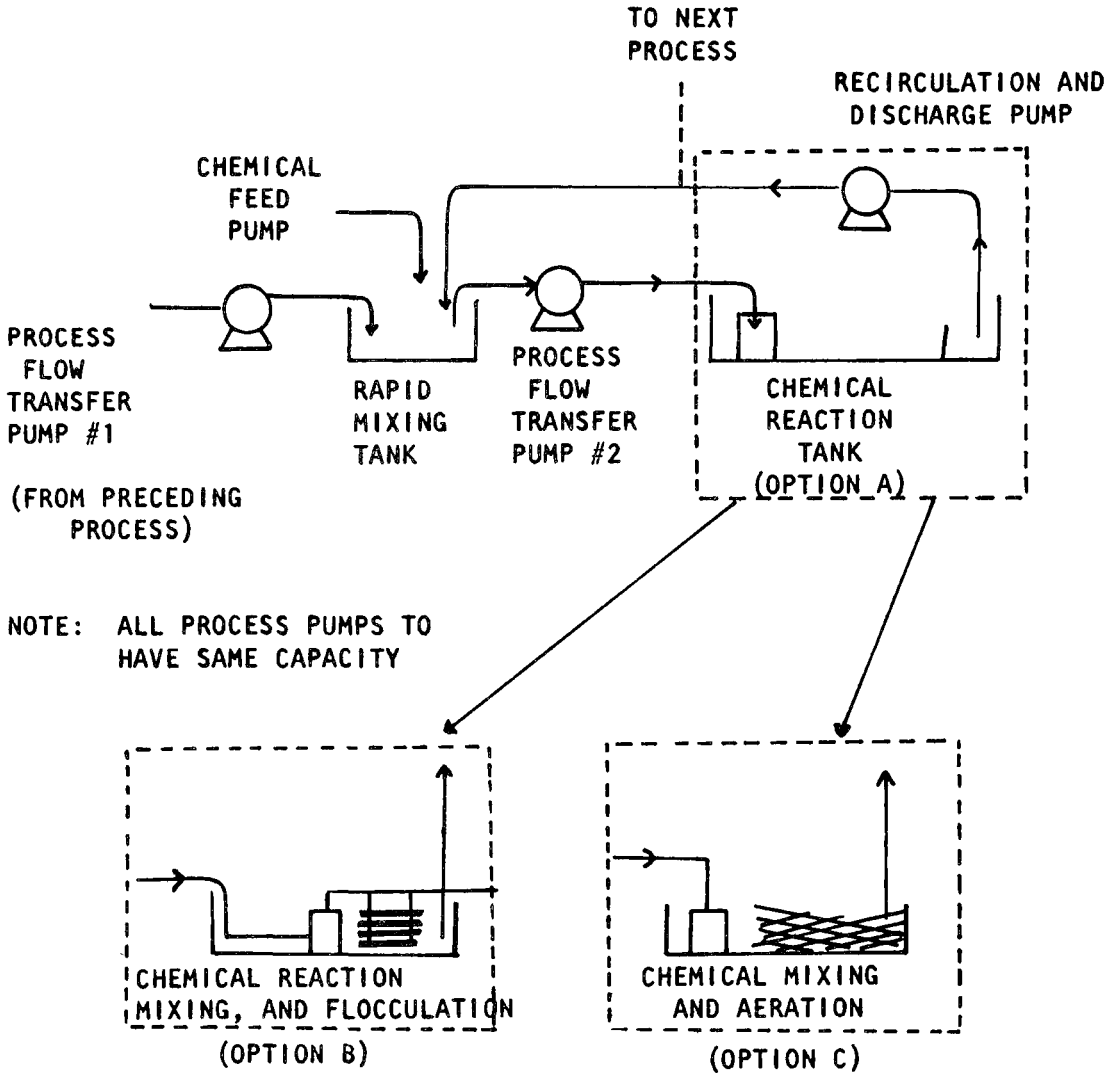


Figure 64. Schematic diagrams of chemical treatment options.

NWMAR116499

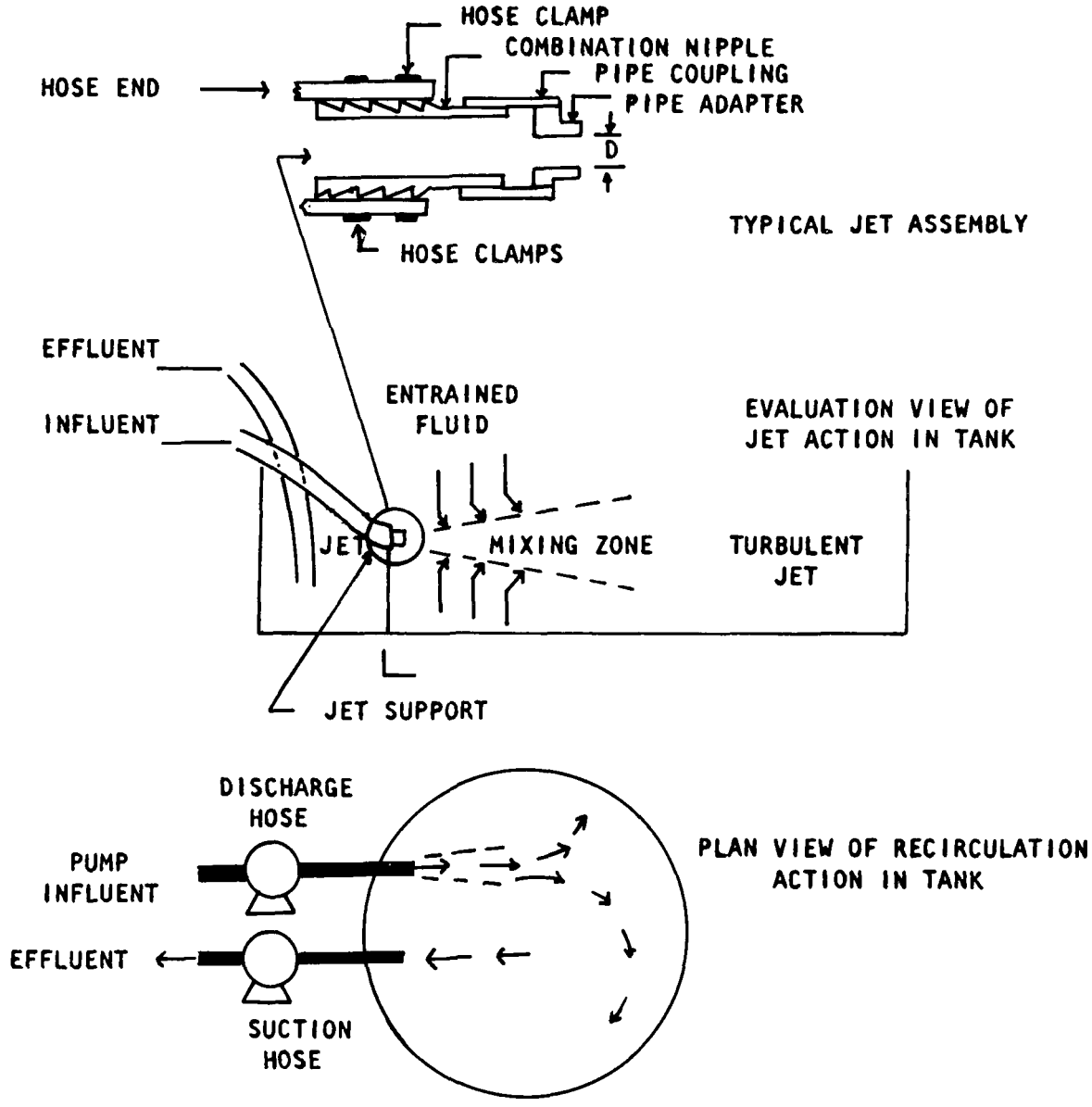


Figure 65. Installation of jet mixer in rapid mix tank.

NWMAR116500

and so it is desirable to obtain bushings in the size range calculated below and basing the final selection on a trial basis (52)

$$D_j = \sqrt{\frac{Q_p}{7}} \text{ to } \sqrt{\frac{Q_p}{20}} \quad \text{(inches)}$$

where Qp = process flow (gpm) gpm
gpm x 3.785×10^{-3} = cum.

Explanation: The above formula will provide a discharge velocity range from 6.1-9.1 mps (20-40 fps).

2) The jet must be adequately supported in the tank because the reaction force from the jet will tend to push the hose backwards.

3) When sizing the effluent pump add 21.3m (70 ft) to the total friction head to account for the nozzle head loss.

4) Guidelines for placement of nozzle and suction hose: Orient the jet stream so that it traverses a long distance before hitting a tank wall.

Position the effluent suction hose behind the jet. Alter the location of jet and suction as necessary to achieve thorough turnover of the tank contents.

2. Chemical reaction tank - same as construction of sedimentation tank

3. Chemical injection - usually submerged and located in the inlet well.

B. Chemical Addition, Mixing and Flocculation - This option is used for the addition of one or more chemicals followed by flocculation and sedimentation. A schematic diagram of the system is shown in Figure 66. Construction details follow.

1. Rapid Mixing Tank - identical to construction option A, Steps 1-2.

2. Construction of Flocculation Tanks (Figure 66) - Tank sizing has already occurred as part of the design process in Section 6.5.5. The remaining construction steps involve flocculator construction, inlet well, and outlet baffle.

NWMAR116501

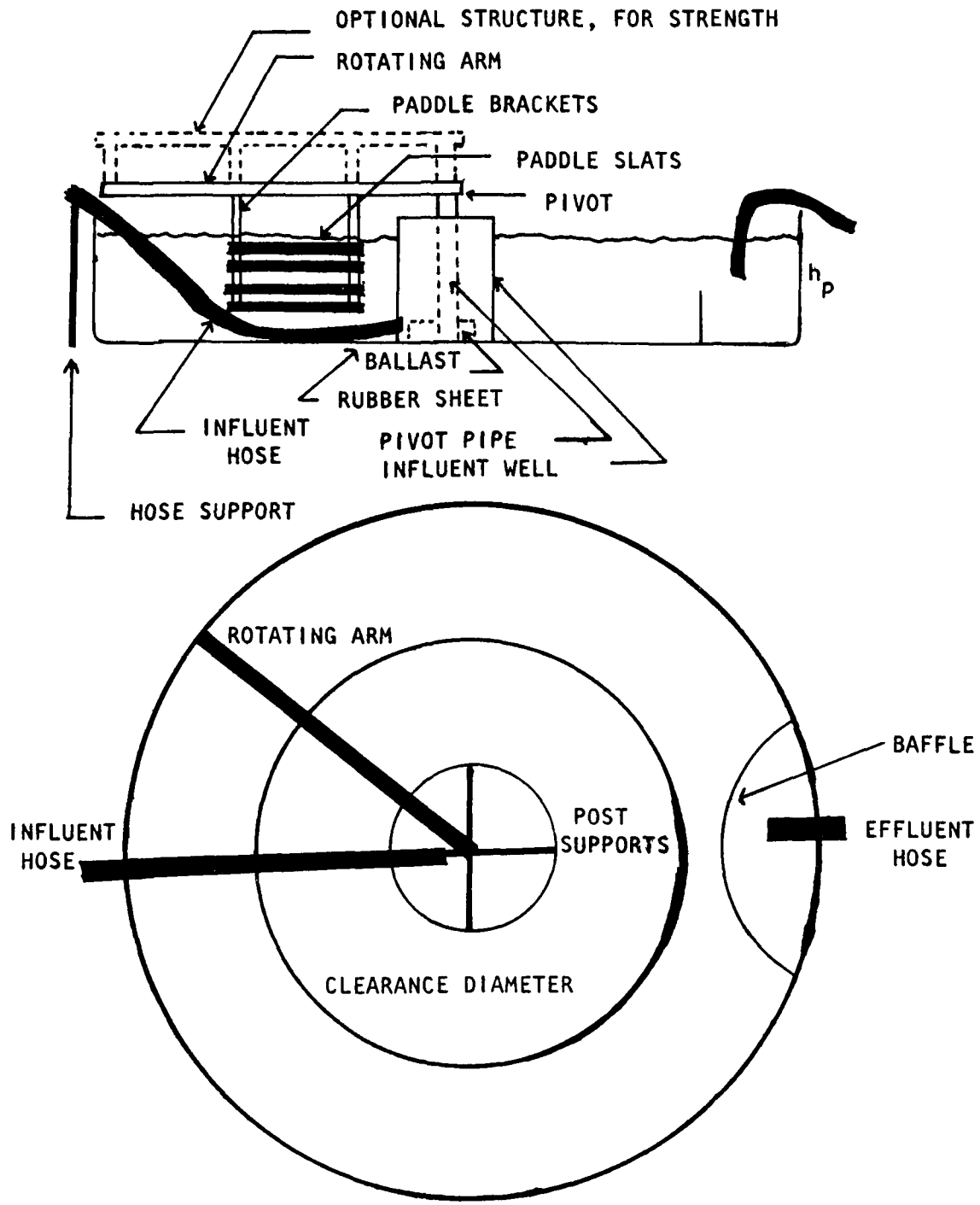


Figure 66. Construction of a mechanical flocculator.

NWMAR116502

The gentle rolling action necessary for flocculation requires a minimum of fluid shear to disrupt the floc. It can be produced with a canoe paddle in certain cases using the sedimentation tank construction described in Section 6.5.5. If possible, the construction of a flocculator as described below will give much more satisfactory mechanical results.

a. Tank installation - A flat bottom tank is required. Tank liners should be protected with rubber sheets under the inlet well and outlet baffle. A 0.9-1.22m (3-4 ft) clear space is needed all the way around the tank.

b. Obtain or construct an inlet well according to the following quidelines.

    1) The configuration of the tank is not important provided that it be sturdy (preferably steel) and have a level top edge.

    2) Total height approx: 3/4 process water height.

    3) Total length of top edge approx 0.336m/lpm (1/2 inch per gpm).

    4) A hole must be cut to permit the installation of the inlet hose. After insertion of the hose into the hole, rags or other packing should be used to close off the opening around the hose.

    5) Install a pivot post, e.g., steel pipe, in the tank. The pipe can be welded to the tank bottom and supported by three bars to act as post supports at the top.

    6) Ballast the tank with heavy weights to provide stability approx. 45.5-91 kg (100-200 lbs) of metal. Place ballast so as not to interfere with free flow of inlet hose.

c. Construct the Flocculator Assembly from wood or pipe as shown in Figure 66 according to the following guidelines.

    Rotating arm - long enough so that it can be held by a person who will walk around the tank.

    Pivot - very solidly joined to rotating arm and extending down about six inches into the pivot pipe.

NWMAR116503

Paddle Brackets - very solidly attached to rotating arm and mounting the paddle slats.

Note: Especially in wooden construction, it may be desirable to use a two-arm construction which would reduce the stress at the high stress points (shown with astericks on Figure 66).

Paddle Slats - About four are necessary with spaces in between. Top slat should be submerged; bottom slat at a height of one-third the process height; and inside and outside rotational diameters to clear the inlet well, outlet baffle, and inlet hose.

d. Construct an outlet baffle and serrate the end of the outlet hose as described in Section 6.5.5, Steps A, 3-4.

6.6.11 Operation and Maintenance of Chemical Reaction Processes

The mode of operation for all chemical reaction processes is batch operation with end point control. Prior to giving explicit operational instructions for each of the three design options described previously, the steps necessary to produce end point control will be outlined. However, prior to any operation, the treatment chemicals must be mixed to the proper feed concentrations. Instructions are included in this section.

Step 1: Mixing the chemicals into the desired feed concentrations.

a. Calculate the amount of water needed to dilute the concentrated chemical (Section 7.8.2).

b. Add water to the chemical tank and agitate using an impeller mixer (Section 7.5).

c. Follow any specific instructions for mixing listed in the chemical data sheets (Section 7.8.3).

d. If no special instructions are given, follow these procedures:

Solids - Slowly drop powder or pellets into the swirling water and mix until dissolved or in suspension. Add more chemical until the entire amount has been added. If a lime slurry is being prepared, continue mixing throughout the entire operating period. Take precautions to avoid breathing dust or directly touching the chemicals.

Liquids - Pump the concentrated liquid slowly into the tank using a chemical feed pump. Mix thoroughly, continue adding liquid until the entire amount has been

NWMAR116504

added. Avoid fast addition which could result in the evolution of large amounts of heat.

Step 2: Endpoint Measurement - In order to accurately measure the reaction completion, the endpoint must be measured during the actual treatment of the system. The efficiency is also a function of the effective mixture of the contents. The amount of chemical expected to be used per batch is first calculated, 75% is added during the influent flow and the remainder is added in increments to the endpoint.

a. Calculate the amount of chemical needed/batch.

$$\frac{\text{volume of feed solution needed}}{\text{volume of wastewater batch}} =$$

$$\frac{\text{volume of batch chemical added from bench test}}{\text{volume of wastewater}} \times \text{conc. of bench scale chemical}$$

$$\frac{}{\text{concentration of feed solution}}$$

$$\frac{\text{volume of feed solution}}{\text{volume of wastewater}} =$$

$$\frac{\text{volume of feed solution}}{\text{volume of wastewater}} / \times \frac{\text{volume of wastewater}}{\text{batch}}$$

Example: Add 25 ml of 1N H_2SO_4 to 500 mls of sample. Volume of process tank is 37.8 cum or (10,000) gal. Use H_2SO_4 at 25% strength or about 9 N.

$$\frac{25 \text{ ml}}{500 \text{ ml}} \times \frac{1N}{9N} = 0.0055 \text{ml } 9N/\text{ml sample}$$

Metric: 0.0055 x 37.8 cum = 0.201 cum of feed H_2SO_4.

English: 0.055 x 10,000 gal./batch = 55.5 gal. of feed H_2SO_4

b. Determine and collect endpoint measuring apparatus.

Explanation: The endpoint device may be a pH meter, portable chemical analysis kit, ORP meter, zinc acetate paper or other specific indicator. The faster the response the better.

c. Add 75% of the calculated volume during the tank filling operation.

NWMAR116505

Explanation: Calculate amount to add (Step a). Use 75% of the chemical to avoid overruning the endpoint. After the first batch, use 75% of the amount added to the preceding batch as the starting point. Since the strength of the wastewater will vary throughout treatment, this procedure provides an extra safety precaution.

Step d - Allow tank to mix.

Step e - Check endpoint of reaction at various points in the tank.

Explanation: This procedure will allow the operator to check the thoroughness of mixing and will allow determination of the endpoint. If the analyses give different results at different points in the tank, then further mixing is necessary.

Step f - Add more chemical in increments to reach the final endpoint (again check the endpoint at various places within the tank to insure complete mixing).

Step g - If more than one chemical is added; add the second chemical after the first following the same procedure except using induced recirculating mixing.

Step h - If flocculation is needed, it should begin after the mixing is completed.

Step i - When the final point is reached, mixing can be continued for the specific reaction period and then terminated and pumpout commenced.

Step 3: Chemical Addition and Mixing-- All Options: At the starting point in the process, the rapid mixing tank is about 2/3 full and the chemical reaction tank is drawn down as far as possible to the sludge layer.

Step a - Turn on the process flow transfer pump #1 and watch for jet nozzle action to begin in the rapid mixing tank.

Step b - Shortly thereafter, turn on process flow transfer pump #2 to pump at the same rate as pump #1.

Explanation: If the rapid mixing tank and the inlet well of the chemical reaction tank are at different levels, it may be necessary to withdraw the suction hose of Pump #2 between operations or to put a valve in the line to prevent syphoning. In that case, the hose must be repositioned or the valve opened before pump #2 can be started

NWMAR116506

Step c - As soon as the two pumps are running, turn on the chemical feed pump at a rate calculated by the following formula:

$$\text{feed rate (gph)} = \frac{\text{volume of feed solution (gallons)}}{60 \frac{\text{min}}{\text{hr.}} \times \text{fill time (min)}}$$

gph x 3.78[b] = liters per hour

Caution: Do not fill the chemical reaction tank above the 0.305m (12 inch) freeboard height to provide a buffer zone to dilute the batch in the case where chemical reaction is carried out past the endpoint.

Step d - Turn off the chemical feed pump and process flow transfer pump #1 and immediately turn on the recirculation pump.

Step e - Through the process of monitoring and adding increments of chemicals, achieve endpoint conditions for chemical #1. Leave the recirculation pump and process flow transfer pump #2 running during the entire procedure.

Step f - If more chemicals are to be added, recalculate a new feed rate from the equation in Step 3.

Step g - Add this amount of chemical, monitor, and then achieve end point conditions as described in Step 5.

Step h - Further Process Steps - After chemical treatment is complete, the following processes may be performed before discharge of the reaction tank contents:

a. Gravity separation - operational procedures in Section 6.5.6

b. Flocculation and aeration - operation procedures described below.

Step i - Discharge the chemical reaction tank contents to the next process using the discharge pump.

Explanation: If the recirculation hose is used for discharge it will be necessary to remove the jet. It would be better to use a separate hose for discharge.

Flocculation - Operational Steps

Step a - with the recirculation pump off, the flocculator arm is moved through complete cycles around the tank to cause a gentle stirring action. If the tank contents begin to speed up in the direction of rotation, the rotation direction can be reversed to achieve more efficient mixing.

NWMAR116507

Step b - Continue flocculation until visual observations indicates that a good floc has formed (usually 10-15 minutes at longest).

Step c - Refer to sedimentation operational steps. Section 6.5.6

6.6.12 Chemical Reaction Troubleshooting

The most common problem would be that the endpoint is overshot. This will most likely occur at the beginning of operation before the kinetics of the reaction are familiar to the operators. When this situation occurs, the following procedure can be used.

1. Take a sample of the overtreated water.
2. Back titrate to the endpoint using contaminated water.
3. Note the volume of wastewater needed to reach the desired endpoint.
4. Scale up the results to determine the increased volume of wastewater to be added using the following formula.

$$\frac{\text{amount of wastewater to reach endpoint}}{\text{amount of overtreated water}} \times \text{volume of wastewater in process tank} = \text{volume of wastewater to be added to process tank}$$

5. Extra freeboard 15cm (6") has been provided in the design to allow the additional wastewater to be pumped into the tank.

Other possible problems involved in chemical reactions include:

1. Concentration gradients in tank:	Check jet mixing systems to be sure they are operating properly.
2. Incomplete chemical reactions; after addition of entire chemical amount:	Repeat bench tests and recalculate required volumes. Also, if lime is used, allow system to react longer since the rate of reaction is slow.

6.6.13 Process Description: Aeration

Aeration is another method for oxidation. Air can be used as an oxidizing agent which is more available but not as strong as chlorine or chlorine compounds. In general, air is introduced into the tank at the bottom and the air bubbles rise to the surface. As they travel through the water column, the oxygen in the air is transferred through the bubble and into the water where it can react with the hazardous compound. However, this technique is only valuable for easily oxidized materials such as ferrous iron. Otherwise, lengthy reaction times would be necessary.

NWMAR116508

Aeration can also be used as a mixing technique, however, the necessity of placing manifolds near or on the tank bottom may preclude this method when sludge is accumulated. Another problem with using aeration for mixing occurs if the sludge layer is disturbed or if a reduction reaction is desired (the oxygen will be reduced before the hazardous compound). Therefore, aeration has only limited application as a mixing technique. When it is to be used, (e.g. for a neutralization system) the construction techniques will be the same as those applied in this section. Rates of aeration reactions are difficult to predict because a myriad of factors affect them. Among the variables which influence aeration rate are the following: manifold efficiency, blower efficiency, oxygen transfer rate, impurities in the wastewater, tank depth, temperature, humidity, etc. Therefore, a bench testing procedure is only used to establish a reaction endpoint and the feasibility of aeration with respect to time. The dissolved oxygen versus time can then be established by aerating a sample until it reaches the saturation point. From this data, an endpoint dissolved oxygen value can be chosen based on the desired efficiency of the reaction. Generally, a level of 70% of saturation can be considered the reaction endpoint. If the aeration reaction has required excessive amounts of time to reach completion, stronger oxidation may be needed. After the feasibility and the endpoint dissolved oxygen level have been established, one full sized reaction tank can be constructed. This procedure would allow the determination of the actual amount of time needed for field reaction. Then calculations regarding the number of tanks needed for field use can be made.

6.6.14 Testing Procedure: Aeration

Equipment needed:

1. ≈ 5 gal pail
2. Diffuser stone
3. Air source
4. Dissolved Oxygen Probe
   or Burette/Burette stand/pipette/beaker/
   500 ml graduated cylinder
5. Stop watch
6. Thermometer
7. Barometer
8. Large graduated cylinder

Chemicals: Reagents for Winkler Titration.

Procedure:

1. Place known volume of wastewater into pail (≈ 3/4 full)
2. Measure initial D.O.
3. Place diffuser stone in bottom and begin air flow
4. Measure D.O. at appropriate increments (varies from 30 sec - 15 min)
5. Keep measuring D.O. until saturation, i.e. no change in D.O. level

NWMAR116509

Calculation Procedure:

1. Plot the DO value versus time of aeration.
2. Choose a suitable endpoint DO valve (usually 70% of saturation)

6.6.15 Design of Aeration System (see References 53-56)

The following design steps are necessary when designing a submerged header with orifices used in conjunction with an air compressor or blower.

Step 1 - Choose an available tank from Section 7.3 according to the following guidelines.

a. Use a flat bottom Type A tank, preferably 1.57-1.63m (62-64 in.) total height. Freeboard height should be 0.305m (12 inches) with a process height of 1.27-1.32m (50-52 inches).

b. Select a tank with a durable liner or else place a protective sheet within tank with thin plastic liners.

Step 2 - Determine the blower horsepower as a function of process volume, V_p, using Figure 67.

Explanation: The graph in Figure 67 was developed through use of the mixing formula:

$$G = \sqrt{\frac{P}{500\ \mu\ Vp}}$$

Where P = mixing power, hp

G = velocity gradient, sec^{-1}

μ = dynamic viscosity of fluid, $lb\text{-}sec/ft^2$

Vp = process volume in ft^3

Because of the wide range of variables affecting this process, the use of the formula in preparing Figure 67 is based on the following assumptions:

G = 400, which is the flash mixing point (high rate mixing). This was used as a safety factor to be sure the blower is not undersized. In the actual case a lower velocity gradient will probably be sufficient.

μ = based on water only, more viscous substances would elevate this number and raise the pressure.

However, blowers may not be readily available and a compressor may have to be substituted even though it is not well suited for this

NWMAR116510

METRIC CONVERSIONS

gal. x 3.785×10^{-3} = liters
hp x 1.014 = hp (metric)
(^{o}F - 32) 5/9 = ^{o}C

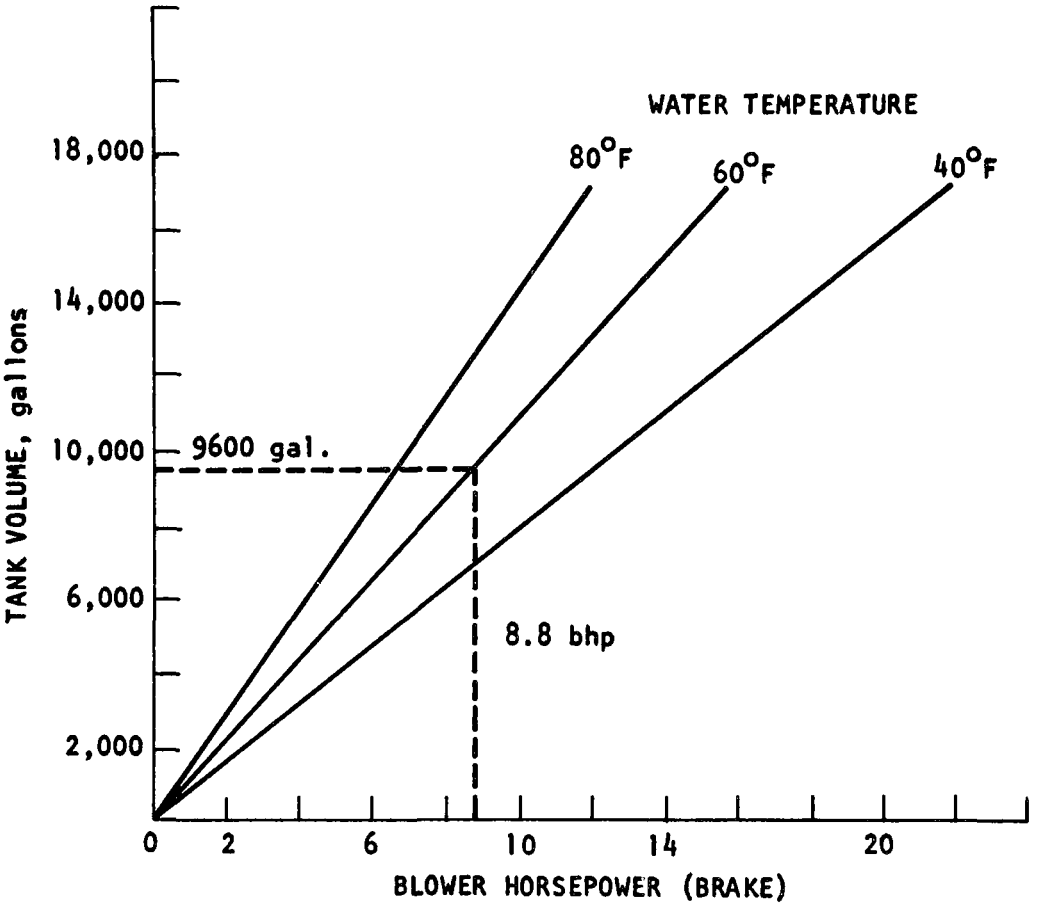


Figure 67. Blower size as a function of process volume for an aeration tank

NWMAR116511

application. The most readily available compressors will need a line regulator to reduce the pressure. Figure 67 does not apply to these high pressure compressors and the manufacturer should be consulted in the proper sizing for the application.

Example: A flat bottom tank with a process volume of 9,600 gallons is to be aerated. The water temperature will be around 60°F . From Figure 67 the required blower brake horsepower is 8.8 bhp.

gal. x 3.78×10^{-3} = cum

hp x 1.014 = hp (metric)

(°F - 32) x 5/9 = °C

Step 3 - Choose an available blower to provide the mixing horsepower at 5 psi of pressure.

Explanation: The low pressure nature of aeration make low pressure blowers, such as the positive displacement blower, the most suitable for this application. The major pressure losses which make up the .34 atm (5 psi) differential pressure are the following conversions: (psi x.0868 = atm).

1. Water head = the height of the water above the orifices. e.g., 36 inches x $\frac{1 \text{ psi}}{27.7 \text{ in}}$ = 1.3 psi.
2. Orifice loss = 0.5 to 2 psi through the potential flow range, Q (CFM) of aeration. (CFM x 0.47=liters per sec).
3. Line losses = valves, elbows, restrictions, etc., assumed to be less than 1 psi.
4. Safety factor = .7 to 2.2 psi to account for some of the variation which can result from temperature and viscosity changes, water height change, some plugging, etc.

Example: (same example as Step 2) A local supplier of positive displacement blowers has a blower that is rated from 2-12 psi and has the following ratings at 4 and 6 psi.

The following conversions are appropriate:

CFM x .472 = liters per sec.

psi x .068 = atm.

hp x 1.014 = hp (metric)

NWMAR116512

Air flow (CFM)		Brake horsepower (BHP)		Motor size (HP)	
4 psi	6 psi	4 psi	6 psi	4 psi	6 psi
211	227	5.3	8.4	7.5	10
350	394	8.8	13.9	10	15
554	536	16.5	21.9	20	25
731	694	17.9	25.6	20	30
1,106	1,041	27.2	37.1	30	40

It is necessary to interpolate this data. We are looking for a bhp rating at 5 psi equal to or greater than 8.8 bhp. Interpolation shows that the second line satisfies this condition at about 11 bhp and 370 CFM. This will require the 15 hp motor. This unit did not come with a variable speed drive and so a bypass valve was also acquired for flow control.

Step 3 - Determine total orifice area A_o according to the following formula:

$$A_o = \frac{Q}{80} \ (in^2) \qquad in.^2 \times 6.45 = cm^2$$

Where Q = blower air flow at 5 psi and mixing horsepower from Figure 67.

Explanation: This formula derives from the continuity equation, $Q = Av$, solved simultaneously with the orifice equation $v = 1{,}096\ c \sqrt{\frac{\Delta P}{\rho}}$

Where v = orifice velocity, fpm

c = orifice coefficient

Δp = differential pressure across the orifice (inches of water)

ρ = density of air (assumed to be .075lbs/ft^3 at standard conditions).

The differential pressure used to calculate the above formulae was just under 24 inches. Only about one foot would have been required, however, it is necessary that the pressure never go below six inches in the tank or there will be uneven aeration. The above formula for sizing the holes will permit a significant reduction in flow from design sizing before poor distribution will occur.

Example: From the previous example:

$$A_o = \frac{370 \text{ CFM}}{80} = 4.62 \text{ in}^2 \qquad (\text{inches})^2 \times 6.45 = cm^2$$

NWMAR116513

Step 4 - Design a header lateral system consisting of 15-20cm (6"-8") diameter pipe headers with 10 cm (4") diameter laterals connected as shown in the typical examples in Figure 69.

Note: When laying out the pipes, leave room in the tank for an inlet well and an outlet baffle as described in Section 6.5.5.

The following are criteria to be used in designing the header:

a. The 10 cm (4") dia. lateral pipes cover a good portion of the tank.

b. A minimum length of lateral should be used so that when 0.5 cm (3/16") to 1.3 cm (1/2") dia. holes are equally spaced along the laterals, the hole spacings are not closer than 10 cm (4") apart.

Example: The smaller the holes, the smaller the bubbles, which is good; however, the smaller the holes, the longer the required laterals, which may be prohibitive to construct. Good judgment is required.

Example: $\frac{4.6 \text{ in}^2 \text{ of holes}}{.027 \text{ in}^2 \text{ per hole}} \times \frac{4 \text{ in}}{12 \text{ in/ft}} = 56.5 \text{ ft.}$

for 3/16" holes

and

$\frac{4.6 \text{ in}^2 \text{ of holes}}{.196 \text{ in}^2 \text{ per hole}} \times \frac{4 \text{ in}}{12 \text{ in/ft}} = 7.7 \text{ ft.}$

for 1/2" holes

inches x 2.54 = cm
ft x .305 = m

c. Any cross distribution header should have at least two headers as shown in the C-, H-, and X- configurations in Figure 68.

6.6.16 Construction Steps: Aeration

Step 1 - Order a blower or blowers to provide the required air flow capacity at 5 psi. See Section 7.6 if a rotary screw air compressor is used. A pressure regulator is needed to reduce pressure from 60 psi down to required pressure. A bypass valve downstream of the pressure regulator will be needed for flow control.

Step 2 - The tank size and aeration header configuration have been established in the design section. The header may be constructed of rigid steel or plastic pipe.

Step 3 - Drill the holes for the orifices a minimum of 10 cm (4") apart in the top side of the laterals. Do not drill the main headers.

NWMAR116514

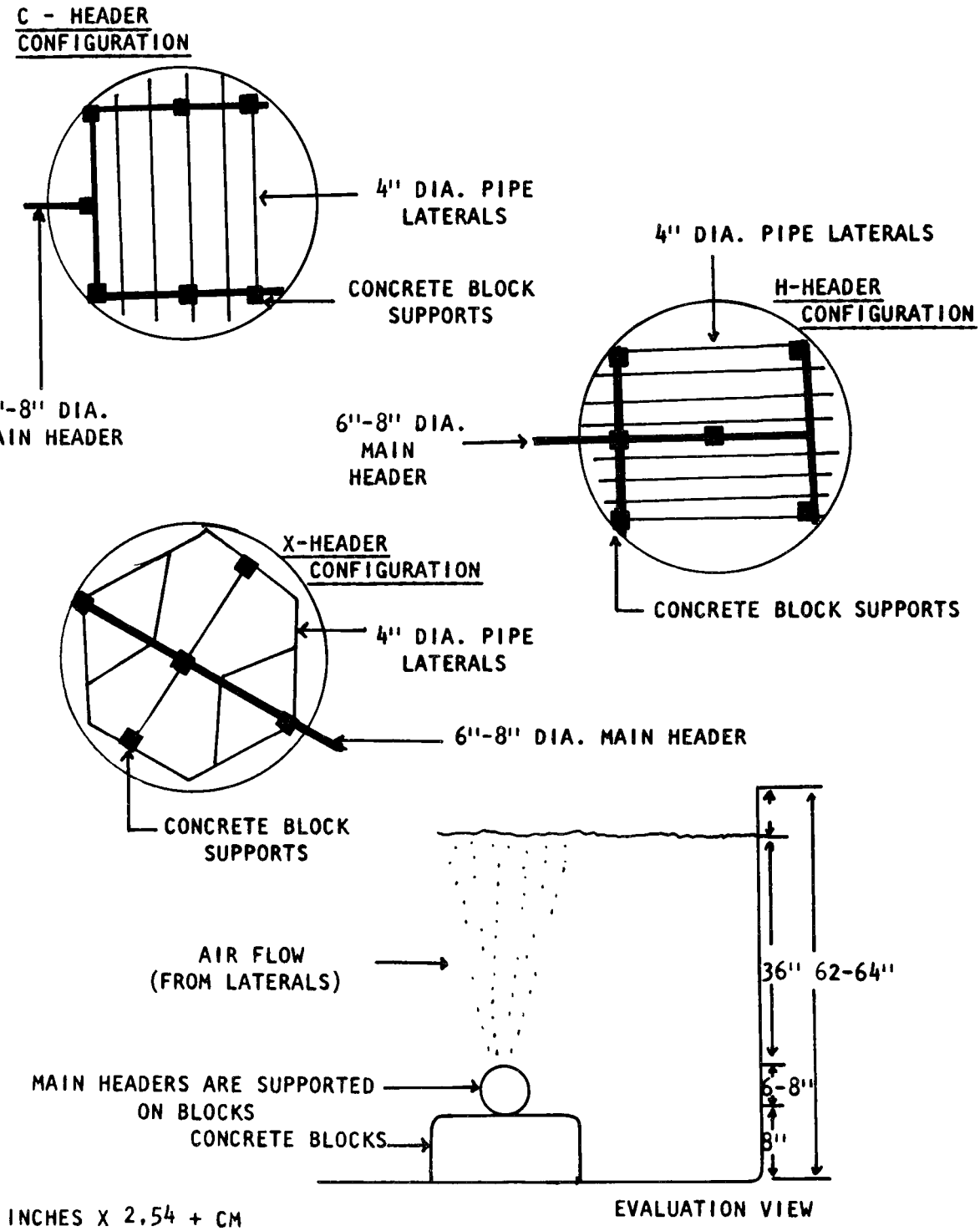


Figure 68. Aeration tank header alternative plan view layouts and schematic of header support

NWMAR116515

Step 4 - Place the header into the tank and support it on six to ten concrete blocks placed at positions as shown in Figure 68. Wire the header to the blocks.

Step 5 - Piping from the header to the compressor should be kept as short as possible. If a positive displacement blower is used no shutoff valves or other restrictions which could terminate flow may be used unless pressure relief is provided. In addition, a check valve is needed or other means of preventing backflow of water through siphoning.

6.6.17 Operation and Maintenance: Aeration

Aeration systems are also operated on the basis of endpoint control. Chemical reactions may take place either preceding or succeeding aeration using the same steps indicated in 6.6.13.

Aeration for oxidation can be done using the following procedure:

1. Pump contaminated water into the tank.

2. Start the compressor and begin air flow, slowly at first, using visual observation to determine proper air flow condition. Please note that when the blower is shutoff, the air header manifold fills with water (and debris). When the blower is turned on again the air must purge the lines. This requires higher than normal pressures. It would be desirable to refrain from shutting off the blower with a full tank unless absolutely necessary.

3. Monitor the dissolved oxygen at various parts of the tank.

4. Continue aeration until a stable dissolved oxygen endpoint is reached.

5. Pump contaminated water out of the process tank into the next process.

6. Desludge when the sludge layer reaches the top of the concrete blocks to avoid clogging lateral holes.

6.6.18 Troubleshooting Aeration

Aeration times may be excessive so the following possible solutions are presented:

Problem: Extremely long aeration times

Possible Solutions: 1) Clean holes in laterals; 2) Check for proper compressor operation; 3) Repeat bench tests to determine if endpoint has changed; 4) Check temperature and barometric pressure to determine if the saturation value has been reduced; 5) Determine if chlorination would be more effective oxidation method by consulting technical advisor.

NWMAR116516

7.0 CHAPTER 7 PROCESS COMPONENTS AND TREATMENT CHEMICALS

7.1 GENERAL

There are many components and materials which are common to all of the treatment unit processes. Therefore, to avoid unnecessary repetition, these components and selection criteria have been presented separately from the construction details. This separation will require the user to cross reference between Chapters 6 and 7 frequently. Therefore it is mandatory that the user be familiar with and understand the information presented in both sections to allow proper use of this Manual.

The information presented here is intended as a guide and basic reference on mechanical components. It is not a comprehensive review of all possible materials. The information presented has been abbreviated and simplified for use. Further information can be obtained from other references. When equipment choices are made by the user, it is advised that this choice be confirmed by equipment manufacturers or other specialists in this field.

It was determined that the components section be broken down into six parts. These parts are summarized as follows:

Process Pump - (sizing and selection)

Process Tanks - (volume calculations and types)

Hoses, Valving and Fittings - (types and applications)

Chemical Feed Components - (requirements)

Blowers and Compressors - (types and sizing)

Materials of Construction - (types and application)

7.2 PROCESS PUMPS

Field implementation of treatment processes will require the availability of pumps which are capable of moving the fluids under a variety of service conditions. Successful implementation demands that properly selected pumps be utilized to assure continuous operation and controllability of the process. Careful selection is necessary because no one pump can meet all service requirements and different pumps are available to meet different needs. Care must be taken not to misapply a pump or failure may result.

NWMAR116517

It is not possible to select a pump on flow requirements alone--other important operating variables will have to be considered before a final selection can be made, e.g., total dynamic head, suction conditions, viscosity, solids content, power source, mobility requirements, corrosivity, pumping explosive or flammable liquids, etc. The pump sizing and selection criteria presented here are condensed and conservative to permit selections without going through much of the detail normally involved in pump selections.

However it is not recommended to grossly oversize the pump, thus eliminating the necessity of performing sizing calculations. Oversizing is generally better than undersizing in emergency situations but with the drawback that pumps lose efficiency and are not as controllable when operated above or below their design ranges. Calculations of required flow and head permit the selection of a pump which can operate in its efficient range. It must also be carefully noted that the pump is not the only critical component in a properly designed pumping system. Other factors such as line sizes and flow restrictions, fittings, type of hose used, and the nature of the operation and the substances to be pumped can determine to a large degree the efficiency of the pumping system. A systems design approach, which takes these important variables into account, will give the designer substantial input concerning the nature of the system. This knowledge becomes invaluable when dealing with problems which may occur. With the exception of certain special pumping conditions such as the pumping of viscous fluids, heavy solids loadings, or flammable or explosive substances, pump selection may be made by first performing pump sizing (Section 7.2.1) and then turning to the pump selection section (Section 7.2.2). Special pumping situations are presented in Section 7.2.3.

7.2.1 Pump Sizing Procedure

The following procedure has been developed to assist in pump selection for typical fluid transfer operations as part of field implemented treatment systems. Assumptions are that the fluid is vapor-free, of low viscosity, and with medium solids content. Inlet and outlet conditions are assumed to be at ambient pressure and temperature conditions (57).

Step 1 - Calculation of System Flow Rate

Based on the volume of fluid to be transferred and the required transfer time, system flow rate is calculated as follows:

NWMAR116518

$$Q_s = \frac{V}{t}$$ where Q_s = system flow rate, $\frac{m^3}{min}$ (gpm)

V = volume of fluid, m^3, (gal.)

t = time, min.

Step 2 - Determination of Pump Capacity

Establish whether the pump will be used continuously (more than 8 hours per day) or intermittently. Determine pump capacity, Q_p, as follows:

Continuous duty	$Q_p = 2xQ_s$	m^3/min (gpm)
Intermittent duty	$Q_p = 1.3xQ_s$	m^3/min (gpm)

Explanation: Pump capacity, Q_p, is only for ordering purposes. All subsequent calculations will be performed using system flow rate, Q_s.

Step 3 - Sketch of Pumping System

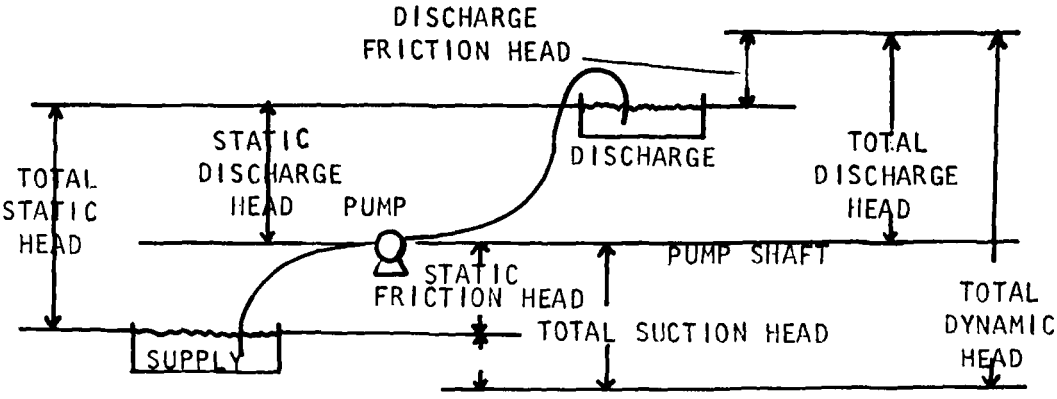
Sketch an elevation view of the proposed pumping system (see Figure 69 and Table 29 for pertinent pumping terms). Determine whether the suction port will be flooded with fluid (Figure 69c) or whether pump location will require a static suction lift (Figure 69a). A static suction lift will require a self-priming pump. Include the following information on the sketch:

a) The vertical distance between the lowest supply fluid level and the highest discharge water level or the free discharge point. This defines the Total Static Head (TSH).

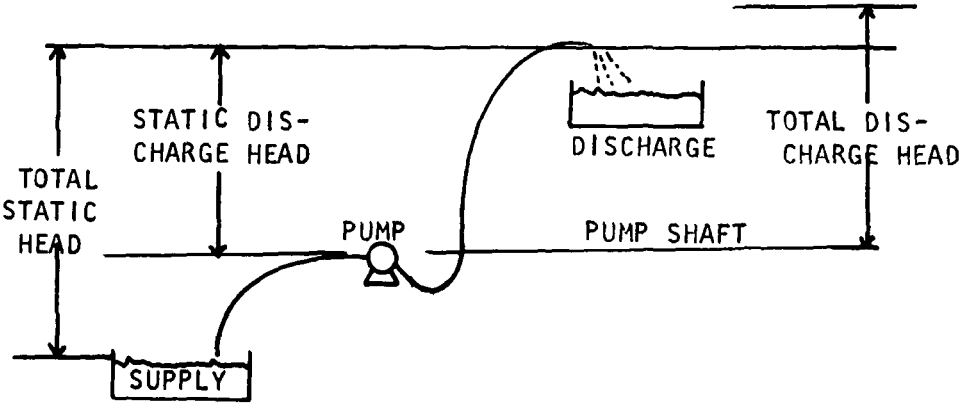
b) For self-priming applications, indicate the vertical distance between the lowest supply level fluid level and the pump centerline. This defines the Static Suction Lift (SSL).

c) Indicate the approximate total length of fluid lines. Note how much is on either side of the pump.

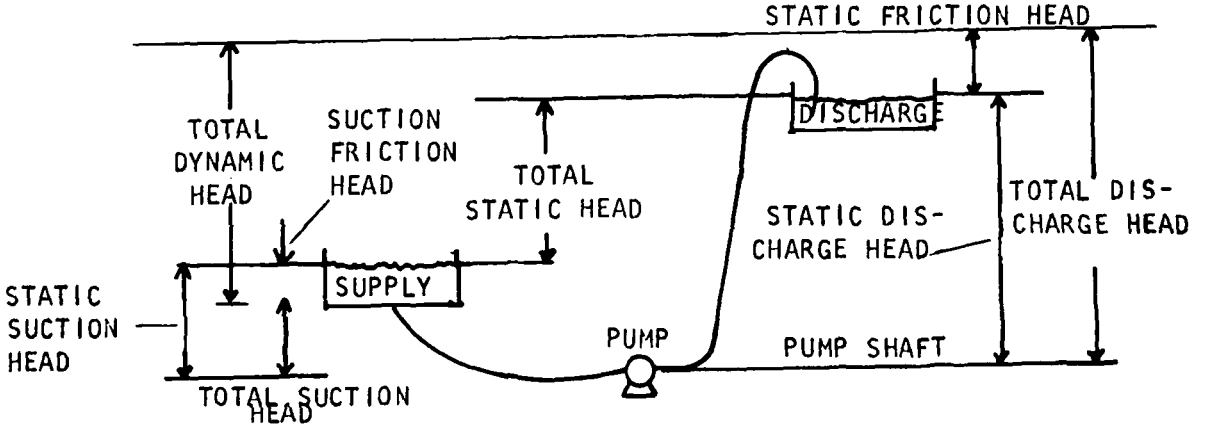
NWMAR116519



(a) SUCTION LIFT AND SUBMERGED DISCHARGE



(b) SUCTION LIFT AND FREE DISCHARGE



(c) STATIC SUCTION HEAD AND SUBMERGED DISCHARGE

Figure 69. Examples of typical system sketches showing pump head relationships

NWMAR116520

TABLE 29. FLUID PUMPING TERMS

Static Suction Lift	Vertical distance in feet between the liquid level of the source of supply and the centerline of the pump when the pump is located above the liquid level of the source of supply.
Static Suction Head	Vertical distance in feet between the liquid level of the source of supply and the centerline of the pump when the pump is located below the liquid level of the source of supply.
Frictional Head	Pressure (expressed in feet) to overcome friction and other losses such as fittings, transitions and valves.
Total Suction Lift	Total pressure (expressed in feet) below atmospheric at the suction port of the pump when the pump is in operation (equals the static suction lift plus the suction friction head).
Static Discharge Head	Vertical distance in feet between the centerline of the pump and the point of free delivery of the liquid.
Total Suction Head	Total pressure (expressed in feet) above atmospheric at the suction port of the pump when the pump is in operation (equals the static suction head minus the suction friction head).
Total Static Head	Sum of the static suction lift and the static discharge head or the difference between the static discharge head and the static suction head.
Total Dynamic Head	Sum of the total discharge head and the total suction lift or the difference between the total discharge head and the total suction head.
Total Discharge Head	Total pressure (expressed in feet) above atmospheric at the discharge port of the pump when the pump is in operation (equals the static discharge head and the discharge frictional head).

NWMAR116521

d) Note on the sketch the location of valves, fittings, elbows, entrances, enlargements, etc., (see Figure 70 for typical examples).

Step 4 - Preliminary Line Sizing

Using Table 30, determine a preliminary line sizing for friction head calculations.

Explanation: Pump or line size availability may later require an iteration of these calculations starting with Step 4. Ultimate pump size is affected by line size.

Step 5 - Computation of Total Dynamic Head

Use the form presented in Table 31 to compute the Total Dynamic Head.

Step 6 - Specifying Pump Rating

When ordering the pump, use the following information: Flow equal to Q_p (Step 2) at Total Dynamic Head from Step 5. Also note whether a suction lift is required and use the Total Suction Lift calculated in Step 5.

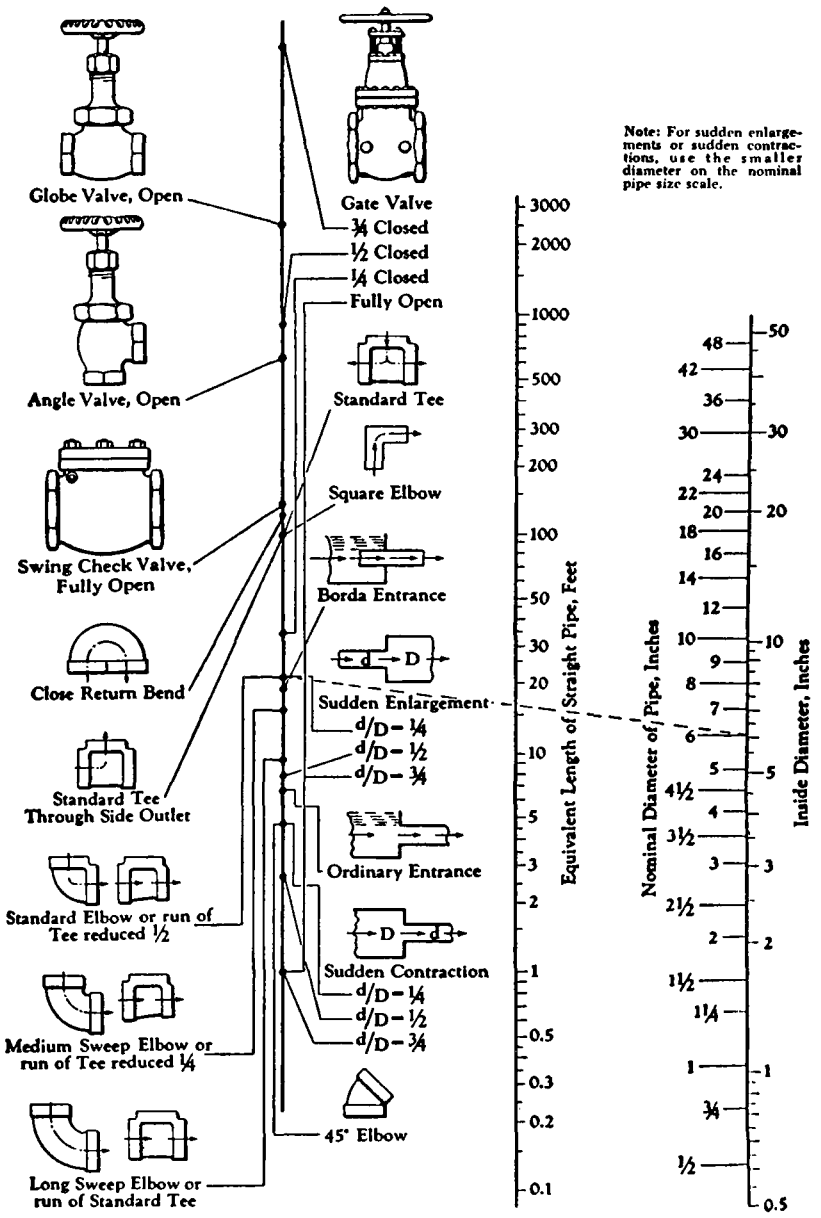
Table 30. PRELIMINARY LINE SIZING CHART

Line size, in.	Flow range, GPM
0.75	5 - 10
1.0	10 - 20
1.25	18 - 35
1.5	28 - 60
2.0	60 - 120
2.5	100 - 220
3.0	170 - 350
3.5	250 - 500
4.0	350 - 720
5.0	600 - 1300
6.0	1000 - 2000
8.0	2000 - 4200
10.0	3800 - 8000

1. Minimum represents a flow corresponding to 5 psi/100 ft friction loss, maximum corresponds to 20 psi/100 ft friction loss.

in. x 2.54 = cm
gpm x 3.785 = lpm

NWMAR116522



Use a straightedge to connect the type of restriction (left vertical line) with the nominal size (right vertical line). Read the headloss in equivalent feet on the center vertical line; e.g., a 6" standard elbow has an equivalent loss of 17 ft. (see chart) (58).

ft x .305 = m
in. x 2.54 = cm

Figure 70. Equivalent length of pipe fittings and valves

NWMAR116523

TABLE 31. FORM FOR CALCULATION OF TOTAL DYNAMIC HEAD (TDH) AND TOTAL SUCTION LIFT (TSL)

Explanation: Total Dynamic Head is needed to size the pump; Total Suction Lift is needed as part of the TDH calculation and to check the suction restriction of the pump.

A. Determine system flow rate, Q_s (from Sizing Procedure, Step 1)

_____ GPM

B. Calculate Total Suction Lift or Total Suction Head (refer to Figure 69).

a. Static suction lift, or _____ Ft.

b. Static suction head _____ Ft.

c. Suction friction head:

Fluid Line Head

Size (Inches)	(x) Length (Ft.)	(y) Friction Loss Per 100 Ft. (psi) From Figure 71	$\frac{(x)\cdot(y)}{40}$ Total Line Loss (Ft.)

_____

Total _____ Ft.

continued

NWMAR116524

TABLE 31 (continued)

Fitting Head

Fitting Type	Size (Inches)	(v) No.	(w) Equivalent Length Per Fitting (From Figure 70) (Ft.)	$\frac{(v)\cdot(w)\cdot(y)}{40}$ Total Equivalent Length (Ft.)

Total _____ Ft.

c. Suction friction head = fluid line head _____ Ft.
+ fitting head _____ Ft. = _____ Ft.

d. Total suction lift = $\frac{(a) + (c)}{\text{Specific Gravity}}$ = _____ Ft.

Explanation: If total suction lift is higher than 15 feet, reduce it by:

1) Lowering the pump
2) Increasing the size of the suction line and/or decreasing the overall length of line
3) Eliminating unnecessary fittings
4) Decreasing the flow

15 ft is the desired maximum condition

e. Total suction head = $\frac{(b) - (c)}{S.G.}$ = _____ Ft.

S.G. = Specific Gravity

continued

NWMAR116525

TABLE 31 (continued)

C. Calculate Total Discharge Head (refer to Figure 69)

f. Static discharge head _____ Ft.

g. Discharge friction head:

Fluid Line Head

Size (Inches)	(x) Length (Ft.)	(y) Friction Loss Per 100 Ft. (psi) (From Figure 71)	$\frac{(x)\cdot(y)}{40}$ Total Line Loss (Ft.)

Total _____ Ft.

Fitting Head

Fitting Type	Size (Inches)	(v) No.	(w) Equivalent Length Per Fitting (From Figure 70) (Ft.)	$\frac{(v)\cdot(w)\cdot(y)}{40}$ Total Equivalent Length (Ft.)

Total _____ Ft.

continued

NWMAR116526

TABLE 31 (continued)

Discharge friction head = fluid line head _____ Ft.

+ fitting head _____ Ft. = _____ Ft.

h. Total discharge head = $\frac{(f) + (g)}{S.G.}$ = _____ Ft.

S.G. = Specific Gravity

i. Total dynamic head (TDH) = Total discharge head + total suction lift or total discharge head - total suction head

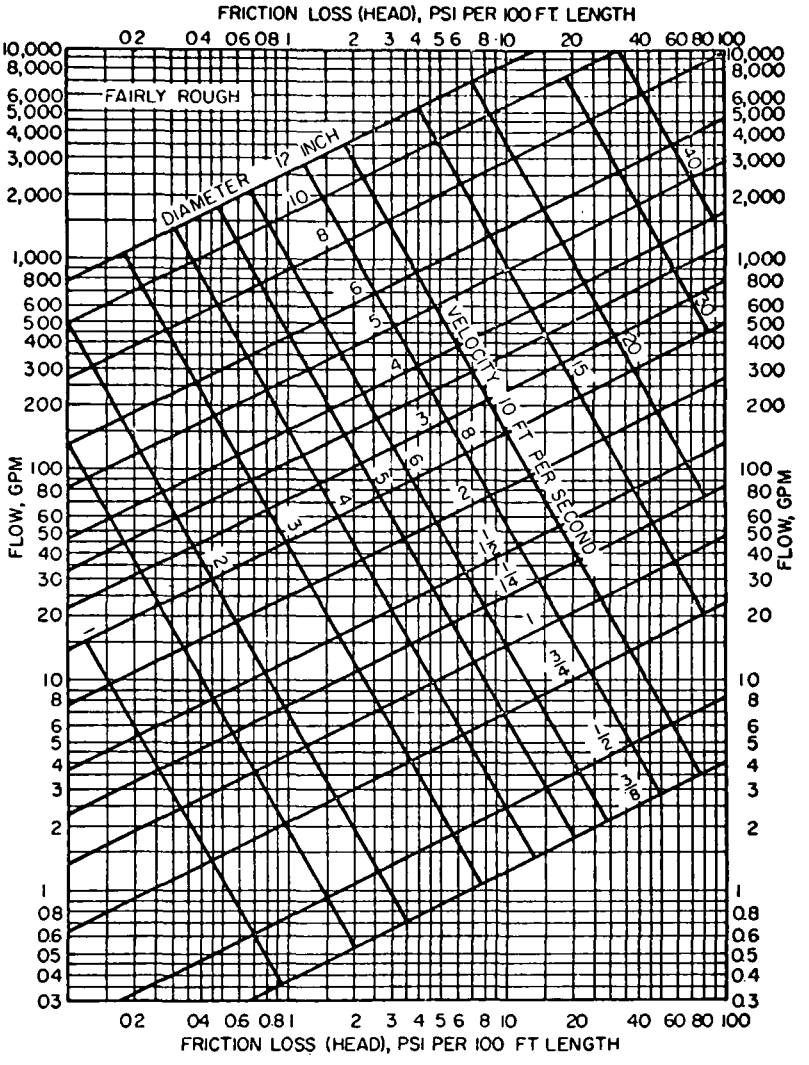
TDH = (h) + (d) _____ Ft.

or

TDH = (h) - (e) = _____ Ft.

ft x .305 = meters

NWMAR116527



METRIC CONVERSION

ft x .305 = meters
gal. x 3.785 = liters
psi x .0703 = kg/cm^3

(REFER TO FIGURE 72 FOR USE OF GRAPH)

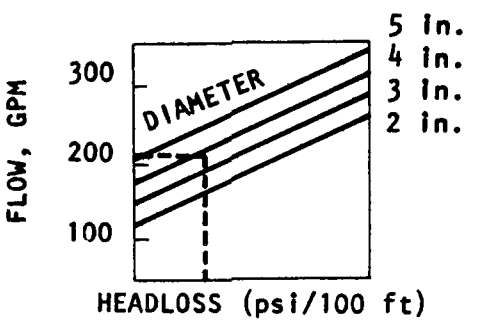
Figure 71. Friction loss in water piping (58).

NWMAR116528

1. Determine the head loss (psi/100 ft.) associated with a flow of 200 GPM through a 4" pipe.

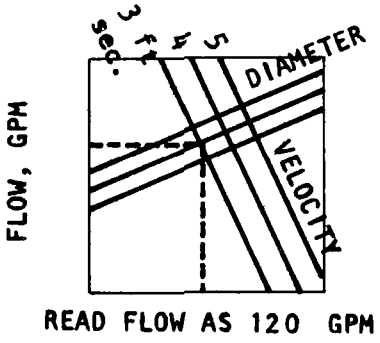
Conversions

gpm x 3.785 = lpm
ft x .305 = m
psi x 703.1 = kg/m^2
in. x 2.54 = cm



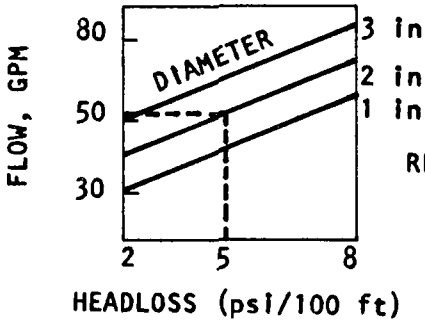
READ HEADLOSS AS 1.5 psi/100 ft EQUIVALENT LENGTH

2. Determine the flow rate (GPM) to produce a minimum flow velocity of 3 ft./sec in a 4 inch line.



READ FLOW AS 120 GPM

3. Determine the line size (inch) to limit head loss to 5 psi/100 ft. at a flow of 50 GPM.



READ LINE SIZE AS 1.8" -- ROUND UP TO 2"

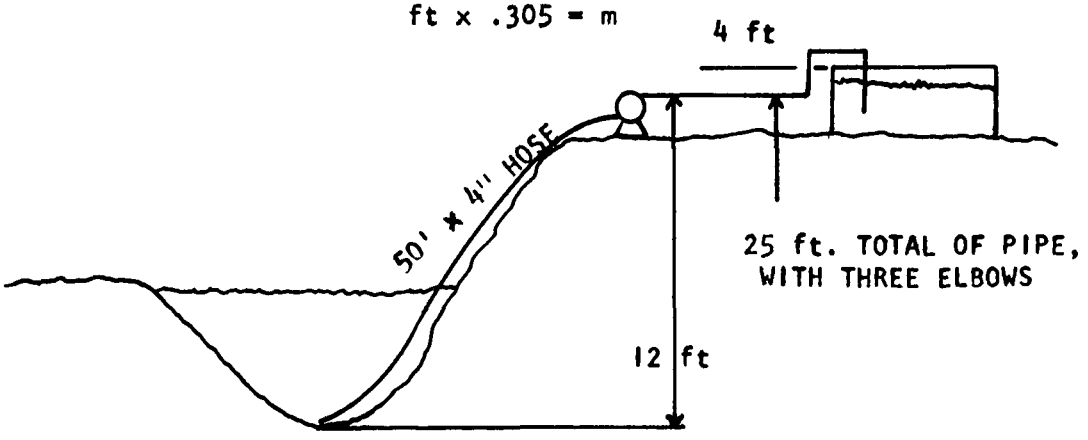
Figure 72. Typical determinations made from the Friction Loss Chart (Figure 71)

NWMAR116529

Example:

Note: All calculations are in English units; the following conversions are appropriate:

gal. x 3.785 = liters
in. x 2.54 = cm
ft x .305 = m



Size a pump to empty a ditch with an estimated capacity of 100,000 gallons in 8 hours. The fluid is water with a dilute contaminant and a low solids content. The liquid will be pumped into a 10,000 gallon swimming pool which will act as a pretreatment tank. Another pump of equal or creater capacity will then pump to subsequent treatment processes. A 4 inch diameter x 50 feet suction hose is available to reach the low point in the ditch from a suitable location for installing the pump. Sufficient pipe of verious sizes is available on site to make the pump discharge connection into the pool. Refer to Table 31a for compilation of the results.

Step 1 - Calculation of System Flow Rate

$$Q_s = \frac{V}{t} = \frac{100{,}000 \text{ gal.}}{8 \text{ hours}} \times \frac{1 \text{ hour}}{60 \text{ min.}} = 208 \text{ GPM}$$

Step 2 - Determination of Pump Capacity

$$Q_p = 2 \times Q_s = 416 \text{ GPM} \quad \text{(Continuous duty)}$$

Step 3 - Sketch of Pumping System

The presence of a suction lift will require a self-priming pump. The highest discharge point is the top of the tank, 4 ft. above the pump centerline. The lowest suction point is 12 ft. below the pump centerline. The Total Static Head is 16 ft.

NWMAR116530

TABLE 31a. COMPLETED FORM FOR CALCULATION OF TOTAL DYNAMIC HEAD (TDH) AND TOTAL SUCTION LIFT (TLS)

Explanation: Total Dynamic Head is needed to size the pump; Total Suction Life is needed as part of the TDH calculation and to check the suction restriction of the pump.

A. Determine system flow rate, Q_s (from Sizing Procedure, Step 1) 208 gpm

B. Calculate Total Suction Life or Total Suction Head (refer to Figure 69).

a. Static suction lift ____ ft
b. Static suction head ____ ft
c. Suction friction head ____ ft

Fluid Line Head

Size, in.	(x) Length, ft	(y) Friction loss per 100 ft, psi (from Figure 71)	$\frac{(x)\cdot(y)}{40}$ Total line loss, ft
4	50	1.9	2.4
		TOTAL	2.4 ft

Fitting Head

Fitting type	Size, in.	(v) No.	(w) Equivalent length per fitting, ft (from Figure 70)	$\frac{(v)\cdot(w)\cdot(y)}{40}$ Total Equivalent length, ft
ordinary entrance	4	1	6	0.3
			TOTAL	0.3 ft

Suction friction head = fluid line head (2.4 ft) + fitting head (0.3) ft

= 2.7 ft

continued

NWMAR116531

TABLE 31a (continued)

d. Total suction life = $\frac{(a) + (c)}{\text{specific gravity}}$ = 14.7 ft.

Explanation: If total suction lift is higher than 15 ft, reduce it by:

1) Lowering the pump
2) Increasing the size of the suction life and/or decreasing the overall length of line
3) Eliminating unnecessary fittings
4) Decreasing the flow

15 feet is the desired maximum condition

e. Total suction head = $\frac{(b) - (c)}{\text{specific gravity}}$ = ____ ft.

C. Calculate Total Discharge Head (refer to Figure 69)

f. Static discharge head 4 ft
g. Discharge friction head:

Fluid Line Head

Size, in.	Length, ft	(y) Friction loss per 100 ft, psi (from Figure 71)	$\frac{(x)\cdot(y)}{40}$ Total line loss, ft.
3	25	8	5
		TOTAL	5 ft

Fitting Head

Fitting type	Size, in.	(v) No.	(w) Equivalent length per fitting, ft (from Figure 70)	$\frac{(v)\cdot(w)\cdot(y)}{40}$ Total Equivalent length, ft
elbow	3	3	8	4.8
sudden enlargement	3	1	1.8	0.4
			TOTAL	5.2 ft

continued

NWMAR116532

TABLE 31a (continued)

Discharge friction head = fluid line head (5 ft) + fitting head (5.2 ft)

= 10.2 ft

h. Total discharge head = $\frac{(f) + (g)}{\text{specific gravity}}$ = 14.2 ft

i. Total dynamic head (TDH) = total discharge head + total suction lift

or total discharge head - total sunction head

TDH = (h) + (d) 28.9 ft

or

TDH = (h) - (e) = ft

ft x .305 = meters

NWMAR116533

Step 4 - Preliminary Line Sizing

From Table 30 choose a pipe which will be suitable on the discharge for the preliminary calculation. A check of the available pipe on site indicates that, of the two sizes, only 3" is available.

Step 5 - Computation of Total Dynamic Head

From form in Table 31a TDH = 28.9 ft.

Step 6 - Specifying Pump Rating

416 GPM at 28.9 ft TDH
Self-priming pump required

7.2.3 Selection of Available Pumps

The best local sources for suitable pumps to implement field treatment processes are probably contractors' supply houses and contractors themselves. They can supply pumps as well as limited lengths of hose. Secondary local sources are the local sewage treatment plant, the department of public works, and fire departments. Table 32 presents a selection chart based on pump usage variables and available pump types. The type designations used (A-D) will be found in other sections of this manual when referring to these pump types. The following are descriptions and typical ratings of these available pumps:

Type A - Medium pressure centrifugals

The most available variety is the self-priming, engine driven centrifugal pump. This type of pump is used by contractors in a variety of sizes and ratings as shown in Table 33.

TABLE 33. TYPICAL RATING FOR MEDIUM PRESSURE CENTRIFUGAL PUMPS

	Portable	Wheel mounted	Skid mounted	Tractor PTO
Size range (inches)	1½ - 3	1½ - 8	10	3-8
Flow range (gpm)	25-350	20-2500	250-3750	50-2000
Total head range (ft)	20-140	0-220	30-120	23-438
Horsepower range	3-7	3-150	100-150	

ft x 3.05 = m
in x 2.54 = cm
fpm x 3.785 = lpm
hp x .746 = kw

NWMAR116534

TABLE 32. PUMP SELECTION CHART

	Medium Pressure Centrifugal	High Pressure Centrifugal	Heavy Duty Trash	Diaphragm
Pump Type Designation	A	B	C	D
1. Fluid Transfer -				
med. pressure	x		x	x
high pressure		x		
Solids handling			x	x
2. Suction Condition				
Flooded suction	x	x	x	x
Suction lift	x		x	x
Submersible pump	x			
3. Power Source				
Engine driven	x	x	x	x
Air driven				x
Electrical	x	x	x	x
Power takeoff	x		x	
4. Mobility				
Portable (by one to three men)	x		x	
Wheel mounted	x	x	x	x
Skid mounted	x	x	x	x
Tank truck mounted			x	

NWMAR116535

Although the pump is self-priming, an initial prime is required. A pipe plug on top of the pump body must be removed and the pumping chamber filled with water. Even though it may run dry for a short period, the pump should still hold its prime by virtue of the priming chamber design. The pump can handle solids, but it is not a good choice as a solids pump because of inaccessibility to remove fouling.

Another available centrifugal pump which finds extensive application in dewatering is the electric submersible pump.

Typical ratings:

	English units	Metric units
Size range	2-8 inches	5-20 cm
Flow range	50-2800 gpm	0.2-10.6 cu m/min
Total head range	10-200 ft	3-61 m
Power	2-95 hp	1.5-71 kw

Type B - High Pressure Centrifugals

These engine-driven pumps are commonly used for high pressure testing of plumbing systems. While not self-priming, they are generally furnished with an exhaust or vacuum primer.

Typical ratings:

Size range	2.5-6 inches	6.3-15 cm
Flow range	50-1800 gpm	0.2-6.8 cu m/min
Total head range	70-460 ft	21-140 m
Power	5-125 hp	3.7-93 kw

Type C - Heavy Duty Trash Pumps

A readily available variety of solids handling pumps is the engine-driven, self-priming, centrifugal, trash pump which has the same variety of sizes, mountings, and ratings as the Type A - Medium Pressure, Engine Driven Centrifugals. There are two major differences between the medium pressure and the trash handling centrifugals:

The pump body and impeller of the trash pump are open to allow the passage of large solids; solids ratings are given as the maximum diameter of a spherical solid which the pump could pass:

Pump size		Largest sphere passed*	
cm	in.	cm	in.
3.8	1.5	2.5	1
5	2	2.8-3.8	1.1-1.5
7.6	3	3.8-6.3	1.5-2.5
10.1	4	5-7.6	2-3
15.2	6	6.3-7.6	2.5-3

* Termed solids handling ability

NWMAR116536

The self-priming trash pump is used on sanitary cleaning trucks, used by septic tank cleaners and other waste fluid haulers. It is typically available in 10.1 cm (4") size on a tank truck of 4.1, 6.0 or 8.3 cu m (1100, 1600, 2200 gal.).

Another type designed for solids-laden streams is the electrical or engine-driven diaphragm pump. This recirprocating pump utilizes a flexible, elastomeric diaphragm which is flexed and extended by a mechanical eccentric drive. Check valves are necessary to permit the pulsing pump action. It is preferred to utilize hardwall hose on both suction and discharge to minimize the surging forces on the hoses, hose supports, and tanks. This pump is normally available in the portable and small wheel-mounted varieties with typical ratings as follows:

	English units	Metric units
Size range	3-4 inches	7.6 cm
Flow range	50-150 gpm	189-568 lpm
Total dynamic head range	5-50 ft	1.5-15 m
Power	0.5-7 hp	6.4-5 kw

Type D - Mechanical and Pneumatic Diaphragm Pumps

This solids-handling pump usually comes in single diaphragm engine-driven, portable varieties with the pumping action occurring because of the reciprocal movement of a diaphragm driven by an eccentric. Swing check valves on inlet and outlet permit fluid pumping. The pulsing nature of the pumping can cause severe hose whipping if hoses are not properly supported. Typical ratings are as follows:

Size range	3-4 inches	7.6-10.2 cm
Flow range	52-150 gpm	197-5680 lpm
Total head range	5-50 ft	1.5-15 m
Power	2.75-6.6 hp	2.0-4.9 kw

Diaphragm pumps function best with a short suction line and low suction lift.

Air Operated Double Diaphragm Pumps

The air-operated diaphragm pump is an excellent pump for solids handling at higher head ratings than the typical mechanical diaphragm pump. It is light weight, portable and self-priming, and may also be utilized as a submersible pump. A single air pressure line is all that is required for hookup, except in the case of the submersible pump, where a vent line must extend above the water surface so that the air suction of the pump does not fill with water when the pump is shut off. The The pump has a reciprocal motion with pumping occurring by the movement of the diaphragm controlled by an air valve and the opening and closing of ball check valves on the inlet and outlet. It has a smoother motion in many cases than mechanical diaphragm pumps. However, hose whipping

NWMAR116537

must be controlled when using this pump also. The pump would be more resistant to explosion or fire hazards than engine-driven or electric motor-driven pumps. It could, however, freeze up in cold weather because of the expansion of air in the air valve. The pumping rate can be easily controlled by controlling air flow to the pump. Typical pump specifications are in the following table. (Table 34)

TABLE 34. TYPICAL AIR PUMP SPECIFICATIONS

Air requirements		Pumping capacity			
		2" size		3" size	
Pressure, psig	Air consumption, scfm	Flow, gpm	Head, ft	Flow, gpm	Head, ft
100	160			170	85
	140			138	125
	120			110	155
	100			83	183
	80	110	55	40	202
	60	58	170	41	218
	40	28	205	25	222
	20	12	220	20	226

psig x 703 = kg/sq m
scfm x .028 = s cu m/min
gpm x 3.785 = lpm
ft x .305 = m

Pumps can also be operated at lower pressures with varying pumping capacities. Maximum solids size ratings are .63 cm (1/4") diameter for a 5 cm (2") pump and 0.95 cm (3/8") for a 7.6 cm (3") pump.

7.2.4 Special and Hazardous Pumping Situations

Special problems occur when handling viscous fluids, high solids content, and flammable and explosive substances. Special care must be taken when applying pumps for these situations because of the danger of failure or of hazards to personnel.

7.2.4.1 Viscous fluids - Increased viscosity above that of water causes a need for a higher pumping head than is needed to pump water at the same flow rate. The viscosity of all fluids varies appreciably with changes in temperature. The viscosity of some fluids is unaffected by the mechanical motions occurring during transport (Newtonian fluids such as mineral oil and water). A liquid is said to be thixotropic if viscosity decreases as agitation is increased (asphalt, molasses). A liquid is said to be dilitant if viscosity increases as agitation occurs (clay slurries).

NWMAR116538

Because of the above complexities as well as the difficulty in getting viscosity measurement in the field, it is not easy to establish a calculation method to be used for field sizing of pumping systems for handling viscous fluids. In the absence of a sizing technique, it is desirable to choose a pump for viscous pumping service which has a head capacity substantially higher than that which is necessary to pump water at the same rate. Ultimate flow rate must be established in actual service. It is desirable when pumping viscous fluids to reduce the number of restrictions and to keep line velocities low and suction line length to a minimum.

7.2.4.2 Solids Handling - Again, calculation methods are not available for solids pump sizing because of a number of factors such as: solids concentration; viscosity; specific gravity; particle size; presence of various constitutents such as silt, clay, sand, debris. Like the viscous flow situation, an elevated head is needed to pump high solids concentrations, but in addition a minimum transport velocity is necessary to insure against solids settling in the lines. This minimum velocity is in the range of 0.61 - 0.92 m/sec (2-3 ft/sec) and is a function of line size and solids concentration.

If the cleanup operation will involve a major amount of dredging it would be desirable to enlist the services of a dredging firm to advise on the best pumping system configuration. Such items as suction line backflush capabilities and pump and hose cleanout must be considered to reduce downtime from clogged lines, pumps, and valves.

7.2.4.3 Flammable and Explosive Substances - Serious hazards can be created by pumping systems when handling explosive or flammable fluids:

1. Ignition sources such as spark plugs, ignition wire and switches, hot mufflers and engine blocks, combustile air filters, open electric motors, static electricity buildup, are ever present dangers when using readily available contractor's pumping equipment.

2) Pump suctions, and restrictions can cause gases to be created in excess of the lower explosive limit because of regions of reduced pressure.

Because of the imminent dangers of field implemented treatment systems when dealing with dangerous substances, it is recommended that the manufacturer of flammable or explosive substances be contacted concerning safe ways to handle these products. In some cases the dangers may preclude field treatment unless the substance can be rendered less hazardous.

NWMAR116539

7.3 PROCESS TANKS

The availability of process tanks is critical to the determination of feasible system flow rates because of the detention times required by the various process schemes. Unlike portable pumps, which are readily available because of extensive requirements by contractors to dewater construction sites, a limited variety of tanks are available which could be turned to field treatment process uses. Some available tanks include:

Open Top Tanks:

1. Commercially available above-ground swimming pools;
2. U.S. Army Corps of Engineers rubber stave tanks;
3. Impermeable membranes as liners for earthen excavations or for steel, concrete, or wooden tanks;
4. Treatment of earthen excavations with high-swelling clay to make the soil impermeable;
5. Culvert, storm, drain, and sewer pipe utilized for vertical column tanks;
6. Specialized steel, fiberglass, and lined wooden tanks borrowed from local industries.

Closed Tanks:

1. ASME tanks with flanged and dished heads;
2. Tank trucks;
3. Collapsible rubber containers.

By far, the most practical tank for field implemented treatment processes is the open top tank, which has the necessary accessibility for operation and control of the process. For most processes, geometry is not a critical parameter, with the notable exceptions of filtration, carbon adsorption, and ion exchange. In gravity feed systems these processes require vertical tanks of uniform cross-section and height-diameter ratios typically greater than two. Closed tanks are mainly limited to storage and transfer functions, such as clean effluent storage for backwash or sludge storage and disposal. In an emergency, process operations can be carried out in closed tanks, however, the operation is tedious.

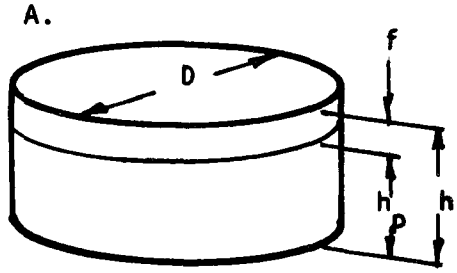
Tank sizing will require that the process volume for the various tanks be known. The following section (Section 7.3.1) gives formulae for calculation of process volumes for a variety of tank configurations. Then, Section 7.3.2 presents a description of various available tanks as well as some pertinent details concerning their installation and use.

7.3.1 Calculation of Process Volume

Typical above ground and in-ground tanks have been classified in Figure 73 as specific tank designations (A-H). These type designations are used in other portions of the manual when referring to specific tank types.

NWMAR116540

TYPE A.

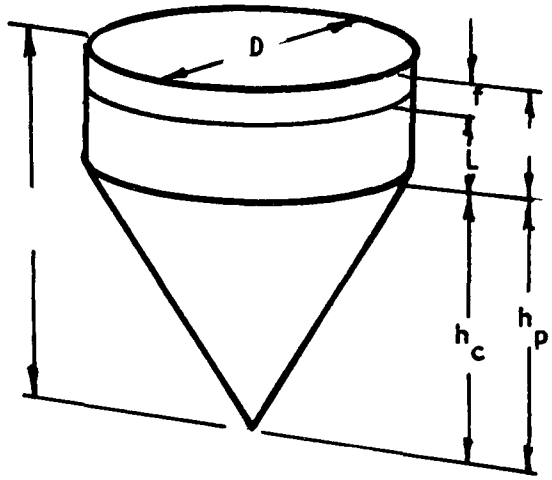


VERTICAL CYLINDER, FLAT BOTTOM, OPEN TOP

D = DIAMETER, m (ft)
h = TANK HEIGHT, m (ft)
h_p = PROCESS HEIGHT, m (ft)
f = FREEBOARD, m (ft)

PROCESS VOLUME $V_p = \frac{\pi D^2}{4} \times h_p = 0.78D^2 \times h_p \ m^3, \ (ft^3)$

TYPE B.

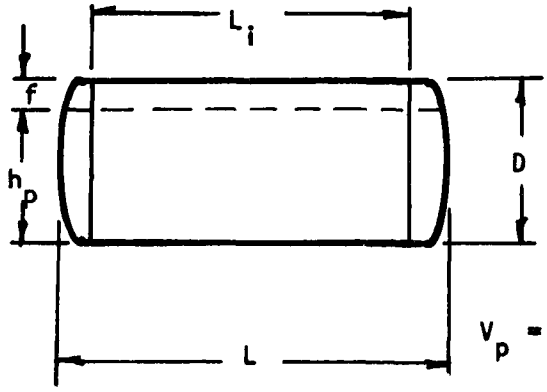


VERTICAL CYLINDER, CONE BOTTOM, OPEN TOP

D = DIAMETER OF CYLINDRICAL SECTION, m (ft)
h = TANK HEIGHT, m (ft)
h_p = PROCESS HEIGHT, m (ft)
f^p = FREEBOARD, m (ft)
L = HEIGHT OF STRAIGHT SECTION, LESS FREEBOARD, m (ft)
h_c = CONE HEIGHT, m (ft)

PROCESS VOLUME $V_p = D \ (.78L + .26 \ h_c) \ m^3, \ (ft^3)$

TYPE C.



ASME TANK, HORIZONTAL

D = DIAMETER, m (ft)
h_p = PROCESS HEIGHT, m (ft)
f^p = FREEBOARD, m (ft)
L_i = LENGTH OF STRAIGHT SIDE, m (ft)
L = TOTAL LENGTH, m (ft)
V_H = VOLUME OF HEAD (See Figure 74)

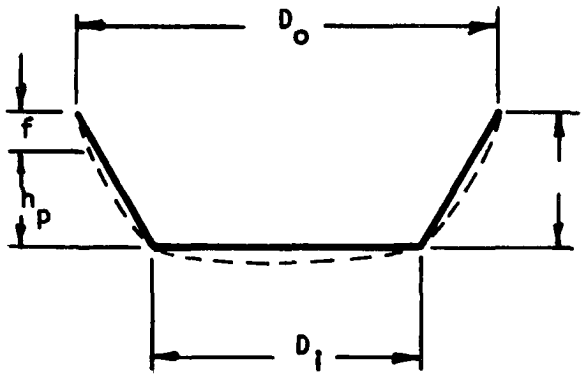
$V_p = .78D^2L_i + 2V_H \ m^3, \ (ft^3)$

1. THIS VOLUME IS TANK CAPACITY WITHOUT SUBTRACTION FOR FREEBOARD

Figure 73. Calculation information for tank volumes.

NWMAR116541

TYPE D.

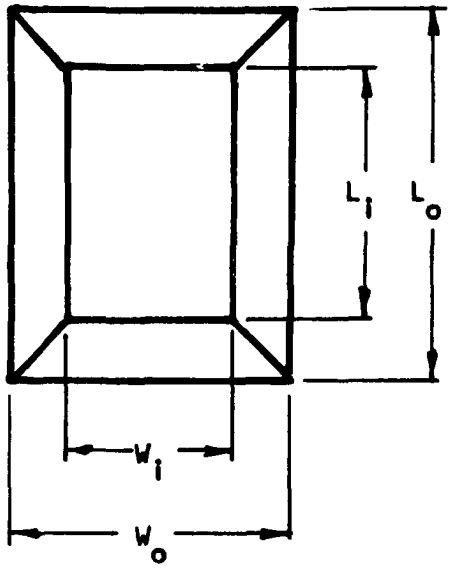


CYLINDRICAL IN-GROUND TANK (APPROXIMATION OF FRUSTRUM OF RIGHT CIRCULAR CONE)

D_o = OUTSIDE DIAMETER, m (ft)
D_i = INSIDE DIAMETER, m (ft)
h_i = TANK HEIGHT, m (ft)
h_p = PROCESS HEIGHT, m (ft)
f_p = FREEBOARD, m (ft)

$$V_p = .52\, D_o^2 \left[1 + \frac{D_i}{D_o} + \frac{(D_i)^2}{(D_o)}\right] \times h_p \quad m^3, \text{ (ft)}$$

TYPE E.



RECTANGULAR IN-GROUND TANK (APPROXIMATION OF OBELISK) (ELEVATION VIEW SIMILAR TO D ABOVE)

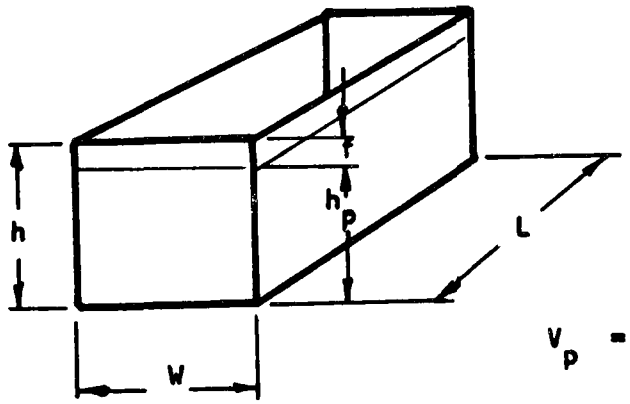
L_o = OUTSIDE LENGTH, m (ft)
L_i = INSIDE LENGTH, m (ft)
W_i = OUTSIDE LENGTH, m (ft)
W_i^o = INSIDE LENGTH, m (ft)
h_i = TANK HEIGHT, m (ft)
h_p = PROCESS HEIGHT, m (ft)
f_p = FREEBOARD, m (ft)

$$V_p = \frac{1}{6}\left[W_o L_o + (W_o + W_i)(L_o + L_i) + W_i L_i\right] \times h_p \quad m^3, \text{ (ft)}$$

Figure 73 (continued). Calculation information for tank volumes.

NWMAR116542

TYPE F.

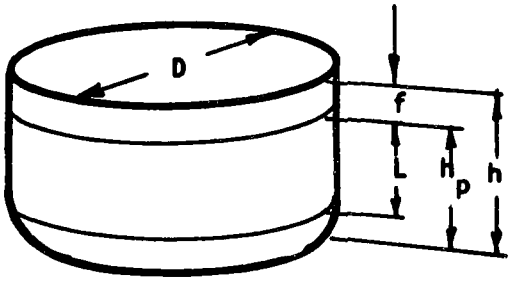


W = WIDTH, m (ft)
L = LENGTH, m (ft)
h = TANK HEIGHT, m (ft)
h_p = PROCESS HEIGHT, m (ft)
f^p = FREEBOARD, m (ft)

FOR SQUARE W = L = SIDE, m (ft)

$$V_p = WLh_p \quad m^3, (ft^3)$$

TYPE G.

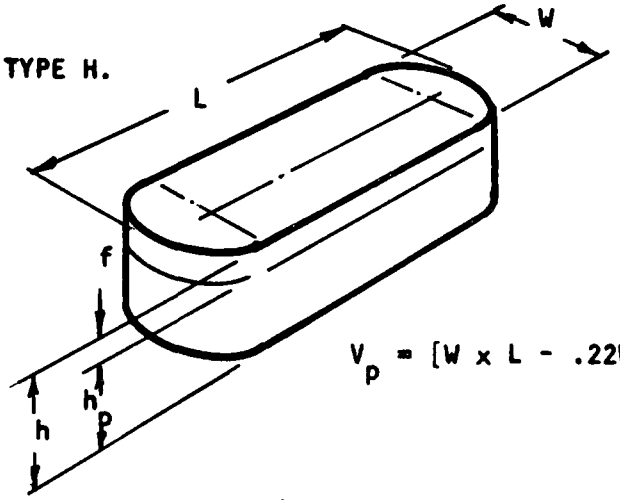


VERTICAL CYLINDER, ASME FLANGED AND DISHED HEAD ON BOTTOM

D = DIAMETER, m (ft)
L = LENGTH OF STRAIGHT SECTION LESS FREEBOARD, m (ft)
h = PROCESS HEIGHT, m (ft)
f^p = FREEBOARD, m (ft)
h = TANK HEIGHT
V_H = VOLUME OF HEAD, m^3 (ft^3) (See Figure 74)

$$V_p = .78D^2L + V_H \quad m^3, (ft^3)$$

TYPE H.



VERTICAL, OVAL-SHAPED CYLINDRICAL TANK

W = WIDTH, m (ft) (diameter of round end)
L = TOTAL LENGTH, m (ft)
h = TOTAL HEIGHT, m (ft)
f = FREEBOARD, m (ft)
h_p = PROCESS HEIGHT, m (ft)

$$V_p = [W \times L - .22W^2] \times h_p \quad m^3, (ft^3)$$

Figure 73 (continued). Calculation information for tank volumes.

NWMAR116543

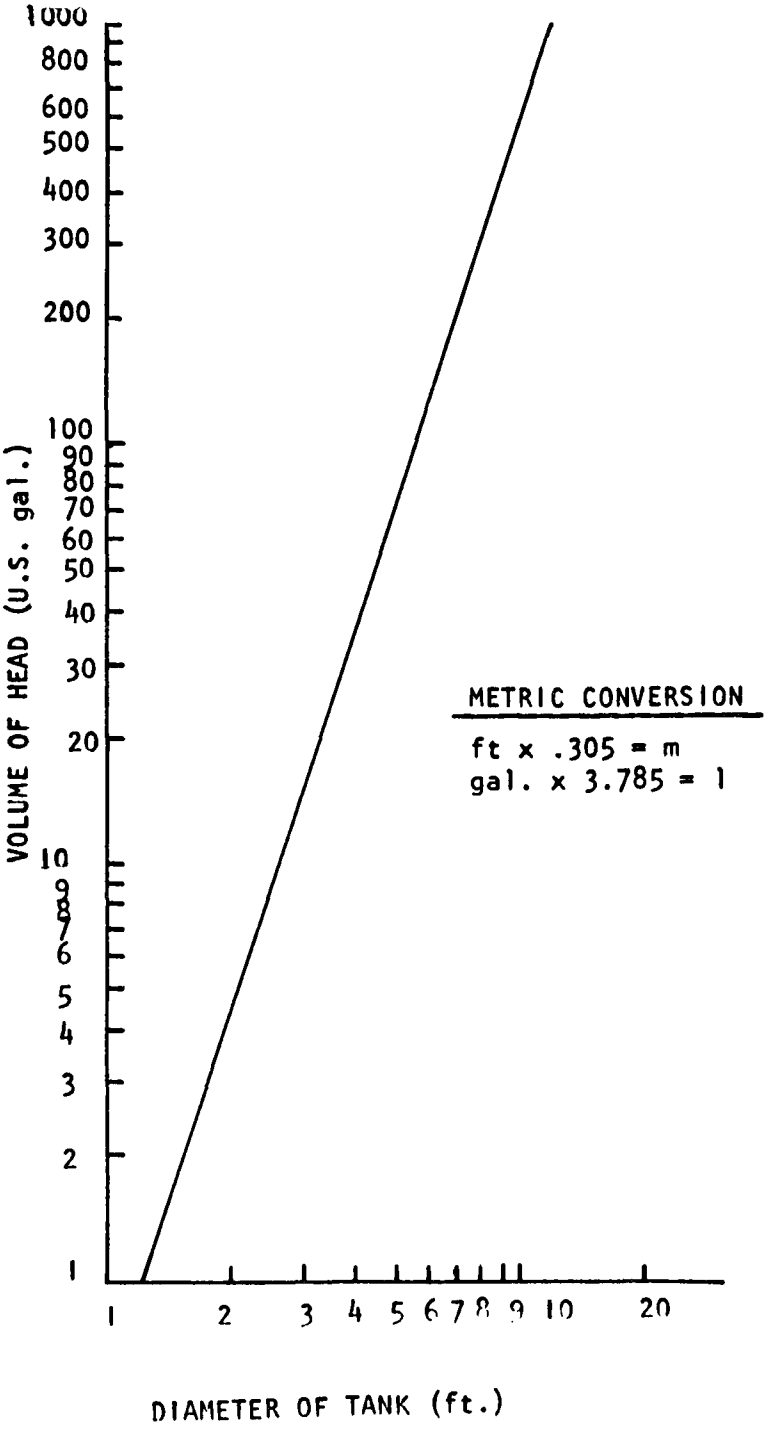


Figure 74. ASTM head volumes

NWMAR116544

The calculation for process volume allows for freeboard, which is a process requirement. Determination of freeboard must also take into account the hazard associated with the fluid, the structural stability of the tank, imminent dangers of leaking or overpressurization and the controllability of the process against overflowing.

7.3.2 Available Tanks - Description and Installation

The following tanks may fit a variety of process requirements. They were chosen on the basis of availability as well as desirability. It will be noted that some tanks most suited for field implemented treatment schemes are probably not locally available, e.g. rubber stave tanks. They are included however, to emphasize the need to make suitable process equipment available to facilitate field-implemented treatment.

Installation details are presented here to allow the user to:

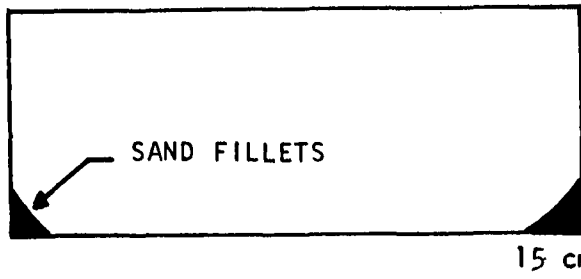
1. Be aware of special requirements for tanks.
2. Allow tank choice based on installation requirements and site considerations.
3. Become familiar with actual methods of installation.

7.3.2.1 Type A - Above Ground Swimming Pools - There are many types of commercially available pools but the most practical variety utilizes a flexible liner (usually 0.5 mm (or 20 mil) vinyl), finished steel sheet sides, and aluminum pedestal supports.

The pools typically come in circular shapes from 4.6 - 8.5 m (15-28 ft) in diameter and from 1.2 - 2.1 m (4-7 ft) deep. Allowing a minimum of 15 cm (6") freeboard, this represents a process capacity range of from 17.5 - 113.2 cu m (620-4000 ft^3). The pools are also typically available in oval shapes from 3.7 x 7.3 m (12 x 24') overall, to 4.9 x 12.2 m (16 x 40') overall, at 1.2 - 2.1 m (4-7') deep. This represents a process capacity range of from 25.5 - 107.6 cu m (900-3800 ft^3). They can probably be set up on a prepared site by three men in four hours. Four specific precautions are necessary in the field use of these tanks:

1. They should be set up on as flat a surface as possible with a solid base under the pedestal supports.
2. A smooth undersupport for the liner is necessary, with all sharp objects removed. It is preferred to support the liner above 5-10 cm (2-4") of sand or to install a ground cloth below the liner for insurance when on an uneven surface.
3. A 15 x 15 cm (6 x 6") curved fillet of sand is necessary to provide a radius of support for the liner at the juncture between the bottom and the walls. (See sketch on following page.)
4. Whenever a process component is introduced into the tank, e.g. hose thrown over the side, submersible pump installed on the bottom, etc., a piece of rubber or thick plastic should be installed to protect the liner from puncture.

NWMAR116545



SIDE ELEVATION VIEW OF TANK SHOWING RADIUS FILLETS OF SAND

Installation steps can be summarized as follows:

1. Choose a flat and open surface for installation.
2. Remove protruding objects, and place 5-10 cm (2-4 in.) of sand or a heavy ground cloth over chosen area to prevent rupture.
3. Build sand fillets around the radius of the pool.
4. Install pool (see Instruction Manual provided with pool).
5. Place protective liner inside the pool for added safety.

7.3.2.2 Type A - U.S. Army Corps of Engineers Portable Tanks - There is an open top tank with far better field implementation possibilities than the swimming pool, but with limited availability. This is the Army Corps of Engineers Collapsible Water Tank. This tank comes in two sizes: 5.7 and 11.4 cu m (1500 and 3000 gal.) A modified version of this tank in the 568 cu m (15,000 gal.) size has been used very successfully in the hazardous spills trailer treatment system. Tank construction is neoprene coated nylon material which is a tough, corrosion resistant material. The tank can be set up almost anywhere, is not easily susceptible to puncture, and has tank fittings to accommodate process hookups. Instead of the aluminum sidewall pedestals used by the swimming pool for support of the liner, the stave tank uses wooden slats which are quickly installed through stave pockets in the tank walls.

On soft or wet ground, boards would be placed under each stave to prevent sinking of the staves, which could result in their bowing out and cracking. Ground surface preparation involves removal of protruding objects which could puncture the liner. Spreading of 5-10 cm (2-4 inches) of sand under the tank can provide insurance against such punctures as well as use of the rubber ground cloth which comes with the tank.

Support bars span the top of the tank to maintain a circular cross section and guy ropes provide restraint against tipping. They can be fastened with stakes or just tied to water-filled or sand-filled barrels. The tank comes with a repair kit should a material failure occur. After disassembly, the tank, staves, and poles can be stored in a relatively small container.

Installation can be summarized as follows:

NWMAR116546

1. Choose appropriate site (flat/open)
2. Remove protruding objects and place 5-10 cm (2-4") of sand under tank to provide safe base.
3. Install tank (see instruction manual provided with tank).
4. If the ground is wet or soft, place boards under each stave.
5. Add support bars and secure guy ropes.

7.3.2.3 Types A, D, E, F, G Impermeable membranes as liners for earthen excavations or for steel, concrete, or wooden tanks - Synthetic flexible membranes have been long used as swimming pool liners and tank liners for water softeners but more recently are being used extensively in lining of ponds and canals, and in many other types of earthen excavations. New materials are being introduced regularly but at the present time, PVC, polyethylene, EPDM rubber, Hypalon, and chlorinated polyethylene, either with or without reinforcements are finding applications. The liners are available in large sheets with the exception of pool liners (20 gauge vinyl) which may be specially constructed to fit a certain size excavation. Where sheets are used in small excavations, a number of ruffled folds are necessary to make the flat sheet fit the contour, but this is not detrimental to process treatment. In large excavations, overlapping and sealing of the sheets is necessary. The differences between the available materials are summarized in Table 35.

Many of the polymers are produced with fabric reinforcements, varying from light-weight nylon scrims to very heavy nylon or polyester scrims, producing a variety of material strengths.

The earth itself has to be loadbearing in order to support the weight of the water and the membrane's function is to make the ground impermeable. It is necessary to remove all debris which might cause damage, including stones, roots, etc. A sand layer base of 5-10 cm (2-4") is desirable. When forming the sand on inclined surfaces the sand should be wetted and trowelled if possible.

When liner sections are overlapped, the water pressure tends to stabilize the joint by compression, minimizing seepage through improper joints.

The following summarizes the installation procedures:

1. Choose or excavate appropriate area.
2. Remove debris.
3. Place a sand layer 5-10 cm (2-4") thick if possible - wet and trowel sand on inclined surfaces.
4. Place and seal liner in place (see instructions accompanying liner).

7.3.2.4 Types D and E - Excavations treated with highly colloidal clay - This method of converting an excavation into a sealed tank involves treating the upper layer of soil with a clay which, when wetted, swells many times its volume and forms an impermeable seal. The material, called volclay, or bentonite, consists chiefly of hydrous aluminum silicate and is mined

NWMAR116547

TABLE 35. SYNTHETIC LINER MATERIALS

Material	Thickness	Guage	Length	Width	Sealing Method	Comments
Polyethylene	2-8 mils	light	any	up to 40'	heat or adhesion	1. least expensive 2. fairly stiff and may not conform to irregularities 3. heat seal is best but difficult to do in the field.
Polyvinyl Chloride	8-40 mil	heavier	up to 700 ft.	up to 70 - 80 ft.	solvent made	1. much stronger and tougher than all 2. Good bonding 3. Expensive
Butyl and EPDM Rubber	32-125 mil	medium	any	20 ft.	heat	1. Difficult to seal since it is a vulcanized product 2. Moderate toughness and puncture resistance 3. highly extensible
Hypalon and Chlorinated Polyethylene	30 mil	medium	any	4-20'	solvent	1. intermediate strength elongation and toughness 2. easily available in large panels
Vinyl	8-35mil	light	any	4-61 ft.	heat, solvent or adhesive	1. normal swimming pool liners 2. excellent puncture resistence

NWMAR116548

almost solely in the Black Hills region of the U.S. Information on the availability of product may be obtained from:

American Colloid Co.
5100 Suffield Court
Skokie, Illinois 60076

The material may be loaded onto a bulk lime fertilizer spreader to apply a uniform cover of the material over the tank area. Using a farm disk, Volclay is mixed into the top 5-7.6 cm (2-3") of soil. The Volclay-soil mixture is returned to its approximate original density with a wobble-wheel or steel wheel roller before being wetted. For small tanks, the above operations could all be performed by hand. Caution. Care must be taken, however, to wear respirators to prevent excessive inhalation of the submicron clay dust.

7.3.3 Column Tank Options

Type A column tanks for filters, carbon columns, and ion exchange columns:

A. Tanks constructed of corrogated steel pipe.

This piping is generally available in 20 foot lengths in the diameters and gauges shown in Table 36. Where fittings are to be installed on the tank or other welding is to be done, 14 gauge or lower is preferred. Pipes can be cut to desired tank height.

B. Tanks constructed of reinforced concrete culvert, storm, drain, and sewer pipe (see Table 37).

Caution: Be sure to use reinforced concrete to avoid excessive strain in the column.

When O-ring gaskets are used, it may be desirable to stabilize the tank by nailing several 2x4 wood straps across the joint at spaced intervals around the periphery.

C. Foundations for Column Tanks

A base of reinforced concrete must be poured for each column tank. These foundations are to be placed on firm soil. Field tests to determine firm soil on the basis of soil strength and density are shown in Table 38.

NWMAR116549

TABLE 36. INFORMATION ON CORROGATED STEEL PIPE (59)

Corrugation & Diam.			** Gages and Thicknesses Available in Inches					
2 2/3" x 1/2" & 2" x 1/2"	3" x 1"	End Area Sq. Ft.	18 .052	16 .064	14 .079	12 .109	10 .138	8 .168
12 in.		.79	*	*	*			
15		1.23	*	*	*			
18		1.77	*	*	*	*		
21		2.40	*	*	*	*		
24		3.14	*	*	*	*		
27		3.98		*	*	*		
30		4.91		*	*	*		
33		5.94		*	*	*		
36		7.1		*	*	*	*	
	36 in.		*	*	*	*	*	*
42		9.6		*	*	*	*	*
	42		*	*	*	*	*	*
48		12.6		*	*	*	*	*
	48		*	*	*	*	*	*
54		16.0			*	*	*	*
	54		*	*	*	*	*	*
60		19.6			*	*	*	*
	60		*	*	*	*	*	*
66		23.8			*	*	*	*
	66		*	*	*	*	*	*
72		28.3				*	*	*
	72		*	*	*	*	*	*
78		33.2				*	*	*
	78		*	*	*	*	*	*
84		38.5					*	*
	84		*	*	*	*	*	*
90		44.2					*	*
	90		*	*	*	*	*	*
96		50.3					*	*
	96			*	*	*	*	*
	102	56.7		*	*	*	*	*
	108	63.6			*	*	*	*
	114	70.9			*	*	*	*
	120	78.5				*	*	*

in. x 2.54 = cm
sq ft x 0.093 = sq m

NWMAR116550

TABLE 37. REINFORCED CONCRETE PIPE INFORMATION

Internal Diameter, inches	WALL A Minimum Wall Thickness, inches	WALL A Average Weight, pounds per foot	WALL B Minimum Wall Thickness, inches	WALL B Average Weight, pounds per foot	WALL C Minimum Wall Thickness, inches	WALL C Average Weight, pounds per foot
12	1 3/4	79	2	93	-	-
15	1 7/8	103	2 1/4	127	-	-
18	2	131	2 1/2	168	-	-
21	2 1/4	171	2 3/4	214	-	-
24	2 1/2	217	3	264	3 3/4	366
27	2 5/8	255	3 1/4	322	4	420
30	2 3/4	295	3 1/2	384	4 1/4	476
33	2 7/8	336	3 3/4	451	4 1/2	552
36	3	383	4	524	4 3/4	654
42	3 1/2	520	4 1/2	686	5 1/4	811
48	4	683	5	867	5 3/4	1011
54	4 1/2	864	5 1/2	1068	6 1/4	1208
60	5	1064	6	1295	6 3/4	1473
66	5 1/2	1287	6 1/2	1542	7 1/4	1735
72	6	1532	7	1811	7 3/4	2015
78	6 1/2	1797	7 1/2	2100	8 1/4	2410
84	7	2085	8	2409	8 3/4	2660
90	7 1/2	2395	8 1/2	2740	9 1/4	3020
96	8	2710	9	3090	9 3/4	3355
102	8 1/2	3078	9 1/2	3480	10 1/4	3760
108	9	3446	10	3865	10 3/4	4160

Large Sizes of Pipe Tongue and Groove Joint

Internal Diameter inches	Internal Diameter feet	Wall Thickness inches	Average Weight, pounds per foot
114	9 1/2	9 1/2	3840
120	10	10	4263
126	10 1/2	10 1/2	4690
132	11	11	5148
138	11 1/2	11 1/2	5627
144	12	12	6126
150	12 1/2	12 1/2	6647
156	13	13	7190
162	13 1/2	13 1/2	7754
168	14	14	8339
174	14 1/2	14 1/2	8945
180	15	15	9572

inches x 2.54 = cm
lbs x 454 = kg

Concrete pipe is available in 2.44 m (8') lengths, a variety of diameters, and in three wall thickenesses. Wall A is preferable because it is the lightest and makes the pipe easiest to handle. Pipe joints are tongue and grooved and can be joined with mortar or gasket package as well as with O-ring gaskets to form tanks of desired height. Required sections greater than 2.44 m (8') high can be obtained by sawing the concrete into desired lengths, and then stacking them together.

NWMAR116551

TABLE 38. SOIL STRENGTH AND DENSITY INDICATORS

SOIL STRENGTH

Term	Unconfined Compressive Strength (After Terzaghi and Peck)	Field Test (After Cooling, Skempton, and Glossop)
Very soft	0-0.5 kips per sq. ft.	Squeezes between fingers when fist is closed
Soft	0.5-1.0	Easily molded by fingers
Firm	1.0-2.0	Molded by strong pressure of fingers
Stiff	2.0-3.0	Dented by strong pressure of fingers
Very stiff	3.0-4.0	Dented only slightly by finger pressure
Hard	4.0 or more	Dented only slightly by pencil point

SOIL DENSITY

Term	Relative Density	Field Test
Loose	0-50%	Easily penetrated with 1/2-in. reinforcing rod pushed by hand
Firm	50-70	Easily penetrated with 1/2-in. reinforcing rod driven with 5-lb. hammer
Dense	70-90	Penetrated a foot with 1/2-in. reinforcing rod driven with 5-lb. hammer
Very dense	90-100	Penetrated only a few inches with 1/2-in. reinforcing rod driven with 5-lb. hammer

kips x .454 x 10^{-3} = kg
sq ft x .093 = sq m
in. x 2.54 = cm

NWMAR116552

Concrete pad details are as follows: 20 cm (8") thick square pads with base dimensions for various tank diameters are as follows:

m	inches	m x m	inches
0.61	24	1.22 x 1.22	48 x 48
0.76	30	1.32 x 1.32	52 x 52
0.91	36	1.42 x 1.42	56 x 56
1.07	42	1.52 x 1.52	60 x 60
1.22	48	1.63 x 1.63	64 x 64
1.37	54	1.73 x 1.73	68 x 68
1.52	60	1.83 x 1.83	72 x 72

Woven wire recinforcement is to be placed near the bottom of the slab. After pouring the slab, but before the concrete gets stiff, the tank is to be placed on the center of the pad and allowed to sink 7.6 cm (3") into the concrete. This will form a water seal at the base. It is very important that the tank be supported in a vertical orientation until setting occurs.

Holes through the concrete tanks for fittings (preferably threaded nipples) can be installed using a chisel. The nipple can then be mortared in. Metal tank fittings can be welded in place.

D. Installation of Column tanks.

1. Choose a suitable location - be sure that firm ground is chosen to prevent the column from moving.
2. Prepare area and pour concrete slab (see previous section for details).
3. Allow concrete to partially set and then place column in the pad.
   Caution: Be sure that the column is supported vertically until the concrete is set. Possible methods would be to place concrete blocks under the column or provide support.
4. If additional height (for concrete columns only) is necessary, use the following procedure:
   a. Cut column to desired height with a concrete saw.
   b. Place gasket, O-ring or mortar around the groove on the base column.
   c. Put column extensions on top of column and seal cracks with excess mortar (trowel smooth).
   d. Provide extra support around the joint.
5. Wooden braces can be used to reinforce the column if necessary.
6. Chisel holes through concrete for fittings and mortar connections.

NWMAR116553

7.3.4 Collapsible Rubber Tanks

These tanks are very handy for treatment systems effluent storage and backwash storage. They are typically available in neoprene and Buna-N in sizes ranging from 1.89 - 37.85 cu m (500-10,000 gal.). The tanks come fitted with inlet and outlet fittings. They must be used with a filler vent pipe installed for air venting and to prevent overpressurization. As in other rubber tanks, care must be taken to prevent puncture from sharp objects. A ground cloth or layer of sand is advised.

7.4 PROCESS FLOW COMPONENTS AND FLOW CONTROL

While tanks and pumps are of primary concern in process system construction, process flexibility and control is provided by other components as well, such as piping, hoses, tubing, valves, etc. Selection of these components is of prime importance if the pumps and tanks are to be used effectively. It is impossible in a short space to summarize all of the plumbing devices and installation methods which could be utilized to achieve proper process connections. In almost all localities the availability of plumbing contractors is a valuable resource for expeditious installation of plumbing systems.

This section will provide information on simple connections using hoses and basic control techniques. Plastic piping is also described for use in very corrosive situations. Simplicity is desired in field operations for process flexibility ease of operation and maintenance. However, in terms of safety from hazards, the simplest system may often be the most dangerous. For example, it is probably possible to interconnect processes without the use of valves in many cases. But the constant manual shifting of hoses is a time-consuming and potentially dangerous operation when extremely hazardous materials are being handled. Discretion and good judgment are required in designing a plumbing system which is feasible in the particular situation, as well as being safe.

7.4.1 Hose, Tubing, and Fittings

7.4.1.1 Process Hosing - Hoses for this service can generally be selected according to the following criteria:

a. Suction or discharge (vacuum or pressure)
b. Necessary configuration and use
c. Pressure rating
d. Materials of construction

Information on commercially available hoses are presented in Table 39. Suction hose is very useful in a spill treatment system. It is the most versatile hose in terms of being able to be used interchangeably for suction or discharge in almost any configuration. There is little concern with kinking, however this hose can be damaged by vehicular traffic. It is rather costly and heavy to handle. The hose has excellent availability. Another suction hose which is less available

NWMAR116554

TABLE 39. COMMERCIALLY AVAILABLE HOSES

Hose Description	Tube Material	Rated Pressure (Psi) / Available Length (Ft.)	Diameter (in.) 1.5	2.0	2.5	3.0	4.0	6.0	Availability
Suction Hose		(Full Vacuum to Positive Pressures as Shown)							
Water Suction (Rubber cover and tube, wire wound)	Neoprene	Psi	100	100	100	100	100	50	Excellent
		Ft.	50	50	50	50	50	20	
Heavy Duty Plastic (Black colored)	PVC	Psi	130*	115	100	85	75	60	Medium
		"	75*	65	65	45	40	35	
		Ft.	60	60	60	60	60	20	
Discharge Hose		(Positive Pressure Only)							
Rubber Discharge (Rubber cover and tube) 4 Ply	SBR/EPR	Psi	250	225	150	125	125	110	Medium
3 Ply	"	"	Not Pressure Rated						
Mill Hose									
Rubber Lined,		Ft.	100	50	50	50	50	50	
Cotton Jacketed	"	Psi.	200	200	200	200	200	200	Excellent
(50 Ft. Lengths)		Ft.	50	50	50	50	50	50	
Synthetic Yarn	PVC	Psi	75	60	55	50	40	40	Medium
Plastic Impregnated		Ft.	300	300	300	300	300	300	

* Pressure rating at 72°F
Pressure rating at 150°F

psi x 703 - kg/sq m
ft x .305 = m
m x 2.54 =cm

NWMAR116555

but lighter in weight is the plastic suction hose. It is preferred to use the heavy duty variety (often black in color). Pressure ratings are affected by temperature for the plastic hose and it can pull a full vacuum only up to 49°C (120°F). It becomes somewhat stiff at cold temperatures.

Discharge hose is lightweight and inexpensive, but not versatile for use in connecting pumps or treatment processes because of kinking. It becomes very useful for pumping long distances, e.g. raw flow and final effluent discharge. These long runs can be carefully laid and then left uninterrupted. It is desirable to use a short section of suction hose on either end of the long run where connection to a pump or into a tank could product a kink. Of the various types of discharge hoses, mill hose is the most readily available, is economical, and is lightweight.

Process hose support and protection must be handled very carefully. The following are some precautions that should be taken:

1. Tie all free hose ends so that the hose cannot become free or change configuration causing spillage. These supports should be rechecked after hose filling because a hose takes on additional weight when water filled. Tying down hoses is extremely critical when utilizing free discharge into a tank from a diaphragm pump or other type of reciprocating pump. Hose whipping can injure personnel and tank linings as well as spraying contaminated water.

2. When laying suction hoses across areas of vehicle access, the hoses should be either buried or strattled with planks. These planks should be pinned to the ground or otherwise supported to prevent movements. These precautions will prevent wire-wound hoses from crushing and causing flow restrictions.

7.4.1.2 Process Hose Fittings - The following readily available fittings are quite suitable for connecting hoses in field implemented pumping systems. They come with shank ends for mounting to hoses or pipe threads for connecting to process components such as pumps and tanks.

1. Quick couplings - adapter slips into coupler and then is sealed against a gasket by moving two cam-actuated arms; quick to remove and versatile; readily available in brass, alumimum, and cast steel.

2. Pin lug couplings - use a pin lug swivel nut to tighten joint; requires two spanner wrenches; good for hoses which are not often separated during operation; readily available in brass, aluminum, and cast steel.

3. Combination nipples - a shank to pipe thread adapter; for hose pipe thread connections that are typically not removed during the process operation; readily available in cast steel.

NWMAR116556

7.4.1.3 Process Hose Clamps - Clamps include two basic varieties: one requiring a special tool, such as Band-It or Punch-Lok clamps, and one requiring only a screwdriver or wrench, such as worm gear clamps or two-bolt clamps. The band material is available in coated steel or stainless steel. The clamps requiring the special tools are often better suited for handling of hazardous fluids because of the leverage which can be applied resulting in a strong clamping. It is preferred to use two clamps per hose end to assure trouble-free operation. It is necessary to attach the clamps on the hose shank portion of the fitting.

7.4.1.4 Installation of Fittings on Hoses - The following are recommended steps for field installation of fittings (normally requires two people):

1. Lubricate the shank portion of the fitting and the inside of the hose with a light oil (preferred) or water.

2. Cut the hose off square with a hacksaw. (Wire-wounded hoses can be cut with a hacksaw, but it is somewhat tricky).

3. (Plastic hardwall hose only) Heat the hose end by immersion in hot water for several minutes.

4. Have one person hold the free hose end vertically upright.

5. The second person can install the fitting, and drive it down into place with a hammer or heavy tool. Do not hit the fitting with a metal tool; cushion the blow by placing a piece of wood in-between.

6. Whenever possible, continue to drive on the fitting until the hose contacts the shoulder on the fitting. The main concern is to have several of the shank bars inside the hose for good clamping.

7.4.1.5 Plastic Pipe and Fittings - Although not as readily available as steel piping, plastic piping and fittings are very useful when pumping corrosives, or when forming manifolds for aeration. Available materials include:

1. PVC (Polyvinyl Chloride) - A very strong plastic pipe: maximum service temperature of 60°C (140°F). Excellent chemical resistance to a wide range of corrosive fluids, but may be damaged by ketones, aromatics and some chlorinated hydrocarbons; is joined by solvent welding or threading.

2. CPVC (Chlorinated Polyvinyl Chloride) - Can handle corrosives up to 85°C (185°F). Comparable to PVC in chemical resistance; is joined by solvent welding or threading.

3. Penton (Chlorinated Polyether) - Very good chemical resistance and is useful up to 121°C (250°F). Costs two to three times as much as PVC piping and is used for elevated temperatures or where other

NWMAR116557

materials lack satisfactory resistance to specific chemicals; is joined by threading.

4. Polypropylene - Finds wide application in pumping mixtures of acids, bases, and solvents; may be used up to 82°C (180°F); is best joined by Thermo-Seal fusion welding.

A variety of fittings, e.g. elbows, tees, couplings, reducers, flanges, etc. are available in both threaded and socket types. Local stocking of pipe and fittings, however, will probably be limited to PVC products.

Plastic piping is installed to look very much like metal piping systemswith the difference that closer support spacings are required.

The following is a brief description of joining methods for plastic pipe:

1. Solvent Welding - The generally preferred method of joining rigid thermoplastics such as PVC and CPVC, is solvent welding. This gives a stronger joint than threading and is also considered faster and simpler. Additionally, solvent welding permits the use of thinner walls, when compared to threaded connections, for equivalent pressure ratings.

2. Threading - As is the case with metal pipe, threading reduces the effective wall thickness of thermoplastic pipe and introduces notch effects which lower strength. Threaded connections should be used with Schedule 80 or heavier pipe. The chief advantage of threading is the ease of disassembly it offers.

3. Thermal Bonding - By taking advantage of the thermoplasticity of the materials, methods of joining solvent-resistant thermoplastics such as polypropylene are available which utilize tools to apply regulated heat uniformly and simultaneously to pipe and fitting mating surfaces so that true melting occurs on the surfaces. Only hand pressure is needed to join the components and as the material cools, a permanent homogenous bond results.

4. Flanging - One of the earliest methods for joining thermoplastic piping, flanging continues to be used extensively for process lines. Thermoplastic flanges and flanged fittings are available in a full size range and may be attached to pipe by solvent welding, by threading, or by thermal bonding, as required by the particular thermoplastic material.

7.4.2 Flow Control

Tanks, pumps, hoses, and fittings constitute the primary means to store, move, and treat fluids in field implemented process systems. However, because not all pumps are variable speed controlled, and because treatment processes involve flow diversions to accomodate the various process

NWMAR116558

modes, valves or other flow control devices will probably be required in most treatment systems. If they are not required for flow control, they are desirable from the standpoint of safety. For example, when treating hazardous fluids, it is preferred from a safety standpoint, to open or close a valve rather than manually changing hose locations and connections. In this manual, no attempt was made to devise valving systems to eliminate hose transfers in the various process modes. Since the local avalability of valves is unknown, it would be advisable for the On-Scene Coordinator to have the services of a person versed in design and construction of plumbing systems for hookups.

The following are flow control techniques which can be employed in field treatment systems:

1. Pump speed control - flow control may be inherent in speed controls which are built in the pump-drive system itself. For example:

   a. Engine driven pumps - engine throttling is used to alter pump speed and thus control flow;

   b. Air-driven pumps - control of air flow is used to regulate fluid flow;

   c. Variable-speed electric pumps - mechanical linkages between motor and pump allow variable drive ratios which alter pump speed and change flow.

2. Changing of pump head-Most direct-coupled electrical pumps, however, will be constant-speed devices and require changes in pressure head to control flow. A variety of pump head control techniques are possible:

   a. Throttling valve control - head loss across the valve is increased or decreased by opening or closing a valve on the discharge side of the pump; a continuous control technique.

   b. Sizes and length of hoses - excess or undersized hosing can alter total friction head and cause flow changes; system must be shutoff and drained. Should be performed on discharge side of pump only.

   c. Changes in static head - changing the location of the receiving water level with respect to the pumping water level; (changing the location of the pump alone will not effect a static head change). System would be shutoff for this change.

3. Bypass systems - Flow control may be achieved by bypassing some of the fluid from the discharge side of the pump either back to the suction side or back to the pumping water body. This can be done without any valves through controlling relative sizes of

NWMAR116559

flow and bypass lines (not a continuous control technique) or a bypass valve may be installed for continuous flow control.

7.4.2.1 Valves (see Reference 62) - Valve function, more than any other single criterion limits the choice of valves. For purposes of discussion, valves may be categorized into three groupings: on-off service, throttling service, and prevention of backflow. Pressure drop through valves can be substantial and so a valve selection which minimizes pressure drop while still meeting other requirements is obviously best. Valves are available in a variety of materials of construction to be compatible with corrosive environments. Materials of construction, however, are sometimes limited to certain sizes. For example, in water service, valves up to 10 cm (4") size are generally available in brass or bronze, whereas in sizes above 10 cm (4") iron and steel bodies are usually available. Small sizes, up to about 5 cm (2") are screwed and the larger sizes flanged.

Care must also be taken in choosing valves for field treatment processes to select a valve which will not clog easily from debris. Few field processes are free of materials which can clog valves and disrupt system flow.

Varieties of the valve groupings are described below:

1. On-Off Service - Gate, plug, ball, and butterfly valves; gate valves are the most readily available; full port valves are best suited for field treatment processes; plug and ball valves come in venturi and reduced port designs which have increased pressure losses and susceptability to clogging; not generally good for throttling because the valve is almost closed before pressure begins to rise; in the almost closed position the full port feature is useless. Butterfly valves, good for on-off or throttling service, are described in the next section.

2. Throttling Service -

   a. Globe valve - unidirectional valve; high pressure drop due to tortuous flow path; Y-pattern and angle-pattern help to minimize pressure loss;

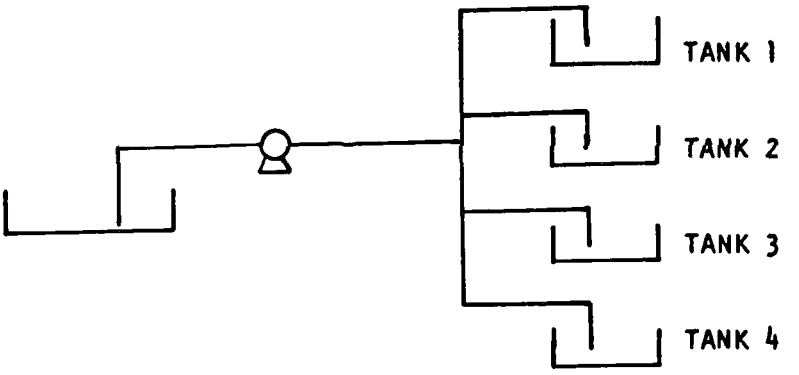
   b. Butterfly valve - built like a stovepipe damper; screwed pipe connections on small sizes (up to 2 inch), wafer design on larger sizes requires mounting between two flanges; low pressure loss; especially well-suited for large flows; quite suitable for slurries or solids-bearing liquids; fast acting;

   c. Diaphragm valve - most commonly available in weir pattern; pressure drop roughly equivalent to globe valve; no packing required because of complete fluid isolation; excellent for viscous media, slurries, and corrosive fluids.

NWMAR116560

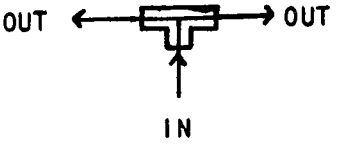
3. Check Valves - prevent reverse flow in fluid line; automatic in operation; are kept open by the pressure of the flowing fluid; available in swing, tilting disc, lift, or stop-check designs' of the four varieties, swing and tilting disk have the straight flow pattern and lowest pressure loss.

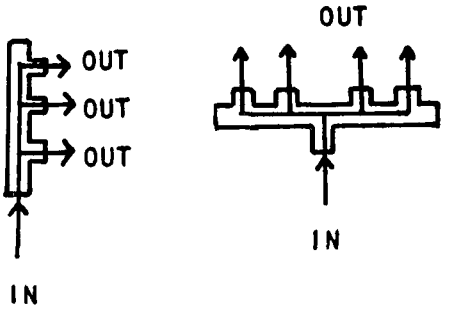
7.4.2.2 Flow Splitting - Because of limited availability of valves and the need to divide flow from a single pump discharge into a number of parallel treatment processes, a flow splitter is required such as is shown schematically below.



The flow splitter is basically a plumbing manifold with a single inlet and multiple outlets. It can be constructed from either screwed plumbing fittings or as a weldment. Below are listed some criteria to be used when designing a flow splitter:

1. Make the fitting as symmetrical as possible from inlet to outlet without making one flow path easier than another.



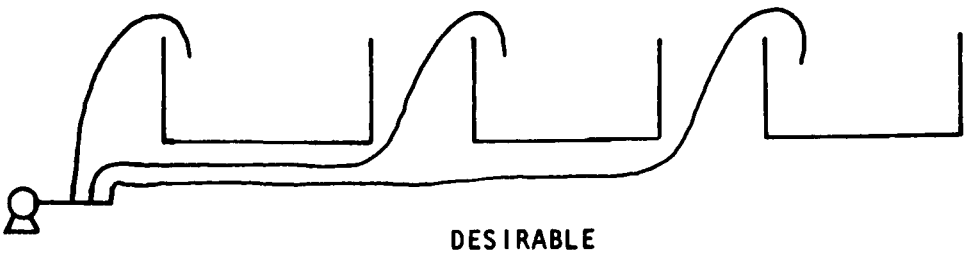


e.g. for the two, three and four outlet manifolds shown above all flow lines from in to out involve the same number of bends.

2. Make the total length of the manifold as short as possible.

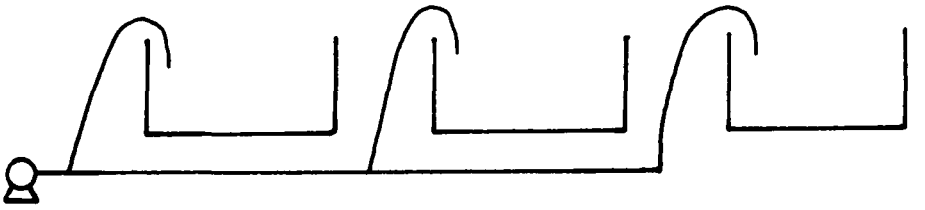
NWMAR116561

a.



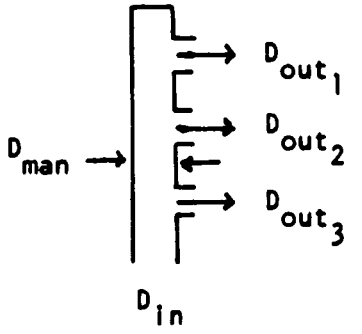
DESIRABLE

b.



UNDESIRABLE

3. The total area of outlet should be less than the manifold area.



$$\frac{\pi D^2}{4}_{man} > \frac{\pi}{4}\left(D^2_{out_1} + D^2_{out_2} + D^2_{out_3}\right)$$

or, generally

$$D^2_{man} > D^2_{out_1} + D^2_{out_2} \cdots D^2_{out_n}$$

Note: The manifold area may be enlarged above the inlet area to meet this requirement.

4. Do not support heavy manifolds from a pump body. A length of lead hose to a manifold lying on the ground is preferred.

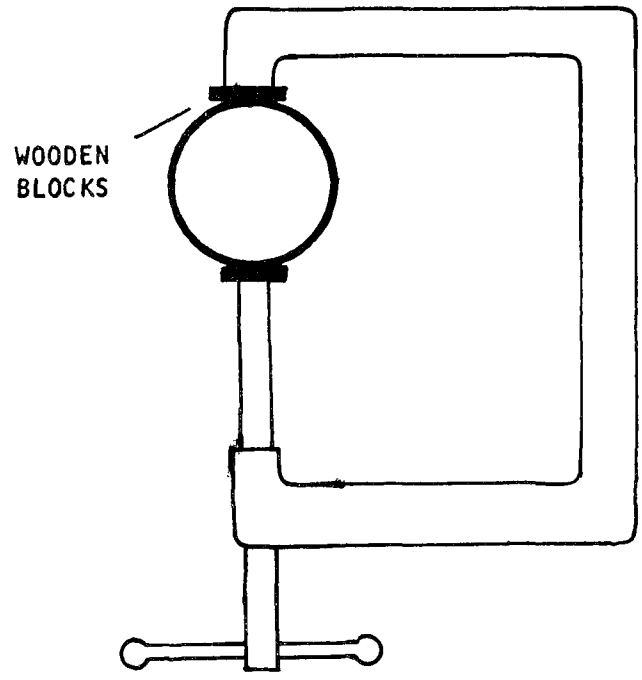
If the flow splitter does not provide as equal a division of flow as in desired without the use of valves, some further flow equalizing techniques may be employed:

1. Varying the discharge elevations of the outlets.

2. Using the longer discharge hoses on the higher flowing lines.

3. Crimping a hose to cause flow restriction, e.g. using a C-clamp valve as shown below in an end view.

NWMAR116562



7.5 CHEMICAL FEED COMPONENTS

7.5.1 General

Equipment which is necessary to safely handle the treatment chemicals is considered separately in two subsections. These chemicals are unsafe to handle using improvised systems due to their high concentrations and corrosive properties. Therefore, specialty equipment manufactured specifically for handling of these chemicals must be obtained locally by the OSC and transported to the treatment site.

The descriptions which follow are intended to provide a basic understanding of the types of available chemical feed pumps, tubing fittings and mixers. This type of equipment is usually handled by suppliers who have ready access to information from which the best equipment for the particular application may be selected. To contact suppliers for a local area, the Yellow Pages should be consulted under the following, or similar subjects:

Hose and Tubing - Rubber and Plastic
Laboratory Equipment and Supplies
Mixing and Agitation Machinery
Pumps
Tanks -Fiber Glass, Plastic, etc.
Tube Fittings
Tubing - Metal

NWMAR116563

Since the suppliers have the needed expertise, no attempt has been made to specify the best components for a certain chemical. This specification may limit the OSC to a certain suitable but unavailable type of equipment, and thereby halt the treatment operation. Instead, a list of information needed to establish the suitable equipment type has been presented. (see Figure 75) To use this approach, the OSC should complete the charts and then relay this information to the supplier. Then the supplier can recommend the equipment needed.

7.5.2 Chemical Metering Pumps

Chemical feed pumps are normally available at pump supply houses. To facilitate selection of chemical feed pumps, available pumps are classified into the following three general headings. These headings differentiate between the different pumping actions and permit identification of wetted parts which is important when selecting proper materials of construction. The classification designating A-C are used in other parts of the manual when referring to these pumps:

Type A. Centrifugal, positive pressure, and gear pumps: Type A pumps are not positive displacement pumps which means that pumping volume is not independent of pressure. Thus they are not normally used where exact metering is critical under all conditions. For most applications though, where pressure does not fluctuate dramatically, reasonably accurate calibrations can be achieved.

The centrifugal or gear pumps are suitable for pumping chemical solutions at higher flow rates (typically 3.7 - 170 lpm (1-45 gpm)) and low to medium pressures (typically up to 1.3 atm (20 psi). They are not self-priming and should be operated with a flooded suction. The positive pressure pumps are capable of pulling suction lifts of 0.9-48 m (3-15 ft) dry and 6.1 - 7.6 m (20-25 ft) primed. They also are suitable for higher flows (typically 3.7-98 lpm (1-26 gpm)) and low to medium pressures (typically up to 3.4 atm (50 psi).

They have impellers or gears which rotate at constant or variable speed. The impellers may be rigid members rotating with a clearance within the pumping chamber; they may be gears or lobes which mechanically mesh; or they may be flexible impellers which have contact with the pumping chamber as they rotate. The pumps are either direct drive, in which case there is a seal around the drive shaft to prevent corrosion of the motor, or magnetically coupled, in which the drive end is completely independent of the fluid end and no shaft seal is necessary. Typical materials of construction for the wetted parts of Type A pumps are listed in Table 40.

Type B. Reciprocating, Positive Displacement Pumps: These pumps are capable of producing a fixed or variably controlled output flow irrespective of system pressure. They are most accurate with a flooded suction and high pressure outlet (typically 40 psi). In low pressure systems this outlet pressure can be created artificially with a backpressure valve.

NWMAR116564

Required information for Establishing Suitable Chemical Feed Equipment.

Pumps

1. What is the required flow rate? _____

2. What chemicals and concentrations are to be pumped*

Chemicals	Concentrations
_____	_____
_____	_____
_____	_____

* One chemical may be pumped at various concentrations so specify both.

3. What suction lift is required (See 7.2.1)? _____

4. What discharge head is required (See 7.2.1)? _____

5. Is flow adjustment needed during operation? _____

6. At what temperatures will the pump operate? _____

7. What electrical requirements exist?

   Voltage _____ single / 3 phase

Tubing and Fittings

1. What sizes are needed (Tube O.D.)? _____

2. What will be the operating pressure? _____

3. What materials and concentrations are to be pumped? (See pump section) _____

4. What are the thread specifications for connected parts? _____

   e.g. nominal size of NPT pipe, threads, male or female threads, etc.

Figure 75 Information needed to obtain suitable chemical feed equipment

NWMAR116565

Tanks

1. What volume is needed? _____

2. What materials and concentrations are to be contained? _____

3. What mixer mount is needed?

   side, center, other

4. Where are fittings to be located and what size is needed?

5. Is the tank to be covered?

Mixers

1. What materials and concentrations are to be mixed?

   _____ _____

   _____ _____

   _____ _____

2. How long will the mixer operate per batch? _____

3. How many batches will be mixed per day? _____

4. What is the tank volume and dimensions? _____

5. What type of mixing is required?

   Rapid mix

   Gentle mix

6. What electrical hookups are available?

   Voltage Single

   3 phase

Figure 75 (continued). Information needed to obtain suitable chemical feed equipment

NWMAR116566

TABLE 40. MATERIALS OF CONSTRUCTION FOR TYPE A PUMPS

Body	Impeller	Shaft	Seal
Centrifugal (Capacities 25-170 lpm (6.6-45 gpm), maximum pressure .2-1.5 kg/cm^2 (4-21 psi)			
polyethylene nylon	polyethylene stainless steel	stainless steel nitrile coated steel	Buna N and stainless steel
stainless steel polypropylene Buna N Penton	polypropylene Buna N Penton		Buna N Carbon or none required for magnetic drive
Positive Pressure (Capacities 11-98 lpm (3-26 gpm)			
bronze	nitrile neoprene	stainless steel Hastelloy "B" and "C"	neoprene Buna N
stainless steel	viton	Titanium	Carbon & stainless
phenolic epoxy	epoxy Buna N		Nitrile Viton or none required
Gear			
stainless steel delrin plastic	stainless steel teflon	stainless steel	neoprene or none required

By utilizing micrometer-adjusted mechanical and hydraulic control linkages, these pumps are capable of accurately metering fluids from high flows down to a fraction of a gph. They can also pump against very high pressures.

There are two basic types of positive displacement pumps - plunger pumps and diaphragm pumps. It is only important here to note that they represent differences in the types of wetted parts: the plunger pump with a piston and packed seal and the diaphragm pump with a flexible displacement element. Both pumps require inlet and outlet check valves to allow the fluid to be pumped. Typical materials of construction for the two types of pumps are as follows: (Table 41)

Type C. Peristaltic and Flexible-stator, eccentric-rotor pumps: These pumps employ a squeegee action to pump the fluid. They are thus positive pressure, rather than positive displacement pumps. They differ from Type A pumps because there is no impeller in the fluid stream. Rather the rotational action is transmitted into a progressive squeezing on either a tube section or a flexible liner within the pump head. The peristaltic or tube-squeezing pump is utilized for flow metering

NWMAR116567

TABLE 41. MATERIALS OF CONSTRUCTION FOR POSITIVE DISPLACEMENT PUMPS

Plunger pump			Diaphragm pump	Check valves		
Pump body	Plunger	Lantern ring	Diaphragm or bellows	Valve Body	Ball	Ball seat
steel	stainless steel	stainless steel	elastometer	steel	stainless steel	stainless steel
iron	ceramic	Allow 20	teflon	stainless steel	PVC	PVC
stainless steel	monel	Hostelloy "C"	polyethylene	PVC	Hostelloy "C" to "D"	Alloy 20
PVC		PVC	Buna N	Allow 20	alumina-ceramic	monel
Alloy 20		alumina-ceramic	neoprene	Hostelloy "C"		Hostelloy "C"
Monel			Viton	monel		
Carpenter 20			resistant steels			

NWMAR116568

at flows less than 1 gpm and pressures to 1.7 atm (25 psi) under continuous use. The flexible stator pump has a capacity range of from 1.1 - 15 lpm (0.3-40 gpm) at up to 2.4 atm (35 psi) continuous pressure. Both pump types are self-priming and both pumps are susceptible to tube or liner failure after extended use.

The wetted parts used in typical Type C pumps are listed as follows:

Pump body	Peristaltic tubing	Flexible stator liner
polyethylene	tygon	gum ribber
teflon	viton	Buna N
bakelite	silicone	neoprene
stainless steel		hypalon
		butyl
		viton

7.5.3 Thermoplastic Tubing and Fittings

Thermoplastic tubing and fittings are perhaps the most versatile for field hookups of chemical feed systems, particularly because of their flexibility and ease of assembly. They are suitable for use with a wide range of chemicals. Typical sizes and ratings are given in Table 42.

Thermoplastic fittings can also connect tubing constructed of the following materials: copper, brass, steel, stainless steel, glass, plastic, aluminum.

7.5.3.1 Thermoplastic Insert Fittings - Polyethylene or nylon shank fittings (require clamps) can be used with either reinforced or non-reinforced clear vinyl plastic hosing or rubber hosing in the 0.5-5 cm (3/16 - 2 in.) inside diameter range and at working pressures up to 8.5 atm (125 psi). Clear vinyl tubing and hosing can be obtained in a variety of wall thickenesses for use with these insert fittings, providing a wide range of pressure ratings.

7.5.3.2 Metal Tubing and Fittings - Metal tubing fittings are available in brass, stainless steel, steel, and aluminum typically in sizes from 0.17 - 2.5 cm (1/16 - 1 in.) O.D. They can be used with steel, stainless steel, copper, aluminum, glass, and plastic tubing. Many types require only wrenches to install. However, tube cutting and bending devices are desirable when using metal tubing.

7.5.4 Chemical Feed Tanks

Several varieties of polyethylene and fiberglass tanks are available out of stock from the manufacturers. The most readily available are flat bottom, open top tanks in the 0.23-1.7 cu m (60-450 gal.) range. Also available but probably not from stock are dished bottom, open top tanks, with bottom fittings to accommodate filling and emptying. Concrete tanks, such as septic tanks or tanks constructed from sewer tiles as described in Section 7.3.3 can also be used to mix and store chemicals.

NWMAR116569

TABLE 42. TYPICAL THERMOPLASTIC TUBE SIZE

	Pressure rating, psi	Lengths, ft	Outside diameter, in.
polypropylene (rigid)	190	10	3/8, 1/2, 5/8
nylon	250	500	1/8, 3/16
	250	250	1/4, 5/16, 3/8, 1/2
vinyl (clear)	65	50	1/4
(formula PV-1 or PV-2)	55	50	5/16, 3/8
	45	50	1/2
	30	50	5/8
polyethylene	120	1000	1/4
	145	500	5/16
	125	500	3/8
	90	250	1/2
	70	100-500	5/8

Fittings - nylon and polypropylene

pressure ratings - Tube O.D.	Working Temperature, °F		
	up to 75	76-125	126-175
1/4	300	300	300
5/16	300	300	300
3/8	250	250	150
1/2	200	200	150
5/8	150	100	50

available fittings: unions, connectors for tubing to male or female pipe threads, tees, reducer unions, elbows

psi x .068 - atm
feet x 0.305 = m
meters x 2.54 - cm
(°F - 32) x 5/9 = °C.

NWMAR116570

7.5.5 Chemical Feed Mixers

Impeller mixers, both direct drive and gear drive are available, although the gear drive operating at about 350 rpm is more suitable for chemical mixing. The shaft length and number and configuration of impellers must be based on the geometry of the chemical tank. Portable mixers are usually equipped with clamp mounts and ball and socket index positioning joints. Stainless steel, Type 316, shaft and impellers are typically used on chemical service, with rubber covering used on some severe corrosives such as ferric chloride.

Power requirements range from .18 - 2.2 kw (1/4 - 3 HP) are available and the following preliminary sizings are presented for reference:

1. For dissolving chemicals and mixing acids and bases - .25 kw for 1,893 ℓ tank, and .56 kw for a 3,785 ℓ tank (1/3 hp for 500 gallon tank, 3/4 hp for 1000 gallon tank).

2. For mixing polyelectrolytes or lime - .56 kw for a 1,893 ℓ and 1.2 kw for a 3,785 ℓ tank (3/4 hp for 500 gallon tank, 1 1/2 hp for 1000 gallon tank.

7.6 AIR COMPRESSORS AND BLOWERS

The typical uses for air in field implemented treatment operations are for use on air driven diaphragm pumps and for aeration. The most readily available compressor is the rotary screw compressor, which is a constant volume device, capable of pressure control down to 4 atm (60 psi). In applications such as aeration where pressures less than .34 atm (5 psi) are required, an additional pressure regulator and flow bypass valve will be needed to provide flow control. Table 43 summarizes potential sources of air compressors and blowers.

7.7 SELECTION OF CORROSION RESISTANT MATERIALS OF CONSTRUCTION

This subsection provides information on the various materials of construction which are available. Included is information regarding trade names, corrosion resistances and typical uses of both ferrous and non-ferrous metals and other nonmetallic materials. The general corrosion resistance properties are discussed. In most spill situations, the flow stream will contain only diluted contaminants so corrosion problems will be minimal. The most corrosive materials are the treatment chemicals and special types of chemical feed pumps and components must be obtained. It is recommended that the user contact the manufacturers of various equipment, detail the specific conditions of the contaminated water and treatment chemicals and then choose the type of materials needed. This section will then allow the user to augment his knowledge of the materials involved and check the recommended application. The material presented is summarized in most part from "Corrosion Engineering" written by M. G. Fontana and N. D. Green (63). Further information regarding materials is available in this text and other references.

NWMAR116571

7.7.1 Metals

1. Cast iron - This material is found in many cast process components such as pump bodies, impellers, valve parts, etc. Cast iron is a general term applied to high carbon-iron alloys containing silicon. Common varieties are: gray, white, malleable, ductile, and nodular. The material is quite susceptible to oxidation or "rust".

   Increasing the silicon content to over 14% produces an extremely corrosion resistant material, e.g. Duriron, which is very hard and resists erosion-corrosion (notable exception: hydrofluoric

TABLE 43. SOURCES AND SIZES OF AIR COMPRESSORS

Air Compressors:

Sources	Size	Pressures	Comments
Contractor Supply House	150-650 scfm	100-125 psig	Low capacity are gas engine powered and higher capacity are diesel engine powered. Require pressure regulators to give lower delivery pressures. Can normally be rented.
Local Sewage Treatment Plant	150-650 scfm	100-125 psig	
Local DPW	150-650 scfm	100-125 psig	
Fire Dept.	150-650 scfm	100-125 psig	
Manufacturers of Blowers	Wide range of sizes	Low pressure up to 15 psi	Generally must be purchased.

scfm x .028 = scum/min.
psi x .068 = atm

NWMAR116572

acid). The alloy is sometimes modified by the addition of 3% molybdenum, e.g. Durichlor or Durichlor 51, for increased resistance to hydrochloric acid and chlorides.

In addition to alloys using silicon and molybdenum, other alloys using nickel, chromium and copper also produce improved corrosion resistance. Copper addition causes the metal to better withstand attack from sulfuric acid. High nickel-chromium cast irons with and without copper, e.g. Ni-Resist and Ni-Hard, produce very tough castings to resist erosion-corrosion in near-neutral and alkaline solutions or slurries.

2. Carbon steel - Carbon steel is alloyed, in various combinations, with chromium, nickel, copper, molybdenum, phosphorous, and vanadium. Low-alloy steels (2% total maximum alloying elements or less) are generally the more corrosion resistant. However, like cast iron, it is very susceptible to rusting.

   Steel products are cast and also readily available in sheet, plate, and structural forms, as well as in a variety of products. Steels can be easily field cut and welded.

3. Stainless Steel - Stainless steel has the same versatility of usage as carbon steel, with greatly improved corrosion resistance. Desired corrosion resistant properties are produced by alloying at least 11 percent of chromium. The chromium is reactive, but sets up a passive film to inhibit further corrosion. The following (64) is a brief description of the five types of corrosion resistant alloys most commonly used in chemical applications:

Type 304	The basic 18% Cr-8% Ni type for relatively mild corrosion resistance.
Type 316	The "18-8" type with 2.0/3.0% Mo for superior resistance to pitting and to most types of corrosion, particularly in reducing and neutral solutions.
Type 317	The "18-8" type with 3.0/4.0% Mo, which has moderately better resistance than type 316 in some conditions, such as high concentrations of acetic anhydride and hot acetic acid.
"20"	A 29% Ni-20% Cr steel with copper and molybdenum, developed specifically for resistance to sulfuric acid.
Ni-o-nel	A 42% Ni-21.5% Cr alloy with copper and molybdenum, developed to meet more severe corrosion and stress-corrosion conditions than can be handled by the stainless steels but where nickel-base alloys are not needed.

NWMAR116573

4. Aluminum and Alloys - Next to carbon steel and stainless steel, aluminum represents a versatile metal for construction, available in cast form and sheet, plate, and structural forms and in a variety of commercially available process components.

   Aluminum is reactive but develops a passive oxide film which protects it from further corrosion in many environments. This film remains stable in neutral and many acid solutions, but is attacked by alkalies. The passive film is produced after contact with the chemical environment, unless the film has been artificially produced through anodizing. Structural members are typically produced from high-copper alloys, whereas process components are usually constructed of the low-copper or copper-free alloys, which have better corrosion resistance.

5. Magnesium and Alloys - A lightweight material often found on portable devices and vehicles, however one of the least corrosion resistant. It must generally be physically separated from other metals or it will become a sacrificial anode for them. It is capable of forming a good passive film, however, the film breaks down in salty air conditions, necessitating that special coatings or other surface preparations be used. Magnesium is susceptible to erosion-corrosion. It is much more resistant to alkalies than is aluminum. It is attacked by most acids except chromic and hydrofluoric. The corrosion product in HF acts as a protective film.

6. Lead and Alloys - Used often on corrosion resistant applications in such forms as : sheet linings, solder, cable sheath, bearings, and piping. Lead forms protective films consisting of corrosion products such as sulfates, oxides, and phosphates. It is subject to erosion-corrosion because of its softness. Chemical-resistant lead, containing about 0.06% copper, is resistant to sulfuric, chromic, hydrofluoric, and phosphoric acids, neutral solutions, and seawater. It is rapidly attacked by acetic acid and generally not used in nitric, hydrochloric, and organic acids.

7. Copper and Alloys - Copper alloys are found in pump bodies and impellers, process component bodies and parts, and in pipe tubing and fittings, tanks, bearings, wire and screen.

   A good chemically resistant material, copper is a noble metal and is not corroded by acids unless oxygen or other oxidizing agents (e.g. HNO_3) are present. Copper-base alloys are resistant to neutral and slightly alkaline solutions (exception: ammonia). Common alloys are: brass, bronze, and cupernickel. Bronze, aluminum brass, and cupranickel are stronger and harder than copper and brass and less subject to erosion-corrosion.

8. Nickel and Alloys - A workhorse in severe corrosion applications, nickel and its alloys are found in many commercially available

NWMAR116574

process components, especially pumps, valve parts, and other critical process parts. Nickel is resistant to many corrosives and is a natural for alkaline solutions, found in many tough applications on caustics. It shows good resistance to neutral and slightly acid solutions. It is not resistant to strongly oxidizing solutions, e.g. nitric acid, ammonia. Among the common varieties:

Monel - natural for hydrofluoric acid

Chlorimet 3 and Hastelloy C - two of the most generally corrosion-resistant materials commercially available

Chlorimet 2 and Hastelloy B - very good in cases where oxidizing conditions do not exist

9. Zinc and Alloys - Not a corrosion-resistant metal, chiefly used in galvanized steel.

10. Tin and Tin Plate - Usually found as a coating and is used in solder and babbit bearings, is corrosion resistant, easily formed and soldered; and provides a good base for organic coatings. Tin has good resistance to dilute mineral acids in the absence of air, and many organic acids, but is corroded by strong organic acids; generally not used for handling alkalies.

11. Titanium and Alloys - A newcomer to corrosion resistant construction, is available as castings in pumps, valves, and other process components. Titanium is a reactive metal which depends on a passive oxide film for corrosion resistance. Titanium has resistance to seawater and other chloride salt solution; hypochlorites and wet chlorine; and nitric acid. Salts such as $FeCl_3$ and $CuCl_2$, which tend to pit other metals do not corrode titanium. It is not resistant to relatively pure sulfuric and hydrochloric acids.

7.7.2 Nonmetallics

1. Natural and Synthetic Rubbers - Rubber is an important process material with an extensive range of uses: hoses, tanks, tubing, gaskets, pump diaphragms and impellers, sheets, liners, etc. Rubber has excellent chemical resistance, and has been a standard for handling of hydrochloric acid. Generally, the synthetic rubbers have better chemical resistance than the natural rubbers. Vulcanization, the process of hardening rubber by adding sulfur and heating, can produce a wide range of hardnesses from soft gaskets to hard pump impellers. Corrosion resistance generally increases with hardness.

   A wide variety of synthetic rubbers is available, including combinations with plastics. In developing the various products,

NWMAR116575

plasticizer fillers and hardeners are compounded to obtain a large range of properties, including chemical resistance.

Table 44 shows chemical resistance and other properties of commercially available rubber products. One of the newer elastomers which should be added to the list is Hypalon, which has excellent resistance to oxidizing environments such as 90% sulfuric acid and 40% nitric acid at room temperature.

2. Plastics - Used extensively in chemical process applications as process component bodies and parts, tanks and tank liners, pipe, valves, tubing, and fittings, sheets, structurals, etc., plastics are high-molecular weight organic materials that can be shaped into a variety of useful forms.

When comparing plastics to metals, the former are softer and weaker, more resistant to chloride ions and hydrochloric acid, less resistant to concentrated sulfuric and oxidizing acids such as nitric, less resistant to solvents, and have definitely lower temperature limitations.

Plastics, when subjected to corrosive environments do not fail as metals do. Rather than dissolving, they are degraded or corroded because of swelling, loss in mechanical properties, softening, hardening, spalling, and discoloration. Table 45 lists the properties of some commercially available plastics.

For ease of using this table, commonly used tradenames and other designations are listed here alphabetically in reference to the chart classification to which they belong:

Material	Chart Classification
Aeroflex	Polyethylene
Alathon	Polyethylene
Araldite	Epoxy
Avisco	Urea
Bakelite	Phenolic
Beelte	Urea
Dacron	Polyester
Durcon	Epoxy
Durez	Phenolic
Dypol	Polyester
Epon	Epoxy
Excon	Polypropylene
Kel F	Fluorocarbon
Lauxite	Urea
Lucite	Methyl methacrylate
Lustrex	Polystyrene
Moplen	Polypropylene

NWMAR116576

TABLE 44. PROPERTY COMPARISONS - NATURAL AND SYNTHETIC RUBBERS (63)

Property	Natural rubber	Butyl (GR-I)	Buna S (GR-S)	Neoprene	Nitrile (buna N)	Polyacrylic rubber	Silicone rubber
Hardness range (Shore "A") [a]	40-100	40-90	40-100	30-90	45-100	50-90	40-80
Tensile strength, psi [b]	4500	3000	3500	3500	4000	1500	900
Max. elongation, %	900	900	600	1000	700	200	250
Abrasion resistance [c]	Excellent	Good	Excellent	Very good	Excellent	Fair	Poor
Resistance to compression set at 158°F [c]	Good	Fair	Excellent	Good	Excellent	Good	Excellent
Resistance to compression set up to 250°F [c]	Poor	Poor	Excellent	Fair	Excellent	Good	Excellent
Aging resistance (normal temp.)	Good	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Max. ambient temp. allowable, °F [c]	160	275	275	225	300	400	580
Resistance to weather and ozone [c]	Fair	Very good	Fair	Excellent	Fair	Excellent	Excellent
Resistance to flexing	Excellent	Excellent	Good	Excellent	Fair	Excellent	Poor
Resistance to diffusion of gases	Fair	Excellent	Fair	Very good	Fair		
Resilience	Excellent	Poor at low temp. Good at high temp.	Fair	Very good	Fair	Poor	
Resistance to petroleum oils and greases	Poor	Poor	Poor	Good	Excellent	Very good	Good
Resistance to vegetable oils	Good	Good					
Resistance to non-aromatic fuels and solvents	Poor	Poor	Poor	Fair to good	Very Good		Fair
Resistance to aromatic fuels and solvents	Poor	Poor	Poor	Fair	Good		Poor
Resistance to water and anti-freezes [c]	Good	Good	Good	Fair	Excellent	Poor	Fair
Resistance to dilute acids	Good	Good	Good	Good	Good		
Resistance to oxidizing agents	Poor	Fair	Poor	Poor	Poor		
Resistance to alkali	Fair	Fair	Fair	Good	Fair		
Dielectric strength [c]	Excellent	Good	Excellent	Fair	Fair		
Flame resistance	Poor	Poor	Poor	Good	Poor		
Processing characteristics	Excellent	Good	Good	Good	Good	Fair	Poor
Low temp. resistance [c]	Very good	Fair	Good	Fair	Good	Poor	Excellent
Tear resistance	Excellent	Excellent	Good	Good	Good	Fair	Poor

a 100 Durometer reading is bone hard and indicates that ebonite or hard rubber can be made.
b Indicates soft-rubber type. Hard-rubber types run higher in value.
c These properties available in specific compounds.

NWMAR116577

TABLE 45. PROPERTIES OF COMMERCIALLY AVAILABLE PLASTICS (63)

Material	Acids		Alkalies		Organic solvents	Water absorption, %/24 hr	Oxygen and ozone	High vacuum	Ionizing radiation	Temperature Resistance	
	Weak	Strong	Weak	Strong						High	Low
Thermoplastics											
Fluorocarbons	inert	inert	inert	inert	inert	0.0	inert	-	P	550	G-275
Methyl methacrylate	R	A-O	R	A	A	0.2	R	decomp.	P	180	-
Nylon	G	A	R	R	R	1.5	SA	-	F	300	G-70
Polyether (chlorinated)	R	A-O	R	R	G	0.01	R	-	-	280	G
Polyethylene (low density)	R	A-O	R	R	G	0.15	A	F	F	140	G-80
Polyethylene (high density)	R	A-O	R	R	G	0.1	A	F	G	160	G-100
Polypropylene	R	A-O	R	R	R	<0.01	A	F	G	300	P
Polystyrene	R	A-O	R	R	A	0.04	SA	P	G	160	P
Rigid polyvinyl chloride	R	R	R	R	A	0.10	R	-	P	150	P
Vinyls (chloride)	R	R	R	R	A	0.45	R	P	P	160	-
Thermosetters											
Epoxy (cast)	R	SA	R	R	G	0.1	SA	-	G	400	L
Phenolics	SA	A	SA	A	SA	0.6	-	-	G	400	L
Polyesters	SA	A	A	A	SA	0.2	A	-	G	350	L
Silicones	SA	SA	SA	SA	A	0.15	R	-	F	550	L
Ureas	A	A	A	A	R	0.6	A	-	P	170	L

NOTE: R = resistant, A = attacked, SA - slight attack, A-O = attacked by oxidizing acids, G = good, F - fair, P = poor, L = little change.

NWMAR116578

Mylar	Polyester
Nylon	Nylon
Penton	Polyether
Plexiglas	Methyl methacrylate
Plioflex	Vinyl
Polythene	Polyethylene
Pro-Fax	Polypropylene
PVC	Polyvinyl chloride
Resinox	Phenolic
Saran	Vinyl
Styron	Polystyrene
Teflon	Fluorocarbon
Tygon	Vinyl
Vibrin	Polyester
Vinylite	Vinyl
Viton	Fluorocarbon

3. Other Nonmetallics - Used as materials of construction and lining of process systems:

   Ceramics - compounds of metallic and non-metallic elements; include magnesia, brick, stone, fused silica, stoneware, glass, clay tile, porcelain, concrete, abrasives, mortar, high temperature refractories. Most ceramics exhibit good chemical resistance, with the exception of hydrofluoric acid and caustic.

   Carbon and Graphite - often used for shaft seals; inert to many chemical environments; good resistance to alkalies and most acids; attacked by oxidizing acids such as nitric, concentrated sulfuric, and chromic; also attacked by fluorine, iodine, bromine, chlorine, and chlorine dioxide.

   Wood - Typical chemically resistant woods are cypress, pine, oak, and redwood; generally limited to dilute chemicals; strong acids, oxidizing acids, and dilute alkalies attack wood.

7.7.3 Protective Coatings

Paints, varnishes, lacquers, and similar coatings are capable of preventing corrosive attack of the substrate material when they are properly selected and correctly applied. Three main areas of concern are surface preparation, and selection of primer and top coat.

1. Surface preparation - involves removal of dirt, rust, mill scale, oil, grease, and other impurities. Surface should be roughened to give a good mechanical bond. Cleaning techniques include scrubbing, wire brushing, sanding, chipping, hole filling, torching, solvent cleaning, etc.

NWMAR116579

2. Primers - can contain rust-inhibitive pigments such as zinc chromate and zinc dust; short drying time paints can expedite field application of top coat.

3. Top coats - vinyl and epoxy paints are commonly used for corrosion applications; many other varieties are also available.

7.8 INFORMATION ON TREATMENT CHEMICALS

7.8.1 General

This section details information on various chemicals which can be used to treat the hazardous spilled materials. Many of the chemicals recommended for use are in themselves very hazardous and must be handled with caution. Two subsections are included. The first deals with the various calculations necessary when chemicals are being handled. The steps include scaleups from bench testing values to ordering the necessary amounts of chemicals to diluting the concentrated chemicals to feed concentrations. The calculations are outlined in this portion of the manual. The second subsection includes additional information on each of the specific chemicals. The information included is as specific as possible but the manufacturer or supplier should be requested to send additional detailed information with the shipped material.

7.8.2 Calculations for Chemical Ordering and Mixing

7.8.2.1 General - The following calculations are designed to allow ordering and mixing of chemicals for the treatment processes. These calculations yield the minimum amounts to order. It is suggested that a 25% excess over the calculated value be ordered to prevent chemical shortages from varying waste quality and chemical spillage, etc. Frequently, unused and unopened containers of chemicals can be returned to the supplier. Chemicals should be ordered as soon as possible to insure arrival on site when the treatment facilities are completed.

7.8.2.2 Conversion of bench scale results to mg/ml - When conducting bench scale tests it is necessary to express the optimum chemical dosage as a weight to volume ratio so that the results can be applied to ordering and mixing chemicals.

Solution: $$\frac{(\text{Bench test chemical conc. mg/ml}) \times (\text{mls added})}{\text{mls of sample treated}} =$$

$$\frac{\text{mg bench test chemical}}{\text{ml of sample}}$$

Example: What is the mg of NaOH required per ml of sample for the following test results?

Volume of sample tested: 500 ml
Amount of NaOH added: 25 ml

NWMAR116580

7.8.2 Mixing chemical to desired strength - After receiving the treatment chemicals it usually is necessary to dilute them to an acceptable concentration for addition.

Solution: If chemical is in the dry form its weight will be known. If it comes as a liquid it can be converted to a weight as follows:

Metric: kg of chemical = l of chemical x density (g/l) x 10^{+3}

English: lbs of chemical = (gallons of chemical) (8.34) (Specific gravity of chemical)

Knowing the desired chemical feed concentration the gallons of water needed per pound of chemical can be determined as follows:

$$\frac{\text{gallons of water needed}}{\text{lb of chemical}} = \frac{\text{\% purity}}{\text{\% feed concentration}}$$

Example: Determine the amount of water needed to mix 20 pounds of NaOH into a 5% solution.

$$\frac{\text{gallons of water needed}}{\text{lb of chemical}} = \frac{(94)+}{5 \times 8.34} = 2.25$$

Total amount of water needed = $\frac{(2.25 \text{ gallons})}{\text{lb}}$ (20 lb) =

45 gallons.

gal. x 3.785 = l
lb x .454 = kg

Solution: If a known amount of dilution water is to be used and the desired feed concentration is known, the amount of chemical to be added can be calculated as follows:

$$\frac{\text{lbs of chemical}}{\text{gallon of water}} = \frac{\text{\% feed concentration} \times 8.34}{(\text{\% purity})}$$

Example: Determine the amount of NaOH at 94% purity needed to mix 100 gallons of a 5% NaOH solution.

$$\frac{\text{lbs of chemical}}{\text{gallon of water}} = \frac{5 \times 8.34}{(94)} = 0.44$$

Total pounds required = $(0.44 \frac{\text{lbs}}{\text{gal.}})$ (100 gal.) = 44.4lbs.

gal. x 3.785 = l
lb. x .454 = kg

NWMAR116581

7.8.2.5 Ordering liquid chemicals - The purity of certain treatment chemicals is often expressed in degrees baume (Be'). By asking the supplier or referring to a chemical handbook the concentration of the chemical itself can be determined. The normality of the solution should also be known. Listed below are some of the concentrations of chemicals used in treatment.

Chemical	% by weight	Density $D20^{o}_{40}$	Baume' degrees	Approximate normality
Acetic acid	96	1.06	8	17
Acetic acid	99-100	1.06	8	18
Hydrochloric acid	36	1.18	22	12
Sulfuric acid	95-97	1.84	66	36

If the results from bench scale tests are reported in mls needed per ml of liquid to be treated, it is possible to calculate the amount of chemical needed as follows:

Solution: Gallons of chemical required =

$$\frac{(\text{mls used})\ (\text{Normally used in lab tests})}{(\text{mls of sample})\ (\text{Normality of chemical ordered})} \times (\text{Gallons to be treated})$$

Example: How much 66° Baume' 36N sulfuric acid is required to treat 1,000,000 gallons if bench scale tests using 2N sulfuric showed that 25 ml were needed for each 500 ml to be treated?

Gallons of chemical required = $\frac{(25)}{(500)}\ \frac{(2N)}{(36N)}\ (1{,}000{,}000) = 2778$ gal.

gal. x 3.785 = l

If the chemical ordered is based on bench scale tests expressed in mg/l the amount of chemical needed can be determined.

Solution: Knowing the % by weight and the density of the solution, the concentration of the chemical itself can be calculated as follows:

Concentration of chemical in lb/gallon = (Density of solution x .0834 x % by weight of solution)

The number of pounds required is simply determined as follows:

NWMAR116582

Concentration of NaOH test solution: 100 mg/ml

$$\frac{(100 \text{ mg/ml NaOH}) \times (25 \text{ ml})}{500 \text{ ml sample}} = \frac{2500 \text{ mg/ml}}{500} = 5 \text{ mg/ml NaOH}$$

7.8.2.3 Calculating the total amount of chemical to order - Using the previous example, the total of amount of chemical required can be determined:

Solution: $$\text{kg needed} = \frac{(\text{liters to treat})\ (\text{mg/ml dosage})}{\%\ \text{purity of chemical}\ 0.00834}$$

$$\text{lbs. needed} = \frac{(\text{gallons to treat})\ (\text{mg/ml dosage}) \times 0.834}{\%\ \text{purity of chemical}}$$

Example: How much 94% pure NaOH is needed to treat a spill of 100,000 gallons?

NaOH dosage = 5 mg/ml
gallons to treat = 100,000
NaOH purity = 94%

The following metric conversions are appropriate:

gal. x 3.785 = l
lb x 0.454 = kg

$$\text{lbs needed} = \frac{(100{,}000) \times (5) \times 0.834}{94} = 4436 \text{ lbs}$$

If coagulants are used in the bench tests and the desired dosages are given in mg/l the pounds required can be determined.

Solution: $$\text{lbs needed} = \frac{(\text{gallons to be treated})\ (\text{mg/l coagulant})\ (8.34)\ *\text{MWR}*}{\text{purity} \times 10{,}000}$$

*MWR is the Molecular Weight Ratio and represents the molecular weight of the chemical ordered divided by the molecular weight of the coagulant itself.

Example: How much $Ca(OH)_2$ is needed to treat 1,000,000 gallons based upon a required CaO coagulant dosage of 100 mg/ℓ?

Coagulant dosage = 100 mg/ℓ as CaO
Chemical ordered = $Ca(OH)_2$
% purity = 98
Gallons to treat = 1,000,000
MW of CaO = 56
MW of $Ca(OH)_2$ = 74

$$\text{lbs needed} = \frac{(1{,}000{,}000)(100)(8.34)}{98 \times 10000} \times \frac{74}{56} = 1124 \text{ lbs}$$

NWMAR116583

$$\text{lbs required} = \frac{(\text{gallons to be treated})\ (8.34)\ (\text{mg/l})}{1{,}000{,}000}$$

lb x .454 = kg

The number of gallons required is calculated as follows:

Number of gallons = (lbs required) (concentration of chemical in lb/gallon)

gal. x 3.785 = l

Example: How much $FeCl_3$ is required to treat 100,000 gallons if bench scale tests showed that 50 mg/l of $FeCl_3$ is the needed dosage and with a density of 1.430 and is 40% $FeCl_3$ by weight:

Concentration of chemical = (1.430)(0.0834)(40) = 4.77 lb/gal. lb/gal.

$$\text{lbs required} = \frac{(100{,}000)(8.34)(50)}{1{,}000{,}000} = 41.7 \text{ lb}$$

Number of gallons = (41.6)/(4.77) = 8.74 gal.

7.8.2.6 Diluting liquid chemicals - When diluting liquids such as acetic acid, sulfuric acid or hydrochloric acid for feeding to the treatment system, concentrations $\frac{1}{4}$ to $\frac{1}{2}$ of the original concentrations are usually used. Since the reaction itself will be monitored (e.g. pH meters) a precise feed concentration is not necessary, therefore a volume to volume dilution will be sufficient.

Solution: To determine the amount of dilution water necessary to reduce the original concentration, the following formula can be used.

$$\text{Amount of water to add} = \frac{(\text{Original \% concentration}) \times (\text{Original amount of water})}{\text{Desired concentration \%}} - (\text{Original amount of water})$$

Example: Determine the amount of water needed to dilute 500 gallons of 93% pure acid to 33%.

$$\text{Amount of water to be added} = \frac{(93)}{33}(500\text{gals}) - 500\text{gals} = 910\text{gal.}$$

NWMAR116584

7.8.3 Chemical Data Sheets

The following chemical data sheets are provided as guidelines for using treatment chemicals. Approximate prices are given for estimating purposes, however, these vary with the purity and quantity of the chemical ordered.

The safety precautions listed are minimal. More specific information should be obtained from the manufacturer prior to receiving shipment of chemicals. It is stressed that many of the treatment chemicals are hazardous themselves and must be treated as such. All operators handling chemicals should wear goggles and in most cases chemically resistant aprons and gloves should be used. All chemicals on site should be stored in an isolated area so that unauthorized personnel will not come in contact with them. The handling of chemicals on site must eliminate compounding the hazard that already exists.

Other information also included on the data sheets regards recommended bench testing and feed concentrations for the chemical. Special mixing methods are listed as an aid for those handling the chemical. The cautions reiterate some of the specific problems or hazard potentials. Finally the materials of construction which are acceptable for using the chemical are listed. These are general guidelines since the actual corrosiveness of the solution cannot be estimated and the equipment will only be used on a short term basis so a small rate of corrosion can be tolerated.

NWMAR116585

Chemical name: Acetic acid Synonyms:
CH_3COOH

Alternate chemicals: Very dilute HCl/vinegar (not desirable).

Common package sizes: 450 lb drums.

Approximate costs: $28.00/100 lb.

Purities (from manufacturer) and bulk density: 99.5% (glacial acetic)

Bench test concentrations: up to 100%.

End point determinations: pH meter.

Personal safety: Vapors are irritating to eyes, nose and throat/move victim to fresh air. Compound will burn skin and eyes. Harmful or fatal if swallowed. Remove contaminated clothing and shoes. Flush with plenty of water. If swallowed, give water or milk. DO NOT induce vomiting. Avoid contact with liquid or vapor.

Special mixing methods: Acid to water.

Cautions: Gives off heat upon mixing with water/always add acid to water or a danger of explosion exists.

Materials for handling:

Tanks: Process - any
Chemical - concrete/plastic

Pumps & Fittings:

lbx.454 = kg

Figure 76. Data sheet on Acetic acid.

NWMAR116586

Chemical name: Aluminum sulfate (Alum) $Al_2 (SO_4)_3 \cdot 18 H_2O$

Synonyms: Alum
Filter Alum
Sulfate of Alumina

Alternate chemicals: Ferric chloride or ferric sulfate.

Common package sizes: 100 lb bags 250/350 lb barr. bulk C/L

Approximate costs: $5.90/100 lbs.

Purities (from manufacturer) and bulk density: 17% Al_2O_3 (aluminum oxide) 60-75#/ft^3

Bench test concentrations: 100 mg/ml as $Al_2(SO_4)_3 \cdot 18 H_2O$.

Feed concentrations: 3%

End point determinations: Floc is substantial.

Personal safety: Hazardous if ingested or inhaled - avoid breathing dust. May form acid solution capable of causing burns. In case of contact with skin or eyes remove clothing and shoes and flush with plenty of water.

Special mixing methods: Is slow to dissolve so mixing is critical.

Cautions: Granular solid is superior/corrosive and acidic once in solution. Be careful not to breathe dust.

Materials for handling:

Tanks:	Process - any Chemical - concrete/plastic	
Pumps & Fittings:	Dry - iron/steel/concrete	Wet - lead/rubber/Duriron/ asphalt/cypross/316-st. steel

1bx.454 = kg

Figure 77. Data sheet on Aluminum sulfate.

NWMAR116587

Chemical name: Calcium Chloride Synonyms:
$CaCl_2$

Alternate chemicals: None

Common package sizes: Flakes: 100 lb bags Pellets: 80 lb lots

Approximate costs: $7.25 - 11.35/100# $8.65 - 13.50/100#

Purities (from manufacturer): 77-94% as $CaCl_2$.

Bench test concentrations: 100 mg/ml

Feed concentrations: 10-20%.

End point determinations: When Ca ppt is no longer formed.

Personal safety: Do not inhale or ingest. Remove victim to fresh air. Remove contaminated clothing and shoes and flush with plenty of water.

Special mixing methods: Dissolves easily/do not breath dust/heat may be liberated when dissolved.

Cautions: Is Somewhat corrosive/flakes dissolve quickly.

Materials for handling:

Tanks:	Process - any Chemical - concrete/plastic/other	
Pumps & Fittings:	Conc: Rubber	Dilute: Steel (up to 50% cast iron)

1bx.454 = kg

Figure 78. Data sheet on Calcium chloride.

NWMAR116588

Chemical name: Calcium Hydroxide-slaked lime - $Ca(OH)_2$

Synonyms: Chemical lime
Lime
Slaked lime
Hydrated lime

Alternate chemicals: Calcium oxide.

Common packages sizes: 50# bag.

Approximate costs: $2.04/100#.

Purities (from manufacturer) and bulk density: 94-95% 35-50 lb/ft^3.

Bench test concentrations: 100 mg/ml as CaO.

Feed concentrations: Dry or 10% solution (0.93 lb/gal.).

End point determinations: pH and floc production.

Personal safety: Dust irritating to nose and throat - move to fresh air. Will burn skin and eyes. Harmful if swallowed. Remove contaminated clothing and shoes. Flush affected area with plenty of water. If swallowed and victim is conscious have victim drink water or milk. DO NOT induce vomiting.

Special mixing methods: Lime will form a slurry which requires mixing throughout the feeding period. Slaking of $Ca(OH)_2$ requires 30-60 min to complete. Use velocities of 5-7 fps to feed.

Cautions: Heats and expands on reaction with water. Adsorbs H_2O and CO_2 from air to form $CaCO_3$. Do not breathe dust.

Materials for handling:

Tanks:	Process - any Chemical - plastic/other
Pumps & Fittings:	Rubber hose/iron/steel/asphalt/concrete No lead

lbx.454 = kg
gal. x 3.785 = l

Figure 79. Data sheet on Calcium hydroxide.

NWMAR116589

Chemical name: Calcium oxide (lime)
CaO

Synonyms: Unslaked lime
Quick lime
Burnt lime

Alternate chemicals: Calcium hydroxide.

Common package sizes: 80 lb bags.

Approximate costs: $2.28/100 lb.

Purities (from manufacturer) and bulk density: 94-95% 55-70 lb/ft^3

Bench test concentrations: 100 mg/ml as CaO.

Feed concentrations: Slake and dilute to less than 10% - Each pound of CaO will slake to 1.16-1.32 lb of $Ca(OH)_2$ and 2-17% grit.

End point determinations: pH and floc formation.

Personal safety: Dust irritating to nose and throat. Move victim to fresh air. Will burn and eyes. Harmful if ingested. Remove contaminated clothing and shoes. Flush affected area with plenty of water. If swallowed and victim is conscious, have victim drink water or milk. DO NOT induce vomiting.

Special mixing methods: Slaking requires 30-60 minutes with heat evolution and expansion: slurry will require continuous mixing and pumping at 5-7 fps.

Cautions: Basic and adds alkalinity to water/can be corrosive/will increase water temperature. Caution is needed.

Materials for handling:

Tanks:	Process - any Chemical - plastic/other	
Pumps & Fittings:	Dry - iron/steel/concrete	Wet - iron/steel/rubber hose/concrete

lbx.454 = kg

Figure 80. Data sheet on Calcium oxide.

NWMAR116590

Chemical name: Ferric chloride
$FeCl_3$

Synonyms: Ferric chloride
Chloride of iron
Crystal ferric chloride
Anhydrous ferric chloride
Ferric floc

Alternate chemicals: Alum/ferric sulfate
Ferrous sulfate

Common package sizes: 55 gal. drum-42° baume' 175 and 610 lb drums

Approximate costs: $9.65/100 lb (liquid)

Purities (from manufacturer): Liquid - 39% - 11.2-12.4#/ft^3
Solid-hepta hydrate 60% $FeCl_3$-60-64#/ft 3
and bulk density

Bench test concentrations: 100 mg/ml $FeCl_3$.

Feed concentrations: <45% generally, 15% will control hydrolysis.

End point determinations: pH and floc formation.

Personal safety: Forms corrosive acid solution in water. Releases toxic chlorides when heated to decomposition. Mild irritant. Slight ingestion hazard. Remove contaminated clothing and shoes and flush with plenty of water.

Special mixing methods: Dissolves very easily and should be fed in solution.

Cautions: Is a hygroscopic solid and forms an acidic and corrosive liquid/ protect from light.

Materials for handling:

Tasks:	Process - any Chemical - concrete/plastic
Pumps & Fittings:	Rubber/glass/ceramics/plastic

lbx.454 = kg

Figure 81. Data sheet on Ferric chloride.

NWMAR116591

Chemical name: Ferrous sulfate
$FeSO_4 \cdot 7H_2O$

Synonyms: Ferriclear
Copperas
Sugar sulfate
Green vitriol

Alternate chemicals: None

Common packages sizes: 50 and 100 lb bags

Approximate costs: $2.85-3.85/100 lb.

Purities (from manufacturer): 20% Fe (granular), 63-66#/ft^3
and bulk density:

Bench test concentrations: 100 mg/ml (50-200 mg/ml)

Feed concentrations: 240 mg/ml (2 lb/gal.)

End point determinations: Add to floc or dosage

Personal safety: Hazardous if inhaled or ingested. A mild irritant to skin and eyes. Remove contaminated clothing and shoes - Flush with plenty of water. ff swallowed and victim is conscious, have victim drink water or milk and have victim induce vomiting. If swallowed and victim is unconscious or having convulsions, call for help and to nothing except keep victim warm.

Special mixing methods: Mix for at least 5 minutes. Granules dissolve best.

Cautions: Solution formed is quite acidic.

Materials for handling:

Tanks:	Process - any Chemical - concrete/plastic
Pumps & Fittings:	Stainless steel 316 Rubber/lead/ceramic/Duriron

lbx.454 = kg

Figure 82. Data sheet on Ferrous sulfate.

NWMAR116592

Chemical name: Hydrochloric acid Synonyms: Muriatic acid
HCl

Alternate chemicals: Sulfuric acid (sometimes).

Common package sizes: 65, 145, 700 lb drums.

Approximate costs: $6.85-$9.00/100 lb.

Purities (from manufacturer): 22° Baume'.

Bench test concentrations: 100 mg/ml HCl

Feed concentrations: 36% max-use of 18% dilute HCl is safer.

End point determinations: pH

Personal safety: Vapor and liquid irritating to eyes, nose and throat. Will cause difficult breathing. Move victim to fresh air. Liquid will burn eyes and skin. Remove clothing and shoes. Flush affected areas with plenty of water. If swallowed and victim is conscious, have victim drink water. DO NOT induce vomiting.

Special mixing methods: Evolves heat and fumes when mixed with water - add acid to water in all situations.

Cautions: Beware of fumes from the system, wear goggles, rubber gloves, apron. Severely burns skin. Always add acid to water to avoid danger of explosion.

Materials for handling:

Tanks:	Process - any Chemical - concrete/plastic
Pumps & Fittings:	Plastic/rubber/porcelain

lb.454 = kg

Figure 83. Data sheet on Hydrochloric acid.

NWMAR116593

Chemical name: Polyelectrolytes Synonyms: Polymers

Alternate chemicals: $FeCl_3$ or $Al_2SO_4.18\ H_2O$

Common package sizes: 50 lb bags or 55 gal. drums

Approximate costs: $2.00/# (need only small amounts so should purchase in pound lots).

Purities (from manufacturer) and bulk density: 99% 40-50#/ft^3

Bench test concentrations: 1 mg/ml (0.5-1 mg/ml)

Feed concentrations: 0.5-1%

End point determinations: Floc formation

Personal safety: Do not breathe fumes or touch powder. Flush with plenty of water.

Special mixing methods: Difficult to mix/add to rapidly swirling water/ mix at least 1 hour prior to use/mix and use the same day.

Cautions: Viscous fluids requiring mixing and high pumping rates.

Materials for handling:

Tanks:	Process - any Chemical - concrete/plastic/other
Pumps & Fittings:	Do not use aluminum or galvanized equipment. Use: plastic/stainless steel/cast iron

lbx.454 = kg
gal.x3.785 = l

Figure 84. Data sheet on Polyelectrolytes.

NWMAR116594

Chemical name: Potassium Permanganate Synonyms:
$KMnO_4$

Alternate chemicals: None

Common package sizes: 50, 100, 150 lb drums

Approximate costs: $52-69/100 lb

Purities (from manufacturer): 97% minimum

Bench test concentrations: 10-100 mg/ml as $KMnO_4$

Feed concentrations: 10%

End point determinations: Oxygen demand

Personal safety: Highly toxic if inhaled or ingested. High concentrations are cuastic. A strong irritant. Remove clothing and shoes and flush with water. If swallowed and victim is conscious have victim drink water or milk and have victim induce vomiting. If swallowed and victim is unconscious or having convulsions, call for help and keep victim warm.

Special mixing methods: Will dissolve better in cold water: (an oxidizing agent).

Cautions: Easily reduced by natural reducers (e.g., organics, sulfite, nitrite, etc).

Materials for handling:

Tanks:	Process - any Chemical - concrete/plastic (low conc.)
Pumps & Fittings:	Cast iron, plastic/stainless steel/steel

lbx.454 = kg

Figure 85. Data sheet on Potassium Permanganate.

NWMAR116595

Chemical name: Sodium Bicarbonate $NaHCO_3$ Synonyms: Baking soda

Alternate chemicals: Sodium carbonate

Common package sizes: 100 lb bags

Approximate costs: $6.95/100 lb

Purities (from manufacturer) and bulk density: 99.6% 59-62#/ft 3

Bench test concentrations: 100 mg/ml as $NaHCO_3$.

Feed concentrations: 60 mg/ml (0.5 lb/gal.)

End point determinations: pH

Personal safety: Do not ingest or inhale. In case of contact with eyes or skin, flush with plenty of water.

Special mixing methods: None - dissolves quite easily.

Cautions: Slightly alkaline - 1% solution - pH 8.2 alkalinity increases at higher temperatures.

Materials for handling:

Tanks:	Process - any Chemical - concrete/plastic/other
Pumps & Fittings:	Iron, steel, rubber, stainless steel

lbx.454 = kg
ft3x.028 = m

Figure 86. Data sheet on Sodium bicarbonate

NWMAR116596

Chemical name: Sodium bisulfite Synonyms:
$NaHSO_3$

Alternate chemicals: Sodium metabisulfite or Sodium sulfite

Common package sizes: 100 lb bags

Approximate costs: $18.05/100 lb.

Purities (from manufacturer): 99% as $Na_2S_2O_5$ 70-80 #/ft 3 65.5% SO_2
and bulk density:

Bench test concentrations: 50 mg/ml as $NaHSO_3$

Feed concentrations: 60 mg/ml

End point determinations: Large ORP change.

Personal safety: Slowly release toxic gas if exposed to fire, water or acids to produce a highly corrosive hazard. Prevent inhalation and ingestion of solid and liquid. If inhaled move victim to fresh air, Irritating to eyes nose, and throat. In case of contact, remove clothes and shoes and flush with plenty of water. If swallowed, drink water or milk.

Special mixing methods: None

Cautions: Acidic solution - $NaHSO_3$/eventually oxidized to sulfate.

Materials for handling:

Tanks:	Process - any Chemical - concrete/plastic/other
Pumps & Fittings:	Lead, rubber, glass, ceramic, chrome, nickel, stainless steel.

$lbx.454 = kg$
$ft^3x.028 = m^3$

Figure 87. Data sheet on Sodium bisulfite.

NWMAR116597

Chemical name: Sodium carbonate (soda ash) Na_2CO_3

Synonyms: Soda ash
Soda ash - 58%
Sol. soda

Alternate chemicals: Sodium bicarbonate

Common package sizes: 100 lb bags

Approximate costs: $3.70/100 lb

Purities (from manufacturer) and bulk density: 99% Na_2CO_3 30-65#/ft^3
58% Na_2O (sodium oxide)

Bench test concentrations: 100 mg/ml as Na_2CO_3

Feed concentrations: 120 mg/ml

End point determinations: pH

Personal safety: Avoid inhaling or ingesting. Move victim to fresh air. Very caustic, will cause burns to skin and eyes. Remove clothing and shoes. Flush affected area with plenty of water.

Special mixing methods: Mix at least 10-20 min/#/gal. of added Na_2CO_3/ mixes with large evolution of heat.

Cautions: Alkaline solution (ph 11.6) hygroscopic solid.

Materials for handling:

Tanks:	Process - any Chemical - concrete/plastic/other
Pumps & Fittings:	Iron, steel, rubber hose

lbx.454 = kg
ft3x.028 = m3

Figure 88. Data sheet on Sodium carbonate.

NWMAR116598

Chemical name: Sodium Hydroxide (caustic) NaOH

Synonyms: Caustic soda
Caustic soda lye

Alternate chemicals: Potassium hydroxide
Ammonium hydroxide (undesirable)

Common package sizes: 650 lb drum - 50% solution/400 # flake

Approximate costs: $10.-12/100# (liquid) $\frac{\$21.60\text{-}27.55}{100}$ (flake)

Purities (from manufacturer) and bulk density: 50% liquid 76% flake and bulk density

Bench test concentrations: 100 mg/ml.

Feed concentrations: 12-50%

End point determinations: pH

Personal safety: Very caustic. Do not handle with bare hands, do not ingest or inhale dust. Move victim to fresh air. In case of contact remove contaminated clothing and shoes and flush with plenty of water. If swallowed and victim is conscious, have victim drink water or milk. DO NOT induce vomiting.

Special mixing methods: Diliquescent, causes poison - be careful not to add solid too fast, solution feed is absolutely necessary/large heat evolution when mixed.

Cautions: Very dangerous to handle - alkaline to pH 12.9 - at 1% solution/ wear goggles, rubber gloves, aprons (rapidly adsorbs water and CO_2 from air.

Materials for handling:

Tanks: Process - any

Pumps & Fittings: Cast iron, rubber, steel

1bx.454 = kg

Figure 89. Data sheet on Sodium hydroxide.

NWMAR116599

Chemical name: Sodium Hypochlorite
NaClO

Synonyms: Chlorox
Liquid bleach
'aville water
Chlorine bleach

Alternate chemicals: Calcium hypochlorite

Common package sizes: 5, 15, 50, 1,000, 4,500, gal. (12.5%)

Approximate costs: $0.36 - 0.48/100 lb

Purities (from manufacturer): 12.5% (available chlorine) 13.1 % Na & Cl

Bench test concentrations: 0.5-5% chlorine

Feed concentrations: 5.0%

End point determinations: Chlorine residual

Personal safety: Vapor or liquid harmful or fatal if inhaled or ingested. Can cause burns upon contact with eyes or skin. In case of contamination remove shoes and clothing and flush with water. If swallowed and victim is conscious, have victim drink water or milk and have victim induce vomiting. If swallowed and victim is unconscious or having convulsions, call for help and keep victim warm.

Special mixing methods: Is a very corrosive material.

Cautions: Avoid breathing vapors/do not mix with ammonia.

Materials for handling:

Tanks:	Process - any Chemical - concrete/plastic/other
Pumps & Fittings:	Rubber, plastics, glass, ceramics

lbx.454 = kg

Figure 90. Data sheet on Sodium Hypochlorite.

NWMAR116600

Chemical name: Sodium Sulfate Synonyms: Glaubers salt
Na_2SO_4

Alternate chemicals: Potassium sulfate

Common package sizes: 100 lb bags

Approximate costs: $6.50/100 lb

Purities (from manufacturer): 99.5%

Bench test concentrations: 100 mg/ml

Feed concentrations: 10-20%

End point determinations: Sulfate test

Personal safety: Do not inhale or ingest. Can be irritating to eyes or skin. Remove clothing and shoes and flush with water.

Special mixing methods: Neutral solution pH 6-7 when mixed.

Cautions:

Materials for handling:

Tanks:	Process - any Chemical - any
Pumps & Fittings:	Stainless steel, rubber, plastic, cast iron

lbx.454 = kg

Figure 91. Data sheet on Sodium sulfate.

NWMAR116601

Chemical name: Sodium sulfide
Na_2S or $Na_2S.9H_2O$
(Sodium sulfide enneahydrate)

Synonyms:

Alternate chemicals: Ammonium sulfide

Common package sizes: 100 lb drum

Approximate costs: $26.50/100 lb

Purities (from manufacturer): 60-62%

Bench test concentrations: 50

Feed concentrations: 10%

End point determinations: Zinc acetate paper/removal of metal ion.

Personal safety: Yields sulfur dioxide and hydrogen sulfide which is extremely flamable and toxic on contact with acids or fire. Irritant-remove victims clothing and shoes and flush with water. If swallowed and victim is conscious have victim drink water or milk. Dust irritating to nose, eyes and throat. Move victim to fresh air.

Special mixing methods: Mix slowly checkingpH add $Ca(OH)_2$ or NaOH if pH drops below 7/however most solutions are alkaline: should be used immediately.

Cautions: Caution to avoid evolution of toxic H_2S which occurs at low pH values. Do not expose solid to air without the use of a self contained breathing apparatus.

Materials for handling:

Tanks:	Process - any Chemical - any
Pumps & Fittings:	Cast iron

lbx.454 = kg

Figure 92. Data sheet on Sodium Sulfide.

NWMAR116602

Chemical name: Sulfuric acid
H_2SO_4

Synonyms: Oil of Vitriol
Battery acid
Fertilizer acid

Alternate chemicals: Hydrochloric acid

Common package sizes: 5 gal. carboys/ 55, 110 gal. drums

Approximate costs: $8.40 - 15.35/100#

Purities (from manufacturer): 66° Baume'

Bench test concentrations: 50 mg/ml - H_2SO_4 (1N)

Feed concentrations: up to 96% to use diluted at 25%.

End point determinations: pH.

Personal safety: Vapors are irritating to eyes, nose and throat. Move victim to fresh air. Compound will burn skin and eyes. Harmful or fatal if swallowed. Remove contaminated clothing and shoes and flush with plenty of water. If swallowed and victim is conscious, have victim drink water or milk. DO NOT induce vomiting.

Special mixing methods: Acid to water - ONLY - has high affinity for water - add very slowly to reduce heat evolution.

Cautions: Corrosive and hygroscopic/very acidic pH 1.2, need goggles, rubber gloves, aprons/burns skin. Heat evolved upon mixing/always add acid to water to avoid danger of explosion.

Materials for handling:

Tanks:	Process - any Chemical - concrete/plastic
Pumps & Fittings:	Conc. steel/iron Dilute/lead, porcelain, rubber, glass

1bx.454 = kg

Figure 93. Data sheet on Sulfuric acid.

NWMAR116603

7.9 SUPPLIERS INFORMATION

7.9.1 General

This section includes information regarding sources of supply for the various media and chemicals needed. The amounts of materials needed have been calculated as indicated in other sections, but this amount should be verified with the manufacturer. It is critical that all of these materials be ordered immediately since the shipping time may exceed 24 hours. It may be necessary to make special arrangements to allow shipment to the spill site immediately.

The phone numbers of suppliers are included where possible. To obtain treatment chemicals, the OSC should check with local suppliers, then complete the table in this subsection and provide phone numbers to handle all situations. Possible local sources are also listed.

7.9.2 Filter Supplies

Media	Source	Yellow Pages Heading
Coarse gravel:	Local sand and gravel dealer	Sand and Gravel
Filter sand:	Local water treatment plant	
	Sandblast supplier (to get sandblast sand)	Sandblasting Equipment and Supplies
Filter Coal: (crushed anthracite)	Local water treatment plant	

Suppliers:

1. Carbonite Filter Company
   P. O. Box 1
   Delane, PA 18220
   717/467-3350

2. Palmer Filter Equipment Co.
   P. O. Box 50
   Fairview, PA 16415
   814/474-5555

NWMAR116604

7.9.3 Ion Exchange Media

Ion Exchange Media must be ordered from the following suppliers and information transferred to these dealers regarding the specific wastewater to treat:

1. Bio-Red Laboratories
   32nd and Griffin Ave.
   Richmond, CA 94804
   415/234-4130

2. Dow Chemical Co.
   2030 Dow Center
   Midland, MI 48640
   517/636-1000

3. E.I. du Pont Nemours and Co. - Plastics Division
   1007 Market Street
   Wilmington, DE 19898
   302/774-2421

4. Ionac Chemical Co. - Division Sybron Corp.
   P. O. Box 66
   Birmingham Road
   Birmingham, NJ 08011
   609/894-8211

5. Mallinckrodt Chemical Works
   P. O. Box 5439
   St. Louis, MO 63160
   314/231-8980

6. Rohm and Haas Co.
   Independent Mall West
   Philadelphia, PA 19105
   215/592-3170

7. Union Carbide - Linde Division
   270 Park Avenue
   New York, NY 10017
   212/351-2345

7.9.4 Granular Activated Carbon

Manufacturer	Order Points	Shipping Points	Method of Shipment
Calgon Corp.	Calgon Adsorption Systems Box 1346 Pittsburgh, PA 15230 412/923-2345	Cattettsburg, KY	Bags, 60 lb Bulk Truck, 20-40,000 lb Rail, 80,000 lb

NWMAR116605

Manufacturer	Order Points	Shipping Points	Method of Shipment
	7405 Page Ave. St. Louis, MO 63133 314/683-3200	Houston (Bayport), TX	Bags, 60 lb Bulk Truck, 20-40,000 lb
	4800 W. 34th St., Suite B-8 Houston, TX 77018 713/682-1301	Seattle, WA	Bags, 60 lb
		City of Industry, CA	Bags, 60 lb
Witco Chemical Corp.	277 Park Ave. New York, NY 10017 212/644-6435	Petrolia, PA	Bags or bulk
Westvaco	Eastern States J.F. Henry Chemical Co. East Rutherford, NJ	Same	--
	Westvaco Carbon Sales Dept. Covington, VA 24426	Same	Bags or bulk
	Herbert Chemical Co. Cincinnati, OH	Same	--
	Western States Van Waters & Rogers San Francisco, Los Angeles, Portland, Kent, Denver	Same	--
ICI America, Inc. Atlas Chemicals Div.	Chicago, IL 312/775-4900 Dallas, TX 214/330-9580 New York, NY 212/688-1430 San Francisco, CA 415/341-5891 Wilmington, DE 302/658-9311 Los Angeles, CA 213/872-0127	Marshall, TX	Bags or bulk

NWMAR116606

7.9.5 Treatment Chemicals

Local Sources -

Chemical	Use	Possible Local Source
Acetic Acid	Neutralization pH control	Grocery Store/Vinegar Industry/ Industrial Supplier
Aluminum Sulfate (Alum)	Precipitant/ Coagulant	Water Treatment Plant Industry/ Industrial Supplier
Calcium Chloride	Precipitant/ Coagulant	Industry/Industrial Supplier
Calcium Hydroxide (Slaked Lime)	Neutralization/ Precipitant	Agricultural Supply/ Water and Wastewater Treatment Plant/ Industry/Industrial Supplier
Calcium Oxide (Lime)	Neutralization/ Precipitation	Agricultural Supply/Water and Wastewater Treatment Plant/ Industry/Industrial Supplier
Ferric Chloride	Precipitant/ Coagulant	Wastewater Treatment Plant/ Industry/Industrial Supplier
Ferrous Sulfate	Reducing Agent/ Precipitant/ Coagulant	Wastewater Treatment Plant/ Industry (pickle liquor)/ Industrial Supplier
Hydrochloric Acid (Muriatic Acid)	Neutralization/ pH control	Industry/Industrial Supplier
Polyelectrolytes	Coagulant ion	Sewage Treatment Plant/Water Treatment Plant
Potassium Permanganate	Oxidizing Agent	Industry/Industrial Supplier
Sodium Bi-carbonate	Neutralization/ precipitation	Grocery Store/as baking soda Industry/Industrial Supplier
Sodium Bisulfate	Precipitant	Industry/Industrial Supplier
Sodium Bisulfite	Reducing Agent	Industry/Industrial Supplier
Sodium Carbonate (Soda Ash)	Precipitation	Water Treatment Plant/Industry/ Industrial Supplier

NWMAR116607

Chemical	Use	Possible Local Source
Sodium Hydroxide (Caustic Soda)	Neutralization/ Precipitant	Industry/Industrial Supplier
Sodium Hypo-chlorite	Oxidizing Agent	As Bleach/Grocery Store/ Industry/Industrial Supplier
Sodium Sulfate	Precipitant	Industry/Industrial Supplier
Sodium Sulfide	Reducing Agent/ Precipitant	Industry/Industrial Supplier
Sulfuric Acid	Neutralization/ pH control	Industry/Industrial Supplier

When chemicals are not readily available locally, they must be ordered from a manufacturer. The OSC should prepare a list of chemical sources which includes a 24 hour phone number, the location of the regional warehouse, and the availability of chemicals. The following format is presented to aid the OSC in collecting sufficient information. The chart should be completed for each of the 19 treatment chemicals.

7.10 CALCULATION AIDES AND DEFINITIONS

The following tables are designed to clarify the information which is presented in the preceding subsections. It also eliminates the requirement for definitions throughout the text by placing them in one general listing. The following three subjects are covered:

- Unit Abbreviations - Gives the meaning of the abbreviation, the definition and unit type
- Conversion Factors - Common English to Metric conversion factors are given as are interconversion between various weights and measures
- Glossary - Terms used in the text are defined regarding the context in which they are used in this report

NWMAR116608

Chemical	Supplier and Location	Office Phone	24 Hour Phone	Amount Immed. Available	Time Needed to Order Larger Amount

Figure 94. Format for chemical suppliers information

NWMAR116609

Unit Abbreviations

Symbol	Definitions	Dimensions	Type of Unit
cm	centimeter	L	length
fpm	feet per minute	L/T	velocity length/time
ft	feet	L	length
ft^2	square feet	L^2	generally surface area
gal	gallons	L^3	volume
gpd	gallons per day	L^3/T	volume/time
gpm	gallons per minute	L^3/T	volume/time
gpm/ft^2	gallons per minute per square ft	$\frac{L^3/T}{L^2}$	loading rate
Hp	process height	L	length
hr	hour	T	time
in	inch	L	length
in. Hg	inches of mercury	L	pressure
l	liter	L^3	volume
lb	pounds	W	weight
m	meter	L	length
min	minute	T	time
mg	milligram (1/1000th gram)	W	weight
ml	milliliter (1/1000th of a liter)	L^3	volume
m^3	cubic meters	L^3	volume
N	normality	-	concentration
n_p	number of process tanks	-	-
n_s	number of sludge tanks		
POI	position of the interface	L	length
Qp	process flow rate	L^3/T	volume/time
sec	second	T	time
Sp.g	specific gravity	-	-

NWMAR116610

Symbol	Definitions	Dimensions	Type of Unit
t_d	detention time for reaction	T	time
t_{ds}	time to desludge	T	time
t_{draw}	time to draw	T	time
t_{fill}	time to fill	T	time
t_T	total detention time	T	time
Vp	process volume	L^3	volume
Vp (eff)	corrected process volume	L^3	volume
#	pounds	W	weight
	pump	-	-
%	percent	-	-
	chemical feed system	-	-

Conversion Factors

English Unit	Multiplier	Metric Unit
acre	0.405	ha
acre-ft	1,233.5	cu m
Btu	0.252	kg-cal
Btu/lb	0.555	kg-cal/kg
bu	35.24	l
bu	0.03524	cu m
cfm	0.028	cu m/min
cfs	1.7	cu m/min
cfs/acre	4.2	cu m/min/ha
cfs/sq mile	0.657	cu m/min/sq km
cu ft	0.028	cu m
cu ft	28.32	l
cu in.	16.39	cu cm
cu yd	0.75	cu m
cu yd/mile	0.475	cu m/km
cu yd/sq mile	0.29	cu m/sq km
^oF	0.555 (^oF-32)	^oC
fathom	1.8	m
ft	0.3048	m
ft-c	10.764	lumen/sq m

NWMAR116611

gal	0.003785	cu m
gal	3.785	l
gpd/acre	0.00935	cu m/day/ha
gpd/cu yd	5.0	l/day/cu m
gpd/ft	0.0124	cu m/day/m
gpd/sq ft	0.0408	cu m/day/sq m
gpm	0.0631	l/sec
gpm/sq ft	40.7	l/min/sq m
hp	0.7457	kw
in.	2.54	cm
lb	0.454	kg
lb/day/acre	11.2	kg/day/ha
lb/day/acre-ft	3.68	g/day/cu m
lb/1,000 cu ft	16.0	g/cu m
lb/acre/day	0.112	g/day/sq m
lb/day/cu ft	16	kg/day/cu m
lb/day/cu yd	0.6	kg/day/cu m
lb/day/sq ft	4,880	g/day/sq m
lb/ft	1.51	kg/m
lb/mil gal	0.12	g/cu m
mgd	3,785	cu m/day
mgd/acre	9,360	cu m/day/ha
mile	1.61	km
ppb	10^{-3}	mg/l
pcf	16.02	kg/cu m
psf	4.88	kg/sq m
psi	0.0703	kg/sq cm
sq ft	0.0929	sq m
sq ft/cu ft	3.29	sq m/cu m
sq in.	6.452	sq cm
sq miles	2.590	sq km
tons (short)	907	kg
tons (short)	0.907	metric tons

Taken From: The Journal of the Water Pollution Control Federation

Length

Miles	Yards	Feet	Inches	Centimeters
1	1760	5280	--	--
--	1	3	36	91.44
--	--	1	12	30.48
--	--	--	1	2.540

1 m = 100 cm = 3.281 ft = 39.37 in.

NWMAR116612

Area

Square Miles	Acres	Square Feet	Square Inches	Square Centimeters
1	640	--	--	--
--	1	43,560	--	--
--	--	1	144	929.0
--	--	--	1	6.452

1 sq m = 10.76 sq ft

Volume

Cubic Feet	Imperial Gallons	U. S. Gallons	Cubic Inches	Liters
1	6.23	7.481	1728	28.32
--	1	1.2	277.4	4.536
--	--	1	231	3.785
--	--	--	57.75	0.946
--	--	--	61.02	1

1 cu m = 35.31 cu ft - 264.2 gal

1 Imperial (UK) gal weighs 10 lb 1 US gal weighs 8.34 lb

1 cu ft of water weighs 62.43 lb 1 cu m weighs 2283 lb

1 cu m - 10^3 l and weighs 1000 kg

Velocity

Miles per Hour	Feet per Second	Inches per Minute	Centimeters per Second	Kilometers per Hour
1	1.467	1056	--	1.609
--	1	720	30.48	--
--	--	1	0.423	--

Time

Days	Hours	Minutes	Seconds
1	24	1440	86,400
--	1	60	3,600
--	--	1	60

Weight

Tons	Pounds	Grams	Grains	Metric Tons
1	2000	--	--	0.9078
--	1	454	7000	--
--	--	1	15.43	--

1 long ton = 2240 lb

1 ppm = 1 mg/l = 8.34 lb per mg

NWMAR116613

Discharge

Cubic Feet per Second	Million Gallons Daily	Gallons per Minute
1	0.6463	448.8
1.547	1	694.4

1 in. per hour per acre = 1.008 cfs
1 cu m/sec = 22.83 mgd = 35.32 cfs

Pressure

Pounds per Square Inch	Feet of Water	Inches of Mercury
1	2.307	2.036
0.4335	1	0.8825
0.4912	1.133	1

1 atm = 14.70 psia = 29.92 in. Hg = 33.93 ft water = 76.0 cm Hg

Power

Kilowatts	Horsepower	Foot-Pounds per Second	Kilogram-Meters per Second
1	1.341	737.6	102.0
0.7457	1	550	76.04

Work, Energy, and Heat

Kilowatt-Hours	Horsepower-Hours	British Thermal Units	Calories
1	1.341	3412	8.6×10^5
0.7457	1	2544	6.4×10^5

Temperature

Degree Fahrenheit = $32 + \frac{9}{5}$ x degrees Centigrade

0	5	10	15	20	25	30	35	40	45	50	55	60	C
32	41	50	59	68	77	86	95	104	113	122	131	140	F

Taken From: Fair, Geyer and Okun
Water and Wastewater Engineering (15)

NWMAR116614

GLOSSARY OF TERMS

Accessibility - The ease and safety of approaching a site.

Acidic - A solution which has acid properties and contains excess (over neutral) concentration of hydrogen ions.

Activated Carbon Adsorption - A process by which granular activated carbon selectively removes some organics and inorganics by physical surface attraction.

Adsorption Capacity - An indicator of the amount of contaminant a certain type of carbon can remove.

Aeration - The oxidation of contaminants by forcing air through a solution of wastewater.

Alkaline - A basic solution which contains large amounts of hydroxyl ions.

Anion - A negatively charged ion. (Anionic - possessing a negative charge)

Backwash - Forcing water at a high flow rate in tne opposite direction of operational flow to remove particulates that blind the media.

Ballast - A heavy material placed in a container to enhance the stability.

Batch - 1. The volume of fluid equal to the process capacity of a tank. 2. An operation which is not continuous whereby all operations are done on one volume in the same tank.

Bench Testing - Small scale procedures to establish the treatment parameters for a specific wastewater.

Breakthrough - A condition which occurs when a media's capacity for removing a contaminant is exhausted.

Cation - An electron having a positive charge. (Cationic - possessing positive charges)

Chemical Injection - The process of adding a treatment chemical to the wastewater. Specific points of addition and methods are needed.

Chlorination - The oxidation of contaminants by addition of chlorine or other chlorine compounds.

NWMAR116615

Clarification - The removal of turbidity and solids from a solution through the sedimentation or flotation process.

Coagulation - A physical-chemical process which involves the reduction of surface charges and the formation of complex hydrous oxides.

Desludging - Operation of removing settled material (solids) from the bottom of a sedimentation or precipitation reaction tank by pumping into a separate holding tank.

Detention Time - The length of time a volume of solution is contained in the treatment process. Does not include filling and drawing time in this context.

Diffuser - A mechanical device that allows bubbles of air to be injected into a solution. Various types are available from a small porous stone to a tube of steel covered with porous bags.

Downtime - The time during which process flow is stopped and backwashing, desludging and maintenance operations are performed.

Effective Size - That size of media that 10% by weight is smaller than and 90% by weight is larger than.

Endpoint - The indication of the process completion. The type depends on the test being used.

Equalization Tank - An extra process tank used to balance inconsistant flows and provide an even flow of wastewater to downstream processes.

Fill Time/Draw Time - The amount of time needed to fill (draw) a process tank. Equivalent to the process volume of the tank divided by either the system or pump flow rate.

Filtration - The removal of particulate matter by passing a waste stream through a bed of graded media.

Filtration Rate - The flow of water through a unit of filter surface area [$l/min/m^2$ or gpm/ft^2].

Fines - The small particles which are present with most coarse media and can cause surface blinding.

Floc - The enlarged particles that are formed after chemical addition and contact. Generally a physiochemical reaction creates a desirable large and distinct floc.

Flocculation - This is the opportunity for particle contact to allow increased size of the particles. It is done at a speed just fast enough to keep the materials in suspension without breaking up the floc.

NWMAR116616

Flotation - A unit of operation to separate solid or liquid particles from the liquid phase which have a specific gravity less than water.

Freeboard - In a process tank the vertical distance from the fluid level to the top of the tank.

In Situ - Within the system/in this situation referring to treatment within the contaminated water body.

Inorganic Contaminants - Spilled compounds consisting of any element except carbon.

Insoluble - Not capable of being dissolved, generally considered in water.

Ion Exchange - A process in which ions held by electrostatic forces to functional groups on the surface of a solid or exchanged for ions of a different species in solution.

Limiting Factors - Those variables (or variable) which establish a maximum process flow rate through the system.

Mixing - To agitate sufficiently to blend the contents of a tank with the added materials.

Neutralization - The adjustment of pH to approach a value of 7.

Nonionic - Possessing an excess of neither positive or negative charges.

Off Stream Treatment - Treatment of a contaminant by removing the wastewater and treating it in a location adjacent to the waterway.

Organic Contaminants - Spilled materials which are compounds of carbon.

ORP - (Oxidation Reduction Potential) - A measurement of the positive and negative ion concentration. Measured by a platinum electrode on a meter.

Oxidation - The chemical reaction which involves a loss of electrons by the waste species being treated.

Parallel Operation - A mode of operation in which a wastewater is treated by splitting the flow into a group of simultaneous process units.

pH Meter - An electric meter which measures the pH by the use of a calomel electrode. It may require manual temperature compensation.

pH of a Solution - pH is the negative log of the hydrogen ion concentration ($-\log [H^+]$) and is a measure of the intensity of acid or alkaline condition of a solution.

pH Paper - Dyed paper which gives a rough indication of the pH (e.g. H^+ ion concentration) of the solution.

NWMAR116617

Precipitation - Treatment process in which reagents are added to form insoluble products with the specific pollutants.

Presettler - A process tank used to remove the bulk of solids or sludges that settles rapidly from a water column. It is continuously desludged and used when solids volume is greater than 3% of the flow,as well as in other applications.

Pretreatment - Early removal of certain contaminants to reduce the load on downstream treatment processes.

Process Effluent - The treated fluid exiting a process element.

Process Head Loss - The pressure necessary to overcome the resistance to flow through the process media and media supports.

Process Height - The height to which the tank is filled and it is equal to the total height of the tank minus the freeboard.

Process Influent - The fluid entering a process element.

Process Tanks - Fluid containers in which batch treatment processes are accomplished; geometry and size of these tanks are dependent on the specific operation.

Process Volume - The total volume of wastewater that must be handled during a certain unit process.

Pump Rating - The volume, headloss and type of wastewater that a pump can handle in a certain situation. Defined by the fluid flow (GPM) and the Total Dynamic Head (ft); these are the two coordinates of the pumping curve from which the pump efficiency and horsepower may be read.

Reactant - A substance or chemical participating in a reaction,in this situation considered the chemical being added to a solution of wastewater.

Reduction - The chemical reaction which involves a gain of electrons by the waste species being treated.

Regeneration - A process by which the concentrated solution of the exchangeable ion is passed through the bed. The contaminant is then collected in this solution.

Saturation - A state of solution at which time it is in equilibrium with excess solute and no more solute can be placed in solution.

Scaleup - Scaleup is the translation of bench test values to large scale process units.

Sedimentation - The removal of solid particles from a suspension by gravity settling.

Series Operation - A mode of operation in which a wastewater is treated by passing the entire flow through successive process operations.

NWMAR116618

Settling Rate - The speed with which a discrete particle falls through the solution expressed in units of distance over time.

Sludge - The concentrated solids after sedimentation.

Slurry - A mixture of solids and liquid (usually water).

Specific Gravity - The ratio of the mass of a solid or liquid to the mass of an equal volume of distilled water at 4°C or of a gas to an equal volume of air or hydrogen under prescribed conditions of temperature and pressure.

Storage Tanks - Fluid containers such as equalization tanks and backwash storage tanks which do not contain the process operations but nevertheless are necessary to accomplish the treatment scheme.

Supernatant - The clarified layer of wastewater above the sludge layer after solids removal.

Surface Blinding - The situation which occurs in a filter due to the hydraulic gradation during backwash. The fine media is near the top of the bed so very rapid lead loss occurs in the first inch of bed depth.

Time to Desludge - The amount of time needed to desludge. It depends on the solids pumping capacity and the volume of sludge to be removed.

Underdrain - A mechanical barrier used to separate the cleaned water from the media and to distribute the filter and backwash flows evenly over the filter area.

Uniformity Coefficient - The ratio of the size such that 60% by weight is smaller than the effective size i.e., the 60%/10% size.

Viscosity - A measure of the amount of resistance to flow. The higher the "viscosity" the more difficult it is to make the fluid flow.

Volume of Spill - The entire volume of area contaminated by a spill which must be treated or otherwise handled.

NWMAR116619

8.0 STANDARD OPERATING PROCEDURES DURING CLEANUP

8.1 SAMPLING PROCEDURES

The collection and subsequent analyses of samples is important in evaluating the progress of the spill cleanup. As stated in Chapter 3 of this manual (Methodology for Spill Assessment), it is also important to collect samples as soon as possible after the spill occurs for spill identification and assessment and for later use as evidence. L kewise, it is important to collect samples at the beginning of and during the cleanup operation to document the progress of the cleanup. The general sampling methodology described here may be applicable to all situations, although the EPA "Field Detection and Damage Assessment Manual" (5) should be used as a guideline when samples are to be collected specifically for assessment or enforcement purposes.

8.1.1 Method of Sampling

There are two methods of sample collection: automatic and manual. "Automatic" refers to the use of an automatic sampler to collect samples while "manual" refers to collection of samples by a person at the scene. Sampling at the scene of a spill will usually be performed manually because of the emergency and temporary nature of the situation. Also, the presence of personnel on the scene may make it convenient and economical to take manual samples. Guidance on selection and use of automatic samplers can be found in other publications (65-67). The following discussion will assume manual sample collection although the theory could also apply to the use of an automatic sampler.

8.1.2 Type of Samples

There are two types of samples which can be collected for analysis:

1. Grab (discrete samples).
2. Composite samples.

Grab or discrete samples characterize the water quality at a particular instant in time. The purpose of a composite sample is to mix discrete samples in such a way to represent the average characteristics over a period of time. In addition to generating an average value, compositing is often done to reduce the analytical load placed on the laboratory.

The choice of the type of sample should depend on the objective of the sampling and the variability of the water. If the variability of the parameter of interest is low (that is, if the concentration of the parameter of interest changes little over time), then a grab sample may characterize the quality adequately. On the other hand, if the variability is high, then a composite should be formed from grab samples taken at short intervals, or the grab samples themselves should be collected and analyzed. If nothing is known about the variability of the water, then grab samples should

NWMAR116620

be collected and analyzed initially to determine the variability of the water. Judgment will have to be exercised in terms of the allowed variability. As a general rule, though it is wise to form a composite sample for analysis unless directed otherwise.

3.1.3 Types of Composite Samples

A composite sample is a sample formed by mixing discrete samples taken at periodic points in time or consisting of a continuous portion of the flow. There are four commonly used methods of forming composites;

1. Constant time - constant volume: samples of equal volume are taken at equal increments of time and composited to make an average sample.

2. Constant time - volume proportional to flow increment: samples are taken at equal increments of time and are composited proportional to the volume of flow since the last sample was taken.

3. Constant time - volume proportional to flow rate: samples are taken at equal increments of time and are composited proportional to the flow rate at the time each sample was taken.

4. Constant volume - time proportional to flow increment: samples of equal volume are taken at equal increments of flow composited.

In the case of continuous sampling the time intervals in methods 1 and 3 would be zero.

In many cases where a constant-speed pump is used, the treatment rate will be constant so that the volume - proportional methods are identical to the constant time-constant volume method. In this case the constant time - constant volume method should be used. Continuous sampling is best when it is feasible. Where the treatment rate is variable, a flow-proportional compositing method should be used. Methods 2, 3, and 4 all give similar results and the method which is easiest to apply should be chosen. Methods 1, 2, and 3 are the easiest to use since the time interval is constant and a timer can be set to remind personnel to collect a sample. If a totalizer is provided on the flow measurement device, method 2 should be used. If a totalizer is not available but the record can be obtained from a flow chart, the volume treated since the last sample was taken can be estimated from the flow curve.

3.1.3.1 Mechanics of Compositing - For the "constant time-constant volume" method, the contents of all the bottles can be poured into one container, mixed, and the desired volume of sample withdrawn, assuming all the bottles contain an equal volume. Alternately, the contents of each discrete bottle can be mixed and an equal volume, as calculated below, can be taken from each bottle for the composite;

$$V_d = \frac{V_c}{n}$$

NWMAR116621

V_d = volume of each discrete sample to be used

V_c = composite volume desired

n = number of discrete samples

For the "constant time - volume proportional to flow increments" method, the volume of each discrete sample to be used for the composite can be calculated as follows:

$$\frac{V_d}{V_c} = \frac{F_s}{F_t} \quad \text{or} \quad V_d = \frac{F_s}{F_t} \cdot V_c$$

Where

V_d = volume of the discrete sample to be used

V_c = composite volume desired

F_s = flow volume since last sample

F_t = estimated total flow volume

For the "constant time - volume proportional to flow rate" method, the flow rate should be noted at the time each of the discrete samples was collected. Then the portion of each discrete sample to be used for the composite can be calculated from the equation:

$$ax + bx + cx = V_c$$

Where:

a, b, c = flow rates when discrete samples were taken

x = volume of sample/unit of flow

V_c = composite volume desired

So that

ax = volume of discrete sample "a" to be used

bx = volume of discrete sample "b" to be used

cx = volume of discrete sample "c" to be used

3.1.3.2 Sampling a Batch Process - A single grab sample or a number of grab samples composited will often adequately characterize the discharge of

NWMAR116622

effluent from a batch process. However, if a single sample or a small number of samples are to be used it is imperative that the contents be thoroughly mixed prior to sampling or in the case where quiescent conditions must be maintained, a number of samples at various locations throughout the process container should be taken.

8.1.4 Sampling Location and Parameters

As a general rule it is recommended that samples be taken from the influent and effluent of each process during the entire time of operation. This will not necessarily result in an overbearing number of samples since many samples will serve as the effluent from one process and the influent to another process. Also, samples taken at frequencies as low as a few minutes apart can be composited so that only one sample will result for subsequent analysis.

Although it is obvious that the most critical sample to be taken is the final effluent sample, there are many significant reasons for sampling at other locations. Sampling of the raw flow coming to the treatment process is important since this will allow a determination of the mass of contaminant being removed when the raw is compared to the final effluent. This can become especially critical in cases where it is difficult to get a representative sample of the contaminated watercourse and the only operational way of determining the progress of cleanup is to measure the mass removed and compare this to the original mass spilled.

Taking samples between treatment processes serves many purposes also. samples allow a determination of the efficiency (or lack of efficiency) of a certain process and then a decision can be made as to whether further operation of this process is required. Also, where filtration, adsorption or ion exchange is used, sampling before and after a process allows calculations of the mass of solids, organics, ions, etc., that have been removed by the process and it can be estimated in advance when backwashing, regeneration or replacement will be required. This will prevent the situation of having to stop all operations because a filter has clogged or a column has broken through when these problems could have been remedied during a previous "down time". By analyzing samples for such parameters as suspended solids, total organic carbon, turbidity, etc., in addition to the hazardous material of concern, it will be possible to maintain good process control. Also, some of these analyses can serve as indicators of the hazardous material requiring fewer analyses of the hazardous material itself, which oftentimes involves complex, expensive and long analytical procedure.

8.1.5 Sample Containers

Samples must be taken into appropriate sample containers to reduce the possibility of contamination or adsorption which will yield incorrect results. The container must be completely clean and equipped with a tightly fitting cap. Organic hazardous materials must be contained in a glass jar or bottle to reduce adsorption to the container walls. Specifically, oils and grease, pesticides, or even short chain organic compounds should be

NWMAR116623

placed into glass containers. Other materials such as metallic salts, can be stored in plastic containers with no adverse effect.

Sample containers should be provided from the nearest analytical laboratory to insure use of the proper type or, if necessary, the bottles can be purchased from a local bottle supplier. If possible, use wide mouth containers with a lined cap except where interaction between the sample and cap material must be modified. (Then use narrow necked containers). If commercial sample bottles can not be obtained, wide mouth canning jars can be used if an aluminum foil liner is provided. Where a plastic container is applicable, distilled water can be purchased, the bottles emptied and the containers used when no other bottles are available. However, the use of these bottles is not recommended without specific instructions from the OSC.

To clean sample containers prior to reuse, the following procedure has been found to be effective:

1. Wash containers and caps with a non-phosphate detergent and scrub strongly with a brush.

2. Rinse with tap water, then distilled water.

3. Invert to drain dry.

4. If additional cleaning is needed, rinse with sulfuric acid, tap water and distilled water.

In certain cases, sample bottles are further rinsed with chemicals to remove traces of materials left by previous samples. These procedures are outlined as follows:

1. Acid Rinse: If metals are to be analyzed, rinse the container with a solution of one part nitric acid to four parts water, then with distilled water. If phosphorus is to be analyzed, rinse the container with a solution of one part hydrochloric acid to one part water followed by distilled water.

2. Solvent Rinse: If oil and grease or pesticides are to be analyzed, rinse the sample container with hexane, then acetone, and distilled water. The container should have been previously cleaned with acid solution. Treat the container caps similarly.

For long term monitoring, however, the analytical laboratory performing the analyses should provide prepared bottles for sampling.

3.1.6 Sample Preservation and Identification

The purpose of sample preservation is to maintain the constituents of interest in the same concentration as when the sample was collected. Even with preservation, the concentrations of the constituents may be a

NWMAR116624

function of the time between sample collection and analysis. Therefore, for any given preservation method a maximum holding time is also specified. Other factors related to preservation that may affect the integrity of the sample include the type and material of the sample container, sample identification, and the chain of custody for sampling handling. For the preliminary or initial sampling, icing or refrigeration of the samples should be adequate. While not effective for all parameters, icing or refrigeration is recommended as a standard technique since it comes closest to being a universal preservative and does not interfere with any analyses. The use of ice cubes and an insulated chest is usually an effective and convenient method for storage and transport of samples.

For a long term sampling program or for process monitoring samples, the laboratory performing the analyses should be consulted for specific instructions regarding preservation techniques and sample containers.

8.1.6.1 Sample Identification - Once the sample is taken, certain procedures must be followed to allow the identification of the sample and to record the chain of custody. It is important that these techniques be standardized and become a part of normal field procedure.

Each sample should be assigned a unique number to allow easy identification in the field and the laboratory. It is important that the number include relatively few digits so that it will not be abbreviated during successive handling. It is recommended that each person who samples be assigned a roll of peel-back labels. These labels would include the person's initials and sequential numbering. As a sample is taken and sealed, a number will be affixed to the bottle. The label would include sufficient space for added information such as date, preservative added, etc. Then the specifics regarding the sampling location, type of sample, and other pertinent facts would be recorded in the field notebook.

8.1.6.2 Chain of Custody - In cases of litigation, there must be proof of the chain of possession that occurs from the time of sample collection to final destruction. If a sample cannot be traced completely, the validity of the analytical result may be doubtful. Therefore, it is important that procedures for a written record of chain of custody be included as normal field practice. A person has custody of a sample if one of the following requirements is fulfilled:

1. It is in his actual physical possession.

2. It is in his view after being in his actual physical possession.

3. It was locked up by him after being in his physical possession.

4. It was kept in a secured area, restricted to authorized personnel after being in his physical possession.

When the sample leaves his custody, then a record should be made indicating that this has been done.

NWMAR116625

The most important aspect of field procedures is to keep an accurate notebook. Once the sample is taken and a sample identification label affixed to the container, all pertinent information should be recorded in the notebook. The following information should be included:

1. Sample identification number.
2. Date and time of collection.
3. Location of sampling point in detail.
4. Method used to collect the sample.
5. Volume collected and type of container.
6. Preservation method.
7. Analyses to be performed on the sample.

The person performing the actual sampling should be certain to sign and date the record and, if possible, include the signature of a witness in the sampling party.

After the labeling and notation, the sample should either be placed in a chest which will be sealed or a seal should be placed on the container cover. The seal should be of a material which will readily indicate any tampering. Then the person performing the sampling should record in the field notebook how the sample was transported to the lab and indicate if any analysis request sheet was sent with the sample.

If the sample was shipped, all receipts or shipping identification numbers should be kept in the field notebook along with the address of the recipient. The signature of the person receiving the sample should also appear in the notebook. The time and location of the sample while it was in custody of the sampling personnel should also be recorded in the notebook.

Whether or not a rigorous chain of custody procedure will be required for all treatment process samples will be a decision of the OSC and his legal advisors. However, it is estimated that these procedures will at least be required for the raw samples which may supply required data in later litigation.

8.2 RECORDS

The importance of keeping written records cannot be emphasized too strongly. As documentation of the events surrounding the spill and its cleanup, these written records may have important legal implications particularly in cost recovery or reimbursement. The records may also serve as a learning tool in that the knowledge gained from the spill can be applied to future spill situations. It is a good practice after the spill is cleaned, and the emergency is over, to go back and assess the measures taken at the scene. Evaluation of this sort is important in improving response techniques. A record of the progress being made in the cleanup is also important in making decisions at the scene of the spill.

NWMAR116626

It is recommended that the OSC keep in a permanent bound book a log or diary of the chronological events from the minute of notification of the spill until the cleanup and his duties are completed. All events of any significance should be recorded in the log with notation of the date and time. The information should include records of flow, operation, maintenance, sampling, fuel used, problems encountered, telephone conservations, meetings held, orders issued, weather observations, etc. The log should be kept in a bound, sequentially numbered notebook. Entries should be made in the log immediately and the date and time indicated. No pages should be removed from the notebook. If a page is ruined, it should be marked "VOID". Important observations involving judgment and sampling records should be signed by the principal investigator and countersigned by a witness.

The important records that should be kept in the notebook can be listed as follows:

1. General events - for each day start/stop times for cleanup activities, arrival or procurement of equipment, documentation for authorization, weather observations.

2. Treatment - gallons treated by each process, hours of operation of each process, maintenance needed and/or performed, fuel used, equipment breakdowns, ultimate disposal.

3. Sampling - records of sampling, sample preservation methods, and destination and analyses required of samples.

4. Personnel - a record of all personnel on site, their function, and the actual times present should be recorded. This is especially important for those personnel, whether from a government agency or third party contractor, associated with the cleanup/treatment operation itself. It is imperative that the OSC develop a rigid communication network with the person in charge of the cleanup/treatment operation so that the OSC knows at all times the status of each operation and the personnel attending the respective operation.

NWMAR116627

SECTION V

METHODOLOGIES FOR SPILL PREVENTION

IN-PLANT SPILL PREVENTION

Management Considerations

The full utilization of proper plant design and effective control systems is essential for an effective spill prevention program. All control systems are of little value unless backed by management committed to utilizing these systems to their fullest extent. It is generally recognized that assignment of responsibility to the smallest supervisory unit practicable is an effective management approach to improve performance. In spill prevention this unit would be the smallest group of facilities that are physically separable from others in terms of measurable pollutional loadings.

Management considerations for the prevention of spills are multitudinous. Spill prevention objectives, investigation of spills to avoid a repetition, and promotion of open and frank communication channels should be some of the prime management objectives. All of these objectives aid in the rapid identification of spill sources and the minimization of spills (68).

Spills may be caused by mechanical failure or personnel error, or more rarely, by fire, explosion, power failures, or "acts of God". However, since most spills are a result of mechanical failure and/or personnel error, the following measures can go a long way in preventing or minimizing their occurrence (69):

Sound basic design

Thorough training of operating, technical and maintenance personnel

Strict job responsibility

Sound process control and alarm and monitoring systems

Proper maintenance of equipment and facilities

Maintenance should review existing operating and maintenance procedures and develop vulnerability studies. From these studies critical portions of the manufacturing process can be singled out and modified to decrease the probability of a hazardous spill. The spill prevention program of any plant should include an action diagram or plan to be followed when a spill occurs. In this plan, responsibilities should be definitely assigned (preferably by

NWMAR116628

name) to establish the chain of command so that there is no confusion or time wasted. A primary consideration should be to prevent the spill from contaminating the environment outside the plant (surface or groundwater, municipal sewers, soil, etc.).

Physical means of stopping spills from reaching areas outside the plant should be provided. Examples would include: maintaining neutralizing agents near bulk storage areas, maintaining personal protective safety equipment in potential spill locations so that spills may be localized. When lighter than water chemicals are handled, adequate length of flotation spill-contaminant booms or absorbent booms should be available along with the proper means to deploy them. An adequate supply of dispersants (that have been approved by state authorities) should be stored at the plant for treatment of spills (70).

Plant Drainage

Proper plant drainage is a prime means of containing hazardous material spills and preventing them from reaching receiving waters. When a drainage system is designed, consideration to entrapping as much potentially polluted water as possible and diversion of these waters to the proper final destination are the predominant concerns (71).

The following recommendations relative to plant drainage were part of the Guidelines for Spill Prevention, Containment and Countermeasure Plans (SPCC) (72).

1. Drainage from diked storage areas should be valve-restrained to prevent a spill or other excessive leakage of a product into the drainage discharge or in-plant effluent treatment system.

2. Valves used for the drainage of diked areas should, as far as practical, be of manual, open-and-close design. The condition of the retained stormwater should be determined before drainage, especially if such drainage of impounded waters goes into watercourses and not into wastewater treatment plants.

3. All plant drainage systems, if possible, should flow into ponds, lagoons, or catchment basins designed to retain materials less dense than water. Consideration should also be given to possible chemical reaction, if spilled chemicals are commingled.

4. If plant drainage is not engineered as above, the final discharge of all in-plant drainage ditches should be equipped with a diversion system that could, in the event of an uncontrolled spill, be returned to the plant for treatment, the objective being to work toward a closed-cycle system.

5. Where drainage waters are chemically treated in more than one treatment unit, natural hydraulic flow should be used. If pump transfer

NWMAR116629

is needed, two "life" pumps should be provided, and at least one of the pumps should be permanently installed.

Monitoring Process Variables

The monitoring of physical and chemical quantities involved in plant processes is an extremely useful aid in avoiding hazardous spills. Either specific apparatus or entire process systems are commonly monitored. Normally process variables such as temperature, pressure, flow, specific gravity, viscosity, and chemical composition are measured. Often these measuring devices are used with automatic controls which regulate process variables to achieve optimum utilization of raw materials. In order to do this, the control keeps process variables within predetermined specifications. Such a device may also have a vital role during abnormal situations triggering corrective action, or, in extreme cases, in safely shutting down the system.

When monitoring hazardous materials, it is normal to use redundant or backup instrumentation. Because the sampling probe is in direct contact with the usually extreme condition of heat and corrosive vapors, it is the least reliable part of the system. Frequently it is desirable to use a device having a different principle of measurement as a backup unit. An example of this is the use of a resistance bulb to sense the operating temperature of a reaction vessel. The backup device could be a thermocuple.

After determining that something is wrong, the proper corrective action should be initiated. The corrective action depends entirely on the nature of the hazard and the consequences to the plant or operation. An electrical interlock system to shut down pumps and close valves leading to the process unit which is malfunctioning is a common device to prevent more material from being added to a potential spill.

Monitoring equipment should warn personnel that an operating abnormality has occurred. Commonly a flashing light and horn, which can be silenced by the operator, are used to attract the operator's attention to a particular control loop. Operation of the alarm should be independent of any control mechanism so that the alarm will still function properly even though a malfunction might occur in the control mechanism. Further monitoring equipment, such as a siren, should be employed to signal hazardous situations that might require evacuation of personnel from the area. Monitoring systems can also be obtained which use prerecorded messages to indicate the nature of the problem for the operator (73).

Inventory control systems and materials balance determinations may also indicate if leakage or spillage is occurring. The hazard potential of the following should be determined (69).

Raw materials	Waste materials
Intermediate process compounds	End products
By-products	

NWMAR116630

In-Plant Piping

Pipelines used for in-plant transportation of hazardous materials should be constructed or modified so that the following SPCC guidelines are adhered to (72).

1. Each product pipeline should be clearly marked by lettering (coded or otherwise), color banding, or complete color coding to indicate the product transferred therein. The coding should conform with company policy or standard plant practice which, in turn, should conform with state or federal requirements.

2. Each oil or hazardous material product-fill line which enters a tank below the liquid level should have a one-way flow check valve located as closely as possible to the bulk storage tank. In addition to confining the product to the tank, in the event of valve or pipeline failure, the check valve should permit overhaul of the main shut-off valve and should aid in preventing shock loading of the pipeline and valves from a "slug" of the tank content caused by backflow into an empty fill line. As far as practical, the product flow in suction lines should be controlled by use of a positive displacement pump.

3. Buried pipelines should be avoided. However, buried installations should have a protective wrapping and coating and should be cathodically protected if soil conditions warrant. A section of the line should be exposed and inspected annually. This action should be recycled until the entire line has been exposed and examined on a regularly established frequency. An alternative would be the more frequent use of exposable pipe corridors or galleries.

4. When a pipeline is not in service, the terminal connection at the transfer point should be capped or blank-flanged, and marked as to origin.

5. Wood-to-metal should be avoided as a pipeline support since it is apt to retain moisture and cause pipeline corrosion which, when coupled with the abrasive action caused by the pulsating action of the line, could cause line failure with resulting leakage. Supports should be designed with only a minimum point of surface contact that allows for the pulsating movement (expansion and contraction) of the line (i.e., rollers).

6. All above-ground valves and pipelines should be subjected to a regular monthly inspection at which time the general condition of items, such as flange joints, valve glands and bodies, catch trays, pipeline supports, locking of valves, and metal surfaces, should be assessed.

7. Elevated pipelines should be subjected to constant review to

NWMAR116631

insure that the height of vehicular traffic granted plant entry does not exceed the lowermost height of the elevated line; gate check-in and in-plant travel routes warrant attention in this respect.

8. As far as practical, all pumps should be located as close as possible to the storage tank.

9. Flapper-type drain valves should not be used to drain diked areas. Such drain valves should be of manual open and close design, and they should be kept in the closed position when not in service. The drain lines from dike areas should drain directly or indirectly into treatment or holding tanks or ponds or catchment basins.

Solid Material Storage

Solid material storage should conform to the following SPCC guidelines (72):

1. The open stockpiling of ores, chemicals and minerals should be discontinued. Piles of bulk material should be covered to prevent leaching and runoff. If open shed-like structures are used for bulk storage, retention curbing should be provided around the perimeter of the pile, or perimeter drainage trenches should direct runoff into a suitable wastewater treatment facility.

2. Bulk storage should not be positioned on the natural earth. Storage pads of concrete or other impervious materials should be used as a base to prevent ground water leaching and percolation into the earth.

3. Metal and fiber containers should be loaded, stored, and unloaded so as to minimize possibility of container damage. The containers should be stored in a covered area, off the ground in a manner which will preclude damage and weathering to the container, and subsequent leakage. The area itself should be provided for drainage to a treatment facility in an analogous manner to diked storage tank areas.

4. If some conainers contain corrosive substances, these should be stored so that leakage of these substances will not corrode through adjacent containers.

5. All items outlined under this heading should be periodically inspected to insure physical and mechanical integrity of the drainage and containment systems.

Bulk Storage

Bulk storage of materials should conform to the following SPCC guidelines (5):

NWMAR116632

1. No tank should be used for the storage of oil or hazardous substances, unless its material and construction are compatible with the material stored.

2. All bulk storage tank installations should be planned so that a secondary means of containment is provided for the entire contents of the largest single tank. Dikes, containment curbs and pits are commonly employed for this purpose, but they may not always be appropriate. An alternative system would consist of a complete drainage trench enclosure arranged so that a spill could terminate and be safely confined in an in-plant catchment basin or holding pond.

3. Drainage of rainwater from the diked area into a storm drain or an effluent discharge that empties into an open watercourse, lake, or pond, and by-passing the in-plant treatment system may be acceptable if:

    1. The by-pass valve is normally locked closed.

    2. Thorough analysis of the rainwater ensures compliance with applicable water quality standards.

    3. The by-pass valve is unlocked, and relocked following drainage under the supervision of responsible management.

    4. Adequate records are kept of such events.

4. The storage tanks located immediately adjacent to the dike itself should be oriented with respect to the dike so that no manholes face the dike. This is considered desirable, so that if a manhole fails, the resulting discharge from a full tank will not be aimed over, or at the dike.

5. If storage tanks located immediately adjacent to the dike itself are equipped with fill lines which enter the tank near the bottom and if the fluid pumped has suspended abrasive material, the discharge into the tank should be on the dike side, discharging against the tank side away from the dike. Alternatively, a baffle plate located inside the tank opposite the pump discharge in the area apt to be abraded, may be provided.

6. Buried storage tanks represent a potential for undetected spills. A buried installation, when required, should be wrapped and coated to retard corrosive action. In addition, the earth should be subjected to electrolytic testing to determine if the tank should be further shielded by a cathodic protection system. Such buried tanks should at least be subjected to regular hydrostatic testing. In lieu of the above, arrangements should be made to expose the

NWMAR116633

outer shell of the tank for external examination at least every five years. A means of conducting regular internal examinations of the tank at five-year intervals should be provided (down-hole television, etc.).

7. Partially buried tanks for the storage of oil or hazardous materials should be avoided, unless the buried section of the shell is adequately coated since partial burial in damp earth can cause rapid corrosion of metallic surfaces, especially at the earth/air interface.

8. Above-ground tanks, depending on design (floating roof, etc.) should be subjected to integrity testing, either by hydrostatic testing, visual inspection, or by a system of nondestructive shell thickness testing. When the latter system of integrity testing is used, comparison records of shell thickness reduction should be maintained.

9. The foundation and/or supports of all bulk storage tanks should be subjected to at least annual examination by a person with the technical competence to assess the condition of the foundation and/or supports.

10. To control leakage through defective integral heating coils, the following factors should be considered and applied:

    a. The past life span of internal steam coils should be determined, and a regular system of maintenance and replacement that does not exceed the anticipated life span should be established.

    b. To reduce failure from corrosive action, prolong life, and reduce replacement costs, the temperature and environment have to be carefully considered when selecting heating coil materials.

    c. The steam return or exhaust lines from integral heating coils which discharge into an open watercourse should be monitored for contamination, or passed through a settling tank, or skimmer, etc.

    d. The feasibility of installing an external heating system should also be considered.

11. Each bulk storage tank should be externally examined at least once a month. Each inspection should include an examination of streams, rivets, nozzle connections, valves, and pipelines directly connected to the tank.

12. New and old tank installations should, as far as practical, be fail-

NWMAR116634

safe engineered or updated into a fail-safe engineered installation. Consideration should be given to providing the following devices;

a. High liquid level bell or horn alarms with an audio signal at a constantly manned operating or listening station; in smaller plants and audible air vent may suffice.

b. Low liquid-level alarms with an audio signal at a constantly manned operation of listening station; such alarms should have a non-bypassing reset device that can be readjusted to a given operating level following tank fill or liquid removal.

c. High liquid-level pump cutoff devices set to stop flow at a predetermined tank content level.

d. Direct audible or code signal communication between the tank gauger and the pumping station.

e. At least one fast response system for determining the liquid level of each bulk storage tank such as digital computers, telepulse, or direct vision gauges.

13. "Normal" plant effluent should be constantly monitored by a proven monitoring system, and any deviation from normal should be engineered to activate a visible readout recorder with an audible alarm that can be heard at a constantly manned operation or listening station. If practical, the monitoring device should be designed to operate a bypass to release the effluent discharge into a holding pond.

14. Visible product leaks from tank seams and rivets should be promptly corrected.

15. Tanks should not be used with the knowledge that the "head" or "top" is in a corroded-through condition. Action should be taken to drain such tanks and repair the defective member as promptly as possible.

16. When practical, each bulk storage tank should be lettered (code or otherwise) or color coded to indicate its chemical content, the Manufacturing Chemists Association or Department of Transportation coding being preferred, and the coding should duplicate those used for chemical transportation identification.

17. The use of wooden tanks should be confined to water storage and should be avoided for liquid chemical storage.

The Manufacturing Chemists' Association has developed a checklist to aid in developing spill prevention and control programs for chemical plants. This checklist is presented in the end of this section.

NWMAR116635

SPILL PREVENTION DURING TRANSPORT

General Considerations

The Code of Federal Regulations (CFR), Title 49, Parts 170-178 was originally published by the Department of Transportation to control surface transportation of hazardous materials. For air transport, more specific controls were deemed necessary and the Federal Aviation Regulations (FAR), Vol. VI, Part 103 were drafted to modify 49 CFR. CAB 82 is an air line tariff which must be followed where it is more restrictive than 49 CFR or FAR 103. The International Air Transport Association (IARA) Restricted Articles Regulations must also be followed for all U.S. import and export shipments. Within the U.S., state and local agency requirements must also be met.

All the regulations are designed to prevent spills from occurring and to protect life and property. In complying with the regulations, the following activities are required.

1. Identification by proper DOT name
2. Classification by DOT hazardous material class
3. Packaging
4. Marking and labeling
5. Preparation of shipping papers

Both shippers and carriers are legally obligated to comply with the applicable regulations. Before a shipment is consigned to a carrier, the following must be checked by the shipper (74).

1. That DOT authorized containers have been used.

2. That proper closures have been used and no leaks are evident.

3. That outside packages are properly labeled and have required outside marking.

4. That shipping documents include proper DOT shipping name, hazardous material class, signed certificate, proper count and weight. Abbreviations must not be used for required entries.

5. That non-compatible materials are not tendered in the same shipment. If non-compatible shipments are tendered to the same carrier, make certain that the carrier recognizes the situation. Check the loading and storage charts.

6. That the driver is made aware that the shipment contains a hazardous material.

7. That a carrier representative has an opportunity to approve the

NWMAR116636

placement, securing and blocking of the material before closing out and sealing the load (if seals are used), if the material is loaded by the shipper's personnel.

8. That placards are properly displayed before the carrier leaves.

The carrier should check that the shipper has met his requirements before accepting a shipment. In addition, the carrier's personnel have certain responsibilities regarding spill prevention (75).

Freight Handlers:

1. Must have broad hazardous material knowledge involving proper DOT shipping names, classes, required packaging, compatibility, labeling, marking requirements, placarding and shipping documents.

2. Must check hazardous material freight against documents. If they do not check out, make certain that the discrepancies are resolved before freight is allowed to move any further.

3. Must refuse to accept hazardous material freight from shippers or interline carriers if the shipping documents are improperly prepared or do not check out with the freight involved or if the containers are leaking, damaged or otherwise improper.

4. Must inspect all hazardous material freight for leakage or damage each time it is handled.

5. When damaged containers are discovered, must isolate and make certain they are not moved until they are in proper condition for further transportation. Make certain that all container information is obtained for use in preparing the required report to the Department of Transportation. (NOTE - In some instances immediate telephone notification to DOT is also required).

6. When contamination occurs or when it is necessary to dispose of hazardous materials or containers, must make certain that a qualified individual supervises such activities.

7. Must make certain that non-compatible hazardous materials are not loaded into the same vehicle.

8. Must make certain that proper placards are placed on vehicles when required and that placards are removed or covered when not required.

9. Must make certain that hazardous material containers will not be damaged by other freight or by nails or rough sides and flooring within the vehicle.

10. Must make certain that all hazardous material is properly blocked

NWMAR116637

and secured before closing out vehicle.

11. Must make certain that class A or B poisons are not loaded with foodstuffs or other contaminatible cargo.

12. Must be familiar with, and have available for reference, provisions of 49 CFR Part 177, Subpart B, titled "Loading and Unloading" and Subpart C, titled "Loading and Storage Chart".

Drivers

1. Must have a broad hazardous material knowledge involving proper DOT shipping names, classes, required packaging, compatibility, labeling, marking requirements, placarding and shipping documents.

2. Must have in his possession, and available for immediate use, proper shipping papers covering all hazardous materials loaded on his vehicle.

3. Must have specific instructions (preferably written) as to handling procedures in case of hazardous material incidents.

4. Must know what to do and what information to pass on to firemen, police and others should emergency arise.

5. Must report all discrepancies and irregularities observed during trip (including such things as leaking containers or defective tank truck valves).

6. Must understand their responsibilities as to attendance requirements when transporting a hazardous material.

7. Must refuse to accept hazardous material freight from shippers or interline carriers if the shipping documents are improperly prepared or do not check out with the freight involved or if the containers are leaking, damaged or otherwise improper.

For specific requirements shippers and carriers should check the appropriate regulations. These regulations can be obtained as follows:

49 CFR	Superintendent of Documents U.S. General Printing Office Washington, D.C. 20402
CAB 82	Airline Tariff Publishers, Inc. Dallas International Airport P.O. Box 17415 Washington, D.C. 20041

NWMAR116638

IATA Restricted
Articles Regulations

International Air Transport Assn.
ATTN: Mr. Gordon Young
1155 Mansfield Street
Montreal, Quebec H3PQ

In addition to these requirements it is recommended that emergency information cards, describing actions to be taken in emergencies, accompany the shipment. These Chemcards (Cargo Information Cards for Water Transportation) were developed by and are available from the Manufacturing Chemists' Association, 1825 Connecticut Avenue, N.W., Washington, D.C. 20009.

Railroad

Equipment Features - The Association of American Railroads (AAR) favors the use of relief valves on tank cars instead of rupture disks since a relief valve will close once the pressure is reduced (76). The DOT Federal Railroad Administration, Hazardous Materials Branch recommends that valves be placed internally or otherwise protected if they are to be placed on the bottom of tank cars, as is becoming more common (76). Also recommended are protective "skids" to minimize contact of the tank with exterior forces in the event of an accident. The AAR has designed a coupler ("shelf coupler") which is less likely to disengage due to vertical motion at the time of derailment (76). If the couplers remain together, they are unlikely to puncture a car.

Preventive Maintenance and Safety Precautions - Many spills can be prevented and the severity of those which do occur decreased by the exercise of maintenance checks and safety precautions (76).

1. Prevention of overloading - Pressure can be generated by thermal expansion when a tank car is overloaded. This can cause failure of a rupture disk or opening of a relief valve.

2. Routine inspection - Tank cars should be routinely inspected for dents, gouges, or other damage. The running gear should also be checked. Gaskets should be routinely replaced, say, on an annual basis. Caps and plugs should be routinely inspected and replaced as necessary.

3. Closing of valves - The importance of tightly closing valves should be emphasized to all employees.

4. Placarding - The placarding regulations established by DOT should be observed for all hazardous cargo.

5. Positioning of cars - The DOT regulations specifying the positioning of cars (3) containing hazardous substances should be followed closely.

NWMAR116639

The following guidelines have been provided by EPA for the development of Spill Prevention, Containment and Countermeasure (SPCC) Plans by industry (72).

Tank Car and Tank Truck Loading/Unloading

Relative to tank car and tank truck loading/unloading procedures, the requirements and regulations of the Department of Transportation should be met. The following recommendations should be emphasized.

1. A system of containment curbs should be used for tank truck unloading areas, using ramps to provide truck access into the confines of the containment curb. The curb enclosure should be designed to hold at least the maximum capacity of any single tank truck loaded or unloaded in the plant.

2. A trenching system should encompass each railroad tank car unloading area. The trench should be designed to carry away any spill to a catchment basin or holding pond, at least equal in capacity to the capacity of the largest tank car loaded or unloaded in the plant.

3. As a fail-safe precaution, an interlocked warning light or physical barrier system, or warning signs, should be provided in loading/unloading areas to prevent vehicular departure before complete disconnect of flexible or fixed transfer lines.

4. Prior to filling and departure of any tank truck, the lowermost drain and all outlets of such vehicles should be closely examined for leakage, and if necessary, tightened, adjusted, or replaced to prevent liquid leakage while in transit.

Trucking

Equipment Features - Anti-jackknife devices are effective but are expensive and limit maneuverability. Bottom-loading and vapor-recovery units help to prevent spills and air pollution (76).

Preventive Maintenance and Safety Precautions - Routine inspection and maintenence procedures should be performed as for railroad cars. In the case of a truck, though, the driver may have greater personal responsibility and he should inspect the rig before leaving for his destination to make sure it is safe to operate. The driver should make sure he has the shipping papers and that they contain sufficient information to identify the cargo (chemical name, shipper, manufacturer, telephone numbers). Placarding of the truck should be performed as required by DOT regulations. The driver should consider the nature of his cargo in judging the appropriate driving speed. Also DOT regulations on drivers working hours per week should be strictly observed.

NWMAR116640

SPCC Plan guidelines for tank truck loading/unloading were given in the discussion on railroads.

Maritime

Equipment Features - Probably the construction feature that is most significant in preventing maritime spills of bulk cargoes is the doublehull vessel. For this type of vessel in many cases a collision or grounding would affect only the outer shell and not the actual container of the chemical cargo.

Preventive Maintenance and Safety Precautions - Routine inspection and maintenance should be performed for vessels and loading/unloading facilities. These procedures are covered in the EPA SPCC Plan Guidelines (77).

Barge Loading and Dock Site Facilities

Spill prevention, detection, containment, and safety practices here dictate that:

1. All flexible hoses must be hydrostatically tested annually, and inferior hoses must be discarded and replaced.

2. Barge loading lines must be routinely inspected during loading operations.

3. Adequate mooring lines forward and after are secured to all barges to minimize movement during loading.

4. Hoses must be water-flushed into the barges after loading.

Transporting Barges Through Territorial Seas

Transporting barges through territorial seas to the disposal sites must comply with the U.S. Department of Transportation regulations. Special emphasis must be applied to insure that;

1. No permittee will knowingly send a barge to sea with leaks or defects that can lead to a spill.

2. The tugboats employed for transporting the waste barges must be inspected and must comply with U.S. Coast Guard regulations.

3. The barge must carry the following permits and certificates;

    a. An Environmental Protection Agency ocean dumping permit.

    b. A U.S. Coast Guard consolidated certificate of enrollment and license for coasting trade

NWMAR116641

c. The International load line certificate issued by the American Bureau of Shipping.

Drummed Wastes

1. Drums are stored on curbed concrete pad while the barge shipment is being assembled. In the event a drum is damaged, any liquid spilled must be soaked up and redrummed. Solids spills must also be redrummed.

2. The barge is equipped with a toe board and railing to prevent slippage.

3. The drums are stored on deck in two rows with a walkway in the center. Each row of drums is secured firmly together with two strips of 5 cm (2 in.) steel binding to prevent shifting of the cargo.

4. If, in spite of the precautions taken to prevent emergecies and accidents, a drum is dumped or lost in any manner and/or location other than that specified, regardless of the circumstances, the U.S. Coast Guard must be notified immediately and action will be taken in accordance with their recommendations. A full report of the incident and action taken must be filed with EPA within 30 days.

Pipeline

Equipment Features - Safety devices have been extensively relied upon because of the extent of pipeline networks. These include fire detection equipment with automatic alarm and shutdown, automatic extinguishing systems, and closed-circuit television. Systems have been developed which monitor the flow and pressure at points along the pipeline. If a variation in pressure is detected, the line can be shut down until the leak is located and repaired (78,79):

Preventive Maintenance and Safety Precautions - Routine inspection and maintenance should be performed on the pipeline system. Aerial inspection is presently widely used to detect leaks or digging activity near the pipeline (76). Markers indicating the presence of the pipeline should be installed at all roads and other crossings where possible dredging or ditching might take place.

Airways

The best preventive measure for an air shipment is to be sure that the hazardous material is properly packaged and identified as to the potential hazard so that it will be properly handled by airline employees. This will be achieved if the regulations on hazardous shipments are followed:

NWMAR116642

For shipments within the U.S.

Federal Aviation Regulations, Vol. VI, Part 103

Code of Federal Regulations Transportation, Title 49, Parts 170-189.

CAB 82, Official Air Transport Restricted Article Tariff No. 6-D.

For international shipments all of the above plus;

International Air Transport Association Restricted Articles Regulations.

All applicable foreign law.

SAFETY OR PREVENTION DEVICES

Certain specialized devices can be employed by operating personnel as spill prevention and control measures. These devices can basically be used, 1) to provide early warning or detection of a spill, and 2) to contain the spill at an early stage.

Monitoring/Detection Devices

In large industrial plants or industrial rivers the expense of installing detectors may be justified. Union Carbide has successfully used continuous total carbon analyzers, pH meters, and hydrocarbon vapor analyzers for spill detection at its plants (80). Other devices have been found applicable for detecting pollutants in water (81).

Device	Detection of
Catalytic combustion sensor	Volatile organics
Electrical conductivity sensor	Ionic solutes
pH and specific ion probes	Acids, bases, metallic pollutants
Multicolor transmissometer	Less volatile organics
Colorimeter	Heavy metals

It is simpler and often just as effective to monitor a process characteristic rather than the hazardous chemical itself. Characteristics that might be monitored include flow, temperature, tank level and pressure (6). These devices can serve a warning function only or can be tied in to a control device to automatically control, correct, shut down equipment, or provide safe disposal of the overflow. For example, pumps could be shut down and valves closed to prevent a spill from occurring or becoming worse.

Containment/Control Devices

The objective of these devices is to stop or contain the flow of the spill. Excess flow valves are in-line safety devices that act to limit the flow of liquids or gases out of a pressurized system. They will pass normal

NWMAR116643

rates of flow; however, they will close against excess outward flow rates in the event the pressurized system is opened to the atmosphere due to pipe breakage or because of system misoperation. These devices are used extensively in pressurized liquified gases and in chlorine tank car discharge lines (73).

The automatic sealing imbiber valve is simply a metal cylinder with necked openings at each end and filled with imbiber beads retained by supported porous membranes. Relying upon the void volume which naturally occurs in a bed of packed spheres, the valve passes water freely. However, when contacted by a hazardous fluid, the beads swell rapidly, stopping all flow (82).

Other devices such as dikes, curbs, and container plugs are discussed in other sections of this report. Examples of catchment systems that can be used to prevent spilled materials from contaminating the environment are shown on the following pages.

NWMAR116644

6.1 DEFINE AND ASSESS THE HAZARDS OF MATERIALS HANDLED

6.1.1 Raw Materials

Have *all* raw materials been considered?

Have the potential consequences of use of each raw material been defined?

Has each raw material been identified in a spill rating guide?

Is the inventory control of raw materials adequate?

Is the purchasing or procurement section aware of raw materials quality control effects on possible hazards?

6.1.2 Intermediate Process Compounds

Have all intermediates been identified?

What are the possible consequences of spillages of intermediate compounds?

Have intermediates been considered in the spill rating guide?

Do you have means for detecting and measuring the losses of intermediate materials and compounds?

6.1.3 End Products

Have all end products been considered?

Have the potential consequences of spills of each end product been defined?

Has each end product been identified in a spill rating guide?

Is the inventory control of end products adequate?

6.1.4 By-Products and Waste Products

Have all by-products and waste products been considered?

Have the potential consequences of spills of each by-product and waste products been defined?

Has each by-product and waste product been identified in a spill rating guide?

Is the inventory control of by-products and waste products adequate?

6.1.5 Rating Guide

Has a rating guide been prepared or considered?

Have the frequency, detectability, consequences, and local conditions factors been considered?

Have all raw materials, intermediates, by-products, waste products, and end products been rated?

Who has access to and uses the rating guide?

6.2 ASSESS THE POTENTIAL OF SPILL OCCURRENCE

6.2.1 Receiving and Unloading

Has the "anything that can happen, will" philosophy been applied?

Are the operations controlled and supervised by dependable and knowledgeable personnel?

Are losses monitored?

Are maintenance and preventive maintenance inspections reporting adequate?

6.2.2 Storage and Transfer

Are all materials inventoried and controlled?

Is the best equipment utilized?

Are small spills reported and properly and promptly handled?

Has the probability of a major spill incident been established?

6.2.3 Process Operations

What is the practice of controlling and reporting emergency discharges?

Are process upsets and equipment failures repetitive? If so, why? Are process errors recognized and reported?

Do the operating personnel know and recognize the detrimental effects of spills and accidental discharges?

6.2.4 In-Process Transfer

What are the practices of controlling and reporting emergency discharges?

Are process upsets and equipment failures repetitive? If so, why?

Are process errors recognized and reported?

Do the operating personnel know and recognize the detrimental effects of spills and accidental discharges?

6.2.5 Laboratory and Pilot Operations

Are the potential ill effects of accidental or unusual discharges recognized?

NWMAR116645

Are spill prevention and controls factors applied in planning and design?

Is there adequate consideration of the waste products or hazards influencing feasibility factors in development work?

[illegible] control practiced in laboratory production, pumping, handling, disposal and trial operations?

6.2.6 [illegible] Clean-up

Are procedures developed with spill prevention and control in mind?

Can the unusual be isolated and handled as a special case?

Are personnel aware that the problem can't be flushed down the drain?

Have personnel been alerted to the unusual hazards involved in start-up and shutdown, especially emergency shutdowns?

6.2.7 Maintenance Procedures

Are maintenance personnel aware of spill prevention and control problems?

Do production, technical and waste control personnel coordinate with maintenance?

6.2.8 Auxiliary and Support Operations

Do these other departments recognize their involvement in spill prevention and control?

Does overtaxing support equipment and operations present spill problems?

6.3 EVALUATE INFLUENCING PHYSICAL FACTORS

6.3.1 Plant Site

Are physical factors such as terrain and proximity to receiving water considerations in planning, prevention, and control of spills?

Do the backup, stoppage, and overflow of waste waters affect the overall programs for spills control?

Are dikes and other containment devices influenced by physical factors of slope, runoff, flooding, soil conditions, etc.?

Is the property underlain by shallow ground waters which would be subject to pollution via percolation of spills through the soil?

6.3.2 Machinery and Equipment

Are the existing plant machinery and equipment significant factors in spill prevention?

Is related auxiliary and support equipment properly maintained?

Does spill prevention and control equipment receive adequate inspection and preventive maintenance?

6.3.3 Buildings and Structures, Yard and Grounds

What is the influence of buildings and other structures in the prevention and control of spills?

Are roof deposits potential spill hazards?

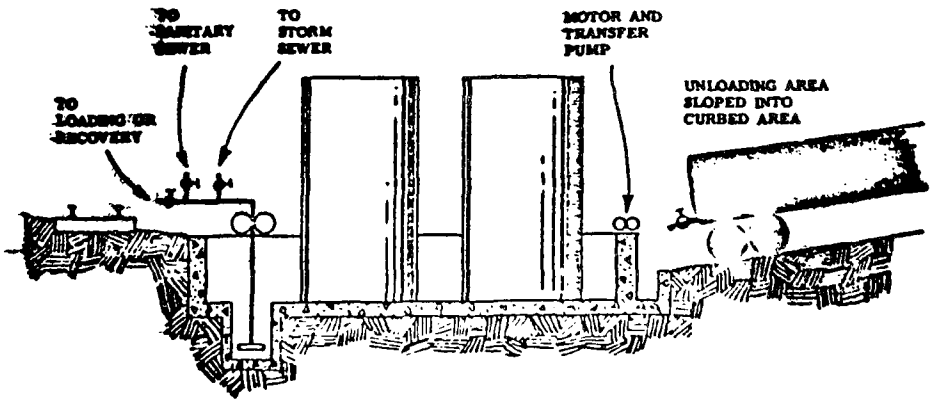
Are ground deposits potential spill hazards?

6.3.4 Operating Areas

Are spilled materials handled promptly and properly?

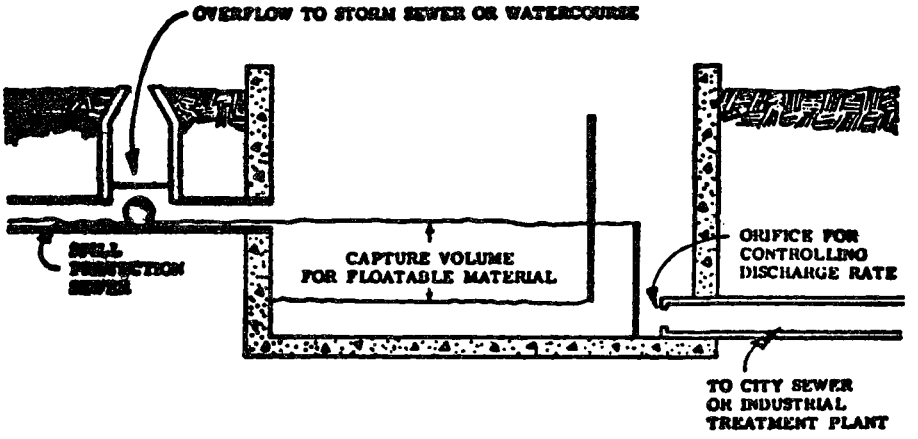
Do accumulations of small spills present a problem?

Can maintenance be performed without bypassing safety devices and procedures?



Containment curb-type spill catchment system, depressed area form.

NWMAR116646



Catchment basin system of flow-through type, with orifice-controlled discharge rate.

6.3.5 Sewerage Systems

Are sewers segregated or combined?

Can spills be diverted to minimize effects?

Is the plant sewerage system maintained properly?

Are blockages and back-up flooding a problem?

6.3.6 Storm Water Runoff and Collection

Has the effect of storm water been considered?

Can storm water be diverted away from spill areas?

Are roofs, buildings and ground a source of "Act of God" spill effects?

Are storm water effluents measured, sampled and evaluated?

6.3.7 Utilities and Utilities Transmission

Do spill prevention and control devices have adequate uninterrupted power?

What is the effect of power interruption on alarms, control systems, pumping, etc.?

Do the power plant and water treatment plant contribute to potential for spills?

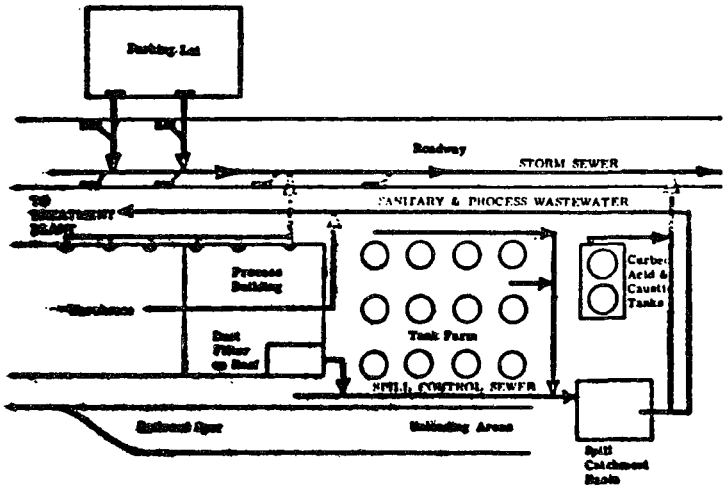
6.3.8 Potential of Natural Disasters

Has the probability of natural disasters been determined or considered?

What areas could be affected by natural disasters?

Can waste treatment ponds be influenced?

Is sewerage back-up a problem?



Basin-type spill catchment system.

NWMAR116647

REFERENCES

1. U.S. Congress. Federal Water Pollution Control Act as amended. Public law 92-500, 92nd Congress, S.2770. Washington D.C., Oct. 18, 1972. p. 89

2. Federal Highway Administration, Bureau of Motor Carrier Safety. Truck Placarding Chart.

3. Code of Federal Regulations, Title 49, Parts 170-179, Subchapter A paragraph 174.589. Hazardous Materials Regulations Board.

4. Code of Federal Regulations. Title 14, CFR, Part 103, Sec. 103.3.

5. U.S. EPA Field Detection and Damage Assessment Manual for Oil and Hazardous Materials Spills. EPA Contract No. 68-01-0113. June 1972.

6. Department of Transportation and U.S. Coast Guard. Hazard Assessment Handbook. CG - 446-3. Jan. 1974.

7. Marks, L.S. Mechanical Engineers Handbook, Fourth Ed. NY, McGraw-Hill Book Co., NY, 1941, p. 278.

8. Department of Transportation and U.S. Coast Guard. A Condensed Guide to Chemical Hazards. Chris CG-446-1 Jan. 1974.

9. Cargo Information Cards, (Chemcards), Manufacturing Chemists Association, 1825 Connecticut Ave, N.W., Washington D.C. 20009.

10. USEPA Oil and Hazardous Materials Technical Data Assistance System, Division of Oil and Hazardous Materials, Office of Water Programs, EPA.

11. Perry, R.H. and Chilton, C.H., Chemical Engineers Handbook. McGraw Hill Book Company. NY 1973. p. 7-32 - 7-33, 6-90 - 6-91.

12. Dawson, G.W., Shuckrow, A.J. and Swift, N.H. Control of Spillage of Hazardous Polluting Substances. Federal Water Quality Administration Report No. 15090 FOZ. November 1970.

13. Wilder, I. and Brugger, J.E., "Present and Future Technology Requirements for the Containment of Hazardous Material Spills", Proc. of the 1972 National Conference on Control of Hazardous Materials Spills, p. 77-83.

14. Pontius, P.W., "Containment and Disposal of Product from Leaking Drums in Transit", Proc. of the 1974 National Conference on Control of Hazardous Material Spills, Aug. 1974, p. 217-218.

NWMAR116648

15. Friel, J.V., Hiltz, R.H. and Marshall, M.D., "Control of Hazardous Chemical Spills by Physical Barriers", Environmental Protection Agency, Edison, EPA-RZ-73-185, March 1973, p. 91.

16. Hiltz, R.H., "A Physical Barrier System for Control of Hazardous Material Spills in Waterways", Proceedings of the 1972 National Conference on Control of Hazardous Material Spills, March 1972, p. 85-92.

17. Johanson, E.E., Bowen, S.P., "Recovery and Processing of Hazardous Spills in Water", Proc. of the 1974 National Conference on Control of Hazardous Material Spills, Aug. 1974, p. 188-193.

18. Proposed EPA Regulations on Designation of Hazardous Substances, Section 311, P.L. 92-500, 40FR 59960 Dec. 30, 1975.

19. Ottinger, R.S., Blumenthal, J.L., Dal Portou, D.F., Gruber, G.I., Santy, M.J., and Shih, C.C., "Recommended Methods of Reduction Neutralization, Recovery and Disposal of Hazardous Waste", Environmental Protection Agency, EPA-670/2-73-053a, Aug. 1973.

20. Patterson, J.W., and Minear, R.A., "Wastewater Treatment Technology", 2nd Ed., January 1973, p. 361.

21. Ludzach, F.J. and Ettinger, M.B., "Chemical Structures Resistant to Aerobic Chemical Stabilization", Jour. WPCF, Vol. 32, No. 11, Nov. 1960, p. 1173-1200.

22. Personal Communication to Environmental Sciences Division from R.C. Smith, Wetco Chemical Corp., New York, NY, July 31, 1972.

23. Roberts, J.D. and Caserio, M.D., Basic Principles of Organic Chemistry, W.A. Benjamin, Inc., New York, 1965, p. 1315.

24. Curry, N.A., "Philosophy and Methodology of Metallic Waste Treatment", Proceedings of the 27th Industrial Waste Conference, Purdue University, May 1972, p. 85-94.

25. Betz Handbook of Industrial Water Conditioning, Betz Laboratories, 6th Edition, 1962, p. 427.

26. Lange, N.A., Handbook of Chemistry, McGraw Hill Book Company, New York, NY, 1967, p. 2001.

27. Marion, C.V., Malaney, G.W., "Ability of Activated Sludge Micro-Organisms to Oxidize Aromatic Organic Compounds", Proceedings of the 18th Industrial Waste Conference, Purdue Univ. 1963, No. 115, p. 2.

NWMAR116649

28. Manufacturing Chemists Association Laboratory Disposal Manual, Washington D.C., July 1974, 176 p.

29. Chemical Hazards Response Information System, Hazardous Chemical Handbook, Department of Transportaion, CG 446-2, Jan. 1974.

30. Preston, S.T., A Guide to the Analysis of Pesticides by Gas Chromotography, Polyscience Corporation, 2nd Edition, 1969. p. B-1 to B-54.

31. Pilie, R.J., et al., "Methods to Treat Control and Monitor Spilled Hazardous Materials", Environmental Protection Agency, EPA-670/2-75-042, p. 137.

32. Lindstedt, K.D., Houch, C.P., and O'Connor, J.T., "Trace Elements Removals in Advanced Wastewater Treatment Process", Journal WPCF, 43:1507-1513, July 1971.

33. Personal communications to J. Moser, Envirex from A. Jennings, US EPA.

34. Stahl, Q.R.,"Air Pollution Aspects of Chlorine Gas", Technical Report Litton Systems Inc., Bethesda, MD, PB-118-08, Sept. 1969.

35. Personal communication to Rhodia Inc., Chipman Div., Portland, Oregon, C. Shih, TRW, to R. Gitschlag, 5/25/72.

36. Personal communication to Diamond Shamrock Chemical Co., Cleveland, Ohio, C. Shih, TRW, to G. Lawrence, 5/26/72.

37. Leigh, G.M., "Degradation of Selected Hydrocarbon Insecticides", Journal WPCF, 41,(2), R 450-46-, Nov. 1969.

38. Young, R.A., Cheremisinoff, P.N., and Feller, S.M., "Tertiary Treatment: Advanced Wastewater Techniques", Pollution Engineering, April 1974, p. 26-34.

39. Kunz, R.G., Giannelli, J.F., and Stensel, H.D., "Vanadium Removal from Industrial Wastewater", 30th Annual Purdue Industrial Waste Conference, May 1975.

40. The Western Company, "Gelling Crude Oils to Reduce Marine Pollution from Tanker Oil Spills", WQO Environmental Protection Agency, 15080 DJNL/71 , p. 138.

41. Chemical Hazards Response Information System, Response Methods Handbook, Department of Transportation, C6-446-4, Jan. 1975.

42. Hammer and Nicholson, S.G., "A Survey of Personnel Protective Equipment and Respiratory Apparata for use by Coast Guard Personnel in Response to Discharges of Hazardous Chemicals", U.S.C.G. NTIS-ADA-010-110.

NWMAR116650

43. Bauman, C.R. and J.L. Cleasby. Design of Filters for Advanced Wastewater Treatment. Presented at Technology Transger Design Seminar. Seattle, Washington. Oct. 31 and Nov. 1, 1973, p. 42.

44. Cleasby, J.L. Backwash of Granular Filters Used in Wastewater Filtration. Office of Research and Monitoring. U.S. EPA. Project Number R802140. Sept. 1973, p. 34.

45. Culp, R.L. and G.L. Culp. Advanced Wastewater Treatment. Van Nostrand Reinhold Company, New York. 1971, p. 310

46. U.S. EPA Process Design Manual for Carbon Adsorption. Technology Transfer. Oct. 1973, p 3-1 - 3-70.

47. Darco Activated Carbons. Evaluation of Granular Carbon for Chemical Process Applications. ICI American Inc. 1971.

48. Eckenfelder, W.W. and D.L. Ford. Water Pollution Control - Experimental Procedures for Process Design. Pemberton Press, New Yourk. 1970, p. 269.

49. Rohm and Haas Company. Technical Bulletin Ion Exchange Department. Amberlite IR 120 Plus and IRC 84. Sept. 1969.

50. Clark, J.W. and W. Viessman, Jr. Water Supply and Pollution Control. International Textbook Company. Scranton, Pa. 1970, p. 274-275.

51. Parson, William A. Chemical Treatment of Sewage and Industrial Waste. National Lime Association. Washington, D.C., 1968. p. 139.

52. Rushton, J.H. and J.Y. Oldshue. Mixing - Present Theory and Practice. 49:4. p. 161-168.

53. ASCE, AWWA and CSSE, Water Treatment Plant Design. AWWA. New York, 1969, p. 351.

54. ASCE and WPCF, Sewage Treatment Plant Design, WPCF. 1959. p. 371.

55. Parker, H.W., Wastewater System Engineering. Prentice Hall. New York.

56. Fair, G.M., Geyer, J.C. and D.A. Okum, Water and Wastewater Engineering. John Wiley and Sons. New York, 24-1 - 18.

57. Hydraulic Institute Pipe Fiction Journal. Hydraulic Institute, 1961, Third edition.

59. Corrugated Steel Pipe Handbook.

60. American Concrete Pipe Association. Concrete Pipe Design Manual. American Concrete Pipe Association. 1970, p. 381.

NWMAR116651

61. Peuritoy, R.L., Construction Planning, Equipment and Methods, McGraw Hill Book Company, Mew York. 1970, p. 696.

62. Glickman, M. and A. Hein. Chemical Engineering Deskbook, April 14, 1969, p. 131-146.

63. Fontana, M.G. and N.D. Greene, Corrosion Engineering, McGraw Hill Book Company. New York, 1967, p. 391.

64. Guide to Corrosion Resistance, Climax Molybdenium Co., New York, NY.

65. Lauch, R. P., Application and Procurement of Automatic Wastewater Samples, U.S. EPA National Environmental Research Center, Cincinnati, Ohio, EPA-670/4-75-003, Methods Development and Quality Assurance Research Lab., April 1975, p. 24.

66. ASTM, Water Pollution Assessment: Automatic Sampling and Measurement, ASTM, Philadelphia, PA, Publication Code No. 04-582000-16, August 1975, p. 126.

67. Moser, J. H., and Huibregtse, K. R., Development of Guidelines for Sampling and Sample Preservation of Water and Wastewater, Envirex, Inc., Milwaukee, WI. In press. EPA NERC - Cincinnati, Methods Development and Quality Assurance Research Lab, p. 488.

68. Bess, F. D., "Operational and Management Considerations for the Prevention of Hazardous Material spills in Process Plants", "Control of Hazardous Material Spills, Proceedings" 1972, p. 25.

69. "Guidelines for Chemical Plants in the Prevention, Control and Reporting of Spills", Manufacturing Chemists Assn., Inc., 1972.

70. Goodier, J. L., "Spill Prevention Techniques for Hazardous Polluting Substances", EPA Report No. 15080, 2/71, p. 9-10.

71. Corley, J. W., "Process Plant design for Control of Hazardous Material Spills", Control of Hazardous Material Spills, Proceedings, 1974, p. 15.

72. Cox, J. B., "The Spill Prevention, Containment and Countermeasure (SPCC) Plan of the Refuse Act Permit Program", Control of Hazardous Material Spills, Proceedings, 1972, p. 27.

73. Kern, J. L., "Control Systems for Prevention of Hazardous Material Spills in Process Plants", Control of Hazardous Material Spills, Proceedings, 1972, p. 19-23.

NWMAR116652

74. U.S. DOT Office of the Secretary, Operations Division, Office of Hazardous Materials, Guide for Shippers of Hazardous Materials, (Revised February 1971).

75. U.S. DOT Office of the Secretary, Operations Division, Office of Hazardous Materials, Guide for Carriers of Hazardous Materials, (Revised February 1971).

76. Wood, W. S., "Transporting, Loading and Unloading Hazardous Materials", Chem. Eng. 80 (15): 72-94 (June 25, 1973).

77. Code of Federal Regulations, Title 49, Parts 170-179, Subchapter A, Paragraph 174.589, Hazardous Materials Regulations Board.

78. Musser, T. W., "The Ocean Disposal Permit Program and Spill Prevention", *Control of Hazardous Material Spills, Proceedings*, 1974, p. 99-101.

79. Pipe Line News Annual Automation Symposium, Pipe Line News, 43 (11): 4, 11-21, 24-25, (October 1971).

80. A Pipeline Failure Warning System, Chem. Process Eng. (London), 52 (9): 72 (September 1971).

81. Carlson, L. E., Erdmann, J. F., and Hanks, G. J. Jr., "How One Chemical Company Is Attacking the Spill Problem", Control of Hazardous Material Spills, Proceedings, 1974, p. 106-118.

82. Bock, D. H. and Sullivan, P. F., "Methods for the Detection and Marking of Spilled Hazardous Material", Control of Hazardous Material Spills, Proceedings, 1972, p. 119-127.

83. Hall, R. H. and Haigh, D. H., "Automatic Sealing Imbiber Valves", Control of Hazardous Material Spills, Proceedings, 1974, p. 127-129.

NWMAR116653

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-77-227		

4. TITLE AND SUBTITLE
MANUAL FOR THE CONTROL OF HAZARDOUS MATERIAL SPILLS
Volume One - Spill Assessment and Water Treatment Techniques

5. REPORT DATE
November 1977 issuing date

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
K. R. Huibregtse; R. C. Scholz; R. E. Wullschleger; J. H. Moser; E. R. Bollinger; C. A. Hansen

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Envirex Inc., A Rexnord Company
Environmental Sciences Division
5103 W. Beloit Road
Milwaukee, Wisconsin 53214

10. PROGRAM ELEMENT NO.
1BB610

11. CONTRACT/GRANT NO.
Contract No. 68-03-2214

12. SPONSORING AGENCY NAME AND ADDRESS
Industrial Environmental Research Lab. - Cin., OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final 6/1/75 - 6/30/77

14. SPONSORING AGENCY CODE
EPA/600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

A manual for control of hazardous material spills using improvised treatment systems was developed under this contract. Spill control techniques have been emphasized, although a brief overview of spill prevention methodology is included. The main body of the manual has been subdivided into eight chapters. The following topics are covered: 1) notification, 2) an inventory of information sources, 3) identification and assessment of human danger potentials, 4) determination of the best handling method, including a thought guide question approach to specific spill incidents and suggested treatment schemes for 303 hazardous chemicals, 5) safety considerations and a limiting factor process design, 6) construction and operation of five improvised treatment processes (filtration, carbon adsorption, ion exchange, gravity separation and chemical reaction), 7) process components and treatment chemicals and 8) standard sampling and record keeping procedures.

It is stressed that previous familiarization with the contents is necessary for its effective use and that the improvised systems should be used only when other equipment is unavailable. Suggested treatment schemes and procedures have not been field tested, so extreme care must be taken to follow all safety precautions. The report is submitted in fulfillment of contract 68-03-2214 by Envirex Inc. and covers the period June, 1975 to June, 1977.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
hazardous materials; water tanks; contaminants; waste treatment; chemical removal (water treatment); filtration, ion exchanging, adsorption, clarification	Notification procedures, chemical identification human danger assessment information sources treatability decision	13B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	unclassified	487
	20. SECURITY CLASS *(This page)* unclassified	22. PRICE

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1978-757-140/6622 Region No. 5-11

NWMAR116654

EPA-600/2-78-005
January 1978

Environmental Protection Technology Series

OIL SPILL AND OIL POLLUTION REPORTS: August 1977 - October 1977

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

NWMAR116655

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

NWMAR116656

EPA-600/2-78-005
January 1978

OIL SPILL AND OIL POLLUTION REPORTS

August 1977 - October 1977

by

Penelope Melvin, Helmut Ehrenspeck, and Elizabeth Sorenson
Marine Science Institute
University of California
Santa Barbara, California 93106

Grant No. R805052-01

Project Officer

L. T. McCarthy, Jr.
Oil & Hazardous Materials Spills Branch
Industrial Environmental Research Laboratory-Cincinnati
Edison, New Jersey 08817

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

NWMAR116657

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory-Cincinnati, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ENVIRONMENTAL PROTECTION AGENCY

NWMAR116658

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report is a product of the above efforts. It cites current events, literature, research, patents, and other material relevant to the oil pollution abatement program and is published in an abstract format on a quarterly basis. As such, it serves as a basic reference document for all those interested in oil spill and oil pollution control. This project is part of the continuing program of the Oil and Hazardous Materials Spills Branch, IERL-Ci, to assess and mitigate the environmental impact of oil pollution.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

NWMAR116659

A B S T R A C T

OIL SPILL AND OIL POLLUTION REPORTS is a quarterly bulletin designed to review current scientific and technical publications and research projects in the field of oil pollution. Subject coverage includes aquatic and terrestrial oil pollution with emphasis on the marine environment. This issue contains summaries of research projects and published information selected from the scientific and technical literature during the period August, 1977 through October, 1977.

The following sections are included in the report:

I. Reports, Publications, and Patents

II. Current Research Projects

III. Current Oil-Related Conferences

The report is submitted in partial fulfillment of EPA Grant No. R805052-01 by the Marine Science Institute, University of California, Santa Barbara, California, under the sponsorship of the Environmental Protection Agency.

NWMAR116660

CONTENTS

Page

Abstract iv

Acknowledgments viii

Introduction ix

Abbreviations - Acronyms x

Sections

I. Reports, Publications, and Patents

A. Oil Pollution Detection and Evaluation

1. Reporting 1

2. Monitoring 12

3. Remote Sensing 19

4. Sampling 23

5. Analysis 25

6. Source Identification 34

B. Oil Pollution Prevention and Control

1. Containment 37

2. Cleanup and Recovery 41

3. Restoration 59

4. Oil Transfer and Transport 60

5. Waste Treatment and Disposal Methods 63

6. Reclamation and Reuse 88

7. Personnel Training and Education 90

8. Contingency Planning 91

9. Prevention and Control Measures 92

NWMAR116661

C. Effects of Oil Pollution — Page

1. Biological Effects . . . . .
2. Physical Effects 129
3. Economic Effects 129
4. General Effects 131

D. Effects of Oil Exploration and Production

1. Biological Effects 138
2. Economic Effects 140
3. General Effects 141

E. Fate of Oil in the Environment

1. Biodegradation 155
2. Physical Changes of Oil 164
3. Chemical Changes of Oil 166
4. General Fate of Oil 167

F. Oil Pollution Regulations

1. U.S. Legislation 175
2. International Legislation 178
3. Foreign Legislation 178
4. Standards and Guidelines 180
5. Agreements and Conventions 181

G. Bibliographies 183

II. Current Research Projects 187

A. Oil Pollution Detection and Evaluation

1. Monitoring 188
2. Sampling 189

NWMAR116662

Page

3. Analysis 189

4. Source Identification 191

B. Oil Pollution Prevention and Control

1. Containment 192

2. Oil Transfer and Transport 192

3. Waste Treatment and Disposal Methods 193

4. Prevention and Control Measures 195

C. Effects of Oil Pollution

1. Biological Effects 196

2. General Effects 201

D. Effects of Oil Exploration and Production

1. General Effects 204

E. Fate of Oil in the Environment

1. Biodegradation 205

2. General Fate of Oil 206

III. Current Conferences 208

Master List of Keywords 224

Subject Index 229

Author Index 271

Appendix: Periodicals Reviewed 277

NWMAR116663

ACKNOWLEDGEMENTS

The authors appreciate the assistance of Mrs. Mary Ankeny and Ms. Kathy Courtney in typing the camera-ready copy of OIL SPILL AND OIL POLLUTION REPORTS. We also wish to thank the personnel of the Science-Engineering Library, University of California, Santa Barbara, for their assistance during the research stages of the project.

NWMAR116664

INTRODUCTION

OIL SPILL AND OIL POLLUTION REPORTS is a quarterly bulletin which reviews pertinent scientific and technical publications and research projects to provide its readers with current developments in the field of oil pollution. This issue contains summaries of articles, reports, patents, documents, and other materials relating to oil pollution published during the period 1975 to 1977 (Section I); summaries and status of current research projects (Section II); and current oil-related conferences (Section III).

Subject coverage includes aquatic and terrestrial oil pollution with emphasis on the marine environment. Items in Section I are categorized by seven major subdivisions which are divided into thirty-two specific subject categories. These are presented in the Table of Contents. Patents and patent applications are announced under appropriate subject categories. Subject and author indexes for entries in Section I are provided at the end of the report. A list of the periodicals reviewed in preparing this series appears in the Appendix.

Section II presents titles of active or recently completed oil pollution research projects, summaries of project objectives, and current status information and/or resulting publications provided upon request by the principal investigators or performing organization. Notices of research projects were obtained from the Smithsonian Science Information Exchange (SSIE). Entries are arranged according to the same subject categories as in Section I and are ordered by serial number within each subject division. Some of the current projects listed in previous Oil Pollution Reports have been recently renewed. These projects have been relisted and headed by the same serial number as originally reported, followed by the word (renewal). Renewal entries are listed at the beginning of each subject category.

Section III, Current Oil-Related Conferences, contains descriptive information on recently held and upcoming conferences relevant to any aspects of oil pollution. Conference dates are listed; and, when information is available, titles, authors, and abstracts of conference papers are included. All information for this section was obtained from the periodicals reviewed (Appendix) and from responses to written inquiries concerning the meetings.

Entries in Section I and II have separate serial numbers. The letters preceding the serial numbers designate the following: C, reports, publications, and patents; and R, research projects.

NWMAR116665

ABBREVIATIONS

atm	atmosphere
bbl	barrel
°C	degrees Centigrade
cm	centimeter
dwt	dead weight ton
EIS	environmental impact statement
°F	degrees Fahrenheit
ft	foot
g	gram
gal	gallon
GLC	gas-liquid chromatography
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
ha	hectare
hr	hour
i.e.	(id est), that is
in	inch
IR	infrared
kg	kilogram
km	kilometers
kn	knot
L	liter
lb	pound
LNG	liquefied natural gas
LOT	load on top
LPG	liquefied petroleum gas
m	meter
mg	milligram
mi	mile
min	minute
ml	milliliter
mm	millimeter
OCS	outer continental shelf
oz	ounce
PAH	polycyclic aromatic hydrocarbon
pH	the negative log of the H ion concentration
ppb	part per billion
ppm	part per million
sp.	species
TLC	thin-layer chromatography
U.S.	United States
USSR	Union of Soviet Socialist Republics
UV	ultraviolet
VLCC	very large crude carrier
wt	weight
yr	year
%	percent
/	per
µ	micron
µg	microgram

ACRONYMS

API	American Petroleum Institute
BLM	Bureau of Land Management
CEQ	Council on Environmental Quality
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
FEA	Federal Energy Administration
IMCO	International Maritime Consultative Organization
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards
NOAA	National Oceanic and Atmospheric Administration
NTIS	National Technical Information Service
UN	United Nations
USCG	United States Coast Guard (DOT)
USGS	United States Geological Survey
USDI	United States Department of Interior
USDA	United States Department of Agriculture
USN	United States Navy

NWMAR116666

SECTION I. REPORTS, PUBLICATIONS, AND PATENTS

A. OIL POLLUTION DETECTION AND EVALUATION

1. REPORTING

C-1634-77
Untitled. (news brief)
Anon. 1977.
Environment 19(5):26-27.

Oil spills, Crude oil, Fate, Ekofisk blowout

The Phillips Petroleum Company's oil well in the North Sea spilled 75,700 L (20,000 gal.) a day of crude oil for 10 days until it was finally capped on May 1, 1977. It was the largest spill to date in the North Sea, comparable to the 1969 Santa Barbara blowout, with a slick estimated to be 48 km (30 mi) wide and 72 km (45 mi) long. Although the slick was expected to be dispersed by weather and wave action, concern centered on long-range effects such as tarballs that may persist for up to 2 years.

C-1635-77
Untitled. (news brief)
Anon. 1977.
Petroleum Engineer International 49(7):1.

Cost analysis, Ekofisk blowout, Offshore drilling, Offshore exploration, Norway

The cost of the April, 1977, Ekofisk blowout has been assessed at over $130,000,000. One future effect of the blowout is the Norwegian government's postponement of drilling north of the 62nd parallel planned for 1978. Norway has also stopped plans for exploration of 16 blocks to be offered to oil companies this year.

C-1636-77
Untitled. (news brief)
Anon. 1977.
Marine Pollution Bulletin 8(7):149-150.

Pollution control, Oil-water separation, Distillation, Oil discharges, USSR

A recent Moscow conference reported two new oil pollution control measures. All Soviet Black Sea ports now have separating equipment to distill and purify oil effluents from visiting ships. Within the next three years, separators will also be installed in Soviet ships for the purification of oil-polluted discharge water and other waste.

NWMAR116667

C-1637-77
Untitled. (news brief)
Anon. 1977.
Marine Pollution Bulletin 8(7):149.

Oil spills, Statistics, Sources, North Sea, UK

There were 595 oil spill incidents around Britain in 1976, increasing the 1975 figure of 500 spillages by nearly 20%. The Advisory Committee on Oil Pollution of the Sea 1976 survey cites leaks and intentional dumping from ships as the main sources of pollution, but also notes a serious increase in the number of spills from North Sea off-shore oil fields.

C-1638-77
Untitled. (news brief)
Anon. 1977.
Marine Pollution Bulletin 8(6):125.

Environmental protection, Contingency planning, Arctic Ocean, Canada

Canada's Environmental Protection Service has begun a five year technology program to develop oil spill countermeasures for arctic waters. Research areas will include blowouts, movement of oil spills in ice-covered waters, biological effects, recovery, containment and disposal equipment, and shoreline cleanup. The ultimate goal is a comprehensive contingency plan.

C-1639-77
Untitled. (news brief)
Anon. 1977.
Marine Pollution Bulletin 8(6):125.

Oil spills, Regulations, Oil transfer, Biological effects, Birds, Scotland

Occidental Oil's new terminal on the island of Flotta off Orkney has issued new loading regulations after the April, 1977, spill there. Accepted operating conditions have been lowered from force 10 winds to force 5. The spill, claimed to be due to equipment failure, contaminated 12 km of Scapa Flow shoreline and killed more than 100 birds.

NWMAR116668

C-1640-77
ARGO MERCHANT DISASTER 'INEVITABLE' (news brief)
Anon. 1977.
Marine Pollution Bulletin 8(6):124.

Argo Merchant spill, Tankers, Liability, Spill cleanup

Alarming facts about the ill-equipped "Argo Merchant" and its negligent command are revealed. The history of its accidents and other mishaps is briefly reviewed. The tanker's owners, Thebes Shipping Company, are attempting to limit their liability for the loss of the ship and to avoid paying compensation for cleanup costs and pollution damage.

C-1641-77
ARGO MERCHANT SPILL DISAPPEARS; SHIP HULL STRENGTHENING URGED. (news brief)
Anon. 1977.
Sea Technology 18(7):26-27.

Argo Merchant spill , Monitoring, Movement, Pollution prevention, Tankers, USGS

In order to improve methods of prediction, USGS scientists have studied the movement of the Argo Merchant spill by use of a buoy dropped into the spill in December, 1976. An MIT professor monitored grounding events of the tanker and has made several suggestions in a recent report for preventing tanker break ups. Also, new methods of oil spill trajectory analysis and their relation to this famous spill were reported at the annual American Geophysical Union meeting.

C-1642-77
BLOWOUT EMERGENCY VESSEL DESIGNED FOR NORTH SEA (news brief)
Anon. 1977.
Offshore 37(8):13.

Pollution control, North Sea, Norway, *Blowouts, *Emergency vessel

Paul "Red" Adair is working with three Norwegians to have this vessel operating by late 1978. He is also setting up a division of his company in Norway to handle oil pollution incidents, and is discussing similar plans with British officials.

NWMAR116669

C-1643-77
BRAVO
Anon. 1977.
Noroil 5(6):25-27.

Ekofisk blowout, Environmental effects, Production, North Sea

The following factors emerged from the Ekofisk Bravo blowout: a combination of luck and calculation limited the effects of the spill; the political and practical experiences of the blowout will be limited in both time and extent; considerable attention will be directed toward development of oil spill equipment; and production from the Bravo platform will start up later and possibly at a lower capacity than anticipated.

[from Petroleum Abstracts 17(34):#237,226. 1977]

C-1644-77
CREW SET TO CAP FALSE RIVER BLOWOUT (news brief)
Anon. 1977.
The Oil and Gas Journal 75(36):20.

Oil wells, Blowouts, Louisiana, *Gas-wells

A Chevron Oil Co. gas-well in the False River field at Point Coupee Parish, Louisiana, blew out August 31, 1977, after high pressure caused failure of the blowout preventers. A crew from the Red Adair Co. was preparing capping operations, and minimal equipment damage was reported at press time.

C-1645-77
DANGER OF OIL POLLUTION - HOW BIG? (news brief)
Anon. 1977.
Ocean Industry 12(4):164.

Oil spills, Norway, Blowouts, *Prediction

A Shell-sponsored analysis was conducted in an attempt to estimate potential danger from blowouts in waters offshore Norway. After computer analysis of 5,000 possible blowouts, it was concluded that only five percent of a spill (largest estimate 100,000 barrels) would reach the coast, and usually only after two or three weeks allowing time for preparations.

NWMAR116670

C-1646-77
'DON'T DISTORT THE FACTS' SAY LIBERIAN SHIPOWNERS
Anon. 1977.
Canadian Shipping and Marine Engineering 48(7):22-23.

Tankers, Oil spills, Safety, Economics, *Liberian registry

Flag-of-convenience shipowners have had adverse publicity centered on them following numerous tanker oil spills off the U.S. eastern coastline and elsewhere. The Liberian Shipping Council disclaims 'misleading reporting' by the media and discusses safety standards, economics, taxes, and employment. Apparently an effort is being made to improve the situation.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10422. 1977]

C-1647-77
EKOFISK OIL SPILL (news brief)
Anon. 1977.
Marine Pollution Bulletin 8(6):123.

Oil spills, Fish, North Sea, Ekofisk blowout

A blow-out on the Phillips Bravo 14 platform in the North Sea Ekofisk field on April 25, 1977, pumped an estimated 20,000 tons of oil into the sea over a period of seven days. Norwegian anti-pollution ships were unequipped to deal with the spill initially due to gale force winds. The slick covered 1500 sq. km, threatening several fish species.

C-1648-77
MARITIME WATERS GENERALLY POLLUTION-FREE (news brief)
Anon. 1977.
Water & Pollution Control 115(3):6.

Tar, Oceans, Distribution, Canada, Atlantic Ocean, Sargasso Sea

A survey by the Bedford Institute of Oceanography, headed by Dr. E. Levy, shows that Canada's Atlantic seaboard is generally free from pollution. However, waters from Massachusetts to the West Indies have a small but widely distributed amount of oil pollution, mostly in the form of persistent tar balls. The Sargasso Sea vortex appears to be the center of floating tar pollution in the North Atlantic.

NWMAR116671

C-1649-77
NEW MARINE INFORMATION SERVICE (news brief)
Anon. 1977.
Marine Pollution Bulletin 8(7):147.

Information systems, Statistics, Pollution control, Offshore development, *Data bank, UK

The Natural Environment Research Council's Institute of Oceanographic Sciences (UK) has set up a Marine Information and Advisory Service to provide data about the marine environment to any organization or private individual. The development of a computerized data bank will include coverage of offshore operations, coastal protection, and pollution control. For further information contact the Publicity Officer, Marine Information and Advisory Service, Institute of Oceanographic Sciences, Wormley, Godalming, Surrey GU8 5UB.

C-1650-77
OIL SPILL POLICY (news brief)
Anon. 1977.
Nature 268(5619):395.

Spill cleanup, Dispersants, UK, *Oil spill policy

The British government has adopted a policy to let oil spills degrade naturally where possible, and to use dispersants only for serious incidents. Plans will be made to deal with spills of 16,000 tons per day offshore, and 1,000 tons per day inshore.

C-1651-77
PUMP STATION MISHAP CLOSES TAPS, TANKERS MILL (news brief)
Anon. 1977.
The Oil and Gas Journal 75(34):60.

Oil spills, Pipelines, Crude oil, Alaska, *Pump station accident

Alyeska Pipeline Service Co. shut down the 1280 km (800 mi) trans-Alaska pipeline again on August 15, 1977, after a sump tank overflowed thirty bbl of crude oil inside a pump station. Head of the Department of Interior's Alaska Pipeline Office, Jack Turner, has cited human error as the cause of the incident.

NWMAR116672

C-1652-77
RED ADAIR COMPANY TO OPEN BRANCH TO OPERATE IN NORWAY (news brief)
Anon. 1977.
Sea Technology 18(7):26.

Blowout prevention, North Sea, Norway, *Red Adair Co.

The Red Adair Company, Norway, is expected to begin operating a security and prevention station for the North Sea in 1978. Adair will be working in cooperation with three Norwegian companies and will concentrate on the Statfjord Field where high rise Condeep fixed rigs present special difficulties in blowout prevention.

C-1653-77
TAPS GOES BACK ON STREAM, PUMP STATION GEAR SALVAGED (news brief)
Anon. 1977.
The Oil and Gas Journal 75(36):44.

Oil spills, Crude oil, Pipelines, Alaska, *Pump station accident

The latest Alaska pipeline shutdown occurred from August 15 to August 20, 1977, due to a sump tank overflow at Pump Station 9. As a result, Alyeska is following a recommendation to use separate sumps for the pumps and the turbine lube-oil system. Pump Station 8, destroyed in a July explosion, is being rebuilt and equipment repaired.

C-1654-77
ECOFIASCO (editoral)
Bourne, W. R. P. 1977.
Marine Pollution Bulletin 8(6):121-122.

Oil spills, Ekofisk blowout, Spill cleanup, Pollution control, North Sea

The author compiles facts about the April, 1977, Ekofisk blowout on the Phillips Bravo 14 platform in the North Sea. Attention is drawn to a series of apparent mistakes made prior to and during the blowout, and cost estimates for well-capping and cleanup operations are indicated. Questions are raised as to the management of the platform, corrosiveness and physical characteristics of Ekofisk oil, oil toxicity and use of dispersants, and pollution control measures.

NWMAR116673

C-1655-77
NORTH SEA OIL POLLUTION IN SCAPA FLOW (news brief)
Bourne, W. R. P. 1977.
Marine Pollution Bulletin 8(6):123.

Oil spills, Oil transfer, Tankers, Environmental protection, Surveillance, North Sea

The author reviews a March, 1977, oil spill from the tanker "Nacella" which was loading oil from an Occidental terminal at Flotta in Orkney. Two equipment failures, involving the mooring chain and the single point mooring, were responsible for the spill during bad weather conditions which were claimed to be accepted operating conditions. The incident draws attention to the difficulties found in loading vessels in uncertain weather, the inefficiency of booms, and the limited environmental surveillance covering the North Sea.

C-1656-77
THE URQUIOLA OIL SPILL, LA CORUÑA, SPAIN: CASE HISTORY AND DISCUSSION OF METHODS OF CONTROL AND CLEAN-UP.
Gundlach, E. R., and M. O. Hayes. 1977.
Marine Pollution Pollution Bulletin 8(6):132-136.

Urquiola spill, Fate, Pollution control, Spill cleanup, Coasts, Spain

Details are given of the "Urquiola" oil spill of May, 1976, which spilled 100,000 tons of Persian Gulf crude oil. Most of the oil burned, but nearly one third washed ashore on 215 km of coastline. Over 2000 tons of dispersants were used, but oil control and clean-up operations were generally ineffective, largely due to lack of an oil spill contingency plan.

C-1657-77
OIL SPILLS IN THE ALASKAN COASTAL ZONE, THE STATISTICAL FUTURE
Harrald, J. R., B. D. Boyd, and C. C. Bates. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p.1-7. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Oil spills, Oceans, Statistics, Coasts, Alaska

This paper reviews the statistical studies published in recent years regarding the global influx of petroleum hydrocarbons into the oceans in order to inform workers in the field of oil pollution of what these statistical budgets do and do not provide.

NWMAR116674

C-1658-77
INTERNATIONAL ACTION FOLLOWING THE EKOFISK BLOWOUT (news brief)
Hudson, M. 1977.
Marine Pollution Bulletin 8(6):123-124.

Ekofisk blowout, Environmental protection, Wildlife, North Sea

The British Nature Conservancy Council immediately reviewed contingency plans to protect wildlife following the Ekofisk oil spill. Scientists from England, Norway, and Denmark met to assess consequences, and future meetings are planned for all countries with North Sea coasts.

C-1659-77
JERSEY TO TAX OIL COMPANIES FOR FUTURE CLEANUPS
Janson, D. 1977.
New York Times Jan 7:B2.

Legislation, New Jersey, Spill cleanup, Compensation, Oil industry, *Spill fund

Governor Byrne of New Jersey went to the site of the "Olympic Games" tanker spill in the Delaware River to sign the most comprehensive state legislation in the U.S. regarding spill cleanup and damage compensation. The new law will assess a 1¢/bbl tax for oil brought into the state in order to create a $25 million spill cleanup and compensation fund.

[from Environment Abstracts 7(4):#77-02762. 1977]

C-1660-77
LIBERIAN REGISTERED TANKER SPILLS OIL INTO DELAWARE RIVER - CONSERVATIONISTS SEEK TO CLEAN UP
Janson, D. 1977.
New York Times Jan 5:9.

Tankers, Olympic Games spill, Birds, Spill cleanup, Delaware, *Delaware River

After the tanker,"Olympic Games", ran aground in the Delaware River and spilled 507,000 L (134,000 gal) of oil, volunteers and specialists attempted to save oiled ducks and geese and protect some 60,000 water fowl threatened by 40 km (25 mi) of oil slicks. Indictment of the ship's captain and a lawsuit against the ship's owner were being sought.

[from Environment Abstracts 7(4):#77-02761. 1977.]

NWMAR116675

C-1661-77
FLAG OF CONVENIENCE OIL TANKERS MAGNIFYING CONCERN ABOUT SPILLS
Kifner, J. 1977.
New York Times Feb. 13:1.

Tankers, Oil spills, *Liberian registry, *Flags of convenience

Recent tanker accidents have aroused national concern over oil pollution and its relation to ships flying flags of convenience. Liberia is at the center of this concern, as Liberian registry offers relatively restriction-free and profitable operation and seems to allow dangerously unsafe ships and their crews to ply the seas and pollute the shores.

[from Environment Abstracts 7(5/6):#77-03182. 1977]

C-1662-77
TANKER LOSSES SET RECORD IN '76 PERIOD (news brief)
Kifner, J. 1977.
New York Times Jan. 10:1.

Oil spills, Tankers, Oceans, Statistics, Tanker accidents

Records for oil tanker losses and the amount of oil spilled were set in the first nine months of 1976 - well before the wreck of the "Argo Merchant" and the following rash of tanker mishaps. Thirteen tankers were declared a total loss, and nearly 200,000 tons of oil were spilled into the world's oceans during that period.

[from Environment Abstracts 7(4):#77-02475. 1977.]

C-1663-77
SPILLAGES FROM OIL INDUSTRY CROSS COUNTRY PIPELINES IN WESTERN EUROPE. STATISTICAL SUMMARY OF REPORTED INCIDENTS, 1975.
King, E. M., and P. Rogier. 1976.
Stichting CONCAWE Report 7. 13p.

Oil spills, Oil transport, Pipelines, Spill cleanup, Europe, *Cross country pipelines

In 1975, cross country pipeline systems in Europe totalled 17,900 km in length, had a combined throughput of 483 million m^3 of petroleum products, and had 20 reported spill incidents, with a total loss of under 400 m^3. The spillage amounted to 0.00008% of the total volume transported. None of the spills took more than one month to clean up, and no known instances of contamination of potable water resources resulted.

[from Environmental Health and Pollution Control 11(9). 1977.]

NWMAR116676

C-1664-77
EDITORIAL - THE 1977 OIL SPILL CONFERENCE
Kleinman, B. 1977.
Ecolibrium 6(3):1.

Oil spills, Fate, Environmental effects, Spill cleanup, Monitoring, Behavior, *1977 Oil Spill Conference

The 1977 Oil Spill Conference which was held in March, 1977, in New Orleans,was the fifth conference on oil spills sponsored jointly by government and industry. In the first conference in 1969, 41 technical papers were presented; in this most recent meeting, 123 technical papers provided the latest information on the behavior of oil under different environmental conditions, on the known environmental effects of spills, and on procedures useful in preventing, controlling, monitoring, and cleaning up a spill.

C-1665-77
NORTH SEA BLOWOUT TAMED QUICKLY
LeBlanc, L. 1977.
Offshore 37(6):32-33.

Ekofisk blowout, North Sea, Pollution control

The eight day blowout of Phillips Petroleum Company's Bravo platform in the Ekofisk field in late April, 1977, is reviewed, and the successful capping of the well by the Red Adair team of specialists is described in detail. The spill comprised 178,000 bbl of oil, at one point forming a slick approximately 70 km (45 mi) long by approximately 50 km (30 mi) wide.

C-1666-77
Untitled (news brief)
Thompson, G. B. 1977.
Marine Pollution Bulletin 8(6):125.

Dispersants, Fish, Toxicity, Tropical regions, Japan, *Warren Springs Laboratory, *Hong Kong

On January 1, 1978, the Hong Kong Agriculture and Fisheries Department will introduce controls on the use of oil dispersants due to their adverse effects on fish. Toxicity testing is being done and it appears that toxicity classifications determined at the Warren Springs Laboratory (UK) may not be applicable under tropical or sub-tropical conditions.

NWMAR116677

2. MONITORING

C-1667-77
Untitled. (book review)
Anon. 1977.
Chemical Engineering 84(17):15.

Monitoring, Contaminants, Analytical techniques, Sampling

A brief review of E. D. Goldberg's Strategies for Marine Pollution Monitoring (New York, John Wiley & Sons,1976. 310p) is presented. This book was fostered by a U.S. National Oceanic and Atmospheric Administration workshop, and reviews recent analytical techniques for organic and inorganic substances. Sampling methods and pollutant transport are also included.

C-1668-77
Untitled. (news brief)
Anon. 1977.
Marine Technology Society Journal 11(1):53.

Monitoring, Argo Merchant spill, Chesapeake Bay

Marine Technology Society and American Society of Naval Engineers members attended a recent seminar on oil spills (University of Connecticut at Avery Point, February, 1977). A panel of USCG and EPA scientists observed that virtually none of the Argo Merchant oil spill had sunk below the water's surface. The oil was dispersed, and one slick was sighted 880 km (550 mi) due east of Chesapeake Bay.

C-1669-77
ELECTRICALLY DRIVEN FOAM/WATER MONITOR (product information)
Anon. 1977.
Offshore Engineer 5:98.

Monitoring, Design and engineering, Pollution control

This new remote-controlled monitor, offered by Svenska Skumslacknings, was designed for marine needs and the suppression of oil fires at docks and platforms. There is a choice of voltage and dc or ac for the motors. The circle of movement is 170° and elevation limits are -45° to +85°.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10454. 1977]

NWMAR116678

C-1670-77
OIL CONTENT MONITOR (product information)
Anon. 1977.
Journal Water Pollution Control Federation 49(7):474a.

Monitoring, Chemical analysis, Oil spills, Waste oil, *IR absorption

Sahkoliikkeiden Oy, a Finnish manufacturer, has designed an oil content analyzing and monitoring system that will report waste spills immediately with direct measurement from the water. The IR absorption technique used is unique in that it does not need recalibration at less than ± 10% accuracy. Contact: Trade Commissioner, Consulate of Finland, One IBM Plaza, Chicago, Ill 60611.

C-1671-77
INPUT OF LOW-MOLECULAR-WEIGHT HYDROCARBONS FROM PETROLEUM OPERATIONS INTO THE GULF OF MEXICO
Brooks, J. M., B. B. Bernard, and W. M. Sackett. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p.373-384. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Monitoring, Hydrocarbons, Sources, Platforms, Gulf of Mexico, *Gas venting, *Brine discharge

Dissolved C_1 to C_4 hydrocarbon patterns measured during the last 6 years in the Gulf of Mexico indicate that underwater venting of waste gases and brine discharges, both associated with offshore platforms, are the major sources of non-methane light hydrocarbons to upper Gulf coastal waters. Although these compounds are apparently not toxic to marine organisms, they are proving to be highly sensitive indicators of the most toxic components of petroleum which are entering the sea from man's activities.

C-1672-77
DISTRIBUTION OF PETROLEUM HYDROCARBONS IN WESTERNPORT BAY (AUSTRALIA): RESULTS OF CHRONIC LOW LEVEL INPUTS
Burns, K. A., and J. L. Smith. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p.442-453. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Monitoring, Hydrocarbons, Sources, Distribution, Chronic effects, Australia, *Mytilus edulis, *Indicator species

The mussel, Mytilus edulis, was the major indicator species used to establish problem areas and probable sources of petroleum

NWMAR116679

input. Two major sources of pollution were identified: refinery and other industrial outfalls, and boating activities. Pollution levels varied from no detectable petroleum hydrocarbons to amounts close to saturation levels of body lipids in mussels (29 mg/g lipid). This discussion includes means of relating amounts found in indicator species to level of input and implications on the toxicity to various components of the ecosystem.

C-1673-77
FATE AND EFFECTS OF CRUDE OIL SPILLED ON PERMAFROST TERRAIN. FIRST YEAR PROGRESS REPORT
Collins, C., F. Deneke, T. Jenkins, L. Johnson, and T. McFadden. 1976.
Cold Regions Research and Engineering Laboratory, report CRREL-SR-76-15. 11p.

Monitoring, Fate, Crude oil, Movement, Biological effects, Microorganisms, Chemical effects, Alaska, *Permafrost terrain

This study is concerned with the long-term effects and ultimate fate of crude oil spilled on permafrost-underlain tundra. Two experimental oil spills of 7570 L (2,000 gal) each on 1295 km^2 (500 sq mi) test plots near Fairbanks, Alaska were designed for the project. This report concerns the first one, a winter spill in February 1976; the second spill is planned for the peak growing season in the summer. Monitoring techniques will cover oil movement, temperature regime, biological effects, microbiological changes, permafrost impact, and chemical degradation of the oil.

[from ERDA Energy Research Abstracts 2(15):#37008. 1977]

C-1674-77
DEVELOPMENT OF BUOY MOUNTED HYDROCARBON VAPOR SENSORS FOR USE IN LOCAL AREA POLLUTION SURVEILLANCE SYSTEMS
Goodson, L. H., W. B. Jacobs, S. Dick, and E. T. Fago, Jr. 1976.
Final report, USCG-D-127-76; Contract DOT-CG-34320-A. 50p.

Monitoring, Oil spills, Detection, Design and engineering, *Buoys, *Gas sensors

A low cost system for the rapid detection of small amounts of spilled oil uses two Taguchi Gas Sensors (semiconductor, stannic oxide on a support), one of which responds to oil vapors and engine exhaust. The other sensor is protected by a semipermeable membrane which has little or no effect on the sensor's response to carbon monoxide yet is able to retard its response to hydrocarbon vapors. An alarm is signalled when the uncovered sensor responds and the covered sensor does not.

[from Government Reports Announcements 77(11):#AD-A037 237/5GA. 1977]

NWMAR116680

C-1675-77
ULTRASONIC POLLUTION MONITOR
Houlihan, T. M., and F. K. McGrath. 1976.
Environmental Technology '76, Philadelphia. 1976. p.487-480.

Monitoring, Pollution control, Oil-water separation, Ships, *Ultrasonic monitor

An ultrasonic oil/water separation and monitoring system has been developed and tested and will be applied toward controlling pollution from naval vessels. The ultrasonic monitor has been found to be effective and to have the necessary degree of sensitivity.

[from Environment Abstracts 7(4):#77-02465. 1977]

C-1676-77
ENERGY-RELATED MARINE DATA MANAGEMENT IN THE PACIFIC NORTHWEST
Hughes, P. 1977.
Environmental Data Service. p.4-11.

Monitoring, Baseline studies, Environmental effects, Offshore development, OCS, Information systems, NOAA, BLM, Alaska Coast

Environmental baselines are being established in the Alaskan Outer Continental Shelf Environment Assessment Program (OCSEAP), run by NOAA's Environmental Research Laboratories and funded by the Department of the Interior's Bureau of Land Management. Details of the data management system provided by the Environmental Data Service are outlined. A similar project - the Puget Sound Energy-Related Project - deals with potential environmental effects of intensified petroleum activities.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10591. 1977]

C-1677-77
INSTRUMENTATION FOR ENVIRONMENTAL MONITORING/VOLUME 2, WATER.
Lawrence Berkeley Laboratory, Environmental Instrumentation Group. 1976. Report LBL-1. 18p. Third update.

Monitoring, Source identification, Chromatography, Design and engineering, *Instrument survey

This survey, originally compiled in 1973 and periodically updated, includes a chapter on oil and grease in water. Information from 1975 includes a laboratory analysis and manufacturer's specifications of seven oil identification instruments (gas chromatographs). It is recommended that the instrument descriptions not be used alone, but in conjunction with the introductory information, the referenced literature, and manufacturers' publications given in this survey.

NWMAR116681

C-1678-77
SEDIMENT HYDROCARBONS AS ENVIRONMENTAL INDICATORS IN THE NORTH-EAST GULF OF MEXICO
Lytle, J. S., and T. F. Lytle. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p.404-412. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Monitoring, Hydrocarbons, Sediments, Sources, Gulf of Mexico *Continental shelf

Hydrocarbons were analyzed in sediments collected from the Gulf of Mexico along the continental shelf from Pascagoula, Mississippi, to Fort Myers, Florida, in an effort to survey the hydrocarbons in this area and detect man-induced seasonal effects in hydrocarbon profiles. Three zones are distinguished by their aliphatic hydrocarbon distribution and are discussed in detail.

C-1679-77
A PILOT STUDY ON THE DESIGN OF A PETROLEUM HYDROCARBON BASELINE INVESTIGATION FOR NORTHERN PUGET SOUND AND STRAIT OF JUAN DE FUCA
MacLeod, W. D., D. W. Brown, and R. G. Jenkins. 1976.
NOAA Technical Memorandum ERL MESA-8. 59p.

Monitoring, Hydrocarbons, Environmental effects, Oil transport, Pipelines, Refineries, Puget Sound

Hydrocarbon baseline levels must be measured in the title regions in order to assess the potential future environmental impact arising from increased tanker traffic, pipeline transport, and refining operations when the Alaska pipeline comes into operation. This report presents results of a pilot study and offers recommendations for a first year Petroleum Hydrocarbon Baseline Investigation.

[from Selected Water Resources Abstracts 10(14):#W77-06875. 1977]

C-1680-77
OIL POLLUTION COMPLIANCE MONITOR
Moreau, J. O. 1976.
U.S. Patent 3,985,020

Monitoring, Oil discharges, Tankers, Regulations, Design and engineering, Patent

The monitoring system consists of adsorbing an oil sample which is proportional to total oil discharged and rate of oil discharged

NWMAR116682

on a continuously moving lipophilic belt and subsequently analyzing the belt after the voyage has been terminated when required to prove that the tanker has not exceeded ocean pollution requirements.

[from ERDA Energy Research Abstracts 2(11):#25910. 1977]

C-1681-77
EFFECTS OF HIGH DISCHARGE AND AN OIL REFINERY CLEANUP OPERATION ON HEAVY METALS IN WATER AND SEDIMENTS IN SKELETON CREEK
Namminga, H. E., and J. Wilkin. 1976.
Proceedings of the Oklahoma Academy of Science 56:133-138.

Monitoring, Streams, Sediments, Wastewaters, Refineries, Sampling, *Heavy metals

Grab samples of water and sediment were collected for seven months in 1973. After high discharge, heavy metal concentrations decreased exponentially with time. After the refinery cleanup, Cu decreased with time, but Cr, Pb, and Zn were at peak concentrations during the first week. No significant changes occurred in the sediments.

[from Chemical Abstracts 87(6):#43861v. 1977]

C-1682-77
FREE RADICAL OXIDATION PROCESSES IN SEA WATER AND METHODS FOR MONITORING THEM [in Russian]
Simonov, A. I., V. I. Chernyshov, E. S. Lebedeva, and Yu. S. Takuev. 1975.
Materialy Vsesoyuznogo Simpoziuma "Okeanograficheskie Aspekty Okhrany Vod ot Khimicheskikh Zagryaznenii", Moscow, 1974. p.140-145.

Monitoring, Petroleum products, Oxidation, Seawater, *Chemiluminescence

"The experimental data show that the chemiluminescence method is suitable for monitoring free radical destruction of petroleum and phenols in seawater."

[from Chemical Abstracts 86(22):#160897b. 1977]

NWMAR116683

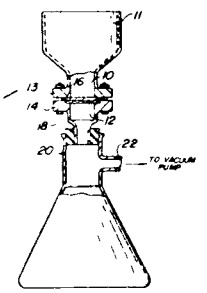
C-1683-77
METHOD FOR DETECTING OIL IN WATER
Thyrum, P. T. 1977.
U.S. Patent 4,004,453

Monitoring, Detection, Dispersions, Patent, *Oil soluble dye

To detect oil dispersed in water, a sample of the water is passed upward through a porous filter, the upper end of which contains a pad impregnated with a hydrophobic, oil-soluble dye. A color stain on the visible surface of the pad indicates the presence of oil.

[from Underwater Information Bulletin 9(4):41,#77/08/29. 1977]

4,004,453
METHOD FOR DETECTING OIL IN WATER
Per T. Thyrum, 100-D Phelps Ave., New Brunswick, N.J. 08901
Filed Dec. 8, 1975, Ser. No. 638,471
Int. Cl.² G01N 33/18
U.S. Cl. 73—61.1 R 27 Claims



C-1684-77
DEVELOPMENT OF AN OIL-WATER POLLUTION MONITORING SYSTEM
Tyler, B., W. Gongaware, and T. M. Houlihan. 1977.
Naval Engineers Journal April:125-128.

Monitoring, Ships, Bilges, Design and engineering, Detection

A prototype automatic oil pollution monitor has been built and tested. The monitoring system utilizes the "Direct Difference Method of Total Organic Carbon Determination" and in tests was capable of determining the concentration of any type of oil in a known water sample. This monitoring system is undergoing further testing and development for use in determining oil concentrations of shipboard bilge waters.

NWMAR116684

C-1685-77
DEVELOPMENT OF AN OIL-WATER POLLUTION MONITORING SYSTEM
Tyler, B. D., and T. M. Houlihan. 1976.
Oceans '76 Conference, Washington, D.C., 1976. p. 12F-17F.

Monitoring, Design and engineering, Bilges, *Total organic carbon determination

The development and testing of an oil pollution monitor using a Direct Difference Method of Total Organic Carbon Determination is reported. With this monitoring system it was possible to specify the concentration of any oil, independent of type, in a known water sample. Applications of the system include monitoring oil concentrations in bilge waters.

[from Environment Abstracts 7(5/6):#77-03173. 1977]

C-1686-77
LEAK DETECTION ON PETROLEUM PIPELINES
Young, H. A. 1976.
International School of Hydrocarbon Measurement Conference, 51st, Norman, Oklahoma, 1976. p.393-398.

Monitoring, Detection, Leakage, Pipelines

A description of the leak detection systems is included along with information on process calculations and process considerations.

[from ERDA Energy Research Abstracts 2(13):#31876. 1977]

3. REMOTE SENSING

C-1687-77
LANDSAT SATELLITES DETECT OIL SLICKS OFF U.S. AND ELSEWHERE (news brief)
Anon. 1977.
Sea Technology 18(6):31-32.

Remote sensing, Oil slicks, Natural seepage, Pollution control, *Landsat

A USGS Department of the Interior hydrologist, Morris Deutsch, has reported on the detection of oil spills and natural seeps by Landsat images, and discusses the future use of the satelite in the pollution control and offshore exploration. Slicks have been detected since August, 1972.

NWMAR116685

C-1688-77
SATELLITES DETECT OFFSHORE OIL SLICKS (news brief)
Anon. 1977.
Offshore 37(9):94.

Remote sensing, Oil slicks, Monitoring, Pollution control, *Landsat

Landsat satellites have detected oil slicks off the coasts of the U.S. and other nations, in an Interior Department USGS-managed EROS (Earth Resources Observation Systems) program. The environmental monitoring potential for Landsat is inferred.

C-1689-77
MARKING THE SEA SURFACE WITH ARTIFICIAL SEA SLICKS AND FLUORESCENT DYES TO AID SEARCH AND RESCUE OR OCEAN DUMPING SURVEILLANCE OPERATIONS
Barger, W. R., and W. D. Garrett. 1976.
Final report, USCG-D-107-76. 80p.

Remote sensing, Oil slicks, Surveillance, Oceans, *Dye/slick seamarking device

A new technique of marking the ocean surface with monomolecular films in combination with dyes was studied in order to develop a practical sea marker which can be detected by airborne remote sensing devices in addition to visual observation. A series of mathematical equations was developed to approximate the shapes, sizes, and lifetimes of monolayer slicks under different wind conditions.

[from Government Reports Announcements 77(11):#AD-A037 140/1GA. 1977]

C-1690-77
REMOTE DETECTION OF WATER POLLUTANTS BY COMPUTERIZED LASER-RAMAN SPECTROSCOPY
Brown, C. W. 1976.
Completion report, W77-00154, OWRT-A-054-Ri(1). 31p. PB-258 777.

Remote sensing, Petroleum products, Detection, Chemical analysis, Spectroscopy, *Computerized Raman spectroscopy

Hazardous chemicals in water were analyzed remotely and by conventional instrumentation using digitized Raman spectrometry. In addition, an entirely new method for fingerprinting light petroleum product contaminants was developed. The method involves the removal by chemical extraction of fluorescing petroleum components that obscure parts of the Raman spectrum, and then analyzing the complete spectrum.

[from Scientific and Technical Aerospace Reports 15(11):#N77-20555. 1977]

NWMAR116686

C-1691-77
USE OF LANDSAT DATA FOR THE DETECTION OF MARINE OIL SLICKS
Deutsch, M., A. E. Strong, and J. E. Estes. 1977.
Offshore Technology Conference, Houston, 1977. 8p.

Remote sensing, Oil slicks, Detection, Monitoring, Coasts, Natural seepage, *Landsat data

Reflectance anomalies associated with oil slicks have been visually detected on film data, by photo-optical enhancement techniques, and by computer processing. Applications of Landsat oil slick data include environmental monitoring of coastal waters and detection of natural seeps, such as in the Santa Barbara Channel, for exploration purposes.

[from International Aerospace Abstracts 17(14):#A77-32244. 1977]

C-1692-77
PROCEEDINGS OF CONFERENCE ON ENVIRONMENTAL QUALITY SENSORS, 2ND, NATIONAL ENVIRONMENTAL RESEARCH CENTER, LAS VEGAS, NEVADA, OCTOBER 10-11, 1973
Environmental Protection Agency. 1976.
EPA/600/9-76/031. 779p.

Remote sensing, Contaminants, Environmental effects, Monitoring, Oil spills

Among the topics covered at the conference are: remote sensing systems for monitoring pollutants; in situ monitoring systems; remote sensing techniques for land use mapping, environmental impact assessment, water surface temperature determinations, and oil and hazardous material spills identification.

[from Government Reports Announcements 77(11):#PB-264 183/5GA. 1977]

C-1693-77
RADAR DETECTION OF OIL CONTAMINATIONS OF THE SEA SURFACE [English summary]
Galayev, Y. M., A. I. Kalmykov, A. S. Kurekin, Y. A. Zementa, B. A. Nelepo, et al. 1977.
Fizika Atmosfery I Okeana 13(4):406-414.

Remote sensing, Crude oil, Petroleum products, Detection, *Sea surface, *Radar

Results are presented of a study on the radiowave reflectance characteristics of a sea surface polluted by oil. Tests were carried out under moderate sea state conditions with radiowaves λ = 3.3 cm and 10 cm and high coordinate resolution. The presence of oil was found to lead to a reduction of the scattered signal in the area of the spot detection, reaching more than 20 db at λ = 3.2 cm and more than 18 db at λ = 10 cm.

NWMAR116687

C-1694-77
SATELLITE SENTINEL FOR OIL SPILLS IN 1978?
Hovis, W. A., and D. R. Jones. 1977.
Ecolibrium 6(3):4-6.

Remote sensing, Oil slicks, Detection, Surveillance, Natural seepage, Santa Barbara Channel, *Coastal Zone Color Scanner

The limited capabilities of existing satellite remote sensing systems for the detection and monitoring of oil slicks are discussed and contrasted with the much greater capabilities of the proposed Coastal Zone Color Scanner (CZCS), designed to be onboard Nimbus G in 1978. Preliminary tests of the CZCS in high altitude U-2 overflights have demonstrated its capabilities in detecting oil slicks. Further refinement of the system is underway or planned.

C-1695-77
SATELLITE, AIRCRAFT, AND DROGUE STUDIES OF COASTAL CURRENTS AND POLLUTANTS
Klemas, V., G. Davis, J. Lackie, W. Whelan, and G. Tornatore. 1977.
IEEE Transactions on Geoscience Electronics Vol. GE-15:97-108.

Remote sensing, Oil slicks, Coasts, Movement, Wastewaters, *Current circulation, *Satellite-aircraft-drogue studies

A satellite-aircraft-drogue approach employs remotely tracked expendable drogues together with satellite and aircraft observations of waste plumes and current tracers such as dyes or suspended sediment. Tests indicate that the approach provides a cost-effective means of studying current circulation, oil slick movement, and ocean waste dispersion under a wide range of environmental conditions.

[from International Aerospace Abstracts 17(12):#A77-30004. 1977]

C-1696-77
REMOTE SENSING OF OIL POLLUTION AT THE SEA SURFACE. 2. DAMPING OF WATER WAVES BY AN OIL LAYER AS A POSSIBLE INDICATOR FOR SLAR OBSERVATIONS
Pronk, A. C. 1975.
Ph.D. thesis, NIWARS-Publ-22; NTIS No. HC A02/MF A01. 12p.

Remote sensing, Oil slicks, Oceans, *Wave damping, *Oil properties

The damping action of oil pollution on sea waves is discussed in regard to observation from the air. Oil layers of all thicknesses damp a part of the wave spectrum, but only in thicker layers is the damping related to the nature of the oil. The distance over which the sea waves damp out after an oil slick has entered seems a useful indicator for the oil properties.

[from Scientific and Technical Aerospace Reports 15(14):#N77-23583. 1977]

NWMAR116688

C-1697-77
REMOTE SENSING OF OIL POLLUTION AT THE SEA SURFACE. 1. REVIEW OF REMOTE SENSING METHODS EMPHASIZING RADAR
vanKuilenburg, J. 1975.
NIWARS-Publ-21; NTIS No. HC A03/MF A01. 29p.

Remote sensing, Oil slicks, Oceans, Bibliographies, *Radar, *Sea surface

The remote sensing methods applicable to the monitoring of oil pollution are reviewed. A discussion is presented on radar observations of oil slicks and of the surrounding sea surface, and a selected bibliography is included.

[from Scientific and Technical Aerospace Reports 15(14):#N77-23582. 1977]

4. SAMPLING

C-1698-77
SEASONAL VARIATIONS OF HYDROCARBONS IN THE WATER COLUMN OF THE MAFLA LEASE AREA
Calder, J. A. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p.432-441. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Sampling, Hydrocarbons, Seawater, Chemical analysis, Oil-gas leasing, Gulf of Mexico, *Seasonal variations, *MAFLA lease area

A series of 15 stations in the Gulf of Mexico were occupied during summer, fall, and winter 1975-76. Samples were collected and analyzed by gas chromatography for dissolved hydrocarbons and those associated with suspended particulate material. This report represents the initial evaluation of the three data sets.

NWMAR116689

C-1699-77
CHEMICAL CARCINOGENS IN THE MARINE ENVIRONMENT I. BENZO-(A)PYRENE IN ECONOMICALLY-IMPORTANT BIVALVE MOLLUSCS FROM OREGON ESTUARIES
Mix, M. C., R. T. Riley, K. I. King, S. R. Trenholm, and R. L. Schaffer. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 421-431. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Sampling, PAH, Detection, Mollusks, Carcinogens, Estuaries, Oregon, *Bivalves

Benzo(a)pyrene (BAP) levels were determined in economically-important indigenous shellfish populations from several sites in five Oregon bays. Detectable levels of BAP were present in bivalves from 43 of the 44 sampling sites. High levels (> 15 ng/g) were present in mussels collected from the Newport bayfront in Yaquina Bay and from a marina in Tillamook Bay. Significant levels (> 5 ng/g) were present in Mya arenaria collected along the shipping docks in Coos Bay.

C-1700-77
PELAGIC TAR AND PLASTIC IN THE GULF OF ALASKA AND BERING SEA: 1975
Shaw, D. G. 1977.
The Science of the Total Environment 8(1):13-20.

Sampling, Tar, *Plastics, Distribution, Gulf of Alaska, Bering Sea

Seventy-one tows of 740 m^2 were made in search of pelagic tar and plastics in the Gulf of Alaska and Bering Sea from October, 1974 to October, 1975. The abundance of these substances was found to be substantially lower in the Gulf and Bering Sea than in most other oceanic areas for which values are reported. The tar collected in this study is generally more extensively weathered than typical North Atlantic tar as indicated by $N_{\frac{1}{2}}$ values.

NWMAR116690

5. ANALYSIS

C-1701-77
APPARATUS AND METHOD FOR DETERMINATION OF THE RESIDUAL OILS AND/OR OIL CONTENT IN WATERS
(A. Essers Company) 1977.
German Offenlegungsschriften (unexamined patent application) 2,532,869

Oil-water separation, Detection, Analytical techniques, Patent, *Oil-in-water, *Fluorescence

Petroleum ether or hexane is used to extract the oil from water, and the extract is transferred to a measuring cup containing nonhygroscopic silicic acid gel, a fluorescence indicator. A technique is described for measuring the intensity of fluorescence of the sample and comparing it with a standard.

[from Chemical Abstracts 86(26):#194672q. 1977]

C-1702-77
THE USE OF LASER RADAR FOR DETERMINING THE POLLUTION OF THE SEA SURFACE BY OIL PRODUCTS [in Russian]
Abramov, O. I., V. I. Evemin, L. I. Lobov, and V. V. Polovinko. 1977.
Akademiia Nauk SSSR, Izvestiia, Fizika Atmosfery i Okeana 13: 331-334.

Contamination, Oceans, Petroleum products, *Laser radar, *Sea surface

Backscattering spectra were obtained under laboratory conditions and for the Bosphorus region using a laser emitting at a wavelength of 0.3472 μ. These spectra were used to determine the thickness of oil-product films on water surfaces.

[from International Aerospace Reports 17(16):#A77-35475. 1977]

C-1703-77
ASSESSMENT OF OIL PRODUCT CONCENTRATIONS IN THE OIL FILM FLOATING AT THE SEA SURFACE [English summary]
Anufrieva, N. M., A. B. Gornitsky, M. P. Nesterova, and I. A. Nemirovskaya. 1976.
Okeanologiia 16(2):255-258.

Oil slicks, Chemical analysis, Petroleum products, Seawater, *Sorbents

Tests have been made on various types of sorbing materials suitable for the determination of oil product concentration in

NWMAR116691

surface oil films. Polyurethane plastic has given the best results. Carbon tetrachloride will extract oil products from the sorbent, and quantitative determination of the product is made by the IS-method.

[from Oceanographic Abstracts and Bibliography - Deep-Sea Research 24(1):28. 1977]

C-1704-77
CHARACTERIZATION OF SEDIMENTS IN THE VICINITY OF OFFSHORE PETROLEUM PRODUCTION
Bean, R. M., J. W. Blaylock, E. A. Sutton, R. E. Wildung, and F. M. Davidson. 1977.
Chemistry of Marine Sediments. T. F. Yen (ed.). Ann Arbor, Michigan, Ann Arbor Science Publishers, 1977. p.55-72.

Chemical analysis, Sediments, Offshore production, Venezuela, Statistical analysis

"Sediment samples from Lake Maracaibo, Venezuela were fractionally extracted, the fractions were analyzed for C, H, N, and S, and the molecular weights were detected. Statistical approaches were used in interpreting the results."

[from Chemical Abstracts 86(26):#192138w. 1977]

C-1705-77
CHARACTERIZATION OF VOLATILE HYDROCARBONS IN FLOWING SEAWATER SUSPENSIONS OF NUMBER 2 FUEL OIL
Bean, R. M., and J. W. Blaylock. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p.397-403. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Hydrocarbons, Fuel oil, Chemical analysis, Seawater, Chromatography, *Water-soluble fraction

Dilute suspensions of No. 2 fuel oil in seawater (less than 1 mg/L) have been analyzed for monocyclic aromatic hydrocarbons using helium partition gas chromatography. Results from the gas chromatograms indicate the existance of soluble and insoluble oil phases in suspensions of No. 2 fuel oil in seawater and the presence of monocyclic aromatic components largely in true solution.

NWMAR116692

C-1706-77
CHEMICAL CHARACTERIZATION AND MONITORING STUDIES OF THE EFFLUENTS FROM EMERGING FOSSIL FUEL PROCESSES
Clark, B. R. 1976.
EPA-IAG-D5-E681; Contract W-7405-ENG-26. 9p. Air Pollution Control Association Specialty Conference, Cambridge, 1976.

Wastewaters, Refineries, Fossil fuels, Analytical techniques

Approaches to the chemical characterization of aqueous wastes and gas phase fugitive emissions are reported. Specific studies have included characterization of aqueous by-products from oil shale retorting, coal liquefication, and petroleum refining.

[from ERDA Energy Research Abstracts 2(10):#23950. 1977]

C-1707-77
ELECTROANALYTICAL ESTIMATION OF SEAWATER POLLUTION BY AROMATIC HYDROCARBONS
Cosovic, B., V. Zutic, T. Zvonaric, and Z. Kozarac. 1976.
Rapports et Procés-Verbaux des Réunions Commission Internationale Pour l'Exploration Scientifique de la Mer Méditerranée 23(7): 57-58.

Chemical analysis, Aromatic hydrocarbons, Seawater, *Electrochemical analysis

Electrochemical methods, based on adsorption effects at mercury electrodes, present a rapid and simple technique for estimating the concentration of total oil pollutants in seawater. This report describes the methods and discusses test results which indicate that the presence of dissolved aromatic hydrocarbons is responsible for the observed adsorption phenomena.

C-1708-77
HYDROCARBONS IN EASTERN CANADIAN MARINE WATERS DETERMINED BY FLUORESCENCE SPECTROSCOPY AND GAS-LIQUID CHROMATOGRAPHY
Keizer, P. D., D. C. Gordon, Jr., and J. Dale. 1977.
Journal of the Fisheries Research Board of Canada 34(3):347-353.

Hydrocarbons, Chemical analysis, Chromatography, Spectroscopy, Detection, Canada, Atlantic coast

The title methods were used to analyze and quantify hydrocarbons from coastal waters off eastern Canada. Concentrations of n-alkanes ranged from <20 ng/L to about 1 µg/L at depths of 2 and 50 m, respectively. Based on fluorescence analyses, oil concentrations were estimated to range from 0.2 to 9.3 µg/L, with the highest concentrations found in Bedford Basin off Nova Scotia. Hydrocarbons in other areas appear to be principally biogenic in origin.

NWMAR116693

C-1709-77
DETERMINATION OF ORGANIC POLLUTANTS IN WATER, AS A PART OF ENVIRONMENTAL PROTECTION [English summary]
Kubelka, V., J. Mitera, J. Novak, and J. Mostecky. 1977.
Chemicke Listy 71(3):241-284.

Hydrocarbons, Surfactants, Chemical analysis, Detection, Contaminants, Environmental protection

"A review with 348 references, of the concentration (by extraction or adsorption) and detection of some organic compounds such as petroleum hydrocarbons, surfactants, pesticides, and phenols in polluted water ."

[from Chemical Abstracts 87(2):#11177k. 1977]

C-1710-77
ANALYSIS OF PETROLEUM TYPE HYDROCARBONS IN MARINE SAMPLES USING GAS CHROMATOGRAPHY AND MASS SPECTROMETRY

Laseter, J. L., and M. C. Legendre. 1976.
Oceans '76 Conference, Washington, D.C., 1976. p. 23C-27C.

Hydrocarbons, Chemical analysis, Chromatography, Spectrometry, Zooplankton, Crustaceans, Sediments

Following their extraction with a series of organic solvents, hydrocarbons from zooplankton, shrimp, and sediments are fractionated by column chromatography, resolved by high resolution gas chromatography, and identified by combined gas chromatography-mass spectrometry. Capillary columns enable almost complete resolution of the petroleum-based isoprenoids and branched and cyclic alkanes.

[from Environmental Abstracts 7(5/6):#77-03178. 1977]

C-1711-77
HYDROCARBON ANALYSIS OF SURFACE SEAWATER AND BEACH SAND BY INFRARED ABSORPTION METHODS
Lee. W. T. 1976.
Dissertation Abstracts International B 37(10):5110-5111.

Analytical techniques, Hydrocarbons, Seawater, Beaches, Spectroscopy, Chromatography, Absorption

Infrared spectroscopy was used for quantitative and qualitative determination of hydrocarbons in the marine environment. Gas and thin-layer chromatography were also used for characterizing and separating the samples. Paraffins, aromatics, and olefins were found with evidence of seasonal variance, although the total concentration was usually less than 0.1 ppm. Results indicated that hydrocarbons occur at low concentrations in the presence of other extractable substances, pollution is

NWMAR116694

higher during the colder, winter months, and a positive correlation with boating traffic could not be made.

C-1712-77
IDENTITY, ORIGIN AND DEVELOPMENT OF OFF-FLAVORS IN GREAT LAKES ANADROMOUS FISH
Lindsay, R. C. 1977.
Wisconsin Department of Natural Resources, Madison Completion Report for Project AFC-13. PF-89-304. 7p.

Sources, Contamination, Fish, Chemical analysis, Petroleum products, Great Lakes

The project has consisted of the chemical identification of volatile compounds present in Great Lakes salmon and environmentally related materials. Analytical procedures are described. The occurrence of a number of aromatic hydrocarbons along with the aliphatic even-carbon numbered hydrocarbons would strongly suggest salmon pick-up of oil or petroleum-based product contamination of materials.

[from Selected Water Resources Abstracts 10(14):#W77-06931. 1977]

C-1713-77
INTERTIDAL SEDIMENT HYDROCARBON LEVELS AT TWO SIGHTS ON THE STRAITOF JUAN DE FUCA
MacLeod, W. D., Jr., D. W. Brown, R. G. Jenkins, and L. S. Ramos. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977 p.385-396. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Sampling, Hydrocarbons, Sediments, Analytical techniques, Intertidal zone, Washington

The primary objective of this study was to test analytical techniques for their utility in processing large numbers of marine sediment samples. Solvents/slurry extraction, silica gel chromatography, and glass capillary GC were adapted for analyzing the abundance and variation of hydrocarbons in intertidal sediments from 2 similar sites on the Strait of Juan de Fuca. Results are presented.

NWMAR116695

C-1714-77
STATE-OF-THE-ART CHROMATOGRAPHIC TECHNIQUES APPLIED TO THE ANALYSIS OF HYDROCARBONS IN MARINE TISSUE
May, W. E., S. A. Wise, S. N. Chesler, B. H. Gump, and H. S. Hertz. 1976.
American Chemical Society. Division of Environmental Chemistry. Preprints of Papers 16(2):55-57.

Chemical analysis, Chromatography, Spectroscopy, Detection, Hydrocarbons, Marine organisms, Baseline studies

A method for detecting hydrocarbons at submicrogram/kilogram levels has been developed and will be especially applicable to pollution baseline and monitoring studies. The method consists of extracting from the tissue homogenate the volatile organic components, followed by liquid chromatographic separation of the biogenic components extracted, gas chromatography quantitation, and gas chromatography-mass spectroscopy identification of the petroleum hydrocarbons. Test results for aromatic and aliphatic hydrocarbons are discussed.

[from Pollution Abstracts 8(4):#77-03382. 1977]

C-1715-77
HYDROCARBONS IN MARINE ORGANISMS [English summary]
Mironov, O. G., and T. L. Shchekaturina. 1976.
Gidrobiologiya Zhurnal 12(6):5-15.

Chemical analysis, Sources, Hydrocarbons, Marine organisms, Chromatography, Spectroscopy, Spectrometry

The use of gas-liquid chromatography, infrared spectroscopy, and mass-spectrometry in the discrimination of biogenic from petroleum hydrocarbons is described.

[from Applied Ecology Abstracts 3(6):#3D7193. 1977]

C-1716-77
DETERMINATION OF PETROLEUM PRODUCTS IN SEAWATER [in Russian]
Nemirovskaya, I. A. 1975.
Materialy Vsesoyuznogo Simpoziuma "Okeanograficheskie Aspecty Okhrany Vod Khimicheskikh Zagryaznenii", 1st, Moscow, 1974. V. I. Chernyshov (ed.). Moscow, Akad. Nauk SSSR, Okeanograficheskie Komissiya, 1975. p. 107-115.

Petroleum products, Seawater, Analytical techniques, *Gravimetric analysis, *Spectrophotometry

Gravimetric and spectrophotometric methods for the determination of petroleum products in seawater are described.

[from Chemical Abstracts 86(24):#176950z. 1977]

NWMAR116696

C-1717-77
APPLICATION OF GLASS CAPILLARY COLUMNS TO MONITOR PETROLEUM-TYPE HYDROCARBONS IN MARINE SEDIMENTS
Overton, E. B., J. Bracken, and J. L. Laseter. 1977.
Journal of Chromatographic Science 15(5):169-173.

Chemical analysis, Chromatography, Hydrocarbons, Aromatic hydrocarbons, Monitoring, Sediments, *Glass capillary columns

An analytical method is presented which combines the use of high resolution glass capillary columns and gas chromatography for the analysis of hydrocarbons in marine sediment samples. The method resolves almost all of the petroleum alkanes and many of the important aromatic hydrocarbons and permits the distinction between biogenic and petroleum hydrocarbons.

C-1718-77
ANALYTICAL ASPECTS OF OIL IN WATER
Peake, E. 1976.
Alberta, Canada, University of Calgary, The Environmental Sciences Centre, 1976. Publication No. 76-37. 13p.

Chemical analysis, *Oil in water

Summary not available.

[from Environmental Sciences Center, Kananaskis, University of Calgary, Alberta. IB#24. June 30, 1977]

C-1719-77
RESULTS OF PRELIMINARY STUDIES ON THE CHEMISTRY OF COMMERCIAL OIL-SPILL DISPERSANTS
Penrose, W. R., and L. L. Dawe. 1976.
Manuscript Report Series Fisheries Research Board of Canada, No. 1352. 13p.

Dispersants, Chemical analysis, Surfactants

Oil spill dispersants consist of a nonionic surfactant dissolved as a 10-30% solution in a solvent which may be a hydrocarbon, alcohol, or water depending on the surfactant. This report discusses methods for chemical analysis of dispersant surfactants and details the constituents of oil spill dispersants.

[from Aquatic Sciences & Fisheries Abstracts 7(5):#7Q5951. 1977]

NWMAR116697

C-1720-77
INVESTIGATION OF THE OPTICAL EMISSION OF THE SEA [in Russian]
Polovinko, V. V. 1976.
Geodeziia i Aerofotos'emka No. 6:109-114.

Contamination, *Optical emission, Caspian Sea, Analytical techniques, *Sea surface

Described is an experiment conducted during March, 1975, to determine the relation between the optical emission of the Caspian Sea and the turbulization and pollution of the sea surface by oil. The measuring instrumentation used and results obtained are elaborated.

[from International Aerospace Reports 17(16):#A77-35698. 1977]

C-1721-77
OPREDELENIE NEFTEPRODUKTOV V POCHVE (title not translated)
Potapov, M. P., and L. A. Lukas. 1976.
Gigiena i Sanitariya No. 9:71-72.

Petroleum products, Soil, Chemical analysis

A method for the determinination of oil products in the soil was developed and tested under practical conditons. The procedure is described in detail.

[from Pollution Abstracts 8(4):#77-03938. 1977]

C-1722-77
THE CHEMISTRY OF MARINE PETROLEUM SEEPS
Reed, W. E., and I. R. Kaplan. 1977.
Journal of Geochemical Exploration 7(2):255-293.

Chemical analysis, Natural seepage, Biodegradation, Weathering, Chromatography, Spectrometry, Santa Barbara Channel, Southern California

The occurrence and chemical properites of marine petroleum seeps are reviewed, focusing on those of the Santa Barbara Channel and other parts of the Southern California Borderland. The compositional changes due to weathering by microbial and chemical degradation, evaporation, and dissolution are summarized. The compositions of petroleum seeps are reported based on analysis by gas chromatography and gas chromatography-mass spectrometry, stable isotope studies, and carbon isotope analysis.

NWMAR116698

C-1723-77
THE FOUNDATIONS OF ORGANIC POLLUTANT ANALYSIS
Rosen, A. A. 1976.
Identification and Analysis of Organic Pollutants in Water.
Ann Arbor, Michigan, Ann Arbor Science Publishers, 1976. p.3-14.

Chemical analysis, Oil spills, Source identification

The development of the field of systematic analysis of organic pollutants, which began about 25 years ago, is described. Among the methods first used in pollutant analysis was passive labeling for the identification of oil spill sources.

[from Government Reports Announcements 77(12):#PB-265 309/5GA. 1977]

C-1724-77
COMPARISON OF TWO METHODS FOR OIL AND GREASE DETERMINATION
Short, J. W., S. D. Rice, and D. L. Cheatham. 1976.
Assessment of the Arctic Marine Environment. Selected Topics.
Fairbanks, Institute of Marine Science, University of Alaska, 1976. Chapter 28. p.451-462.

Crude oil, Fuel oil, Analytical techniques, *Oil-grease determination

The authors compare oil content measured by the gravimetric method (used by government agencies for determining levels of oil in discharged waters) with oil content determined by infrared spectrophotometry for toxic water-soluble fractions of two crude oils and a fuel oil. Recovery of all the oils and a synthetic grease standard was 100% by the infrared method. Using the gravimetric method, recovery of the grease standard was 98%, but recovery of the three pure oils ranged from 52 to 65%. It is concluded that the gravimetric method is sensitive only to heavier compounds of the oils.

C-1725-77
INTERLABORATORY CALIBRATION FOR THE ANALYSIS OF PETROLEUM LEVELS IN SEDIMENT
Wise, S. A., S. N. Chesler, B. H. Gump, H. S. Hertz, and W. E. May. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p.345-350. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Hydrocarbons, Sediments, Analytical techniques, Chromatography, Spectroscopy, *Intercalibration

A sample was analyzed by NBS and one other laboratory in order to determine the suitability of Katalla River sediment for a

NWMAR116699

more extensive intercalibration exercise. As a result of the data obtained, an enlarged intercalibration was initiated, which is currently in progress. Comparison of the interlaboratory data should provide a measure of the analytical variability among the participating laboratories.

C-1726-77
ELECTROCHEMICAL DETERMINATION OF SURFACE ACTIVE SUBSTANCES IN NATURAL WATERS. ON THE ADSORPTION OF PETROLEUM FRACTIONS AT MERCURY ELECTRODE/SEA ATER INTERFACE.
Zutic, V., B. Cosovic, and Z. Kozarac. 1977.
Journal of Electroanalytical Chemistry & Interfacial Electrochemistry 78(1):113-121.

Petroleum products, Hydrocarbons, Seawater, Surfactants, Chemical analysis, Adsorption, *Electroanalysis

Dissolved petroleum products in seawater are investigated through electroanalytical techniques. Two methods are used for measuring the adsorption effects of petroleum products and of individual hydrocarbons. Both techniques are discussed in relation to the total surface activity of a seawater sample and the effect of surfactants.

[from Chemical Abstracts 87(4):#28755v. 1977]

6. SOURCE IDENTIFICATION

C-1727-77
PETROLEUM IDENTIFICATION BY LASER RAMAN SPECTROSCOPY
Ahmadjian, M., and C. W. Brown. 1976.
Analytical Chemistry 48(8):1257-1259.

Source identification, Crude oil, Fuel oil, Petroleum products, Analytical techniques, Spectroscopy

The Raman spectra of No. 2 fuel oils, kerosenes, lubricating oils, weathered oils, and actual spill oils were measured. It was found that Raman spectroscopy provides a fast and simple method for identifying petroleum products.

[from Government Reports Announcements 77(11):#PB-264 732/9GA. 1977]

NWMAR116700

C-1728-77
CHEMICAL ANALYSIS GIVES A "FINGERPRINT" FOR THE IDENTIFICATION OF OIL SPILLS [English summary]
Boeler, J. B., R. Lichtenthaler, and P. E. Paus. 1976.
Kjemi 36(10):19-21.

Source identification, Oil spills, Analytical techniques

Systems based on combinations of different analytical techniques which are useful in oil spill fingerprinting are described.

[from Chemical Abstracts 86(26):#194521q. 1977]

C-1729-77
STATUS OF GROUNDWATER CONTAMINATION IN THE UNITED STATES
Geraghty, J. J., and D. W. Miller. 1977.
Water Technology and Research Conference, 96th, New Orleans, 1976. Vol. 2. p.33-1-51-1.

Source identification, Contamination, Groundwater, Oil wells, Production, Wastewaters, *Brine disposal

The mechanisms and major sources of groundwater contamination, and federal legislation for protecting underground waters are reviewed. Industrial wastewater impoundments, land disposal of solid wastes, sludges, and wastewaters, and disposal of brines from oil wells and petroleum processing facilities are among the major contaminant sources.

[from Environment Abstracts 7(5/6):#77-03472. 1977]

C-1730-77
A CHARACTERIZATION OF THE SOURCES OF PETROLEUM HYDROCARBONS IN LAKE WASHINGTON
Wakeham, S. G. 1977.
Journal Water Pollution Control Federation 49(7):1680-1687.

Source identification, Hydrocarbons, Sediments, Lakes

Surface sediments of the title lake have higher concentrations of hydrocarbons (up to 1500 µg/g) than deeper sediments (approximately 30 µg/g); the sources of this contamination were surveyed. Results indicated sources include urban stormwater and freeway bridge runoff, rivers and creeks, rainfall, and dustfall. Although urban and bridge runoff contained the highest concentrations of petroleum hydrocarbons, a budget calculation showed that the rivers (and creeks) contributed nearly equal amounts of hydrocarbons to the lake as did the runoff.

NWMAR116701

C-1731-77
SOURCE OF OIL DISCHARGED INTO WATER
Wardley-Smith, J. 1976.
The Control of Oil Pollution on the Sea and Inland Waters
J. Wardley-Smith (ed.). London, Graham & Trotman Ltd., 1976.
p. 9-26.

Source identification, Oil discharges, Natural seepage, Oil spills, Offshore development, Tankers, International agreements

A brief review is presented of the quantities and sources of oil in the marine environment including natural seeps, offshore exploration and production, spills from offshore wells, tanker accidents, operational discharges from ships and tankers, and oil from atmospheric sources. International oil pollution control agreements and industry agreements are briefly mentioned.

NWMAR116702

B. OIL POLLUTION PREVENTION AND CONTROL

1. CONTAINMENT

C-1732-77
EUROPA - NEW OIL BOOM UNIT (news brief)
Anon. 1977.
Marine Pollution Bulletin 8(7):148.

Booms, Spill containment, Harbors, Inland, *Product information

The EUROPA - Emergency Unit for the Recovery of Oil in Pollution Accidents - is a new unit for dealing with oil on inland waterways and in harbors, made by Hoyle Marine Ltd., Merseyside. The unit can be towed to inaccessible locations (weighing less than 1150 kg) and has boom equipment that can be launched within four minutes to an 80 m extension.

C-1733-77
FLOATING OIL FENCE DESIGNED FOR RAPID DEPLOYMENT (product information)
Anon. 1976.
Ocean Industry 11(8):32.

Spill containment, Booms, Design-engineering, *Oilfence

The Oilfence, a portable floating spill containment barrier manufactured by Oil Spill Control Systems of Oakland, California, is described. The barrier is made of portable, connectible polyurethane sections especially designed for ease of handling in transport and deployment. The flexibility of the system facilitates configurations of the barrier to fit the specific oil containment situation.

[from Oceanic Abstracts 14(3):#77-02652. 1977]

C-1734-77
LARGEST BUBBLE BARRIER (product information)
Anon. 1977.
Ship & Boat International 30(5):31.

Spill containment, Tankers, Ports, Sweden, *Spill Bubble barrier

Atlas Copco has designed and installed at Gävle, Sweden, an oil protection bubble barrier to prevent the spread of an oil spill. A series of interconnected polyurethane air hoses stretch 475 m in a sectorized loop around the berthed tanker. Through numerous holes in the hoses, compressed air, fed

NWMAR116703

from onshore compressors, rises to the surface to create a barrier curtain.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10597. 1977]

C-1735-77
OIL SPILLS PROMPT BOOM DESIGNS (product information)
Anon. 1977.
National Fisherman 58(3):10B.

Booms, Spill containment, Design-engineering, *Product information

Nils Lucander has an un-patented design for what he calls the "Lucan" Bottom Tension Oil Spill Control Boom, claimed to have been invented by a large oil company. According to Lucander, the USCG and the old Water Pollution Control Administration saw his model years ago "and state unequivocally it was the best they had seen and that it should be developed further." For information, contact Lucander at Box 3184, Brownsville, Texas, 78520.

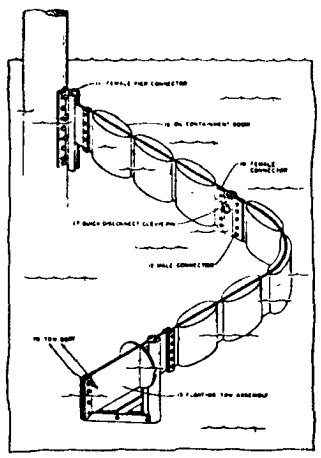
C-1736-77
CONNECTOR HINGE FOR OIL CONTAINMENT BOOMS
Campbell, F. J., and D. J. Graham. 1977.
U.S. Patent 4,016,726

Spill containment, Booms, Design and engineering, Patent, *Connector hinge

A connector hinge is described for attaching oil spill containment booms having a male cylindrical connector which fits loosely within a female cylindrical connector to allow easy movement of both parts in both a vertical and horizontal direction. The connectors can be attached to a floating oil spill containment boom, an immovable object such as a pier or jetty, or a floating tow assembly.

[from Petroleum Abstracts 17(34):#237,302. 1977]

4,016,726
CONNECTOR HINGE FOR OIL CONTAINMENT BOOMS
Francis J. Campbell, Stanford, and Douglas J. Graham, San Francisco, both of Calif., assignors to The United States of America as represented by the Secretary of the Navy, Washington, D.C.
Filed Aug. 21, 1975, Ser. No. 606,696
Int. Cl.[2] E02B *15/04*
U.S. Cl. 61—1 F 16 Claims



NWMAR116704

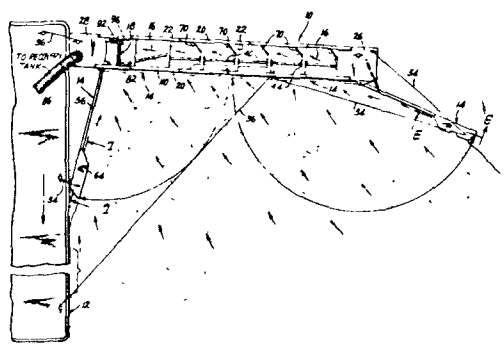
C-1737-77
OIL BOOM FOR COLLECTING AND SKIMMING OIL ON A WATER SURFACE
in'tVeld, C. 1977.
U.S. Patent 4,014,795

Spill containment, Booms, Skimmers, Design-engineering, Patent

Two parallel rows of floating barrier screen panels are supported by a framework which is connected to end floats. Flow diverter vanes beneath the barrier screen panels cause a surface transport current to flow between the 2 rows of the panels toward a surface skimmer located adjacent to one end of the boom.

[from Petroleum Abstracts 17(33):#237,017. 1977]

4,014,795
OIL BOOM FOR COLLECTING AND SKIMMING OIL ON A WATER SURFACE
Cornelis in'tVeld, Vlaardingen, Netherlands, assignor to National Marine Service, Inc., St. Louis, Mo.
Filed Nov. 24, 1975, Ser. No. 634,505
Int. Cl.[2] E02B *15/04*
U.S. Cl. 210—242 R 11 Claims



C-1738-77
OIL SLICK INSTABILITY AND THE ENTRAINMENT FAILURE OF OIL CONTAINMENT BOOMS
Leibovich, S. 1976.
Journal of Fluids Engineering 98(3):98-105.

Spill containment, Booms, Behavior, Oil slicks, *Slick droplet formation, *Entrainment failure

Experimental evidence is shown to be consistent with the view that the onset of droplet formation in contained oil slicks is due to the breaking of finite interfacial waves; these waves result from the equilibration of amplifying Kelvin-Helmholtz waves. Conditions for droplet shedding from the headwave and from the entire slick are derived from this model.

NWMAR116705

C-1739-77
THE USE OF BOOMS
Newman, D. E. 1976.
The Control of Oil Pollution on the Sea and Inland Waters.
J. Wardley-Smith, (ed.). London, Graham & Trotman Ltd., 1976.
p.83-114.

Spill containment, Booms, Design and engineering, Freshwater, Oceans

The use of booms in oil spill containment is summarized with reference to different types of booms, including chemical oil herders and their functions, operations, design, and limitations. Four different spill situations and the effective use of booms are described. The situations cover oil spilled into a stream, oil entering an estuary from the sea, protection of freshwater intakes, and use of booms for corraling or collecting oil in open waters.

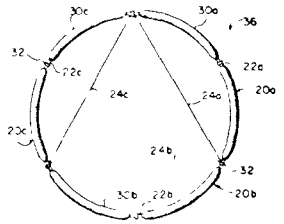
C-1740-77
FENDING DEVICE FOR OIL CONTAINMENT BOOM
Nielsen, E. C. 1977.
U.S. Patent 4,000,532

Spill containment, Booms, Design and engineering, Patent

"The device for floating barriers has an open planar structure with associated buoyancy arrangements to give flotation on water substantially coplanar to the surface of the water. Fenders extend transversely of the plane of the structure and exceed above and below the water line to engage the barrier and block passage thereby."

[from Underwater Information Bulletin 9(4):39,#77/08/01. 1977]

4,000,532
FENDING DEVICE FOR OIL CONTAINMENT BOOM
Erik C. Nielsen, R.D. 3 Box 360-K, Toms River, N.J. 08753
Filed Mar. 5, 1975, Ser. No. 555,366
Int. Cl.[2] B63B *35/00*, E02B *15/04*
U S Cl. 9—8 R 10 Claims



NWMAR116706

C-1741-77
SEABOOM TM, A PERMANENT OIL CONTAINMENT BARRIER
Tedeschi, E. T. 1976.
American Chemical Society. Division of Environmental Chemistry. Preprints of Papers 16(2):123-126.

Spill containment, Booms, Design and engineering, *Seaboom

The Seaboom line of containment barriers consists basically of a sheet of rubber held vertically in the water by continuous flotation chambers containing closed-cell foam and stiffened by vertical ribs. The material does not foul and cannot snag on protruding structures. The booms have been in operation for over 5 years with no degradation in performance and little maintenance required.

[from Pollution Abstracts 8(4):#77-03387. 1977]

2. CLEANUP AND RECOVERY

C-1742-77
DRACONE 'BARGE' (product information)
Anon. 1977.
Ship & Boat International 30(5):33.

Spill recovery, Oil transport, Design and engineering, *Dracone barge

The Dunlop GRG Divison, Skelmersdale, UK, manufactures a 4,500 L capacity Dracone Barge. The 7.3 m (28 ft.) long barge is a towed, flexible unit made from synthetic rubber coated nylon fabric and cord, and is used for collecting and transporting salvaged oil at sea.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10471. 1977]

C-1743-77
FOAM CHIPS FOR OIL RECOVERY (product information)
Anon. 1977.
Ship & Boat International 30(5):33.

Spill recovery, Absorption, Design and engineering, USN, *Foam chips

Ocean Design Engineering Corporation (ODEC), California, has a patented oil-spill recovery system for the open ocean. The system

NWMAR116707

recycles large quantities of urethane foam chips which absorb the oil, and is capable of recovering up to 132,475 L/hr (35,000 US gph) in continuous operation. A prototype has been built for the U.S. Navy.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10470. 1977]

C-1744-77
NEW SYSTEM CLEARS BIG OIL SPILLS(product information)
Anon. 1977.
Offshore Services 10(4):91.

Spill recovery, Blowouts, Booms, North Sea, Norway

Large scale blowouts off the coast of Norway should soon be able to be handled in difficult weather without chemicals. Statoil, negotiating on behalf of the North Sea Operators' Committee, has ordered two complete oil recovery systems and 1000 m of seagoing booms. Descriptions of the equipment, ordered from Thune-Eureka A/S and A/S Nofi, are given.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10594. 1977]

C-1745-77
NEW TANK CLEANING STATION NEEDED AT GOTHENBURG
Anon. 1977.
Holland Shipbuilding 25(12):71.

Oil tanks, Cleanup, Sweden, *Tank cleaning station

The separation technique used on board "Renare Har", a floating tank cleaning station, has been very effective in meeting the oil content limits for discharged waters imposed by the Swedish authorities. Götaverken is offering to carry out conversions of old tankers into similar cleaning stations.

[from Aquatic Sciences & Fisheries Abstracts 7(6):#7Q7585. 1977]

C-1746-77
OIL DISPERSANT SPARES SEA LIFE (product information)
Anon. 1977.
Ship & Boat International 30(5):33.

Spill cleanup, Dispersants, Emulsifiers, Solution, Toxicity

The Gamlen Chemical Co. Ltd., of Uxbridge, UK, has developed an emulsifier without a solvent, named Hydrogamosol LT. It has been approved by the British Warren Springs lab for its

NWMAR116708

effectiveness and low toxicity, and meets the French standards of legislation for bio-degradable detergent products. The agent can be used in solution in sea water at concentrations of 2-4%, and will not deteriorate metal, concrete, rubber, wood, or plastic. When sprayed on the oil spill, a fine emulsion forms which can be dispersed by mechanical means.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10468. 1977]

C-1747-77
OIL RECLAIMER (product information)
Anon. 1977.
Water & Pollution Control 115(4):30.

Spill recovery, Reclamation, Design and engineering

The Olsen reclaimer, a floating, self propelled unit for cleaning up harbor spills and oil slicks, is described. The device collects oil at a rate up to about 570 L/min (150 gpm) depending on the thickness of the oil layer, and it delivers a product that is readily processed for oil reclamation. The unit is available from MSC Engineering Systems Ltd., 265 Canarctic Drive, Downsview, Ontario M3J 2N7, Canada.

C-1748-77
OIL SKIMMER RECOVERS 1-50 GPM (product information)
Anon. 1977.
The Oil and Gas Journal 75(32):93.

Skimmers, Spill recovery, Design and engineering

A floating, weir-type oil skimmer, the Slurp, has no moving parts or necessary adjustments. The producing company, Seaward International Inc., also advertises a self-contained emergency oil-spill response system. Write to Seaward International at 6269 Leesburg Pike, Falls Church, VA.

C-1749-77
OIL SPILL PUMP (product information)
Anon. 1977.
Offshore 37(6):76.

Pollution control, Spill cleanup, *Oil spill pumps

The Frank Mohn Company has developed an oil salvage pump system for use against uncontrolled blowouts or other types of oil spills. The pumps can take up spills at the same rate as oil gushing from the well.

NWMAR116709

C-1750-77
OIL SPILLS
Anon. 1976.
Ocean Industry 11(10):75-79.

Spill recovery, Absorption, Skimmers, Booms, Ships

Recent developments in oil spill recovery technology are examined including the use of absorbent polyurethane foam chips, absorbent ferromagnetic polyfoam, and several specially designed oil spill recovery vessels, booms, and skimmers.

[from Oceanic Abstracts 14(3):#77-02661. 1977]

C-1751-77
OIL SPILLS IN BAD WEATHER: SKUTENG A/S AND A/S BLEHR & TENVIG HAVE THE SOLUTION
Anon. 1977.
Scandinavian Oil Gas Magazine 5(4):27-29.

Spill recovery, Design and engineering, North Sea, *Oil collection systems

The article reports the progress of the title companies toward reaching a solution to the collection of offshore oil spills. Skuteng feel they have developed an ideal system to collect oil during bad weather. Blehr & Tenvig have patented a stabilizer system which can reduce the heaving motion of a ship at sea. Both companies think that the systems could be effectively coordinated for use in the North Sea.

[from Petroleum Abstracts 17(34):#237,304. 1977]

C-1752-77
POLLUTION CONTROL - PUMP SETS FOR OIL SLICK DISPERSAL
Anon. 1977.
Marine Engineers Review 7(February):34.

Dispersants, Booms, Oil slicks, Spill cleanup, *Pumps

Megator Pumps and Compressors Ltd., London, have introduced a 2 pump package for feeding concentrated oil dispersant and seawater to spray vessels' booms. The sets have been approved for use with the Warren Spring Laboratory spray boom system which is designed to apply dispersant to floating oil and then, by means of specially designed breaker boards, to agitate the surface of the treated oil to speed dispersion of the slick.

NWMAR116710

C-1753-77
PUMPS FOR OIL-SPILL CLEARANCE (product information)
Anon. 1977.
Ship & Boat International 30(5):33.

Spill cleanup, Design-engineering, *Oil-spill pump

The self-priming flameproof Wilden pump can pass most solids of up to 5.08 cm (2 in) in size and, if damaged, can be repaired on site. Thus, the dangers of electrical shock or flame hazards from an electric pump are eliminated. The pumping capacities range from a few liters (gallons) up to 757 L/min (200 gpm).

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10469. 1977]

C-1754-77
RCMP LINK WITH NEELS AIDS OIL SPILL CLEAN UP (news brief)
Anon. 1977.
Water & Pollution Control 115(4):13.

Spill cleanup, Spill containment, Canada, *Equipment locator system

The Royal Canadian Mounted Police (RCMP) has been linked with Canada's computer-based National Emergency Equipment Locator System (NEELS) in order to aid the country in quickly locating spill containment and cleanup equipment when a spill occurs.

C-1755-77
SKIMJET REMOVES OIL FROM SURFACE OF WATER (news brief)
Anon. 1977.
Water & Pollution Control 115(4):68.

Spill recovery, Skimmers, Design and engineering, *Skimjet

Skimovex B.V. has developed a unit, the Skimjet, which can remove 98% of oil from a 500 m^2, 2 cm thick oil spill per hour, regardless of the viscosity of the oil. The system uses jets of water to direct and push the oil into a floating, bottomless enclosure. Advantages of the system include simplicity of operation, high capacity, and insensitivity to wind and waves up to 0.7 m. The collected oil contains virtually no water. The unit is adaptable for land based and marine applications.

NWMAR116711

C-1756-77
SYSTEM RECOVERS OIL AT 250 BBL/HR RATE (product information)
Anon. 1977.
The Oil and Gas Journal 75(32):90.

Skimmers, Spill recovery, Design and engineering

The new ZRV Dynamic Skimmer recovers oil by moving an adsorbent floating rope mop in the opposite direction of vessel travel at up to six knots. For more information, write to Oil Mop Inc., Drawer P, Belle Chase, LA. 70037.

C-1757-77
SYSTEM RECOVERS SPILLS FAST (product information)
Anon. 1977.
The Oil and Gas Journal 75(34):141.

Contingency planning, Spill recovery, *Response teams, U.S.

A new system of two crews of six-man teams is on standby twenty-four hours a day for 5-hr on-scene response to over fourteen western states. The system covers oil and other spills at train, truck, boat, or barge accidents. For further informatiom write to Western Environmental Services Div., Willamette-Western Corp., Foot of North Portsmouth Ave., Portland, OR 97203.

C-1758-77
WIDE RANGE OF OIL POLLUTION GEAR FROM U.S. MAKER (product information)
Anon. 1977.
Ship & Boat International 30(5):32.

Spill recovery, Skimmers, Design-engineering, *Seaward International

Seaward International of Falls Church, Virginia, offers SLURP (Self-Levelling Unit for Removing Pollution), the Spiltrol harbour skimmer, and the Huskey offshore skimmer, as well as other pollution control equipment. The skimmers operate in a variety of water conditions and are self-propelled and non-self-propelled.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10467. 1977]

NWMAR116712

C-1759-77
EVALUATION OF ACTIVATED CARBON FOR FUEL OIL ADSORPTION FROM A POTABLE WATER SUPPLY
Allen, D. H. 1976.
Final report, AFCEC-TR-76-46. 12p.

Fuel oil, Contamination, Fresh water, Adsorption, *Activated carbon, *Water supply

The use of activated carbon adsorption for removing diesel fuel from a contaminated Air Force water supply was found to be a highly effective and extremely rapid process.

[from Government Reports Announcements 77(12):#AD-A037 478/5GA. 1977]

C-1760-77
STUDY OF THE CREATION OF PROTECTIVE AND SORBENT MATERIALS FOR OIL SPILLS [in Russian]
Anufrieva, N. M. 1975.
Kompleksnye Issledovaniya Microvom Okeane. M. E. Vinogradov (ed.). Moscow, USSR, Akademia Nauk SSSR, 1975. p.331-335.

Spill cleanup, Spill containment, Absorption, *Polyurethane foams

"Polyurethane foams prepared by foaming easily transportable polyurethane components directly in contact with petroleum on water surfaces, entrap petroleum leaving only a thin film."

[from Chemical Abstracts 87(2):#82718. 1977]

C-1761-77
A FAST-CURRENT OIL RECOVERY DEVICE
Ayers, R. R., and J. M. Ward. 1977.
Ecolibrium 6(3):12-14.

Spill recovery, Skimmers, Design-engineering, *Fast current oil recovery

Currently available oil spill recovery equipment is generally limited to operating in water current speeds of under 4 km/hr (2 knots). The newly developed zero-relative-velocity (ZRV) oil skimmer is described, and its performance in a series of developmental USCG tests is summarized. The ZRV skimming concept has been shown by tests to be capable of recovering oil effectively in 7-18 km/hr (4-10 knot) currents.

NWMAR116713

C-1762-77
INSTALLATION TO COLLECT A LIGHT MATERIAL FLOATING ON A WATER SURFACE
(Ballast Nedam Groep NV). 1975.
Netherlands Application 7,510,151

Spill recovery, Design-engineering, Patent

The installation is submerged in water and consists of a wall around a collection space. Collection mechanisms move the light material to the collection space. The wall consists of a multitude of panels which can be moved into positions to provide water-tight connections between intermediate flexible wall panels.

[from Petroleum Abstracts 17(35):#237,684. 1977]

C-1763-77
A PROCESS FOR ABSORBING OIL FROM WATER
Barnes, R. I. 1977.
British Patent 1,472,964

Absorption, Contaminants, Patent, *Oil-absorbent compound

An oil-absorbent compound consisting of the reaction product of a carbohydrate and a metal oxide is added to the water. The carbohydrate may be a disaccharide, monosaccharide, or polysaccharide; the metal oxide is the oxide of a metal in Group II of the Periodic Table of Elements.

[from Petroleum Abstracts 17(30):#235,883. 1977]

C-1764-77
SPILLAGE INTO WATER - TREATMENT
Canevari, G. P. 1976.
Encyclopedia of Environmental Science and Engineering. J. R. Pfafflin, and E. N. Ziegler (eds.). New York, Edward N. Gordon & Breach, 1976. Vol. 2. p.793-809.

Spill cleanup, Spill containment, *Treatment methods

Various methods in which oil spills can be handled are discussed and the merits of the different methods are compared.

[from Chemical Abstracts 87(2):#8219v. 1977]

NWMAR116714

C-1765-77
SEPARATING OIL FROM OIL-CONTAMINATED SURFACES
Chambers, D. B., B. Walker, E. Chadwick, and J. N. Greenshields. 1977.
German Offenlegungsschriften (unexamined patent application) 2,639,149

Contamination, Oil tanks, Absorption, Patent, *Cleanup

The preparation of a cleaning composition used for the spray cleaning of oils from surfaces of storage tanks, etc., is described.

[from Chemical Abstracts 86(24):#173451b. 1977]

C-1766-77
SOLIDIFICATION OF LEAKED OILS AND OIL LEAKING PREVENTION
Chikami, K. 1976.
Japanese Kokai (unexamined patent application) 76 87,349

Tankers, Leakage, Spill cleanup, Patent, *Oil solidification

A mixture which includes urethane and trichloroethane is added to oils leaked or leaking from oil tankers. This causes rapid solidification and stops the leak.

[from Chemical Abstracts 87(4):#28641e. 1977]

C-1767-77
OIL RECOVERY PERFORMANCE OF THE LOCKHEED DISC-DRUM DEVICE - A PARAMETRIC STUDY
Chung, J. S., and C. E. Rudiger, Jr. 1976.
Oceans '76 Conference, Washington D. C., 1976. p.12B-22B.

Spill recovery, Design-engineering, Lockheed disc-drum device, *Performance

Using test data obtained on Lockheed disc-drum oil recovery devices, parameters affecting their performance were investigated. Very high recovery rates were obtained over a wide range of oil properties and oil layer thicknesses including thin slicks. Optimal recovery rates were obtained for oils with a viscosity between 200-1500 centistokes.

[from Environment Abstracts 7(5/6):#77-03169. 1977]

NWMAR116715

C-1768-77
OIL AND LUBRICANTS IN WATER. HOW CAN MAN REMOVE IT?
Enke, C. G. 1976.
Wasser, Luft und Betrieb 20(12):685-688.

Emulsions, Filtration, Evaporation, Incineration, *Oil removal

Emulsion breaking, ultrafiltration, evaporation, and incineration are emphasized in this review with no references.

[from Chemical Abstracts 87(6):#43551u. 1977]

C-1769-77
SELECTION CRITERIA AND LABORATORY EVALUATION OF OIL SPILL SORBENTS
Environmental Protection Service. 1976.
No. EPS-4-EC-76-5. 53p.

Spill recovery, Absorption, Cost analysis, *Sorbents, *Performance evaluation

Twenty different types of oil spill sorbents were studied in terms of desirable performance and operational criteria. Oil pick-up capacities were determined and then correlated with sorbent prices to give oil sorption costs. Of the materials examined, the synthetic polymeric sorbents exhibited the highest oil pick-up capacities and oil/water ratios.

[from Petroleum Abstracts 17(32):#236,712. 1977]

C-1770-77
SINKING AND DISPERSING OIL
Farn, R. J. 1976.
The Control of Oil Pollution on the Sea and Inland Waters. J. Wardley-Smith (ed.). London, Graham & Trotman Ltd., 1976. p.159-180.

Spill cleanup, Dispersants, Toxicity, Sinking agents

The sinking of oil as a means of spill cleanup is not considered a successful method because of the potential damage to benthic life and fisheries resources in many areas. The use of oil spill dispersants is presently the most effective and widely used method of combatting oil pollution in the open sea, coastal waters, and shorelines. The development and evaluation of the performance and toxicity of various dispersants by laboratory tests and sea trials are described. The methods of dispersant application in various spill situations are reviewed.

NWMAR116716

C-1771-77
PETROLEUM WASTES IN THE SOIL
Harris, J. O. 1976.
Land Application of Waste Materials. Ankeny, Iowa, Soil Conservation Society of America, 1976. p.249-253.

Spill cleanup, Petroleum products, Soil, Sources, Biodegradation, Oxidation, Absorption

Petroleum products likely to pollute land are extremely variable in composition and physical characteristics; and spills may result from pipeline breaks and accidents or leakage during transport or storage. The roles of oxidation and biodegradation of oil by soil microorganisms are reviewed, and methods for onland spill containment, cleanup and recovery are summarized. Cleanup is best achieved by adsorption on straw, hay, ground corn cobs, and various sponge-like plastic absorbents.

[from Pollution Abstracts 8(4):#77-03948. 1977]

C-1772-77
APPARATUS FOR SEPARATING DISPERSIONS OF TWO IMMISCIBLE LIQUIDS [in German]
Hartman, R., and O. Kuz. 1976.
German Patent 2,164,476

Dispersions, Oil-water separation, Spill cleanup, Design and engineering, Patent

"This apparatus for separating dispersions consists of a tank with horizontal baffle plates of corrugated or zigzag sheet metal and a distributor consisting of a fill separated from the baffles by a perforated plate. The space between the baffle plates is filled with a material preferentially wetted by the dispersed phase."

[from Petroleum Abstracts 17(23):#234,065. 1977]

C-1773-77
OIL COLLECTION
Hoketsu, H. 1977.
Japanese Kokai (unexamined patent application) 77 12,687

Spill cleanup, Dispersants, Patent, *Magnetic powder

"Oil on water is dispersed with irregular granules of plastics mixed with powdered magnetic metal and collected magnetically as oil balls."

[from Chemical Abstracts 87(8):#58182y. 1977]

NWMAR116717

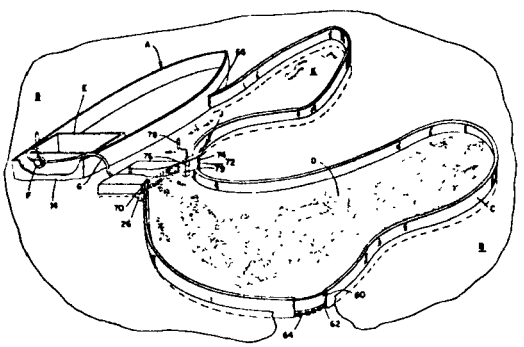
C-1774-77
PROCESS FOR EMERGENCY SMALL SPILL CONTROL
Irons, D. E. 1977.
U.S. Patent 4,006,082

Spill recovery, Booms, Patent

Floating oil or other contaminants are recovered by a process that involves use of a floating sump and a flexible floating boom. The boom is attached to the sump and is placed in the water so as to encircle the sump and at least part of the spill. Take-up arrangements originating at the sump are used to gradually decrease the area of the spill, and the floating pollutant is pumped into a storage vessel.

[from Underwater Information Bulletin 9(4):42, #77/08/38. 1977]

4,006,082
PROCESS FOR EMERGENCY SMALL SPILL CONTROL
Denis E. Irons, San Francisco, Calif., assignor to Murphy Pacific Marine Salvage Co., Emeryville, Calif.
Filed May 12, 1975, Ser. No. 576,944
Int. Cl.[2] E02B *15/04*
U.S. Cl. 210—83 1 Claim



C-1775-77
MECHANICAL DEVICES
Jeffrey, P. G. 1976.
The Control of Oil Pollution on the Sea and Inland Waters. J. Wardley-Smith (ed.). London, Graham & Trotman Ltd., 1976. p.115-140.

Spill recovery, Skimmers, Design and engineering

Five basic types of oil skimmers are described and evaluated based on their underlying principles of operation and deployment. Included are skimmer types that rely on: 1) adhesion of oil to a solid surface such as a metal disk; 2) adhesion to a continuous flexible belt drawn along the the oil/water interface; 3) centrifugal devices that create a vortex for increasing oil layer thickness; 4) devices with one or more weirs; and 5) more than one method of operation.

NWMAR116718

C-1776-77
OIL-ABSORBING MATERIAL
Kumitomo, Y., H. Ono, T. Saida, K. Nakarai, and T. Wagatsuma. 1977.
German Offenlegungsschriften (unexamined patent application) 2,621,961

Spill recovery, Absorption, Incineration, Patent, *Absorbent fibers

Peat fibers are mixed with melted polyolefin to form a material that absorbs floating oil and can be burned after use.

[from Chemical Abstracts 87(2):#7052y. 1977]

C-1777-77
REMOVAL OF SPILLED OIL FROM WATER
Murata, K. 1976.
Japanese Kokai (unexamined patent application) 76,110,479

Spill recovery, Fuel oil, Adsorption, Patent, *Sawdust

A chip or powdered oil adsorbent is spread over an oil spill and then solidified by spraying with an alkali metal silicate and a hardening agent. Experiments used sawdust to remove fuel oil from water.

[from Chemical Abstracts 87(4):#28832t. 1977]

C-1778-77
STUDY OF POLYURETHANE FOAM AS A MEDIUM TO REMOVE PETROLEUM FROM THE SURFACE OF OCEANS [in Russian]
Nemirovskaya, I. A., N. M. Anufrieva, and A. B. Gornitskii. 1975. Kompleksnye Issledovaniya Mirovom Okeane. M. E. Vinogradov (ed.). Moscow, USSR, Akademia Nauk SSSR, 1975. p.327-330.

Spill cleanup, Absorption, Oceans, *Polyurethane foams

"Polyether-based polyurethane foams are unsuitable for absorbing spills, but polyester-based ones absorb 18.6 times their own weight of petroleum, 94.2% of which can later be extracted with petroleum ether containing a small amount of $CHCl_3$."

[from Chemcial Abstracts 87(2):#8270e. 1977]

NWMAR116719

C-1779-77
IMPROVEMENTS IN OIL SLICK DISPERSANT APPARATUS
Noel, R. A. 1976.
South African Patent 75/7,078

Oil slicks, Dispersants, Spill cleanup, Design-engineering, Patent

"The apparatus consists of an eductor, a source of concentrated dispersant connected to an inlet of the eductor, and a pump adapted to pump water through the eductor to at least one suitable nozzle. The water is mixed with concentrate in the eductor."

[from Petroleum Abstracts 17(23):#234,064. 1977]

C-1780-77
RECOVERY OF SPILLED OIL ON SEA WATER OR RIVER WATER
Okhori, K. 1976.
Japanese Kokai (unexamined patent application) 76 87,507

Spill recovery, Seawater, Rivers, Solvents, Flocculation, Coagulation, Patent

Spilled oil is sprayed with an aromatic solvent containing a flocculant, and then with a coolant, such as dry ice, to coagulate the oil and to form an oil fence.

[from Chemical Abstracts 87(4):#28640d. 1977]

C-1781-77
REMOVAL OF PETROLEUM FROM THE SURFACE OF WATER
Pelevin, L. A., G. N. Pozdnyshev, Yu. Kh. Lukmanov, et al. 1977.
USSR Patent 548,573

Spill recovery, Absorption, Surfactants, *Sorbent-wood chips

"Petroleum was removed from the surface of water by treating the water with a sorbent, e.g. wood chips, and then with a 0.1-10.0% solution of a surfactant based on Oxyphos."

[from Chemical Abstracts 87(2):#11414k. 1977]

NWMAR116720

C-1782-77
ABSORBENT PRODUCTS FOR HYDROCARBONS
Porte, P. 1976.
U.S. Patent 3,990,970

Oil slicks, Spill recovery, Absorption, Patent

A pulp of an artificial or synthetic polymer, preferably a polyamide or polyester, is used as an absorbent for petroleum products spread on the surface of water. The pulp can be coated with 1 to 5% of its weight of a hydrophobic and oleophilic material especially a long chain paraffin or chlorinated paraffin.

[from Selected Water Resources Abstracts 10(13):#W77-06456. 1977]

C-1783-77
IMPROVEMENTS IN OR RELATING TO REMOVING OIL FROM BEACHES AND THE LIKE
Rogers, J. 1977.
British Patent 1,478,008

Spill recovery, Beaches, Dispersants, Surfactants, Patent

A stream of water is mixed with a dispersant composition consisting of a solution or suspension in an organic solvent of one or more surfactants (at least one of which is a gelling agent). The mixture is applied to the surface and subsequently permits rinsing of the surface to remove the mixture and contamination.

[from Petroleum Abstracts 17(33):#237,023. 1977]

C-1784-77
FLOTATION PURIFICATION OF SEAWATER BY REMOVING EMULSIFIED PETROLEUM PRODUCTS [in Russian]
Skrylev, L. D., V. K. Ososkov. 1977.
Khimicheskaya Tekhnologiya (Kiev) No. 1:50-51.

Oil-water separation, Emulsions, Seawater, Petroleum products, Flotation

A model emulsion of seawater contained 18 g/L mineral salts and 300-400 mg/L engine oil or diesel fuel dispersed in the form of particles with diameters of 7μ. This emulsion was subject either to pressure flotation at 5 atm or saturated with air dispersed by passage through porous material. The second method was more effective.

[from Chemical Abstracts 86(24):#176692s. 1977]

NWMAR116721

C-1785-77
PROCESS AND APPARATUS FOR RECOVERY OF A SHEET OF LIQUID FLOATING ON WATER
(Soc. Gen. Cons. Elec. Mec. Alst.). 1977.
Belgian Patent 822,629

Oil slicks, Spill recovery, Design and engineering, Patent

This process consists of passing both water and pollutant through a cyclone separation by means of a suction pump placed at the lower outlet of the polluted water.

[from Petroleum Abstracts 17(27):#235,295. 1977]

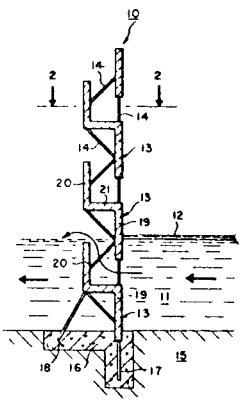
C-1786-77
SKIMMER FENCE
Stovall, L. F. 1977.
U.S. Patent 4,000,618

Spill recovery, Skimmers, Booms, Design-engineering, Patent

An apparatus for removing floating oil from flowing water is described. The device consists of a vertically-deployed, fence-like boom provided with a series of connected, vertical and horizontal baffles that form a number of flow passageways for the entrainment of oil.

[from Underwater Information Bulletin 9(4):39,#77/08/04. 1977]

4,000,618
SKIMMER FENCE
Leland F. Stovall, Corpus Christi, Tex., assignor to Exxon Production Research Company, Houston, Tex.
Filed Apr. 28, 1975, Ser. No. 572,556
Int. Cl.[2] E02B *3/00*
U.S. Cl. 61—1 F 3 Claims



NWMAR116722

C-1787-77
OIL ADSORBENT USEFUL FOR TREATMENT OF SPILLED OIL
Takahashi, R., T. Sone, and T. Hirata. 1977.
Japanese Kokai (unexamined patent application) 77 19,190

Spill cleanup, Adsorption, Gasoline, Fuel oil, Patent

An oil adsorbent is made by mixing a block copolymer with oil, olefin monomer, copolymer, or filler, and then foaming. The resulting foam has oil-adsorbing capacities of 0.30, 0.35, and 0.41 g/cm3 for gasoline, kerosene, and fuel oil, respectively.

[from Chemical Abstracts 87(6):#43818m. 1977]

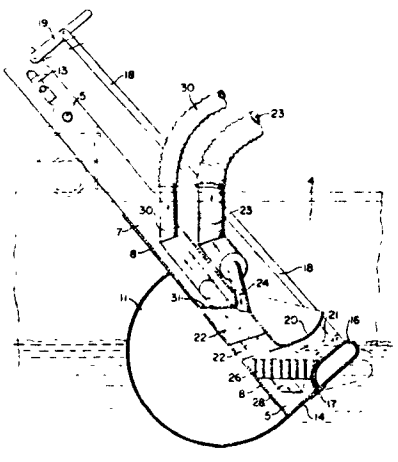
C-1788-77
APPARATUS FOR REMOVAL OF OIL FILMS FROM WATER
Tsunoi, I. 1977.
U.S. Patent 4,006,086

Oil slicks, Spill recovery, Skimmers, Ships, Design-engineering, Patent

The apparatus comprises a floating elongate chamber which is pivotably supported between the hulls of a catamaran-type ship. The forward end of the chamber has an inlet opening behind which an adjustable weir and an inclined, horizontal plate serve to capture the oil film. Two separate pump and conduit arrangements remove water and oil respectively from the chamber.

[from Underwater Information Bulletin 9(4):42,#77/08/39. 1977]

4,006,086
APPARATUS FOR REMOVAL OF OIL FILMS FROM WATER
Ikuo Tsunoi, Yokohama, Japan, assignor to Kabushiki-Kaisha Kyoei Senpaku Kogyo, Yokohama, Japan
Filed May 14, 1975, Ser. No. 577,554
Claims priority, application Japan, July 1, 1974, 49-75217
Int. Cl.² E02B 15/04
U.S. Cl. 210—242 R 2 Claims



NWMAR116723

C-1789-77
A TOWED PLANING HULL SLED FOR FAST SURFACE DELIVERY OF POLLUTION CONTROL EQUIPMENT (product information)
Ward, R. S., and R. M. Larrabee. 1977.
Naval Engineers Journal 89(2):129-137.

Pollution control, USCG, *Equipment, *Fast Surface Delivery System

A Fast Surface Delivery System was developed for the USCG for use in pollution control at sea. The all-aluminum sled, towable by helicopter and surface vessel, can deliver a 9.1 metric ton (20,000 lb) payload and be unloaded manually at sea.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10451. 1977]

C-1790-77
ABSORBENTS, BURNING AND GELLING
Wardley-Smith, J. 1976.
The Control of Oil Pollution on the Sea and Inland Waters.
J. Wardley-Smith (ed.). London, Graham & Trotman Ltd., 1976.
p.141-159.

Spill cleanup, Absorption, Incineration, *Gelling agents

The cleanup of oil spills by using absorbent materials, combustion, and gelling agents that immobilize oil is described, and the efficacy of each method is assessed. Suitable absorbents include inorganic materials like vermiculite, natural organic material such as peat and straw, and synthetics including polyethylene foams and fibres. Combustion of oil spills is not satisfactory in most situations and does not represent a successful method. The gelling of oil products to facilitate handling or to prevent a spill from spreading has been tested and applied successfully but is too expensive for large-scale application.

C-1791-77
SEA AND FRESHWATER SPILLS
Wardley-Smith, J. 1976.
The Control of Oil Pollution on the Sea and Inland Waters.
J. Wardley-Smith (ed.). London, Graham & Trotman Ltd., 1976.
p.181-202.

Spill cleanup, Dispersants, Absorption, Disposal, Coasts, Marshes, Beaches, Seawater, Freshwater

The most suitable methods available for oil spill cleanup along the shore and on beaches include mechanical removal and the use of dispersants and absorbents. The methods for removing oil from swamps, mud flats, sandy and rocky beaches, large rocks, cliffs and manmade structures, and inland spills are briefly described. The disposal of oil contaminated beach material remains a difficult problem; disposal methods on land should be used which assure biodegradation.

NWMAR116724

3. RESTORATION

C-1792-77
CLEANING AGENTS FOR OILED WILDLIFE
Berkner, A. B., D. C. Smith, and A. S. Williams. 1977.
Ecolibrium 6(3):15-19.

Restoration, Wildlife, Oil spills, Surfactants, Solvents, Toxicity

The advantages and limitations of detergents and solvents in saving oiled wildlife are discussed with respect to the type of wildlife affected, the types of oil involved, and the treatment facilities and equipment available. Several commercial detergents are compared for their cleansing ability, optimal concentrations, and toxicity and/or side effects.

C-1793-77
CHANGES IN VEGETATION OF AN OILED SOUTHAMPTON WATER SALT MARSH
Dicks, B. 1977.
Recovery and Restoration of Damaged Ecosystems. J. Cairns, Jr., K. L. Dickson, and E. E. Herricks (eds.). Charlottesville, University Press of Virginia, 1977. p.208-240. Proceedings of the International Symposium on the Recovery of Damaged Ecosystems, Blacksburg, Virginia, March 23-25, 1975.

Restoration, Vegetation, Marshes, Contamination, Wastewaters, Refineries, England, *Salt marsh

Progressive damage was incurred in a salt marsh in Southampton Water, Hampshire, England, due to effluent that was discharged from a refinery between 1951 and 1970. An area 1000 m by 600 m had been denuded of vegetation. This appears to have been a result of repeated contamination of the marsh by oil films. The pattern of recolonization of damaged areas is discussed.

C-1794-77
RECOVERY OF SOME BRITISH ROCKY SEASHORES FROM OIL SPILLS AND CLEANUP OPERATIONS
Nelson-Smith, A. 1977.
Recovery and Restoration of Damaged Ecosystems. J. Cairns, Jr., K. L. Dickson, and E. E. Herricks (eds.). Charlottesville, University Press of Virginia, 1977. p.191-207. Proceedings of the International Symposium on the Recovery of Damaged Ecosystems, Blacksburg, Virginia, March 23-25, 1975.

Restoration, Shorelines, Oil spills, Biological effects, Mollusks, Algae, *Rocky shores, England

The effects of oil spills of varying severity are described. The most striking result is a reduction in the numbers of

NWMAR116725

grazing mollusks, especially limpets, resulting in successive blooms of green and brown algae. Recovery periods varied from up to 7 years after a major crude-tanker wreck to virtually no time after a small spill of heavier oils. Chronic pollution by an oily refinery effluent has modified the balance of shore populations so that complete recovery can never occur.

4. OIL TRANSFER AND TRANSPORT

C-1795-77
TANKERS DISMISSED IN U.S. OIL STORAGE PLAN
Baron, V. C. 1977.
Seatrade 7(4):116.

Tankers, Storage, Crude oil, Environmental protection, FEA

The Petroleum Reserve Plan of the U.S. Federal Energy Administration indicates that FEA's program for long-term crude oil storage will not use tankers. FEA requires storage facilities that are feasible, environmentally acceptable, cost competitive, capable of storing large volumes, and near to pipeline and seaport distribution systems. There are a wide range of pollution prevention and maintenance considerations as well which would raise the costs of using tanker storage.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10842. 1977]

C-1796-77
OIL STORAGE TANK
Bell, A. O., and J. C. Feben. 1977.
British Patent 1,467,238

Storage, Tankers, Design and engineering, Patent, *Oil storage tank

A marine structure for storing oil and for providing a mooring for a tanker is described. The tank controls the flow rate of the oil and allows for discharging water from it. Buoyance is controlled through an air and water discharging system between the tank's inner and outer walls.

[from Petroleum Abstracts 17(23):#234,020. 1977]

NWMAR116726

C-1797-77
CRUDE OIL TRANSPORTATION SYSTEM: VALDEZ, ALASKA TO MIDLAND, TEXAS (AS PROPOSED BY SOHIO COMPANY) - CHAPTERS 1-9
Bureau of Land Management. 1976.
U.S. Bureau of Land Management Draft Environmental Impact Statement. 2233p.

Oil transport, Pipelines, Alaska, Texas, EIS, Crude oil, Oil spills

A pipeline east of the Rocky Mountains is proposed by Standard Oil Co. of Ohio to transport Alaskan crude oil, to relieve the prospective regional crude supply and demand imbalance, and to reduce dependence on foreign crude oil imports. Such a project would reduce the threat of oil spills into the ocean as it would reduce the transport of oil by sea.

[from Energy Information Abstracts 2(2):#77-21489. 1977]

C-1798-77
STRATEGIC PETROLEUM RESERVE.
Federal Energy Administration. 1976.
Final Environmental Impact Statement, FEA/S-76/487-Vol-1; FES-76/2-Vol-1. 583p.

Crude oil, Storage, Environmental effects, EIS, *Salt domes, Oil tanks, *Strategic Petroleum Reserve

Underground storage of crude oil in solution-mined salt domes and conventional mines, and above ground storage in tanks have been proposed as a strategic petroleum reserve. This final environmental impact statement identifies particularly sensitive environmental parameters that are investigated in greater detail in site-specific environmental impact statements.

[from Scientific and Technical Aerospace Reports 15(13):#N77-22675. 1977]

C-1799-77
STRATEGIC PETROLEUM RESERVE
Federal Energy Administration. 1976.
Final Environmental Impact Statement, FEA/S-76/488-Vol-2; FES-76/2-Vol-2. 273p.

Crude oil, Storage, Environmental effects, EIS, *Salt domes, *Mines, *Strategic Petroleum Reserve

"Comments on the programmatic environmental impact statement (Volume 1) from federal, state, and local agencies and private industry concerning storage of crude oil underground in solution - mined salt cavities and in conventional mines are presented."

[from Scientific and Technical Aerospace Reports 15(13):#N77-22676. 1977]

NWMAR116727

C-1800-77
STRATEGIC PETROLEUM RESERVE. BAYOU CHOCTAW SALT DOME
Federal Energy Administration. 1977.
Supplement to Final Environmental Impact Statement, FEA/S-77/129, FES 76-5. 175p.

Crude oil, Storage, Environmental effects, EIS, Louisiana, *Bayou Choctaw Salt Dome

This site-specific EIS Supplement analyzes the environmental impacts caused by site preparation and operation of the proposed St. James oil distribution system, and compares these impacts with those associated with the Addis distribution system considered in the final EIS.

[from Petroleum Abstracts 17(30):#235,912. 1977]

C-1801-77
HOW TO MAKE TANKERS SAFER
Mayer, A. J., et al. 1977.
Newsweek 89(3):60-61.

Oil transport, Tankers, Safety, *Standards, *Accident prevention

The record-breaking rash of accidents involving commercial tankers is likely to result in the imposition of tough new safety standards. Double hulls, segregated ballast, backup systems, and collision-avoidance radar should be standard equipment on all commercial oil tankers, especially supertankers which are considered to be immediately hazardous, difficult to control, and astonishingly fragile.

[from Environment Abstracts 7(5/6):#77-03156. 1977]

C-1802-77
TRANSPORT OF MINERAL OIL COMPONENTS TO GROUNDWATER. PT. 2. INFLUENCE OF LIME, CLAY AND ORGANIC SOIL COMPONENTS ON THE RATE OF TRANSPORT
van der Waarden, A., W. M. Groenewoud, and A.L.A.M. Bridie. 1977.
Water Research 11(4):359-365.

Oil transport, Groundwater, Adsorption, *Lime, *Clay, *Soil components

The adsorption of a model compound and of oil components on lime, clay, and organic soil components is discussed. It is demonstrated that adsorption may reduce the total amount of oil transport to groundwater, reduce concentrations, and delay transport.

[from Petroleum Abstracts 17(27):#235,271. 1977]

NWMAR116728

5. WASTE TREATMENT AND DISPOSAL METHODS

C-1803-77
EVAPORATION AND THERMAL OXIDATION OF LIQUID EFFLUENTS - BY BURNING WITH FLAME IN COMBUSTION CHAMBER
(Inventor unknown). 1976.
French Patent 2,302,483

Wastewater treatment, Refineries, Evaporation, Incineration, Patent, *Thermal oxidation

This process provides for the treatment of effluents containing toxic products from refineries and plants which chemically treat petroleum products. A continuous evaporation process is created and combustible substances are burned and eliminated by thermal oxidation. The effluent is vaporized by convection currents in the combustion chamber. Solid wastes can be burned along with the effluent products by mixing with the fuel.

[from Selected Water Resources Abstracts 10(15):#W77-07227. 1977]

C-1804-77
AN ECONOMIC CASE STUDY OF WASTE OIL AND ITS WIDER SIGNIFICANCE
Anon. 1977.
Solid Wastes 67(2):86-87.

Waste oil disposal, Storage, Economics, UK

About 65,000 tons of reasonably high quality waste oil are wasted each year in the United Kingdom alone. This study concludes that the costs of providing waste oil storage and collection centers are not likely to be small, but would reduce the illegal disposal of oil by motorists and industry.

[from Pollution Abstracts 8(4):#77-03514. 1977]

C-1805-77
FLOTATION MACHINE (product information)
Anon. 1977.
Water & Pollution Control 115(4):30.

Wastewater treatment, Oil-water separation, Emulsions, Flotation, Design and engineering

The Wemco Hydrocleaner flotation machine, which separates oil, solids, and organic matter from wastewater, is described. The system can clean wastewaters containing up to 50,000 ppm oil, depending on type of oil and emulsion, leaving an effluent with typically less than 10 ppm oil. The Wemco Hydrocleaner is available from Envirotech Canada, Ltd., 5155 Creek Bank Road, Mississauga, Ontario, Canada.

NWMAR116729

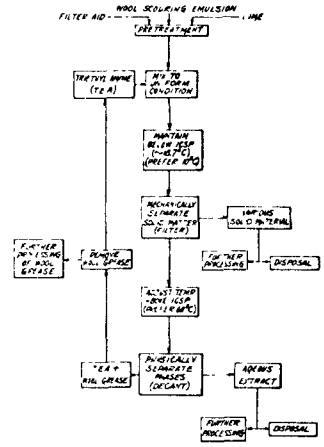
C-1806-77
OIL EMULSION PROCESSING
Ames, R. K., and H. H. Peters. 1977.
U.S. Patent 4,002,562

Oil-water separation, Emulsions, Patent, *Amine addition

A method for separating oil-water emulsions that contain solids is described. The emulsion is mixed with one or more amines in which the oily component is soluble and exhibits an inverse critical solution point in a 2-phase system with water such that the mixture forms a single, continuous liquid phase. Heating to just below the critical solution point removes the solids and amine(s); further heating separates the oil and water phase.

[from Chemical Abstracts 87(2):#8036h. 1977]

4,002,562
OIL EMULSION PROCESSING
Robert K. Ames, Seattle, and Hans H. Peters, Federal Way, both of Wash., assignors to Resources Conservation Co., Renton, Wash.
Filed Sept. 18, 1975, Ser. No. 614,511
Int. Cl.[2] B01D *17/04*
U.S. Cl. 210—22 R 11 Claims



C-1807-77
THE TREATMENT OF WASTE EMULSIFIED OILS BY ULTRAFILTRATION
Bailey, P. A. 1977.
Filtration and Separation 14(1):53-55.

Waste oil treatment, Emulsions, Filtration, *Ultrafiltration

A semi-permeable membrane of polymeric materials was used to treat the waste oils. Under slight pressure, emulisified oil particles are retained while water molecules pass through. The principles of the method and factors which affect its performance were explored. Advantages for ultrafiltration include: little required pretreatment, no necessary chemical additions or heat input, little need for further treatment of water, no sludge formation, and an oil concentrate capable of supporting combustion. About 100 plants have installed this treatment system.

[from Selected Water Resources Abstracts 10(13):#W77-06221. 1977]

NWMAR116730

C-1808-77
ULTRAFILTRATION-THE CURRENT STATE OF THE ART
Bailey, P. A. 1977.
Filtration and Separation 14(3):213-219.

Wastewater treatment, Industries, Filtration, Oil-water separation, Emulsions, *Ultrafiltration

The ultrafiltration process is described and ten major industrial applications of the process are reviewed, including the separation of oil-water emulsions and wastewaters.

[from the UDS Quality Control Digest 8(4):III-29, #7E-131. 1977]

C-1809-77
PROCEDURE AND INSTALLATION TO COLLECT A LIGHT FLOATING MATERIAL FROM A FLUID SURFACE
(Ballast Nedam Groep NV). 1975.
Netherlands Application 7,510,152

Wastewater treatment, Waste oil, Design and engineering, Patent, *Collection reservoir

A light material such as oil is carried into a collection reservoir by the force of a fluid jet stream. The oil floats upward in the reservoir and heavier fluid is removed via exits close to the lower part of the collection reservoir.

[from Petroleum Abstracts 17(35):#237,687. 1977]

C-1810-77
APPARATUS FOR SEPARATING OIL AND SOLIDS FROM WATER
Barra, F. J., and K. R. Murrell. 1976.
Canadian Patent 995,591

Wastewater treatment, Filtration, Oil-water separation, Patent

A multichamber filtering apparatus is described which removes oil-coated solids from water, separates the solids, and recovers the oil.

[from Chemical Abstracts 86(26):#194680r. 1977]

NWMAR116731

C-1811-77
TREATMENT OF OIL-IN-WATER EMULSIONS BEFORE AND/OR DURING ULTRAFILTRATION
Beaton, N. C., and J. D. Hasledon. 1977.
British Patent 1,475,745

Oil-water separation, Emulsions, Filtration, Patent, *Ultrafiltration

An emulsion stabilizer is added to the oil-in-water emulsion and subsequently the stabilized emulsion is subjected to ultrafiltration to produce a purified ultrafiltrate.

[from Petroleum Abstracts 17(30):#235,882. 1977]

C-1812-77
FLUID BED INCINERATION OF WASTES
Becker, K. P. and C. J. Wall. 1976.
Chemical Engineering Progress 72(10):61-68.

Wastewater disposal, Sludge, Refineries, Incineration, *Fluid beds

Fluid bed incineration systems, originally developed for coal gasification, are now being applied to waste disposal problems in various industries. The article discusses applications of this technology to refinery wastewater and sludge treatment.

[from Environment Abstracts 7(4):#77-02593. 1977]

C-1813-77
PERFORMANCE OF DUAL-MEDIA - 1
Brody, M. A., and R. J. Lumpkins. 1977.
Chemical Engineering Progress 73(4):83-86.

Wastewater treatment, Oil-water separation, Filtration, Refineries, Pennsylvania, *Sand filters

The BP Oil Corporation's Marcus Hook, Pennsylvania, oil refinery is described with regard to its use of sand filters for treating refinery wastewaters. Since their installation in 1973, the sand filters have performed well, needing little maintenance and averaging about 60% removal of oil and suspended solids.

NWMAR116732

C-1814-77
EVALUATING COALESCENCE OF OIL EMULSIONS
Chieu, J. N., E. F. Gloyna, and R. S. Schechter. 1977.
Journal of the Environmental Engineering Devision, ASCE 103 (EE2):163-175. Proceedings paper 12852.

Wastewater treatment, Emulsions, Coalescence, Waste oil

The basic concepts of a laboratory unit which can be used to select filter media suitable for the coalescence of oil-water emulsions are described. System variables studies include media wettability, filtration velocity, interfacial tension, coalescer depth, and oil viscosity.

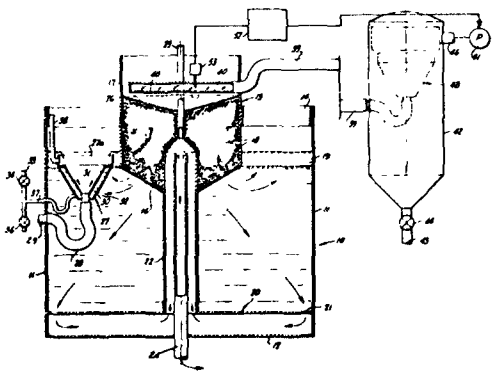
C-1815-77
OIL-WATER SEPARATION PROCESS AND APPARATUS
Cook, D. G. 1977.
U.S. Patent 4,011,158

Oil-water separation, Ships, Coalescence, Flotation, Design and engineering, Patent

Oily wastewaters are passed through a coalescer unit where small oil droplets combine into larger ones and coalesce into a floating layer that is removable by conventional means. The apparatus is designed to accommodate for pitching and rolling movement so that the unit can be used for shipboard oil-water separation applications.

[from Chemical Abstracts 86(26):#194683u. 1977]

4,011,158
OIL-WATER SEPARATION PROCESS AND APPARATUS
Danny G. Cook, Walnut Creek, Calif., assignor to Liquid Processing Systems, Inc., San Leandro, Calif.
Continuation-in-part of Ser. No. 465,168, April 26, 1974, abandoned. This application May 23, 1975, Ser. No. 580,537
Int. Cl.[2] B01D *13/00*
U.S. Cl. 210—23 R 10 Claims



NWMAR116733

C-1816-77
EXTRACTION OF CHEMICAL POLLUTANTS FROM INDUSTRIAL WASTEWATERS WITH VOLATILE SOLVENTS
Earhart , J. P., K. W. Won, C. J. King, and J. M. Prausnitz. 1976. Final report 1971-1975, EPA/600/2-76/220; Grant EPA-R-801030. 531p.

Wastewater treatment, Refineries, Contaminants, Extraction, Solvents

Solvent extraction was studied as a method for treating wastewaters from petroleum refineries and petrochemical plants. A miniplant extraction facility was used to demonstrate the capabilities of extraction for treating 7 different industrial waters and for the purpose of analyzing the underlying mass transfer and axial mixing behavior. The scale-up of the extraction system and the logic of selecting extraction processes for wastewater treatment are explored.

[from Government Reports Announcements 77(15):#PB-266 241/9GA. 1977]

C-1817-77
RECOVERY OF ORGANIC POLLUTANTS VIA SOLVENT EXTRACTION
Earhart , J. P., K. W. Won, H. Y. Wong, J. M. Prausnitz, and C. J. King. 1977.
Chemical Engineering Progress 73(5):67-73.

Wastewater treatment, Refineries, Petrochemicals, Hydrocarbons, *Solvent extraction

Solvent extraction, using light hydrocarbon solvents, was applied experimentally to the treatment of seven real wastewaters from petroleum refining and petrochemical manufacture. Results of the experiments are briefly summarized in this report and demonstrate the usefulness of this method for removing many or all major contaminants, including oil.

C-1818-77
THE REPORT TO CONGRESS: WASTE DISPOSAL PRACTICES AND THEIR EFFECTS ON GROUND WATER
Environmental Protection Agency, Office of Water Supply. 1977. Final report, EPA/570/9-77/001. 531p.

Contaminants, Crude oil, Industries, Disposal, Groundwater, Environmental effects

This document was prepared pursuant to a section of the Safe Drinking Water Act and is an evaluation of the impact of waste disposal practices upon present and future underground sources of drinking water. The sources and pathways of pollutant substances, including crude oil, are identified.

[from Government Reports Announcements 77(13):#PB-265 081/0GA. 1977]

NWMAR116734

C-1819-77
RADIOTRACER APPLICATIONS IN PETROLEUM REFINERY POLLUTION CONTROL
Fries, B. A. 1976.
International Symposium on the Development of Nuclear-based Techniques for the Measurement, Detection and Control of Environmental Pollutants, Vienna, Austria, 1976. p.609-619.

Wastewaters, Refineries, Pollution control, *Radiotracer applications

Radiotracer procedures are probably the best way to measure flow and to study hydraulic behavior; therefore they can assist in measuring the quantities of emissions, studying the control systems, and diagnosing operating problems in petroleum refineries and petrochemical plants. Case studies are presented.

[from ERDA Energy Research Abstracts 2(12):#28693. 1977]

C-1820-77
COMPOSITION OF MICROFLORA OF ACTIVE SLUDGES PURIFYING WASTE WATERS FROM PETROLEUM REFINERIES AT ELEVATED TEMPERATURES [in Russian]
Gasanov, M. V., L. M. Kirillova, and R. M. Subaeva. 1976.
Trudy, Bakinskii Filial Vsesoyuznogo Nauchno-Issledovatel'skogo Instituta Vodosnabzheniya, Kanalizatsii, Gidrotekhnicheskikh Sooruzhenii i Inzhenernoi Gidrogeologii 12:9-12.

Wastewater treatment, Biodegradation, Activated sludge, Refineries

Biochemical purification was optimal at 37°. The predominant microorganism in the activated sludge was Nitrobacter.

[from Chemical Abstracts 87(8):#57968x. 1977]

C-1821-77
ELIMINATION OF OBVIOUS AND LATENT OILS
Gassmann, G. and W. Gunkel. 1977.
German Offenlegungsschriften (unexamined patent application) 2,533,775

Wastewaters, Spill cleanup, Biodegradation, Patent, *H_2O_2

H_2O_2 was added in concentrations from 0.1 to 10% to polluted areas to accelerate biological degradation of oils. H_2O_2 is useful in locations with limited air access, but may also be used on beaches and in open spaces. It is advantageous to add nitrogen and phosphorus nutrients and surfactants.

[from Chemical Abstracts 86(24):#176780u. 1977]

NWMAR116735

C-1822-77
OPTIMIZING GRANULAR MEDIA FILTRATION
Grutsch, J. F., and R. C. Mallatt. 1977.
Chemical Engineering Progress 73(4):57-66.

Wastewater treatment, Refineries, Filtration

"Chemical destabilization of colloids followed by granular media filtration is a valuable method for treating petroleum refinery effluents."

[from Chemical Abstracts 87(6):#43667m. 1977]

C-1823-77
REMOVING OIL PRODUCTS FROM WASTE WATERS BY FLOCCULATION
Gudasheva, V. M., L. A. Alferova, I. L. Mongait, and V. G. Ponomarev. 1977.
USSR Patent 545,590

Wastewater treatment, Petroleum products, Oil-water separation, Flocculation, Patent

"Polyethylenimine was added (2-5 mg/L) as a flocculant to remove oil products from wastewater."

[from Chemical Abstracts 86(22):#160741w. 1977]

C-1824-77
OIL-SEPARATING AGENT FROM EMULSION-LIKE OIL-WATER MIXTURES
Hagiwara, M., M. Mori, S. Nakai, and T. Kishima. 1977.
Japanese Kokai (unexamined patent application) 77 45,593

Oil-water separation, Emulsions, Crude oil, Patent

The agents contain ester or ether derivatives of poly(oxyalkylene) mono(alkylphenyl) ether-HCHO condensation products. When mixed with an oil-water mixture (90% crude oil), 9.5% water was separated after settling and centrifugation.

[from Chemical Abstracts 87(6):#41642a. 1977]

C-1825-77
TECHNIQUES FOR PURIFYING OILY WASTE WATER
Hale, L. C., and D. Bauer. 1977.
Plant Engineering, March 17:131-133.

Wastewater treatment, Oil-water separation, Pollution prevention, Refineries, Waste oil

Alternate recovery methods for removing oily wastes from several industrial effluents were reviewed. Refinery wastes are usually treated in gravity-type separators and then further treated in induced-air flotation units.

[from Selected Water Resources Abstracts 10(15):#W77-07213. 1977]

NWMAR116736

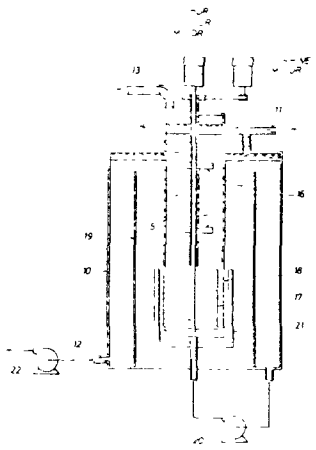
C-1826-77
METHOD AND APPARATUS FOR CONTINUOUSLY SEPARATING EMULSIONS
Heath, J. E., and W. M. Sawyer. 1977.
U.S. Patent 4,017,389

Oil-water separation, Emulsions, Coalescence, Patent, *Cellulose pulp

Cellulose pulp is used to effect coalescence in an oil-in-water emulsion. The emulsion is filtered from one chamber to another for two coalescences, and the floating oil is removed from each chamber.

[from Chemical Abstracts 87(8):#58154r. 1977]

4,017,389
METHOD AND APPARATUS FOR CONTINUOUSLY SEPARATING EMULSIONS
James E. Heath, and Webster M. Sawyer, both of Houston, Tex., assignors to Shell Oil Company, Houston, Tex.
Filed June 6, 1975, Ser. No. 584,450
Int. Cl.2 B01D *17/04*
U.S. Cl. 210—23 R 3 Claims



C-1827-77
APPARATUS FOR SEPARATING OIL, FAT, GASOLINE AND SIMILAR LIGHT MEDIA AS SLUDGE FROM LIQUIDS
Hein, M. 1976.
Austrian Patent 332,317

Oil-water separation, Sludge, Gasoline, Wastewaters, Design and engineering, Patent

Oil and sludge are separated from wastewater by an apparatus which is mounted on a vertical outlet pipe and has a funnel for introducing the mixture into a separation zone. This zone consists of a set of cylindrical partitions that form a zigzag path for the water. Water is siphoned to the outlet pipe and oil and sludge are collected periodically.

[from Chemical Abstracts 87(2):#11125s. 1977]

NWMAR116737

C-1828-77
SEPARATION OF OIL FROM WATER
Hoketsu, H. 1976.
Japanese Kokai (unexamined patent application) 76,151,689

Oil-water separation, Coagulation, Patent, *Plastics powder

Plastics powder is dusted on oil on water and vibrated mechanically to coagulate the oil to balls.

[from Chemical Abstracts 86(24):#176790x. 1977]

C-1829-77
WATER-OIL SEPARATION FROM WATER-CONTAINING WASTE OIL
Ikeguchi, M., N. Kawakami, Y. Nagata, H. Nakagaki, and H. Ono. 1976.
Japanese Kokai (unexamined patent application) 76 96,785

Waste oil treatment, Oil-water separation, Surfactants, Patent

A coal tar-system waste oil containing water is mixed with anionic surfactants, agitated, and then centrifuged for separation.

[from Chemical Abstracts 87(4):#28545b. 1977]

C-1830-77
WASTEWATER TREATMENT AND OIL RECLAMATION AT GENERAL MOTORS, ST. CATHARINES
Johnson, R. E., Jr. 1976.
Ontario Industrial Waste Conference, Ontario, 1976. No. 23. p.345-357.

Wastewater treatment, Industries, Oil-water separation, Reclamation, Reuse, Canada

The treatment of liquid wastes from the General Motors Axle Plant in Ontario is described. Wastewaters are sieved to remove solids, allowed to stand two days to allow oils to separate, and the separated oil is then skimmed off. The pH of the emulsified oil is adjusted to 4.5 with H_2SO_4 and aluminum, and the precipitated flocculant is separated from the water using streams of air and a polyelectrolyte. The recovered oil can be refined and reused.

[from Chemical Abstracts 86(22):#160600z. 1977]

NWMAR116738

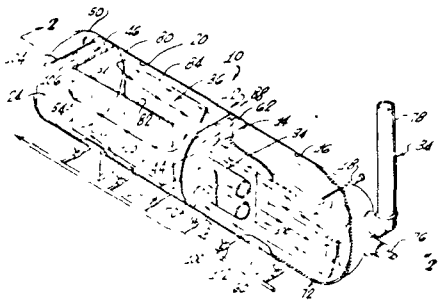
C-1831-77
EMULSION TREATER
Jones, J. A. 1977.
U.S. Patent 4,012,207

Emulsions, Crude oil, Oil-water separation, Patent

A crude oil-water emulsion such as that produced from oil wells is treated by passing the emulsion through a treatment tank which contains a preheating, direct heating, and post-heating zone. Vapor is removed at the top and water is removed at the bottom. A final settling and oil recovery zone completes the separation process.

[from Petroleum Abstracts 17(28):#235,496. 1977]

4,012,207
EMULSION TREATER
Jeffrey A. Jones, Taft, Calif., assignor to Chanslor-Western Oil and Development Company, Sante Fe Springs, Calif.
Filed Apr. 5, 1976, Ser. No. 673,588
Int. Cl.[2] B01D *19/00*
U.S. Cl. 55—174 22 Claims



C-1832-77
TREATMENT OF WASTE WATER CONTAINING EMULSIFIED OIL
Kanamori, M. 1977.
Japanese Kokai (unexamined patent application) 77 25,455

Wastewater treatment, Emulsions, Oil-water separation, Oxidation, Adsorption, Patent

Oily wastewater is mixed with ferrous salt, neutralized with alkali, and oxidized at high temperature. An oxidizing gas is blown into the mixture to produce Fe oxide, which adsorbs the emulsified oil.

[from Chemical Abstracts 87(4):#28619d. 1977]

NWMAR116739

C-1833-77
SEPARATION OF OIL FROM WASTE WATER
Kawaguchi, N., and H. Shibata. 1977.
Japanese Kokai (unexamined patent application) 77 11,179

Wastewater treatment, Oil-water separation, Patent, *Popcorn polymer

Wastewater containing tar-type heavy oil was passed through a tower packed with an oil-absorbed popcorn styrene copolymer and fed into a separation tank. Oil and water phases occurred rapidly in separation.

[from Chemical Abstracts 87(4):#28588t. 1977]

C-1834-77
PERFORMANCE OF DUAL-MEDIA FILTERS - 2
Kempling, J. C., and J. Eng. 1977.
Chemical Engineering Progress 73(4):87-91.

Wastewater treatment, Oil-water separation, Filtration, Refineries, Canada, *Dual-media filters

Based on successful pilot plant simulation of dual media filtration, a full-scale wastewater filtration facility was installed at the Imperial Oil refinery in Sarnia, Ontario, in 1974. Twenty months of operation of the full scale filtration system have shown that the filters remove an average of 1.5 tons/day of oil and suspended solids from the refinery wastewaters.

C-1835-77
REMOVAL OF ORGANIC SUBSTANCES FROM PETROLEUM-CONTAINING WASTE WATERS
Khaimovich, B. N., N. F. Bezuglyi, N. P. Kobyzev, and A. F. Taratunin. 1977.
USSR Patent 301,053

Wastewater treatment, Flotation, Patent, *Tetraethylead removal

"For removal of tetraethylead waste waters are first treated by flotation and $KMnO_4$ is added at 0.2-1g/L."

[from Chemical Abstracts 87(2):#11160z. 1977]

NWMAR116740

C-1836-77
WASTE WATER TREATMENT AND SOLID WASTE DISPOSAL IN THE PETROLEUM INDUSTRY
Kieli, J. 1977.
Prace Naukowe Instytutu Inzynierii Ochrony Srodowiska Politechniki Wroclawskiej 32:143-162.

Wastewater treatment, Solid wastes, Refineries, Poland

This paper discusses waste purification methods for refinery plants in Poland.

[from Chemical Abstracts 87(4):#28508s. 1977]

C-1837-77
DEVELOPMENT STAGE OF SEWAGE PURIFICATION IN PETROLEUM PROCESSING AND PETROLEUM CHEMISTRY IN THE GDR [in German]
Kinder, R., and K. Gabsch. 1976.
Freiberger Forschungshefte A566:75-92.

Refineries, Oil industry, Petrochemicals, Wastewater treatment, East Germany

Methods which have been developed to meet international standards of effluent treatment in the petroleum and petrochemical industries are discussed. Cost-effective methods include mechanical clarification, flocculation, and biological activated sludge treatment.

[from Chemical Abstracts 87(2):#11053s. 1977]

C-1838-77
APPARATUS AND METHOD FOR SEPARATING IMPURITIES FROM WATER USING ULTRASONICS
Koblanski, J. N. 1977.
German Offenlegungsschriften (unexamined patent application) 2,641,330

Oil-water separation, Coalescence, Patent, *Ultrasonics

Oil floating on water can be coalesced into a continuous mass that can be drawn off by focusing ultrasonic energy on the oil-water interface. The ultrasonic energy is focused by a submerged parabolic surface toward a point at which the coalesced oil enters a separate holding chamber.

[from Chemical Abstracts 86(26):#195038z. 1977]

NWMAR116741

C-1839-77
HIGH EFFICIENCY OIL/WATER SEPARATION
Lock, J. 1976.
Processing 22(10):41.

Wastewater treatment, Oil-water separation, Coalescence, Design and engineering

The Flofoil oil-water separation process, developed by ICI Pollution Control Systems, is described. The process can remove oil droplets larger than 10μ with 97-99.6% efficiency to less than 1 ppm concentration; oil droplets smaller than 10μ can be removed with 30-60% efficiency to concentrations under 5 ppm. The system is based on the use of special coalescence filters and fabrics that are incorporated into an oil-water separator unit.

C-1840-77
TRANSFER OF ORGANICS FROM AN OIL FILM INTO WATER
Lysyj, I., and E. C. Russell. 1977.
Fate of Pollutants in the Air and Water Environments, Part 1.
I. H. Suffet (ed.). New York, Wiley, 1977. p.135-144.

Wastewaters, Oil discharges, Fuel oil, Gasoline, Lubricating oil, Monitoring, Environmental effects, *Dissolved organics

Total organic carbon analyses were performed on fuel oils, gasolines, and lubricating oils in this study concerned with monitoring and control of oily wastewater discharges. Conclusions report that the observed concentrations of water soluble petroleum derived organics exceed the "no visual sheen" limit for free oil, which is approximately 10 ppm; therefore, the discharge of oily wastewater containing dissolved petroleum matter could have adverse environmental effects. It is suggested that additional chemical and toxicological data are needed in order to establish regulations and limitations of dissolved oil in waste discharges.

C-1841-77
OIL/WATER SPLITTER SNAGS EMULSIFIED OIL (product information)
Mapco, Inc. 1977.
Chemical Engineering 84(15):77.

Oil-water separation, Wastewater treatment, Coalescence, Design and engineering, *Gravity separation

A combined gravity separation and coalescence oil/water separation system has been developed by the Mapco Process and Pollution Controls Division, Tulsa, Oklahoma. The model is available in 227-5,678 L/min (60-1500 gal/min) capacities; removes oil from a wide range of wastewater streams; and recovers floating, dispersed, and emulsified oil.

NWMAR116742

C-1842-77
BIOLOGICAL METHODS FOR DETOXICATION OF REFINERY AND PETROCHEMICAL WASTE WATERS [English summary]
Miksch, K. 1977.
Przemysl Chemiczny 56(2):67-70.

Petrochemicals, Refineries, Wastewater treatment, *Biological detoxication

"A reivew with 38 references."

[from Chemical Abstracts 86(26):#194451s. 1977]

C-1843-77
DESIGNING PARALLEL-PLATES SEPARATORS
Miranda, J. G. 1977.
Chemical Engineering 83(3):105-107.

Wastewater treatment, Refineries, Oil-water separation, *Parallel plate separators

A method has been developed for designing parallel plate separators which overcome the problems encountered in using API type oil-water separators for petroleum refinery effluents. The parallel plates interceptor (PPI) minimizes difficulties associated with space requirements, evaporation losses, construction cost, fire hazard, and high stream consumption. A theoretical design approach to the PPI is presented.

[from Selected Water Resources Abstracts 10(13):#W77-06222. 1977]

C-1844-77
FILTRATION & SEPARATION: REMOVING COLLOIDAL SOLIDS VIA UPFLOW FILTRATION
Mohler, E. F., Jr., and L. T. Clere. 1977.
Chemical Engineering Progress 73(4):74-82.

Wastewater treatment, Refineries, Filtration, Solid wastes, Design and engineering, Ohio, *Upflow sand filters

In 1972, the Sun Petroleum Company's Toledo, Ohio refinery installed a fully automatic upflow sand filtration system. After in-house improvements to the system, it now meets the 80% suspended solids removal guarantee and also removes significant quantities of other pollutants, including oil. In addition, the system enables the reuse of process waters and has dramatically decreased the amount of wastewaters discharged per barrel of crude oil processed.

NWMAR116743

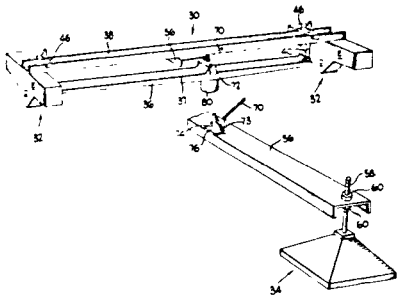
C-1845-77
AUTOMATIC OIL-WATER SEPARATION DEVICE
Morgan, J. E., W. M. Lynch, and P. M. Pelton. 1977.
U.S. Patent 4,010,103

Oil-water separation, Skimmers, Design and engineering, Flotation Patent

The device is used within a tank for skimming the oil off the top of the water and then collecting it in a container. Included is a skimming trough supported by two flotation beams which are designed to restore the trough to the skimming position in the event the unit is submerged.

[from Petroleum Abstracts 17(23):#234,035. 1977]

4,010,103
AUTOMATIC OIL-WATER SEPARATING DEVICE
Jerry E. Morgan, 352 67th St., Clarendon Hills, Ill. 60514; William M. Lynch, 621 Western Ave., Glen Ellyn, Ill. 60137, and Paul M. Pelton, 1209 South Gates, West Chicago, Ill. 60185
Filed Aug. 12, 1974, Ser. No. 496,515
Int. Cl.[2] E02B *15/04*
U.S. Cl. 210—242 R 8 Claims



C-1846-77
ANALYTICAL VARIABILITY OF FIVE WASTEWATER PARAMETERS--PETROLEUM REFINING INDUSTRY
Myers, L. H., T. E. Short, Jr., B. L. DePrater, and F. M. Pfeffer. 1976.
Report EPA-600/2-76-234. 67p.

Wastewater treatment, Refineries, Chemical analysis, EPA, *Analytical variability

"The extent of analytical variability incurred for a specific industrial wastewater, e.g. petroleum refinery effluents, was detected for intralaboratory (repeatability) interlaboratory (reproducibility), and spike recovery for COD, suspended solids, ammonia-N, phenolics, and oil and grease. The Environmental Protection Agency methodology was suitable."

[from Chemical Abstracts 87(2):#11106m. 1977]

NWMAR116744

C-1847-77
LAND DISPOSAL OF OILY WASTEWATER BY MEANS OF SPRAY IRRIGATION
Neal, D. M., R. L. Glover, and P. G. Moe. 1977.
Land as a Waste Management Alternative. R. C. Loehr (ed.). Ann Arbor, Michigan, Ann Arbor Science Publishers, 1977. p.757-767.

Wastewater disposal, Waste oil, Reclamation, Fuels, *Land disposal, *Spray irrigation

Since 1972, over 136 million L (36 million gal) of oily wastewaters have successfully been disposed of through a land application system, and about 2.3 million L (600,000 gal) have been reclaimed in the process and used successfully as boiler fuel. The value of the salvaged oil has more than paid for the entire costs of the project to date.

[from Pollution Abstracts 8(4):#77-03258. 1977]

C-1848-77
REMOVAL OF OIL FROM WASTE WATER
Obara, G. 1976.
Japanese Kokai (unexamined patent application) 76 87,350

Wastewater treatment, Flocculation, Oil-water separation, Patent

Oil-containing wastewater is mixed with n-C_6H_{14}, a neutralizing agent, and two flocculants. The mixture is put into a scum separator, and heated to vaporize the n-C_6H_{14} from the flocs before they are removed. Vapors are recovered through cooling.

[from Chemical Abstracts 87(4):#28537a. 1977]

C-1849-77
REMOVAL OF OIL FROM WASTE WATER
Obara, G. 1976.
Japanese Kokai (unexamined patent application) 76 87,351

Wastewater treatment, Flocculation, Oil-water separation, Patent

A neutralizing agent is mixed with oily wastewater while air is blown into the mixture, and two flocculants are added. The wastewater is then put into a scum separator where the floating flocs are removed by oscillating blades.

[from Chemical Abstracts 87(4):#28536z. 1977]

NWMAR116745

C-1850-77
WASTEWATER TREATMENT
Okumura, M., and K. Sukai. 1976.
Japanese Kokai (unexamined patent application) 76 78,066

Wastewater treatment, Emulsifiers, Sludge, Adsorption, Flotation, Patent

A fibrous agent is made from oil emulsion-treatable fine inorganic particles or an organic polymer. It adsorbs sludge material in wastewater during an air flotation treatment process. The method removes emulsifier oils, has excellent filterability, and needs no pH control.

[from Chemical Abstracts 87(8):#58081q. 1977]

C-1851-77
WASTEWATER TREATMENT BY COAGULATION
Okumura, M., and K. Sukai. 1976.
Japanese Kokai (unexamined patent application) 76 79,959

Wastewater treatment, Coagulation, Patent

The agent described consists of emulsified-oil-treating inorganic particles and/or organic polymers. Any volume of wastewater can be treated by this method, using only a precipitation tank and stirring tank.

[from Chemical Abstracts 87(8):#58085u. 1977]

C-1852-77
BREAKDOWN OF STABLE PETROLEUM EMULSIONS [in Russian]
Pozdnyshev, G. N., and M. V. Shmelev. 1977.
Neftyanoe Khozyaistvo 1977(2):51-54.

Emulsions, Oil-water separation, Crude oil

"Stable oil-in-water and water-in-oil emulsions were broken by feeding 50-100 g Disolvan 4411 ton crude oil."

[from Chemical Abstracts 87(8):#55380a. 1977]

C-1853-77
COMPOSITION FOR SEPARATING HYDROCARBONS FROM WATER
Preus, P. 1977.
U.S. Patent 4,011,175

Wastewater treatment, Spill recovery, Oil-water separation, Absorption, Patent, *Sorbent material

Oil is removed from wastewater or absorbed from spills by adding a comminuted mixture consisting of expanded perlite,

NWMAR116746

asphalt, clay and cellulose fibers, having a particle size < 0.64 cm (0.25 in) and density approximately 80 kg/m^3 (4.5 lb/ft^3). The material floats on water after oil absorption and can absorb oil at a rate of about 75-125 L/kg (9-15 gal/lb).

[from Chemical Abstracts 86(26):#195020n. 1977]

C-1854-77
SEPARATION OF EMULSIONS BY FLOTATION WITH DISSOLVED AIR
Rovel, J. M., and M. Cordier. 1976.
French Demande 2,300,620

Wastewater treatment, Emulsions, Oil-water separation, Flotation, Patent, *Cationic polymers

Wastewater that contains petroleum oil in droplets (<30μ in diameter) is treated separately with two cationic polymers for comparison and then subjected to air flotation.

[from Chemical Abstracts 87(4):#28591p. 1977]

C-1855-77
ASSESSMENT OF INDUSTRIAL HAZARDOUS WASTE PRACTICES IN THE PETROLEUM REFINING INDUSTRY
Sanjour, W., E. Weisberg, and H. Cruse. 1976.
National Petroleum Refiners Association Annual Meeting, 1976. Paper AM-76-33. 22p.

Refineries, Contaminants, Wastewaters, Solid wastes, Disposal, Inland, *Waste disposal practices, *Landfills

In this study of potentially hazardous wastes of the petroleum industry, all waste streams investigated were found to be potentially hazardous in their content of at least one significant trace element. Disposal to secure landfills or land farms was judged to provide a simple, economical, and environmentally adequate waste disposal technique.

[from The Engineering Index Monthly 15(6):#042619. 1977]

C-1856-77
WASTE WATER TREATMENT BY REVERSE OSMOSIS. IV. PRACTICAL EXAMPLE OF WASTE WATER TREATMENT
Sato, T., H. Motomura, and Y. Taniguchi. 1976.
Kagaku Kojo 20(11):72-73.

Wastewater treatment, Refineries, *Reverse osmosis, *Water recovery

Reverse osmosis methods were used to recover water discharged by an oil refinery. The water recovery rate was 90%.

[from Chemical Abstracts 86(26):#194612v. 1977]

NWMAR116747

C-1857-77
DEVELOPMENT AND IMPLEMENTATION OF AN IMPROVED WASTE WATER TREATMENT SYSTEM AT IMPERIAL'S SARNIA REFINERY
Schindel, G. W. 1976.
Proceedings of the Ontario Industrial Waste Conference, Vol. 23: 202-230.

Refineries, Wastewater treatment, Filtration, Water quality, Ontario

Improved wastewater treatment at an Ontario, Canada, refinery resulted in a reduction of process wastewaters from about 57,000 to 11,000 L/min (15,000 to 3,000 gpm), and a significant improvement in effluent quality. An improved dual mode filter was installed which reduced suspended oils in the effluent by 79% and suspended solids by 53%.

[from Chemical Abstracts 87(2):#11024h. 1977]

C-1858-77
SOLVENT RECOVERY FROM SCUM IN OIL-CONTAINING WASTE WATER TREATMENT
Shishido, N., T. Hirano, H. Tsuchiya, and K. Sakaki. 1976.
Japanese Kokai (unexamined patent application) 76 96,778

Wastewater treatment, Flocculation, Solvents, Oil-water separation, Patent, *Solvent recovery

Oil-containing waste water is treated with an organic solvent and a flocculant before steam is blown into the scum layers. After separation the solvent is recovered by distillation. Recovery time was twice as long when steam was not used.

[from Chemical Abstracts 87(4):#28546c. 1977]

C-1859-77
SOLVENT RECOVERY FROM SCUM IN OIL-CONTAINING WASTE WATER TREATMENT
Shishido, N., T. Hirano, H. Tsuchiya, M. Masuda, and K. Sakaki. 1976.
Japanese Kokai (unexamined patent application) 76 96,781.

Wastewater treatment, Solvents, Flocculation, Oil-water separation, Patent, *Solvent recovery

After oily wastewater is treated with an organic solvent and a flocculant, a water-soluble inorganic salt is added to the scum layers. The scum is separated, mixed with NaCl, and distilled for solvent recovery.

[from Chemical Abstracts 87(4):#28547d. 1977]

NWMAR116748

C-1860-77
HEAVY-EMULSION OIL WASTE REDUCED FROM 2000 TO 10 PPM
Smith, A. W., and K. Robe. 1976.
Chemical Processing 39(12):62.

Waste oil treatment, Emulsions, Refineries, Design and engineering

An air flotation system was designed to handle the previously untreatable heavy oil emulsions in wastewaters from the Champlin Petroleum Company refinery. Tests in a pilot unit showed a 90-95% oil removal under varying loads of oil emulsion, and a 1900 L/min (500 gpm) unit was subsequently installed.

[from Environment Abstracts 7(4):#77-02604. 1977]

C-1861-77
CRUDE OIL PRETREATMENT AND ENVIRONMENTAL PROTECTION
Sorkin, Ya. G. 1975.
Chemical Technology of Fuels and Oils (USSR) 11(11-12):913-915.

Wastewater treatment, Crude oil, Refineries, Cost analysis, Economics, USSR

Removal of oil and salts from wastewaters in the refinery requires the construction of expensive treating units. In order to calculate the cost for oil pretreating and emulsion wastewater treating and to determine how these costs are affected by the salt content of the oil entering the refinery, the author has used averaged technoeconomic indices for the operation of a number of USSR refineries in the processing of one million tons of Romashkino crude. Cost data of crude oil pretreatment are tabulated and discussed.

[from ERDA Energy Research Abstracts 2(11):#25903. 1977]

C-1862-77
COALESCENCE OF OIL-IN-WATER SUSPENSIONS BY FLOW THROUGH POROUS MEDIA
Spielman, L. A., and Y. P. Su. 1977.
Industrial and Engineering Chemistry, Fundamentals 16(2):272-282.

Wastewater treatment, Oil-water separation, Wastewaters, Coalescence

This work attempts to resolve aspects of major disagreement regarding the separation of finely disposed liquid-liquid suspensions, and sets down equations governing coalescence of oil by both granular and fibrous media.

[from Petroleum Abstracts 17(34):#237,299. 1977]

NWMAR116749

C-1863-77
COMBINED BIOLOGICAL TREATMENT AND UNDERGROUND INJECTION OF REFINERY WASTE WATER
Sutterfield, F. D., E. C. Donaldson, and F. S. Manning. 1976. National Conference on Complete Water Use, Chicago, 1975. 26p.

Wastewater treatment, Disposal, Refineries, *Biological treatment, *Underground waste injection

The biological treatment and underground waste injection systems for petroleum refinery wastewaters are described, and a possible redesign of the biological unit is presented. Both treatment systems meet current legal requirements for waste processing, and the combined system is more economical than treatment in a single biological system.

[from ERDA Energy Research Abstracts 2(10):#24022. 1977]

C-1864-77
IMPROVEMENT IN THE FLOTATION SEPARATION OF FINELY EMULSIFIED OILS FROM WASTE WATERS [in Russian]
Sviridov, V. V., T. F. Kokovkina, V. G. Vshivtsev, and L. D. Skrylev. 1976.
Koks i Khimiya No. 11:38-40.

Wastewater treatment, Oil-water separation, Emulsions, Flotation

Flotation removal of oils requires 30-70 mg $FeSO_4$/L. Problems resulting from the use of inorganic salt were eliminated by using ultrasonically dispersed 1-5 mg/L of undecyl-, tridecyl-, or cetylpyridine chloride. Residual concentration of oils was lowered to 10-30 mg/L.

[from Chemical Abstracts 86(24):#176666m. 1977]

C-1865-77
TAXONOMICAL AND ECOLOGICAL STUDY IN AN OXIDATION POND SYSTEM ESTABLISHED FOR THE TREATMENT OF OIL INDUSTRY WASTE WATER
Szabo, J., G. Lakatos, M. Tokar, J. Katai, and A. Nagy. 1976.
Acta Biologica Debrecina 13:199-214.

Oil industry, Wastewater treatment, Oxidation

The system studied uses a preliminary settling tank, stabilization, pond, and final settling tank. Hydrobiological investigations report on the O budget, loading, and the calculated efficiency.

[from Chemical Abstracts 87(6):#43725d. 1977]

NWMAR116750

C-1866-77
OIL ABSORBENT
Takeda, N., H. Maki, and E. Ishimaru. 1976.
Japanese Kokai (unexamined patent application) 76,121,494

Wastewater treatment, Petroleum products, Absorption, Patent, *Absorbent polyolefin

Polyolefin of cohesive energy d < 60 is used to absorb oil dispersed in water. In a test, water samples containing 100 ppm heavy oil, turbine oil, or kerosine were reduced to 1, 1, and 3 ppm of the pollutants after addition of the material.

[from Chemical Abstracts 87(2):#11430n. 1977]

C-1867-77
REMOVAL OF OIL FROM WASTE WATER
Tomita, Y. 1976.
Japanese Kokai (unexamined patent application) 76,138,055

Wastewater treatment, Flocculation, Surfactants, Oil-water separation, Patent

Oily wastewater at a stable emulsion state is mixed with an inorganic salt, a flocculant, and/or an electrolytic surfactant, then exposed to ultrasound waves. After settling, the floated oil is removed.

[from Chemical Abstracts 87(4):#28575m. 1977]

C-1868-77
PHYSICO-CHEMICAL PURIFICATION OF PETROLEUM-CONTAINING WASTE WATERS [in Russian]
Vasilenko, I. I., V. Yu. Shchepanyuk, N. A. Sukhoverkhova, and A. P. Ivanenko. 1976.
Neftepererabotka i Neftekhimiya (Kiev) 14:92-94.

Wastewater treatment, Petroleum products, *Coagulation

"Wastewater containing 34.5 mg/L petroleum products was coagulated (optimum efficiency of flotation 76%) by 0.2 g/L of aluminum ammonium sulfate."

[from Chemical Abstracts 87(2):#11058x. 1977]

NWMAR116751

C-1869-77
SEPARATING OIL-IN-WATER EMULSIONS INTO THEIR OIL AND WATER COMPONENTS
Von Preen, W. 1977.
German Offenlegungsschriften (unexamined patent application) 2,528,990

Wastewater treatment, Oil-water separation, Emulsions, Filtration, Patent, *Ultrafiltration

A two stage method for separating oil-water emulsions is described which involves first heating the emulsion under pressure above the boiling point, and then applying ultrafiltration methods.

[from Chemical Abstracts 87(2):#8038k. 1977]

C-1870-77
REMOVAL OF LIPOPHILIC POLLUTANTS IN WATER TREATMENT [English summary]
Weil, L., H. Berger, and K. E. Quentin. 1976.
Dechema Monographs 80(1616-1638):105-114.

Petroleum products, Wastewater treatment, Flocculation

A new process for removing lipophilic substances, including petroleum products, from wastewaters is described and its effectiveness is compared with currently available methods. The new process involves the addition to water of a novel type of PE suspension, which is free from emulsifiers and other substances, and subsequent flocculation.

[from The Engineering Index Monthly 15(7):#053708. 1977]

C-1871-77
SEPARATION OF FREE OIL FOLLOWING COALESCENCE
Wu, C. J., R. S. Shechter, J. F. Malina, Jr., and E. F. Gloyna. 1977.
University of Texas at Austin, Center for Research in Water Resources, Report CRWR-143. 105p.

Wastewater treatment, Emulsions, Coalescence, Oil-water separation

Oil was coalesced by passing a stable oil-in-water emulsion through a polyester felt mat, and then removed by a separator. The method reduced concentrations of 50 mg/L oil to 1 mg/L. Six mechanical separators were evaluated for efficiency and headloss.

[from Chemical Abstracts 87(4):#28805m. 1977]

NWMAR116752

C-1872-77
STUDIES OF THE POSSIBILITY OF USING POLISH RAW MATERIALS AS SORBENTS IN SETTLING FILTRATION [English summary]
Zagorski, K., W. Strzelczyk, and J. Bankowska. 1975. Biuletyn Lubelskiego Towarzystwa Nankowego, Matematyka-Fizyka-Chemia 17(1-2):53-57.

Wastewater treatment, Emulsions, Adsorption, Filtration, Poland, *Cellulose, *Diatomaceous earth

Domestic raw materials were evaluated as sorbents in the filtration of oily waters and emulsions. Cellulose or diatomaceous earth suspensions in water are almost as effective as a commercial product. A suspension of activated C-cellulose mixture has the highest oil adsorption capacity.

[from Chemical Abstracts 87(2):#11019k. 1977]

NWMAR116753

6. RECLAMATION AND REUSE

C-1873-77
LOW-COST ANSWER TO OIL RECYCLING?
Anon. 1977.
Factory Management 10(1):32-33

Waste oil, Lubricating oil, Recycling, Filtration, Coalescence

The high cost of recycling used lubricating and other oils can be lowered by use of a new system which combines filtration and coalescence technologies to first separate oil and water and then remove solids and separate purified oil fractions and gases. Examples of usage of this system are given.

[from The Engineering Index Monthly 15(7):#049942. 1977]

C-1874-77
NEW, MORE ATTRACTIVE ROUTE TO LUBE OIL RECOVERY
Anon. 1976.
Process Engineering, December: 6

Reclamation, Lubricating oil, Waste oils, *IFP process

A new Institute Francais du Petrole process for reclaiming used lubrication oil is claimed to solve several problems which until now have hindered reprocessing. The JFP process avoids acid treatment of oil (9-18% sulfuric acid is used in most conventional methods) and shows a considerable increase in the yield of usable products and a marked decrease in waste sludges and clay.

C-1875-77
OIL RECOVERY SYSTEM ALLOWS RE-USE OF FUEL (PRODUCT INFORMATION)
Anon. 1977.
Water & Pollution Control 115(2):31.

Spill recovery, Waste-water treatment, Oil-water separation, Crude oil, Fuels

The Scavenger oil recovery system, developed by Oil Recovery Systems, is an oil-water separation system designed to recover 99% water-free oil at rates exceeding 18 L/min (5 gpm). The system effectively recovers thin slicks or thick layers and works best with light crude oil, No. 2 fuel oil, diesel oil, gasoline, and jet fuel. The unit is portable for spill recovery applications or can be permanently installed in wastewater treatment facilities. The system is available from Marine Equipment Ltd., Halifax, Nova Scotia.

NWMAR116754

C-1876-77
RECOVERY OF USED INDUSTRIAL OIL
Anon. 1977.
Petroleum Review 31(361):15-16

Waste oil, Reclamation, Reuse, Economics

The recovery and reconditioning of waste oils by industries is recommended as a means of saving new oil costs and staying within the law. Used oil can be reclaimed and reconditioned so that it performs exactly like new oil.

[from The Engineering Index Monthly 15(6):#041251. 1977]

C-1877-77
WASTE OIL BURN-OFF IN COAST GUARD POWERPLANTS. WASTE OIL FILTERING SYSTEMS AND DIESEL ENGINE PERFORMANCE
Hobbs, J. R., and R. A. Walter. 1976.
Final report, TSC-USCG-76-1; USCG-D-78-76. 58 p.

Waste oil, Lubricating oil, Reclamation, Filtration, Oil-water separation, Fuels, *USCG powerplants

In testing waste lubricating oils as possible fuel in U.S. coast Guard powerplants, waste oil cleanup systems were evaluated. A filtration pack was found to be more effective than oil-water separation methods. Up to 10% waste lube oil was used with fuel oil, with no short-term adverse effects on emissions and powerplant engine performance.

[from Scientific and Technical Aerospace Reports 15(11): #N77-20630. 1977]

C-1878-77
UTILIZATION OF WASTE IN PULP, PAPER, SUGAR, PETROLEUM AND AGRO-BASED INDUSTRIES
Iyengar, M. S. 1976.
Chemical Age India 27(12):1045-1051.

Industries, Refineries, Wastewaters, Reclamation, Reuse, India

Wastes from various industries are reviewed and methods developed in India and covered by Indian patents for the effective utilization of wastes are outlined.

[from Chemical Abstracts 87(2):#10994n. 1977]

NWMAR116755

C-1879-77
WASTE OIL RECOVERY. X
Kawase, Y. 1976.
Sekiyu To Sekiyu Kagaku 20(11):76-80

Waste oil, Reclamation, *Review

"A review with 5 references."

[from Chemical Abstracts 86(26):#192113j. 1977]

C-1880-77
WASTE OIL RECOVERY. XI
Kawase, Y. 1976.
Sekiyu To Sekiyu Kagaku 20(10):82-86.

Waste oil, Reclamation, *Review

"A review with 5 references."

[from Chemical Abstracts 86(26):#192112h. 1977]

C-1881-77
THE GARRETT OIL-FROM-WASTE PROCESS AND RESOURCE RECOVERY SYSTEM
Titlow, E. T., and J. K. McCartney. 1975.
Energy and the Environment. Dayton, Ohio. American Institute of Chemical Engineers, 1975. p. 192-198. Proceedings of the Third National Conference, Oxford, Ohio, September 29-October 1, 1975.

Waste oil, Petroleum products, Reclamation, Reuse

A system and flowsheet for the recovery of secondary resources (including petroleum) from municipal wastes are described. The principal products recovered, process economics, and the unit operations are discussed.

[from International Aerospace Reports 17(15):#A77-35162. 1977]

7. PERSONNEL TRAINING AND EDUCATION

C-1882-77
IF THERE'S AN OIL SPILL, WE'RE READY
Glenn, M. C. 1977.
Petroleum Today 18(2):16-20.

Personnel training, Spill cleanup, Pollution control, Texas, *Oil Spill Control Course

The Oil Spill Control Course, taught at Texas A&M University's facilities in Galveston, Texas, is described and illustrated.

NWMAR116756

The course, offered at least 20 times per year, provides seminar instruction in the latest methods of spill containment and control, both on land and in water. Extensive field exercises give students the opportunity to work with modern oil spill equipment in spill simulations.

C-1883-77
OIL SPILL CONTROL TRAINING
Payne, J. L. 1977.
Ecolibrium 6(3):7-8.

Personnel training, Oil spills, Pollution control, Contingency planning, *Spill Control Course

The Oil Spill Control Course conducted by Texas A&M University's Engineering Extension Service at Galveston is described. The program covers spill prevention, control, and cleanup measures and especially emphasizes the need for an effective response when a spill has occurred. The course augments classroom presentations with field exercises and frequent informal discussion sessions in order to optimize active learning.

C-1884-77
BLOWOUT SCHOOL TEACHES PREVENTION, CONTROL
Speer, L. 1977.
Offshore 37(8):138-142.

Blowout prevention, Personnel training, *Blowout school

The University of Oklahoma blowout prevention school at Norman, Oklahoma, one of two such schools in the U.S. is preparing a special class in offshore well control for the fall of 1977. The OU Blowout School will act in liaison with a third school in California at Ventura College, planning to open August, 1977.

8. CONTINGENCY PLANNING

C-1885-77
HISTORY OF THE FORMATION OF AN OIL SPILL CONTINGENCY ORGANIZATION
Barker, C. D. 1977.
Annual SPE of AIME California Regional Meeting, 47th, Bakersfield, 1977. Paper no. SPE-6518. 2 p.

Contingency planning, Oil industry, Oil-gas leasing, OCS, Southern California

Southern California-Petroleum Contingency Organization (SC-PCO) was formed as an unincorporated joint venture in April, 1976,

NWMAR116757

by the petroleum companies involved in the federal leasing program of the Outer Continental Shelf. The work covers a monthly diary describing initial funding, purchase of equipment, field testing, and related topics.

[from Petroleum Abstracts 17(33):#237,022. 1977]

C-1886-77
OIL SPILL CLEANUP--WHAT ARE THE CAPABILITIES?
Kendrick, P. J. 1977.
Journal Water Pollution Control Federation 49(5):733-736.

Contingency planning, Spill cleanup, USCG, EPA

The author reviews the National Oil and Hazardous Substances Pollution Contingency Plan (1972) and the roles played by EPA, USCG, oil spill cooperatives, and private companies in oil spill cleanup. It is concluded that substantial efforts have been made in recent years to improve strategies for handling pollution emergencies.

C-1887-77
FORWARD PLANNING
Wardley-Smith, J. 1976.
The Control of Oil Pollution on the Sea and Inland Waters
J. Wardley-Smith (ed.), London, Graham & Trotman Ltd., 1976.
p. 203-218.

Contingency planning, Spill cleanup, Personnel training, UK, U.S., Europe

The problems of organization for effective spill response are outlined with reference to West European practice and United States practice. In the UK for example, spill cleanup is carried out by the marine branch of the Department of Trade; in the U.S. the spiller is made responsible for cleanup, supervised by an on-scene commander from the U.S. Coast Guard or the Environmental Protection Agency. Contingency planning, and the organization and training of spill response personnel are discussed.

9. PREVENTION AND CONTROL MEASURES

C-1888-77
AVOIDING CONTAMINATION OF THE SEA [in Spanish]
Anon. 1977.
Petroleo International 35(5):25-26.

NWMAR116758

Pollution prevention, Offshore drilling, Emulsions, *Drilling muds, Design and engineering

A system developed by Petrobras permits extensive use of inverted emulsion muds in offshore locations without the risk of harming marine life. An efficient drill-cutting scrubber is used in the apparatus.

[from Petroleum Abstracts 17(32):#236,715. 1977]

C-1889-77
CANNED BY THE EXPERTS
Anon. 1977.
Canadian Shipping and Marine Engineering 48(5):5-6

Pollution prevention, Oil spills, Tankers, Oil tanks, *Tin can containers

A. Thorhill believes that he has discovered a way to prevent oil spills at sea. According to his idea, tankers would carry their cargoes in huge tin cans rather than in fixed ship tanks; and these cans could be discharged to float independently should the ship sink or run aground. Experts state that while the idea is feasible it is not economical.

[from Aquatic Science & Fisheries Abstracts 7(6):#7Q7579. 1977]

C-1890-77
THE GLACIER-PILGRIM 'COASTGUARD' STERNGEAR SYSTEM (product information)
Anon. 1976.
Shipping World & Shipbuilder 169(3921):761.

Ships, Leakage, Pollution prevention, *Sterngear seal system

The Glacier Metal Co. Ltd., Deep Sea Seals Ltd., and Pilgrim Developments Ltd. have developed an aft shaft seal system which is designed to eliminate oil leakage and meet antipollution laws. The design and functioning of the system are described.

[from Oceanic Abstracts 14(3):#77-02700. 1977]

C-1891-77
SPECIAL: OFFSHORE GREENLAND. SAFETY FIRST WHEN DRILLING
Anon. 1977.
Danshore 2(3):36-37.

Offshore drilling, Safety, Pollution prevention, Arctic, *Icebergs, Greenland

Icebergs constitute a serious danger to drilling operations in the arctic waters off Greenland. When icebergs come too close, they can completely destroy a drilling or production

NWMAR116759

platform; therefore these installations must be protected to prevent large-scale oil pollution.

[from Petroleum Abstacts 17(28):#235,458. 1977]

C-1892-77
WAYS TO REDUCE OIL SPILLS RECOMMENDED (news brief)
Anon. 1977.
Sierra Club Bulletin 62(3):37
Pollution control, Oil spills, USCG.

Sierra Club representatives have recently suggested that the U.S. consider establishing a 320 km (200 mi)-wide pollution control zone to protect the marine resources now covered by the fisheries jurisdiction zone. Changes in the U.S. Coast Guard bureaucracy are urged to better effect its role in combatting pollution.

C-1893-77
RAM TYPE BLOWOUT PREVENTION
Arzumanov, S. A., A. A. Danieliants, K. S. O. Aliverdizade, et al. 1977.
British Patent 1,478,724

Blowout prevention, Drilling, Design and engineering, Patent

The elements which comprise the blowout preventer are listed.

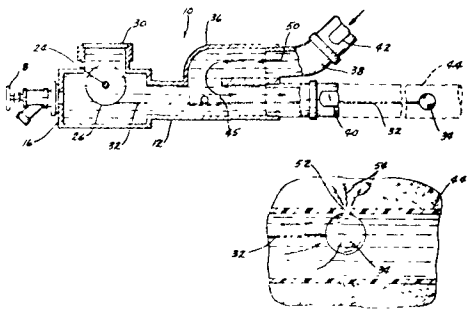
[from Petroleum Abstracts 17(34):#237,177. 1977]

C-1894-77
PIPELINE LEAK LOCATOR AND METHOD
Boyens, V. C. 1977.
U.S. Patent 4,016,748

The method consists of flowing a fluid through a conduit at superatmospheric pressure, placing within the conduit a floatable leak sensor which is responsive to pressure and velocity differentials caused by a leak, and moving the leak sensor through the conduit along with the fluid, whereby the sensor stops movement through the conduit at the location of a leak. The components of the leak sensor are described.

[from Petroleum Abstracts 17(35):#237,658. 1977]

4,016,748
PIPELINE AND LEAK LOCATER AND METHOD
Virgil C. Boyens, R.R. 1, Denison, Iowa 51442
Filed Nov. 10, 1975, Ser. No. 630,694
Int. Cl.² G01M 3/28
U.S. Cl. 73—40.5 R 11 Claims



NWMAR116760

C-1895-77
INSTALLATION TO REPAIR DAMAGED PIPELINES
(British Petroleum Company, Ltd.) 1976.
Netherlands Application 7,606,010

Pipelines, Leakage, Pollution prevention, Design and engineering, Patent

A compressible closing element is pressed by a bracket against the surface of the pipeline. A longitudinal flexible assembly then is placed around the pipeline, and brought under tension in order to exercise a radial inward pressure on the bracket and closing element. There are means to exercise a pulling force on the longitudinal flexible assembly.

[from Petroleum Abstracts 17(25):#234,774. 1977]

C-1896-77
OIL DISTRIBUTION AND WATER POLLUTION [English summary]
Chirac, M. 1977.
Techniques et Sciences Municipales 3:87-92.

Oil transport, Tankers, Pipelines, Pollution prevention, Spill recovery

This paper describes legal precautions for avoiding oil spills at dumps and during transport by tank-wagon, barge, or pipeline. Emergency equipment for containment and recovery is available in case of crashes.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10599. 1977]

C-1897-77
SLIP RINGS - CRUCIAL COMPONENTS FOR DEVELOPING EFFECTIVE BOP SYSTEMS
Cook, L., and J. M. Vanhoozier. 1977.
Offshore 37(9):53-56.

Pollution control, Blowout prevention, *Slip rings, *Equipment

The authors review slip ring development and its major uses. The slip ring, sometimes called an electrical swivel, has been essential in electrical distribution equipment which makes deep sea drilling possible and in particular, for blowout preventer (BOP) control techniques.

NWMAR116761

C-1898-77
CLEAN SOUND--A SUCCESSFUL OIL SPILL COOPERATIVE
Doolittle, J. C. 1977.
Ecolibrium 6(3):9-11.

Spill cleanup, Contingency planning, Puget Sound, Oil Industry, *Oil spill cooperative

Clean Sound, a cooperative oil spill response group active in the Puget Sound area, is described and its inception and development since 1971 is detailed. With their access to specialized equipment and trained manpower, oil spill cooperatives represent a way to reduce oil spill damage in a manner satisfactory to industry, the public, and governmental agencies.

C-1899-77
ENERGY RESOURCE EXTRACTION; OIL AND GAS PRODUCTION
Dorrler, J. S. 1976.
National Conference on Health, Environmental Effects, and Control Technology of Energy Use. Cincinnati, U.S. Environmental Protection Agency, 1976. p. 186-191.

Production, Pollution prevention, Oil spills, Detection, Leakage, Pipelines

New methods to improve petroleum emulsion breaking, waste minimization for offshore oil facilities, and oil spill prevention are needed. The detection of small pipeline leaks also needs more sensitive methods.

[from Chemical Abstracts 86(24):#173815y. 1977]

C-1900-77
ESTUARINE POLLUTION CONTROL AND ASSESSMENT. PROCEEDINGS OF A CONFERENCE. VOLUME I, and II
Environmental Protection Agency, Office of Water Planning and Standards. 1977.
Final report, EPA/440/1-77/007. 760 p.

Pollution control, Estuaries, *Conference

The report provides information to be used in establishing a national program for the prevention, abatement, and elimination of pollution in estuaries with emphasis on heavy metals and oil pollution. Individual papers of the report address important estuarine problems by presenting up-to-date knowledge and experience in this field.

[from Government Reports Announcements 77(14):#PB-265 467/1GA. 1977]

NWMAR116762

C-1901-77
PROCESS AND APPARATUS FOR DETECTING A FLUID LEAK FROM A PIPELINE
Jouve, P. 1977.
Belgian Patent 823, 862

Leakage, Pipelines, Detection, Design and engineering, Patent

The process consists of continuously comparing the pressure difference between the differential pressure in the pipeline and a reference pressure and a predetermined threshold pressure. The threshold pressure is the line pressure at the start of each cycle of comparison.

[from Petroleum Abstracts 17(27):#235,244. 1977]

C-1902-77
OIL SPILLS: ISSUES AND ACTIONS
Leitzell, T. L. 1977.
Marine Technology Society Journal 11(1):26-29.

Oil spills, Tankers, Oil discharges, Safety, Pollution control, Liability, International conventions

Problems of marine oil pollution by tanker spills and accidental or intentional vessel discharges are reviewed. The author believes that vessel-caused pollution can be easier to control than many other sources if certain problems are overcome. Areas discussed are safety in vessel construction, equipment and operation, spill cleanup, damage compensation, and liability assignment. The study explores recent international legislation dealing with these problem areas.

[from Petroleum Abstracts 17(29):#235,724. 1977]

C-1903-77
Title not translated [English summary]
Murzakaev, F. G. 1976.
Gigiena i Sanitariya No. 7:7-10.

Refineries, Petrochemicals, Pollution control, Wastewaters, Water quality, Rivers, USSR

Improvements in the water quality downstream from oil refining and petrochemical plants along the Belaya River, USSR, are described. These industries have taken measures to decrease consumption and discharge of water, and to decrease pollution of the water with oil, petroleum products, and other compounds.

[from Pollution Abstracts 8(4):#77-03222. 1977]

NWMAR116763

C-1904-77
OIL PROTECTION IN THE NORTH SEA
Read, C. M. 1977.
Ship & Boat International 30(5):31-32.

Blowouts, Statistical analysis, Environmental protection, Economic effects, North Sea

The statistical likelihood of a blow-out occurring in the North Sea is considered. Economic effects are discussed and there is disagreement as to which cleanup methods and equipment would be most effective.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10598. 1977]

C-1905-77
OIL SPILL COUNTERMEASURES - THE BEAUFORT SEA AND THE SEARCH FOR OIL
Ross, S. L., W. J. Logan, and W. Roland. 1977.
Canada Department of the Environment, Beaufort Sea Project overview report. 67 p.

Oil spills, Pollution control, Arctic, Beaufort Sea, *Spill countermeasures

This report includes the "State-of-the-art" of oil spill countermeasures for arctic waters and is a digest of Beaufort Sea technical reports on the topic. The Beaufort Sea Project, a set of arctic marine environmental studies, was conducted during the years 1974 and 1975 in order to assess the possible impact of offshore exploratory drilling in the Beaufort Sea.

[from Beaufort Sea Project Office, Institute of Ocean Sciences, 9860 West Saanich Rd., Sidney, B. C. Canada V8L 352]

C-1906-77
THE CONTROL OF OIL POLLUTION ON THE SEA AND INLAND WATERS
Wardley-Smith, J. (ed.) 1976.
London, Graham & Trotman Ltd., 1976. 240 p.

Pollution control, Oil spills, Oceans, Inland, Environmental effects, Spill cleanup

This book explains the effect of oil spills on the marine environment and describes the best methods of cleaning up such pollution. The contents are divided into four main topics: (1) Oil and its Effects; (2) Treatment of Oil on Water; (3) Treatment of Oil on the Land; (4) Organizational Aspects.

NWMAR116764

C-1907-77
THE FUTURE
Wardley-Smith, J. 1976.
Control of Oil Pollution on the Sea and Inland Waters, J. Wardley-Smith (ed.). London, Graham & Trotman, Ltd., 1976. p. 219-223.

Spill cleanup, Dispersants, Environmental effects, Pollution control

In spite of many recent developments in the field of oil spill cleanup, mechanical methods are ineffective in all but calm waters. Dispersants appear to be the only effective overall method available now and in the near future. Although the effects of oil pollution are now considered less serious and long-lasting than previously thought, the prevention and control of oil pollution will continue to receive high priority in the future.

C-1908-77
THE U.S. COAST GUARD AND THE CONTROL OF OCEANIC POLLUTION
Williams, H. D. 1976.
U.S. Naval Institute. Proceedings 102 (879):146-159.

Legislation, Pollution prevention, Oil spills, Law enforcement, USCG

The author discusses the role of recent legislation and the U.S. Coast Guard in environmental protection. Methods for enforcing oil pollution prevention are developed, including a proposal for biennial inspection of crude oil tankers. Several oil spill incidents, response activity by the USCG National Strike Force, and new equipment are also reviewed.

C-1909-77
WAYS OF PREVENTING POLLUTION OF THE BIOSPHERE DURING THE OPERATION OF SHIPS [in Russian]
Yuditskii, F. L. 1976.
Sudostroenie (Leningrad) No. 3:17-22.

Ships, Oil discharges, Oil spills, Leakage, Pollution prevention

The following topics are discussed: air pollution and control exhaust gases and petroleum vapors; discharge of hold, ballast and other waters polluted by petroleum products into rivers, seas, and oceans; and leakages and spillages of petroleum and petroleum products during shipwreck. The maximum allowable concentration is 100 mg/L of seawater.

[from Chemical Abstracts 86(24):#176814h. 1977]

NWMAR116765

C. EFFECTS OF OIL POLLUTION

1. BIOLOGICAL EFFECTS

C-1910-77
Untitled. (Book review)
Anon. 1977.
Chemical Engineering 84(17):15-16.

Oil spills, Environmental effects, Toxicity, Marine organisms

The book, Marine Ecology and Oil Pollution [J. M. Baker (ed.). Barking, Essex, U.K., Applied Science Publishers Ltd., 1976], is called a "comprehensive review" of British oil pollution events and related research occurring since 1971. Environmental effects of the oil industry at Milford Haven are stressed; the book also includes a global review of oil spills and their damage from 1960 to 1975.

C-1911-77
EFFECTS OF EXTERNAL APPLICATIONS OF FUEL OIL ON HATCHABILITY OF MALLARD EGGS
Albers, P. H. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 151-157. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Fuel oil, Birds, Biological effects, *Hatchability, *Mallard duck eggs

Mallard eggs were coated with varying amounts (up to 50 µL) of No. 2 fuel oil and artificially incubated along with controls and eggs coated with other materials. Even very small amounts of fuel oil severely reduced the hatchability of the test eggs. Ducklings from the test eggs exhibited no gross external malfunctions or behavioral abnormalities but did show some growth inhibition, suggesting sublethal physiological damage or internal abnormalities.

C-1912-77
BIOAVAILABILITY OF SEDIMENT-SORBED NAPHTHALENES TO THE SIPUNCULID WORM, PHASCOLOSOMA AGASSIZII
Anderson, J. W., L. J. Moore, J. W. Blaylock, D. L. Woodruff, and S. L. Kiesser. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 276-285. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

NWMAR116766

Hydrocarbons, Sediment, Uptake, Release, Annelids, *Phascolosoma agassizii, *Naphthalenes

The uptake and release of crude oil naphthalenes by the title organism were compared for exposure to oil in aqueous solution, on the sediment surface, or mixed into the sediment. Significant amounts of naphthalenes were detected in the test organisms after 24 hours. When the worms were removed to clean water or sediments, depuration of the naphthalenes to background levels occurred within two weeks, indicating little bioaccumulation of these hydrocarbons.

C-1913-77
RESPONSES TO SUBLETHAL LEVELS OF PETROLEUM HYDROCARBONS: ARE THEY SENSITIVE INDICATORS AND DO THEY CORRELATE WITH TISSUE CONTAMINATION?
Anderson, J. W. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 95-114. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Toxicity, Hydrocarbons, Marine organisms, Metabolism, Behavior, Analytical techniques, *Sublethal levels

Numerous studies are critically analyzed and summarized regarding the effects of petroleum hydrocarbons on physiological parameters including respiration, ionic and osmotic regulation, behavior, growth, and reproduction in marine organisms. Recommendations are made to assure the validity of experimental approaches and analytical methodology applied in such studies.

C-1914-77
TOXICITY OF CRUDE OILS AND FUEL OILS PRESENTED DIRECTLY TO MICROALGAE
Batterton, J. C., K. Winters, and C. Van Baalen 1977.
Journal of Phycology 13 (Supplement):6. Abstract.

Toxicity, Crude oil, Fuel oil, Algae

Fuel oils were much more growth-inhibiting than crude oils for a green alga, a blue-green alga, and a diatom. "Baton Rouge" and "New Jersey" fuel oil samples were toxic but were detoxified by heating. Chemical data suggest that the less water-soluble compounds in the higher boiling aromatic fraction are the cause of toxicity.

NWMAR116767

C-1915-77
THE EFFECT OF PETROLEUM HYDROCARBONS ON REPRODUCTION OF AN ESTUARINE PLANKTONIC COPEPOD IN LABORATORY CULTURES
Berdugo, V., R. P. Harris, and S. C. O'Hara. 1977.
Marine Pollution Bulletin 8(6):138-143.

Aromatic hydrocarbons, Crustaceans, Biological effects, Estuaries, *Copepod

The effect of short-term exposure of Eurytemora affinis to high hydrocarbon concentrations which might occur immediately under an estuarine oil-slick is studied. Exposure to the water-soluble fraction of aromatic heating oil resulted in various biological effects including a reduced feeding rate and sublethal effects on reproduction during the subsequent life span of the female. Comparisons were drawn of the effects of exposure to naphthalene alone.

C-1916-77
USE OF DISPERSANTS TO CONTROL ACCIDENTAL DISCHARGE OF PETROLEUM PRODUCTS AT SEA. ECOLOGICAL EFFECTS [in French]
Bocard, C., G. C. Gatellier, and P. Renault. 1976.
Rueil Malmaison, France, Institut Francais du Pétrole, 1976.
IFP--24162. 22 p.

Dispersants, Spill cleanup, Oil discharges, Toxicity, Marine organisms

The effects of two classes of oil spill dispersants on hydrocarbons and their toxicity are reviewed. Some recommendations are made for the homologation criteria of dispersants.

[from Aquatic Sciences & Fisheries Abstracts 7(4):#7Q4584. 1977]

C-1917-77
ENVIRONMENTAL EFFECT OF OIL AND THE CHEMICALS USED TO CONTROL IT ON 4) BIRDS
Bourne, W. R. P. 1976.
The Control of Oil Pollution on the Sea and Inland Waters. J. Wardley-Smith (ed.). London, Graham & Trotman Ltd., 1976. p. 72-82.

Birds, *Seabirds, Oil spills, Biological effects, Restoration

The vulnerability of birds, especially the pelagic seabirds, to oil pollution is particularly great because they encounter oil floating on water and ingest it from oiled feathers. Their mobility, migratory patterns, tendency to congregate to feed, roost, or breed, and their low reproductive capacity increases their vulnerability to oil pollution. Possible means of frightening birds away from areas of pollution, and the rehabilitation of oiled birds are briefly discussed.

NWMAR116768

C-1918-77
SEABIRDS AND POLLUTION
Bourne, W. R. P. 1976.
Marine Pollution. R. Johnston (ed.). London, Academic Press, 1976. p. 403-502.

Birds, *Seabirds, Biological effects, Oil spills, Oil slicks, Chronic effects

The effects of various pollutants, including oil, on seabirds are detailed. Oil pollution is particularly serious because it causes both physical and chemical damage. Serious oil pollution incidents affecting seabirds are documented, with numerous examples from offshore Europe and the rest of the world. Vulnerability of birds to oil during breeding season, moulting, roosting, and feeding activity is described.

C-1919-77
EFFECTS OF CRUDE OIL ON BACTERIAL AND FUNGAL POPULATIONS IN FRESH WATER ARTIFICIAL PONDS
Breuil, C., and D. B. Shindler. 1977.
American Society for Microbiology Annual Meeting, 77th, New Orleans, 1977. Paper no. Q45. Abstract.

Crude oil, Biological effects, Bacteria, Fungi, Ice, Freshwater, *Oil-under-ice

The effects of winter under-ice crude oil spills on the microbial population of artificial freshwater ponds were monitored for over a year, and seasonal variations in bacterial and fungal populations are reported.

C-1920-77
EFFECTS OF A SEAWATER-SOLUBLE FRACTION OF COOK INLET CRUDE OIL AND ITS MAJOR AROMATIC COMPONENTS ON LARVAL STAGES OF THE DUNGENESS CRAB, CANCER MAGISTER DANA
Caldwell, R. S., E. M. Caldarone, and M. H. Mallon. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 210-220. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Crude oil, Toxicity, Aromatic hydrocarbons, Crustaceans, *Larval development, *Cancer magister Dana

Larval stages of C. magister Dana were exposed continuously to dilutions of Cook Inlet crude oil water-soluble fraction (WSF) or seawater solutions of naphthalene or benzene for periods up to 60 days. Effects on survival, duration of larval development and size were used as indicators of toxicity. The lowest concentration of WSF at which toxic effects were seen was 4.0% of

NWMAR116769

the full strength WSF (0.0049 mg/L as naphthalene or 0.22 mg/L as total dissolved aromatics). The lowest concentrations at which toxic effects were observed with naphthalene and with benzene were 0.13 mg/L and 1.1 mg/L, respectively. Concentrations of aromatic hydrocarbons in the WSF were inversely related to the degree of alkylation in the benzene and naphthalene families, but acute toxicity was directly related to the degree of alkyl substitution.

C-1921-77
THE EFFECT OF PETROLEUM HYDROCARBONS ON THE SURVIVAL AND LIFE HISTORY OF POLYCHAETOUS ANNELIDS
Carr, R. C., and D. J. Reish. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 168-173. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Crude oil, Fuel oil, Toxicity, Polychaetes, *Reproduction

The toxicity of seawater-soluble fractions of No. 2 fuel oil and South Louisiana crude oil to 5 species of polychaetous annelids was determined. A wide variability in species sensitivity to the 2 oils was observed. The water soluble fractions of No. 2 fuel oil were more toxic to all species than South Louisiana crude oil. The effects of petrochemicals on reproduction were measured and results are discussed.

C-1922-77
ARGO EFFECTS BAD BUT NOT DISASTROUS (news brief)
Cornell, C. 1977.
National Fisherman 58(3):21-A, 26-A.

Argo Merchant spill, Biological effects, Invertebrates, Fish, Food web

Several conclusions based on preliminary data were stated at an EPA-sponsored seminar in Narragansett, Rhode Island, on the aftereffects of the "Argo Merchant" spill. Adult fish and commercial invertebrates seem to have escaped damage, although fish eggs and larvae showed high rates of mortality and abnormality, and the food web is endangered by contaminated plankton and copepods. Long-range effects on the ecosystems of Nantucket Shoals and Georges Bank are still unknown.

C-1923-77
SUBLETHAL POLLUTANT EFFECTS UPON THE NATIVE MICROFLORA OF GEORGIA STRAIT
Dietz, A. S., T. Tuominen, and L. J. Albright. 1976.
Proceedings of the Third International Biodegradation Symposium.

NWMAR116770

J. M. Sharpley, and A. M. Kaplan (eds.). Barking, Essex, Applied Science Publishers, 1976. p. 1083-1090. Held in Kingston, Rhode Island, 17-23 August, 1975.

Microorganisms, Crude oil, Fuel oil, Biological effects, Canada, *Georgia Strait, *Heterotrophic potential, *Productivity

Glucose heterotrophic potential, bacterial productivity, and primary productivity of the native microflora in Georgia Strait were determined before and after treatment with crude oil, fuel oil, and 5 other pollutants. Crude oil enhanced bacterial productivity, inhibited primary productivity, and decreased heterotrophic potential. Diesel fuel had no effect on these 3 biological paramaters.

[from Pollution Abstracts 8(4):#77-03315. 1977]

C-1924-77
UPTAKE AND CLEARANCE OF PETROLEUM HYDROCARBONS IN THE RINGED SEAL, PHOCA HISPIDA
Engelhardt, F. R., J. R. Geraci, and T. G. Smith, 1977. Journal of the Fisheries Research Board of Canada, 34(8): 1143-1147.

Biological effects, Hydrocarbons, Crude oil, Uptake, Marine mammals, Beaufort Sea, *Ringed seal

The authors assessed the uptake, distribution, and clearance of Norman Wells crude oil in the title species after exposure by immersion and by ingestion of contaminated fish. In this acute study, the seals showed rapid absorption of hydrocarbons into body tissues and fluids. The results suggest that detoxifying and excretory mechanisms function through the liver, bile, and urine, but it is unknown what effects longer exposure with increased accumulation in the body would have.

C-1925-77
EFFECT OF PETROLEUM HYDROCARBONS ON SALT MARSH MICROBIAL COMMUNITIES
Ereditario, J. M., and F. K. Pfaender. 1977. American Society for Microbiology Annual Meeting, 77th, New Orleans, 1977. Paper no. N72. Abstract.

Hydrocarbons, Fuel oil, Biological effects, Microorganisms, Biodegradation, Marshes, *Salt marsh

The effects of motor oil and diesel fuel hydrocarbons on microbial communities were studied in simulated salt marsh ecosystems. Based on plate and epifluorescence counts, total viable organisms initially decreased coincident with a relative increase of hydrocarbon degraders. After 5 days and until the end of the experiment (5 weeks), the total populations gradually increased,

NWMAR116771

coinciding with a stabilizing of the number of oil degraders. Final species diversity index averages were about the same as the control in the ecosystems receiving low hydrocarbon concentrations and slightly lower in those receiving high concentrations.

C-1926-77
CULTURE TECHNIQUES AND REACTIONS OF BRACKISH WATER COPEPODS TO OIL TOXINS
Fain, G. D. 1977.
Dissertation Abstracts International B 37(9):4354-B.

Crude oil, Toxicity, Crustaceans, *Mississippi Sound, *Copepods

Species of 3 pelagic orders of copepods present in the Mississippi Sound were collected for the laboratory study. The oils used in bioassay preparation were Empire Mix, and Iranian, Nigerian, Saudi Arabian, and Venezuelan crude oils. Nigerian crude oil proved to be the most toxic.

[from Petroleum Abstracts 17(27):#235,288. 1977]

C-1927-77
THE SANTA BARBARA OIL SPILL: AN ECOLOGICAL DISASTER?
Foster, M. S., and R. W. Holmes. 1977.
Recovery and Restoration of Damaged Ecosystems. J. Cairns, Jr., K. L. Dickson, and E. E. Herricks (eds.). Charlottesville, University Press of Virginia, 1977. p. 166-190. Proceedings of the International Symposium on the Recovery of Damaged Ecosystems, Blacksburg, Virginia, March 23-25, 1975.

Oil spills, Environmental effects, Marine organisms, Birds, Biological effects, Santa Barbara Channel

The 1969 Santa Barbara oil spill released over 70,000 bbl of crude oil into the Santa Barbara Channel. The greatest known damage occurred in surfgrass communities and barnacle and bird populations. Cleanup procedures resulted in additional damage on rocky shores and sandy beaches. Although some populations have recovered, the lack of prespill and postspill information makes it impossible to determine adequately the long-term effects.

C-1928-77
CYTOLOGICAL DAMAGE IN MERCENARIA MERCENARIA EXPOSED TO PHENOL
Fries, C. R., and M. R. Tripp. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 174-181. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Biological effects, Mollusks, *Phenol, *Cytology, *Mercenaria mercenaria

NWMAR116772

Gills, gut, digestive gland, and blood cells were damaged when exposed to various concentrations (1 to 50,000 ppb) of phenol. Basophilic tissue staining was evident at lower concentrations; moderate necrosis and sloughing of ciliated epithelial layers were seen at higher concentrations. Blood sinuses were distended and contained precipitated hemolymph. In the gill, only the chitinous supporting rods remained at 50,000 ppb phenol.

C-1929-77
EFFECTS OF TEMPERATURE AND SALINITY OF NAPHTHALENES UPTAKE IN THE TEMPERATURE [sic] CLAM, RANGEA CUNEATA AND THE BOREAL CLAM, PROTOTHACA STAMINEA
Fucik, K. W., and J. W. Neff. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 305-312. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Crude oil, Uptake, Release, Mollusks, *Naphthalenes, *Rangea cuneata, *Prototheca staminea

Representing a temperate and a boreal species, the clams were exposed to a 25% water soluble fraction of Southern Louisiana crude oil for 3 days under varying temperature and salinity conditions, and then allowed to depurate for 3 days under the same conditions. Naphthalene uptake for both clams was greatest at the lowest temperatures; salinity variations had little influence. Tissue naphthalenes concentrations were greater in the temperate clam, R. cuneata, after the same exposure period than in the boreal clam.

C-1930-77
EFFECTS OF VARIOUS LEVELS OF CRUDE OIL ON OLNEY BULRUSH (SCIRPUS OLNEYI) AND MARSHHAY CORDGRASS (SPARTINA PATENS)
Gebhart, J. L., and R. H. Chabreck, 1976.
Proceedings of the Annual Conference Southeastern Association of Game & Fish Commissioners 29:567-577.

Plants, Crude oil, Contamination, Toxicity, *Olney bulrush, *Marshhay cordgrass

The title species were subjected to four concentrations of a light and a heavy crude oil at four water levels over an 8.5 month period. For both plants a fluctuating water level (+5 to -5 cm) at a water level of +5 cm above the soil surface was most detrimental. Results are given comparing the damaging effects of heavy and light oils to growth and survival of these plants.

[from Applied Ecology Abstracts 3(7):#3D8370. 1977]

NWMAR116773

C-1931-77
A BACTERIOLOGICAL STUDY OF FIN ROT IN MULLET ASSOCIATED WITH EXPOSURE TO CRUDE OIL
Giles, R. C., and L. R. Brown. 1977.
American Society for Microbiology Annual Meeting, 77th, New Orleans, 1977. Paper no. Q43. Abstract.

Crude oil, Biological effects, Fish, *Fin rot, *Mugil cephalus

Fin rot infections resulted in mullet (Mugil cephalus) when they were experimentally exposed to 4.0-5.0 mg/L crude oil concentrations in estuarine ponds. Depending on the crude oil used, about 96-97% of the fish developed the infection as compared to 6-7% in control ponds. This paper reports microbiological aspects of the course of the infection as documented from two months of observation following exposure to the oil.

C-1932-77
UPTAKE PATHWAYS AND ELIMINATION OF A NONIONIC SURFACTANT IN COD (GADUS MORRHUA L.)
Granmo, A., and S. Kollberg. 1976.
Water Research 10(3):189-194.

Dispersants, Biological effects, Surfactants, Fish, Toxicity

The nonionic surfactant nonylphenol ethoxylate, NP 10 EO, which is used in the manufacturing of synthetic washing powders and oil dispersants, was studied at exposure concentrations of 5 ppm. Penetration and uptake take place in tissues and organs of cod. It is suggested that the main cause of acute poisoning is asphyxiation through surfactant accumulation in the gills.

C-1933-77
EFFECTS OF CHLORINATED BIPHENYLS AND PETROLEUM HYDROCARBONS ON THE ACTIVITY OF HEPATIC ARYL HYDROCARBON HYDROXYLASE OF COHO SALMON (ONCHORHYNCHUS KISUTCH) AND CHINOOK SALMON (O. TSHAWYTSCHA)
Gruger, E. H., Jr., M. M. Wekell, and P. A. Robisch. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 323-331. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Hydrocarbons, Fish, Uptake, Release, *Coho and Chinook salmon, *Chlorinated biphenyls, *Enzyme activity

The title organisms were fed mixtures of test compounds, one composed of a mixture of hydrocarbons, the other a mixture of chlorinated biphenyls. The latter was found to interact synergistically with the hydrocarbons, inducing aryl hydrocarbon hydroxylase activity in the hepatic microsomes of coho salmon, but depressing it in the chinook salmon. The presence of chlorobiphenyls thus may interfere with the natural accumulation and discharge of petroleum hydrocarbons in organisms.

NWMAR116774

C-1934-77
THE EFFECTS OF ESSO COREXIT 9527 ON THE FERTILIZING CAPACITY OF SPERMATOZOA
Hagström, B. E., and S. Lönning 1977.
Marine Pollution Bulletin 8(6):136-138.

Dispersants, Echinoderms, Toxicity, *Esso Corexit 9527, *Fertilization

The present study of the effect on sea urchin spermatozoa indicates that the water-soluble oil dispersant Esso Corexit 9527 interferes with fertilization and development in concentrations down to 0.0003 ppm. It is believed that such concentrations will be achieved after any use of the dispersant at sea. The components of Esso Corexit 9527 have not been published by the manufacturers.

C-1935-77
FACTORS AFFECTING THE RETENTION OF A PETROLEUM HYDROCARBON BY MARINE PLANKTONIC COPEPODS
Harris, R. P., V. Berdugo, E.D.S. Corner, C. C. Kilvington, and S.C.M. O'Hara. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 286-304. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Hydrocarbons, Crustaceans, Plankton, Uptake, Release *^{14}C-1-naphthalene, *Copepods

Radiolabeled ^{14}C-1-naphthalene was used as a model compound to study retention of aromatic hydrocarbons by 7 species of marine planktonic copepods. Naphthalene concentrations in the range of 0.2 to 1000 µg/L were used in order to simulate concentrations likely to exist in oil spill situations. After uptake the animals were transferred to clean water and 34 days later, they still retained an average of 10% of the initially accumulated ^{14}C-1-naphthalene.

C-1936-77
THE EFFECTS OF PETROLEUM HYDROCARBON EXPOSURE ON THE STRUCTURE OF FISH TISSUES
Hawkes, J. W. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 115-128. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Fish, Biological effects, Hydrocarbons, Analytical techniques, *Tissues, *Morphological changes

NWMAR116775

Literature on the morphological effects of petroleum contamination is reviewed, and new information on cellular and subcellular tissue changes in fish exposed to petroleum is presented. Light microscopy, and transmission and scanning electron microscopy techniques were used to document changes in skin, gills, liver, eye lens, and other organ tissues.

C-1937-77
EFFECTS OF THE CHESAPEAKE BAY OIL SPILL
Hershner, C. H., and K. A. Moore. 1977.
Ecolibrium 6(3):20-21.

Oil spills, Biological effects, Marshes, Marine organisms, Birds, Mollusks, Chesapeake Bay, *Marsh grasses

A study was conducted to determine the biological effects of the February, 1976, Chesapeake Bay oil spill on the marshes of the eastern shore of the Bay. The spill resulted in an unusually high kill of water birds, but the damage to other members of the ecosystem, such as the intertidal mussel, Modiolus demissus, the oyster, Crassostrea virginica, and the snail, Littorina irrorata, was minimal. The marsh grass, Spartina alterniflora, showed an increase in net production and flowering success and a decrease in mean height.

C-1938-77
EFFECT OF CRUDE OIL ON TROUT REPRODUCTION
Hodgins, H. O., W. D. Gronlund, J. L. Mighell, J. W. Hawkes, and P. A. Robisch. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 129-137. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Crude oil, Chronic effects, Toxicity, Fish, *Trout reproduction

Prudhoe Bay crude oil was added to the diet (1g oil/kg food) of sexually maturing rainbow trout in order to assess the chronic effects of the oil exposure on salmonid fish reproductive success. Six to seven months after initial treatment, survival and development of hatched eggs, fertility rates, and morphological and histological abnormalities were compared for test fish and their controls. No significant impairment of reproductive success was detected in the experiment.

NWMAR116776

C-1939-77
ECOLOGICAL RESPONSES OF PHYTOPLANKTON ON CHRONIC OIL POLLUTION
Ignatiades, L., and N. Mimicos 1977.
Environmental Pollution 13(2):109-118.

Contamination, Chronic effects, Phytoplankton, Aegean Sea

The phytoplankton ecology in the chronically oil-polluted Elefsis Bay (Saronicos Gulf, Aegean Sea) inshore environment was studied over an annual cycle. Emphasis was placed on the species composition, dominance, diversity, and succession of diatoms and dinoflagellates, but generally most taxa were tolerant of the oil in concentrations up to 27 mg/L. Results are compared with data on unpolluted environments.

C-1940-77
PETROLEUM, TEMPERATURE, AND TOXICANTS: EXAMPLES OF SUSPECTED RESPONSES BY PLANKTON AND BENTHOS ON THE CONTINENTAL SHELF
Jeffries, H. P., and W. C. Johnson, II. 1976.
Marine Reprint-69, NOAA-77011708; Grant NOAA-04-6-158-44002.
17 p.

Crude oil, Toxicity, Plankton, Benthos, OCS, *New York Bight, New York

Gross population changes enumerated over time in natural communities of the New York Bight are examined. For open coastal areas in the Mid-Atlantic Bight, the direct effect on copepod populations is at present not a concern. Limited, short-term effects are seen only at point discharges. However, on the sea bottom, small-scale environmental changes have cumulative effects that are enhanced in the benthos, rather than dissipated as in the plankton, by ecosystem processes.

C-1941-77
MORTALITY OF MAGELLANIC PENGUINS IN ARGENTINA
Jehl, J. R., Jr. 1975.
Auk 92(3):596-598.

Birds, Contamination, Coasts, Argentina, *Tierra del Fuego, *Penguins, *Mortality

Oiling appears to be an important contributor to the mortality of Magellanic penguins and other birds living along the Tierra del Fuego coast of Argentina. A large number of bird remains have been found on beaches of the area contaminated or completely coated with oil.

[from Ecological Abstracts 1976/6:#76L/4438. 1977]

NWMAR116777

C-1942-77
ALTERATIONS IN SOME CARBOHYDRATE METABOLISM INDEXES IN BLOOD OF SEA BASS AND BLACK SEA SOLE EXPERIMENTALLY POISONED WITH DISSOLVED PETROLEUM PRODUCTS [English summary]
Kotor, A. M. 1976.
Gidrobiologiya Zhurnal 12(6):84-88.

Petroleum products, Toxicity, Metabolism, Fish, *Spicara smaris, *Solea lascaris nasuta.

"Petroleum products at 9.3 mg/L raised the glucose level in the blood of sea bass (Spicara smaris) within 72-120 h, whereas at 16.4-22.2 mg/L decreased it within 5-51 h. However, within 4 h, the petroleum products at 22.2 mg/L raised the blood glucose and glycogen and decreased lactic acid. At 0.05 and 0.1 mg/L, the petroleum products decreased glucose and lactic acid, and raised glycogen during 42 days. In the sole (Solea lascaris nasuta) 0.05 and 0.1 mg/L of petroleum products raised the blood glucose for 20 days, and glycogen and lactic acid for 10 days."

[from Chemical Abstracts 86(25):#184068h. 1977]

C-1943-77
SEZONNAYA DINAMIKA GEMATOLOGISHESKIKH POKAZATELEI U NEKOTORYKH CHERNOMORSKIKH RYB I IKH IZMENENIE PRI EKSPERIMENTAL' NOM OTRAVLENII NEFTEPRODUKTAMI [in Russian]
Kotov, A. M. 1976.
Gidrobiologicheskii Zhurnal 12(4):63-68.

Petroleum products, Toxicity, Fish, *Hematological changes

The effect of dissolved petroleum products on the blood of the fish, Spicara smaris, Diplodus annularis, and Solea lascaris nasuta was studied. The oil products produced pronounced pathological disturbances of the blood, including leukocytosis which occurred in two of the species. Hematological changes can be used as criteria for estimating the toxic effect of soluble petroleum products in fish.

[from Pollution Abstracts 8(4):#77-03237. 1977]

C-1944-77
LONG-TERM EFFECTS OF AN OIL SPILL ON POPULATIONS OF THE SALT MARSH CRAB UCA PUGNAX
Krebs, C. T., and K. A. Burns. 1977.
Science 197(4302):484-487.

Fuel oil, Oil spills, Contamination, Marshes, Crustaceans, Biological effects, Massachusetts, *Uca pugnax

A fuel oil spill at West Falmouth, Massachusetts, in 1969, contaminated salt marshes with up to 6000 ppm oil per gram of mud,

NWMAR116778

and adversely affected local populations of the fiddler crab, Uca pugnax. The oil pollution resulted in reduced crab density, reduced ratio of females to males, reduced juvenile settlement, heavy overwintering mortality, incorporation of oil in body tissues, and behavioral disorders in locomotion and abnormal burrow construction. As yet, recovery of the marsh from this relatively small spill is incomplete.

C-1945-77
INTERACTIVE EFFECTS OF TEMPERATURE, SALINITY SHOCK AND CHRONIC EXPOSURE TO NO. 2 FUEL OIL ON SURVIVAL, DEVELOPMENT RATE AND RESPIRATION OF THE HORSESHOE CRAB, LIMULUS POLYPHEMUS
Laughlin, R. B., Jr., and J. M. Neff. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 182-191. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Fuel oil, Biological effects, Metabolism, Crustaceans, *Temperature, *Salinity, *Limulus polyphemus

Survival of larvae decreased with decreasing temperature and increasing concentrations of water-soluble fractions (WSF) of No. 2 fuel oil. The respiration rates of control animals decreased with decreasing salinity and temperature. The respiration rate of oil-exposed crabs was significantly higher than that of controls at nearly all salinity/temperature combinations. The interaction of salinity and WSF exposure on respiratory rate was highly significant.

C-1946-77
DEVELOPMENT OF AN INVERTEBRATE BIOASSAY TO SCREEN PETROLEUM REFINERY EFFLUENTS DISCHARGED INTO FRESHWATER
Lee, D. R. 1976.
Ph.D. Thesis, Virginia Polytechnic Institute, Blacksburg, Virginia. 118 p.

Refineries, Toxicity, Wastewaters, Freshwater, Monitoring, Invertebrates, *Daphnia pulex, *Bioassay

A simple method which uses unsophisticated equipment has been developed for on-site toxicity testing of refinery effluents. The method uses Daphnia pulex bioassays because the organism is the most sensitive of 15 species of freshwater invertebrates and 3 fish species tested, and because it is inexpensive and easy to maintain. Daphnia bioassays were field tested at several refineries. The test results are in agreement, reproducible, and can be performed readily by refinery personnel.

[from Dissertation Abstracts International B 37(4):1551-1552. 1976]

NWMAR116779

C-1947-77
ACCUMULATION AND TURNOVER OF PETROLEUM HYDROCARBONS IN MARINE ORGANISMS
Lee, R. F. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 60-70. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Hydrocarbons, Uptake, Storage, Release, Marine organisms

This review deals with the uptake, storage, and discharge of petroleum hydrocarbons by marine organisms under laboratory and field conditions. Under the heading, "Bioaccumulation," analyses of organisms collected from oil spill and chronically polluted areas are reviewed. The section entitled, "Biological Transfer Processes," discusses the ability of animals to depurate their hydrocarbons accumulated after exposure to oil.

C-1948-77
TOXICITY EFFECTS OF A CRUDE OIL ON THE PRIMARY PRODUCTION OF THE PHYTOPLANKTON OF THE RANCE ESTUARY: INFLUENCE OF TEMPERATURE AND CONTACT TIME [English summary]
Le Pemp, X., J.-C. Lacaze, and O. Villedon de Naïde. 1976.
Bulletin du Museum National d'Histoire Naturelle, Paris (3e Sér.), Ecologie generale 386(32):107-110.

Toxicity, Crude oil, Phytoplankton, Estuaries, *Kuwait crude

Experiments showed that the toxicity of Kuwait crude oil rises with temperature in the case of a biocenose-extract contact time of 24 hours. However, the temperature dependence is eliminated and the toxicity is reduced to one-seventh when the exposure time is reduced to four hours.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10523. 1977]

C-1949-77
CHRONIC TOXICITY OF A SYNTHETIC TRI-ARYL PHOSPHATE OIL TO FISH
Lockhart, W. L., R. Wagemann, J. W. Clayton, B. Graham, and D. Murray, 1975.
Environmental Physiology and Biochemistry 5(6):361-369.

Toxicity, Chronic effects, Fish, Freshwater, Lubricating oil, *Synthetic oil

A long-term, continuous-flow exposure of rainbow trout (Salmo gairdneri) to IMOL S-140, a synthetic high-temperature lubricating oil, was conducted after concern was raised over past and future dangers of oil losses from natural gas pipeline

NWMAR116780

pumping stations. No sign of acute toxicity was observed, but the fish slowly developed symptoms of chronic poisoning. The toxicity was not revealed by standard 96-hr bioassay methods nor by serum and brain cholinesterase measurements.

C-1950-77
RECOLONIZATION OF RED SEA CORALS AFFECTED BY NATURAL CATASTROPHIES AND MAN-MADE PERTURBATIONS
Loya, Y. 1976.
Ecology 57(2):278-289.

Coral reefs, Biological effects, Contamination,Red Sea, Israel, *Succession, *Recolonization

This paper studies the recovery patterns of hermatypic coral communities following a catastrophic low tide, observing two reef flats in the northern Gulf of Eilat. The control reef was pollution-free, but the other, at the nature reserve of Eilat, Israel, neighbors the port of Eilat and two major oil terminals and is thus chronically polluted. The conclusion is made that the man-polluted coral reef will not return to its former equilibrium, but the naturally disturbed community will recover over time.

C-1951-77
EFFECTS OF PETROLEUM ON ARCTIC AND SUBARCTIC MARINE ENVIRONMENTS AND ORGANISMS
Malins, D. C. 1977.
New York, Academic Press, 1977. Vol. II. Biological Effects of Petroleum.

Hydrocarbons, Biological effects, Marine organisms, Ecosystems, Arctic, Subarctic regions

The impacts of petroleum hydrocarbons on the biota of pristine areas are poorly understood, despite certain relevant data from laboratory experiments with indigenous organisms and a lesser amount of field information. In this volume an attempt is made to compile data on the biological effects of petroleum on marine organisms, evaluate the implications to possible alterations in organisms and ecosystems, and offer suggestions for future work where significant gaps in knowledge exist.

C-1952-77
THE EFFECTS OF AN OIL SPILL ON THE MACROINVERTEBRATES AND FISH IN A SMALL SOUTHWESTERN VIRGINIA CREEK.
Masnik, M. T., J. R. Stauffer, C. H. Hocutt, and J. H. Wilson. 1976.
Journal of Environmental Science and Health A11 (4 & 5):281-296.

NWMAR116781

Oil spills, Fuel oil, Biological effects, Invertebrates, Fish, Streams, Virginia

Approximately 13,000 L of No. 2 fuel oil entered Plum Creek in May, 1973, after the tank of a disabled tractor trailer truck overturned. Immediate mortality of water snakes and waterfowl was high, but collections of benthos and fishes over a five-month period indicated minimal mortality and only slight reductions in population levels. It was recommended that the use of straw booms be reevaluated, as leaching of oil fractions from the straw over time may result in chronic environmental damage.

C-1953-77
MOLTING AND SURVIVAL OF KING CRAB (PARALITHODES CAMTSCHATICA) AND COONSTRIPE SHRIMP (PANDALUS HYPSINOTUS) LARVAE EXPOSED TO COOK INLET CRUDE OIL WATER-SOLUBLE FRACTION
Mecklenburg, T. A., S. D. Rice, and J. F. Karinen. 1977. Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 221-228. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Crude oil, Biological effects, Crustaceans, *Water-soluble fraction, *Molting larvae

Molting larvae were more sensitive than intermolt larvae to the water-soluble fraction (WSF) of crude oil, and molting coonstripe shrimp larvae were more sensitive than molting king crab larvae. When molting larvae were exposed to high concentrations of the WSF (1.15-1.87 ppm total hydrocarbons) for six hours, molting success was reduced by 10-30% and some deaths occurred. When larvae were exposed to these concentrations for 24 hours or longer, molting declined 90-100% and the larvae usually died. Comparisons of sensitivity to oil between different crustacean species or life stages should be based on animals tested in the same stage of the molt cycle.

C-1954-77
THE OCCURRENCE OF FIN ROT IN MULLET (MUGIL CEPHALUS) ASSOCIATED WITH CRUDE OIL CONTAMINATION OF AN ESTUARINE POND-ECOSYSTEM
Minchew, C. D., and J. D. Yarbrough, 1977.
Journal of Fish Biology 10(4):319-323.

Fish, Contamination, Crude oil, Estuaries, *Fin rot, *Mullet

Four ponds were constructed with tidal simulation and stocked with mullet, shrimp, and oysters. A six-month study established a low incidence of disease in the fish. Within one week after Empire Mix crude oil was spilled in two ponds all of the mullet developed fin rot. This disease did not occur in any preliminary laboratory tests of acute exposure of mullet to crude oil.

NWMAR116782

C-1955-77
TOXIC INFLUENCE OF MINERAL OILS AND GASOLINE ON SELF PURIFICATION PROCESSES IN NATURAL WATERS [English summary]
Mueller, D., and H. Hellmann. 1976.
Gas-Wasserfach, Wasser-Abwasser 117(8):369-373.

Crude oil, Petroleum products, Gasoline, Biodegradation, Toxicity, Bacteria, Algae, Freshwater, *Photosynthesis

Samples of crude oil, diesel fuel, motor oil, and gasoline were added to 10-L volumes of tap water exposed to sun and wind; bacterial biodegradation and algal photosynthesis were monitored for 21 days. Gasoline showed initial strong toxicity followed by increased bacterial activity. Water soluble components of diesel and motor oils increased biodegradation and inhibited photosynthesis. Toxic effects of light and medium crudes paralleled those of gasoline.

[from Chemical Abstracts 87(2):#11356t. 1977]

C-1956-77
EFFECTS OF PETROLEUM ON THE LITTORAL ECOSYSTEM [in Norwegian]
Notini, M. 1976.
NORDFORSK, Miljoevardssekretariatet Publikation (2, Organiska Miljoegifter i Vatten, Nordiska Symposiet om Vattenforskning, 12th):299-316.

Intertidal zone, Biological effects, Spill cleanup, Baltic Sea

This review covers sources of oil pollution in the Baltic Sea, special problems in the littoral zone, and techniques for studying the biological effects of oils and cleanup activities on littoral organisms. Twelve references are cited.

[from Chemical Abstracts 87(8):#57795p. 1977]

C-1957-77
EFFECTS OF OIL ON MICROBIAL COMPONENT OF AN INTERTIDAL SILT-SEDIMENT ECOSYSTEM
Norrell, S. A. and M. H. Johnston, 1976.
Occasional Publications, University of Alaska, Institute of Marine Science 4(Assessment of the Arctic Marine Environment, Selected Topics, Symposium):305-327.

Biological effects, Bacteria, Biomass, Sediments, Microorganisms, Intertidal zone

"A review with twenty-seven references of the relations between bacterial biomass and sediment properties and the effects of oil contamination on microbial growth."

[from Chemical Abstracts 87(7):#49854s. 1977]

NWMAR116783

C-1958-77
SOME PRELIMINARY OBSERVATIONS ON THE ENHANCEMENT OF PHYTOPLANKTON GROWTH BY LOW LEVELS OF MINERAL HYDROCARBONS
Parsons, T. R., Li, W. K. W., and R. Waters. 1976.
Hydrobiologia 5(1):85-89.

Phytoplankton, Hydrocarbons, Biological effects, Metabolism, *Plant growth, *Photosynthesis

From field and laboratory experiments it has been observed that low concentrations (ppb) of mineral hydrocarbons can cause an increase in photosynthesis among nanoplankton. It is believed that very low level effects of hydrocarbons on marine phytoplankton may be ecologically important in stimulating the growth of certain nanoplanktonic organisms, causing them to grow faster at the expense of larger phytoplankters.

[from Government Reports Announcements 77(11):#PB-264 727/9GA. 1977]

C-1959-77
MIXED FUNCTION OXIDASES IN MARINE ORGANISMS IN RELATION TO PETROLEUM HYDROCARBON METABOLISM AND DETECTION
Payne, J. F. 1977.
Marine Pollution Bulletin 8(5):112-116.

Hydrocarbons, Metabolism, Detection, Monitoring, Marine organisms, *Enzyme activity, Canada

Several organisms were collected from pollution-free sites in eastern coastal Newfoundland and investigated for mixed function oxidases. AHH activity was detected in some of the phyla, as well as petroleum induced AHH. Only AHH appeared to be a useful enzyme monitor for petroleum, but no invertebrate was considered a useful monitor for petroleum pollution.

C-1960-77
EFFECTS OF DISPERSED CRUDE OIL UPON THE RESPIRATORY METABOLISM OF AN ARCTIC MARINE AMPHIPOD, ONISIMUS (BOEKISIMUS) AFFINIS
Percy, J. A. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 192-200. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Crude oil, Dispersions, Biological effects, Metabolism, Crustaceans, *Sublethal effects, *Arctic amphipod

At low oil concentrations, metabolism is significantly depressed, but with increasing concentration a reversal of the response occurs. An explanation for this response is presented. The

NWMAR116784

effects of oil type, presence of dispersants, nutritional state of the animals, and weathering of the oil on the metabolic response are also considered.

C-1961-77
POLLUTION OF MARINE WATERS
Peres, J. M. 1976.
Paris, France, Bordas, 1976. 231 p.

Pollution control, Biological effects, Benthos, Coasts, *Pelagic organisms

This book brings together several papers on the main problems of marine pollution. Oil pollution control and biological effects of oil contamination are reviewed along with other forms of pollutants. The authors discuss the biological effects on pelagic and benthic communities and on the sea's resources.

[from Aquatic Sciences & Fisheries Abstracts 7(7):#7Q8933. 1977]

C-1962-77
ACUTE TOXICITY AND UPTAKE-DEPURATION STUDIES WITH COOK INLET CRUDE OIL, PRUDHOE BAY CRUDE OIL, NO. 2 FUEL OIL AND SEVERAL SUBARCTIC MARINE ORGANISMS
Rice, S. D., J. W. Short, C. C. Brodersen, T. A. Mecklenburg, D. A. Moles, C. J. Misch, D. L. Cheatham, and J. F. Karinen. 1976.
Northwest Fisheries Center Auke Bay Fisheries Laboratory, Processed report. 90 p.

Crude oil, Fuel oil, Toxicity, Uptake, Release, Marine organisms

This report provides the results of a laboratory study of which the primary objectives were: to determine the acute toxicity of Cook Inlet and Prudhoe Bay crude oils and fuel oil to various life stages and species of fish and shellfish found in Kachemak Bay; to determine the rate and degree of uptake and depuration of hydrocarbons by these organisms when they are exposed to sublethal concentrations of the water-soluble fractions of Cook Inlet crude oil; and to compare results with the published literature in order to determine to what degree Alaskan fish and shellfish differ from species in other areas in their response to oil contamination.

C-1963-77
EFFECT OF PETROLEUM HYDROCARBONS ON BREATHING AND COUGHING RATES AND HYDROCARBON UPTAKE-DEPURATION IN PINK SALMON FRY
Rice, S. D., R. E. Thomas, and J. W. Short. 1977.
Physiological Responses of Marine Biota to Pollutants. New York, Academic Press, 1977.

NWMAR116785

Crude oil, Fuel oil, Toxicity, Hydrocarbons, Metabolism, Fish, *Respiration, *Oncorhynchus gorbuscha

Breathing and coughing rates of pink salmon fry, Oncorhynchus gorbuscha, were monitored during exposure to water soluble fractions of Cook Inlet and Prudhoe Bay crude oils and No. 2 fuel oil. High breathing rates during the first 24 hr of exposure, elimination of most aromatics by 20 hr , and the continued high breathing during a contact dose exposure for 72 hrs indicate that salmon fry can cope with a sublethal exposure to hydrocarbons, but at the cost of an increased metabolic rate. Increased metabolic rates may be detrimental to survival if the stress persists for long periods of time.

C-1964-77
A REVIEW OF COMPARATIVE OIL TOXICITY AND COMPARATIVE ANIMAL SENSITIVITY
Rice, S. D., J. W. Short, and J. F. Karinen. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 78-94. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Toxicity, Marine organisms, Crude oil, Petroleum products, *Comparative toxicity, *Bioassay

This review includes studies dealing with the ability of crude and refined oils to kill marine animals and covers: (1) the behavior of oil in water; (2) the methodology problems associated with bioassays; (3) the comparative toxicity of oil-water mixtures, oils, and components of oils; and (4) the comparative sensitivity of different life stages and species.

C-1965-77
MUSSELS AND POLLUTION
Roberts, D. 1976.
Marine Mussels: Their Ecology and Physiology. B. L. Bayne (ed.). Cambridge University Press, 1976. p.67-80.

Hydrocarbons, Crude oil, Toxicity, Mollusks, Bibliographies, Surfactants, Emulsifiers, *Mussels

This chapter briefly reviews the literature concerning the effects of pollutants on mussels. Seventeen references are cited concerning oil and detergent pollution, dated from 1961 to 1974. The research covers hydrocarbons, crude oil, detergents and oil emulsifiers, and toxicity.

NWMAR116786

C-1966-77
RESPONSES TO CRUDE OIL CONTAMINATION BY CRICOTOPUS (CRICOTOPUS) BICINCTUS AND C. (C.) MACKENZIENSIS (DIPTERA: CHIRONOMIDAE) IN THE FORT SIMPSON AREA, NORTHWEST TERRITORIES
Rosenberg, D. M., A. P. Wiens, and O. A. Saether. 1977.
Journal of the Fisheries Research Board of Canada 34(2):254-261.

Crude oil, Biological effects *Insects, Canada, *Chironomid larvae

The two title species of Chironomidae, common to the Fort Simpson area, were examined for changes resulting from experimental exposure to crude oil. Larvae of both species were more abundant on oiled artificial substrates; larvae of C. (C.) bicinctus tended to dominate. Larvae on oiled substrates appeared to have more rapid life cycles and produced part of another generation per year as compared to larvae on unoiled substrates.

C-1967-77
PLANKTON PROCESSES IN MID-ATLANTIC NEARSHORE AND SHELF WATERS AND ENERGY-RELATED ACTIVITIES
Smayda, T. J. 1975.
Conference on Effects of Energy-related Activities on the Atlantic Continental Shelf, Upton, New York, 1975.

Oil discharges, Hydrocarbons, Contamination, Phytoplankton, OCS, Atlantic coast

The potential effects of temperature and petroleum hydrocarbons on key plankton processes and events are considered, based on phytoplankton physiology. Oil release is a likely source of contamination on the continental shelf; however, shore-based activities of the petrochemical industry and discharges from tankers in shipping lanes and ports may also stress recipient waters.

[from ERDA Energy Research Abstracts 2(12):#30851. 1977]

C-1968-77
THE ACCUMULATION AND DEPURATION OF NO. 2 FUEL OIL BY THE SOFT SHELL CLAM MYA ARENARIA L.
Stainken, D. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 313-322. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Fuel oil, Emulsions, Mollusks, Uptake, Release, *Mya arenaria L.

The title organisms were exposed experimentally to No. 2 fuel oil-in-water emulsions at 4°C to simulate winter spill conditions,

NWMAR116787

and the patterns of accumulation and discharge of petroleum constituents were determined. The clams can rapidly accumulate, concentrate, and release to the environment large amounts of petroleum hydrocarbons by means of a reversible mucus-oil binding mechanism.

C-1969-77
EFFECTS OF CERTAIN PETROLEUM PRODUCTS ON REPRODUCTION AND GROWTH OF ZYGOTES AND JUVENILE STAGES OF THE ALGA FUCUS EDENDATUS DE LA PYL (PHAEOPHYCEAE: FUCALES)
Steele, R. L. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 138-142. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Petroleum products, Fuels, Crude oil, Biological effects, Algae, *Growth, *Reproduction, *Fucus edentatus De La Pyl

The effects of various petroleum products on growth and the early development of the Fucus zygote were studied experimentally. A crude oil had far less of an effect on Fucus growth than did No. 2 fuel oil or two jet fuels. Exposure to any of the oil products immediately prior to or during the release of gametes completely prevented germination or growth.

C-1970-77
SENSITIVITY OF SOME BROWN ALGAL REPRODUCTIVE STAGES TO OIL POLLUTION
Steele, R. L., 1977.
Journal of Phycology 13 (Supplement):64. Abstract.

Toxicity, Algae, *Reproduction, Contamination

The author studied two genera of brown algae, Fucus and Laminaria, to measure oil pollution toxicity in these bioassay organisms. Four kinds of oil were tested and both algae were found to be sensitive at less than 100 ppb. Male reproductive cells were much more sensitive than eggs or female gametophytes.

C-1971-77
BIOLOGICAL SURVEY OF INTERTIDAL AREAS IN THE STRAITS OF MAGELLAN IN JANUARY, 1975, FIVE MONTHS AFTER THE METULA OIL SPILL
Straughan, D. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 247-260. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

NWMAR116788

Metula spill, Biological effects, Marine organisms, Intertidal zone, Strait of Magellan

Biological, physical, and chemical data were analyzed, using techniques of ordination, classification, and discrimation, and results indicate a negative relationship between the biota and presence of petroleum. While grain size was important in governing the distribution and abundance of species at the oiled and unoiled sites, the visible presence of petroleum in the form of mousse was the most significant factor.

C-1972-77
EFFECTS OF BENZENE (A TOXIC COMPONENT OF PETROLEUM) ON SPAWNING PACIFIC HERRING, CLUPEA HARENGUS PALLASI
Struhsaker, J. W. 1977.
Fishery Bulletin 75(1):43-50.

Toxicity, Hydrocarbons, Fish, *Benzene, *Reproduction, *Clupea harengus pallasi

Exposure of female Pacific herring to low (ppb) levels of benzene for 48 hr prior to their spawning resulted in a significant reduction in survival of ovarian eggs, embryos, and larvae due to yolk absorption. Exposure to benzene also induced premature spawning and resulted in aberrant swimming behavior and disequilibrium in adults of both sexes.

[from Selected Water Resources Abstracts 10(15):#W77-07137. 1977]

C-1973-77
EFFECTS OF EXTERNAL APPLICATIONS OF NO. 2 FUEL OIL ON COMMON EIDER EGGS
Szaro, R. C., and P. H. Albers. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 164-167. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Fuel oil, Birds, Biological effects, *Hatchability, *Common eider eggs

Eggs of the Common Eider (Somateria mollissima) were coated with up to 20 µl of No. 2 fuel oil and artificially incubated with other treated eggs and controls. Eggs treated with 5 µl and 20 µl fuel oil had hatching rates of 92% and 69%, respectively, as compared to 96% for the control group. Thus, oil pollution may significantly increase embryonic mortality in marine birds.

NWMAR116789

C-1974-77
ACCUMULATION OF NAPHTHALENES BY GRASS SHRIMP: EFFECTS ON RESPIRATION, HATCHING, AND LARVAL GROWTH
Tatem, H. E. 1977.
Fate and Effects of Petroleum Hydrocarbons on Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 201-209. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Hydrocarbons, Fuel oil, Uptake, Crustaceans, Metabolism, *Naphthalenes,*Hatching, *Larval growth, *Grass shrimp

When P. pugio was exposed to petroleum hydrocarbons (PH) from a No. 2 fuel oil, sampling revealed that naphthalene levels in the exposure solution decreased rapidly while concentrations in the shrimp increased dramatically. Exposure of the shrimp to over 3.0 ppm PH for 5 hr resulted in a lower than average respiration rate. A single 72-hr exposure of gravid female shrimp to 1.44 ppm PH had a detrimental effect on larval hatching. Control females released an average of 45 larvae compared to 9 larvae for exposed females. Larvae continuously exposed to 0.85-0.52 ppm PH weighed significantly less than control animals after 12 days.

C-1975-77
RESPONSE OF THE CLAM, MACOMA BALTHICA (LINNAEUS), EXPOSED TO PRUDHOE BAY CRUDE OIL AS UNMIXED OIL, WATER-SOLUBLE FRACTION, AND OIL-CONTAMINATED SEDIMENT IN THE LABORATORY
Taylor, T. L., and J. F. Karinen. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 229-237. Proceddings of a Symposium, Seattle, Washington, November 10-12, 1976.

Crude oil, Seawater, Sediments, Biological effects, Mollusks, *Water-soluble fraction, *Oil-treated sediment, *Macoma balthica

Gentle settling of crude oil over clam beds had negligible effects on clams observed for two months. Water-soluble (WSF) and oil-treated (OTF) sediment fractions of Prudhoe Bay crude oil inhibited burrowing and caused clams to move to the sediment surface. Responses were directly proportional to the concentrations of the WSF or amount of OTF. The significance of these laboratory tests to survival of M. balthica in the natural environment is discussed.

NWMAR116790

C-1976-77
FOOD CHAIN TRANSFER OF HYDROCARBONS
Teal, J. M. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 71-77. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Hydrocarbons, Uptake, Release, Food web, Oceans, *Food chain transfer

The following subjects are covered in this review: selective accumulation of hydrocarbons; hydrocarbon uptake from food vs. water; hydrocarbon storage and depuration; oceanic food web transfer; and related research needs.

C-1977-77
LONG TERM BIOLOGICAL EFFECTS OF BUNKER C OIL IN THE INTERTIDAL ZONE
Thomas, M. L. H. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 238-245. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Marine organisms, Intertidal zone, Chedabucto Bay, Canada, Oil spills, Toxicity, *Mortalities

In February, 1970, a large spill of Bunker C oil occurred in Chedabucto Bay, Nova Scotia, when the tanker "Arrow" grounded. The major species that suffered mortalities in the communities on this shoreline as a result of this spill were studied. Results are summarized.

C-1978-77
FUNDAMENTAL STUDIES ON THE INFLUENCE OF OIL POLLUTION UPON MARINE ORGANISMS - III. EFFECTS OF OIL-SPILL EMULSIFIERS AND SURFACTANTS ON THE GROWTH OF PORPHYRA-LAVER. [English summary]
Tokuda, H. 1977.
Bulletin of the Japanese Society of Scientific Fisheries 43(5): 587-593.

Toxicity, Surfactants, Emulsifiers, Algae, *Seaweed, *Growth rates

Culture experiments were done to determine the inhibitory effects of six oil-spill emulsifiers and four non-ionic surfactants on the growth of Porphyra yezoensis. Growth rates were studied in assessing the toxicity, and changes in the cellular appearance of the laver were also studied by optical microscopy.

NWMAR116791

C-1979-77
INGESTION OF SUSPENDED OIL PARTICLES AND THE INFLUENCES ON MORTALITY IN THE MOLLUSCAN LARVAE [in Japanese]
Umezawa, S., O. Fukuhara, and S. Sakaguchi. 1976.
Bulletin of the Nansei Regional Fisheries Laboratory, Vol. 9: 77-82.

Toxicity, Mollusks, Uptake, Release, *Oil droplets, *Mortality, *Crassostrea gigas, *Mytilus spp.

Oyster and mussel larvae, Crassostrea gigas and Mytilus spp., respectively, were kept in seawater to which different concentrations of oil droplets were added. The ingestion of the suspended oil droplets and their influences on mortality in these molluskan larvae were investigated. The percentage of the larvae with ingested oil droplets and the diameter of the oil droplets in the stomach of each larvae became greater as the oil droplet concentration in the medium increased. This increase led to an increased mortality rate among the experimental larvae. Molluskan larvae were unable to exude oil droplets ingested in their stomachs; subsequent cohesion of the droplets was the main cause of larvae mortality.

[from Selected Water Resources Abstracts 10(12):#W77-05909. 1977]

C-1980-77
THE EFFECT OF PRUDHOE CRUDE OIL ON PRIMARY PRODUCTION IN ARCTIC PONDS
Vestal, J. R., T. W. Federle, G. R. Hater, and M. C. Miller. 1977.
American Society for Microbiology Annual Meeting, 77th, New Orleans, 1977. Paper no. Q44. Abstract.

Crude oil, Toxicity, Phytoplankton, Arctic, Freshwater, *Primary production

In controlled pond experiments, soluble components of crude oil were found to curtail or completely inhibit primary production of phytoplankton within a few days. As the toxic components of oil were subsequently lost, the primary production slowly recovered, but with a significant shift in the species dominance from Chryptophytes to Chrysophytes.

C-1981-77
ROLE OF MUSSELS MYTILUS EDULIS IN REMOVAL OF PETROLEUM PRODUCTS FROM SEAWATER (UNDER EXPERIMENTAL CONDITIONS)
Vokyo, Y. V., and Y. M. Petrov. 1975.
Hydrobiological Journal 11(2):19-24.

Uptake, Petroleum products, Mollusks, Seawater, *Water purification, *Mytilus edulis

NWMAR116792

In tanks with mussels, the water was purified twice as fast as in the control. After 3 weeks, only 7% of the initial amount of petroleum remained in the tanks with mussels. Of this amount, about 1.4% was depostied by the aquatic organisms on the tank bottoms, 5.6% remained in the surface film, and 0.2% was still dissolved.

[from Selected Water Resources Abstracts 10(15):#W77-07116. 1977]

C-1982-77
BIOLOGICAL EFFECTS OF OIL CONTAMINATION ON THE SEA WITH SPECIAL CONSIDERATION TO THE BALTIC SEA
Von Oertzen, J. A. 1977.
Wasserwirtschaff - Wassertechnik 27(2):34-37.

Contamination, Biological effects, Baltic Sea

"A review with 37 references."

[from Chemical Abstracts 87(1):#726n. 1977]

C-1983-77
EFFECTS OF OIL DISPERSANTS ON THE DEVELOPING EMBRYOS OF MARINE FISH.
Wilson, K. W. 1976.
Marine Biology 36(3):259-268.

Dispersants, Biological effects, Fish, Spill cleanup, *Embryo development

This paper details the effects of three oil dispersants, B1002, Finasol ESK, and Corexit 7664, on the development of plaice, sole, and herring. Concentrations of dispersants and exposure length leading to deleterious effects have been defined, but it is unknown if similar conditions would occur at sea after spill cleanup operations. It is also speculated that use of recently developed dispersants with lower toxicity claims would not produce significant mortality in fish embryos.

C-1984-77
GONADAL AND HEMATOPOIETIC NEOPLASMS IN MYA ARENARIA
Yevich, P. P., and C. A. Barszcz. 1976.
Marine Fisheries Review 38(10):42-43.

Oil spills, Biological effects, Mollusks, Maine, *Gonadal neoplasms, *Mya arenaria

"Microscopic examinations of clams collected from Long Cove, Maine, where there was an oil spill in 1971, revealed gonadal neoplasms in males and females. In other clams neoplastic

NWMAR116793

growth was observed in cells that appeared to be of hematopoietic lineage. Extensive accumulations of neoplastic cells were observed in the gills, siphon, foot, and connective tissues."

[from ERDA Energy Research Abstracts 2(14):#36211. 1977]

NWMAR116794

2. PHYSICAL EFFECTS

C-1985-77
AN ASPECT OF COASTAL POLLUTION - THE COMBINED EFFECT OF DETERGENT AND OIL AT SEA ON SEA SPRAY COMPOSITION
Fontana, M. 1976.
Water, Air & Soil Pollution 5(3):269-280.

Oil slicks, *Detergents, Physical effects, Seawater, *Sea spray formation

The natural formation of sea spray droplets was simulated under laboratory conditions in order to study the interaction of anionic detergents and oil slicks. Presence of detergents increased the production of sea spray, and the presence of a 1 mm oil slick inhibited the formation of marine aerosols.

[from Chemical Abstracts 86(26):#194756v. 1977]

C-1986-77
THERMAL CONDUCTANCE OF IMMERSED PINNIPED AND SEA OTTER PELTS BEFORE AND AFTER OILING WITH PRUDHOE BAY CRUDE
Kooyman, G. L., R. W. Davis, and M. A. Castellini. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p.151-157. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Marine mammals, Biological effects, Crude oil, *Thermal conductance, *Sea otters, *Pinnipeds

Thermal conductance (C) of the sea otter and several species of pinnipeds was measured during immersion, after oiling, and after cleaning. Sea otter pups were found to have the greatest C after oiling; adult pinnipeds were only slightly affected by oiling. Even a light oiling would have significant detrimental effects on the thermoregulatory abilities of otters and fur seals at sea.

3. ECONOMIC EFFECTS

C-1987-77
ANTIPOLLUTION COSTS TO SOAR (news brief)
Anon. 1977.
Ecolibrium 6(2):19.

Regulations, Oil industry, Pollution control, Wastewater treatment, Refineries, Cost analysis, API

An API-sponsored study of the cost to the oil industry of complying with expected environmental regulations has been conducted by the

NWMAR116795

Battelle Laboratories, Columbus, Ohio. Total costs to industry are expected to be in the range of $10 billion and $17 billion per year. Of this amount, a major expenditure will be for the treatment of refinery wastewaters and rainfall effluent, and for the removal of sulfur and lead from petroleum products.

C-1988-77
OIL SPILL SUPERFUNDS SEEM UNNECESSARY (news brief)
Anon. 1977.
Oil and Gas Journal 75(24):28-29.

Legislation, Liability, Compensation, Tankers, Oil spills, Oil industry, *Spill superfunds

Representatives from two international voluntary oil spill funds, Tovalop and Cristal, feel that the proposed $200 million superfunds to compensate for offshore oil spill damages are far larger than necessary. In contrast, U.S. oil industry officials argue that the existing patchwork of state and federal funds and laws is inadequate and should be replaced by a comprehensive and uniform system.

C-1989-77
REGS [sic] SET FOR TAPS SPILL FUND (news brief)
Anon. 1977.
Oil and Gas Journal 77(27):46.

Oil spills, Liability, Regulations, Tankers, Oil transfer, Ports, Alaska, *Oil spill fund

Regulations providing for the supervision and administration of a $100 million oil spill liability fund have been finalized. The fund will pay damages from oil spills occurring during oil transfer operations at the Alaskan Port of Valdez and at any point enroute between Valdez and the unloading point in a U.S. port.

C-1990-77
WHAT REFINERY POLLUTION ABATEMENT COSTS
Jenkins, D. M., and W. J. Sheppard. 1977.
Hydrocarbon Processing 56(5):154-157.

Regulations, Oil industry, Pollution control, Economic effects, Cost analysis, API, EPA

In this API report, attempts are made to compare and reconcile differences between previous studies of the economic impact of environmental regulations on the petroleum industry. Differences in the cost estimates made by EPA and those made by API are attributed to the methodology used, involving philosophical and regulation selection differences.

NWMAR116796

C-1991-77
THE HIGH COST OF AN OIL SPILL
White, J. 1977.
Outdoor California 38(2):15.

Oil spills, Inland, Economics, Spill cleanup, Restoration, California

The high cost and difficulty of cleaning up a small inland spill is briefly documented. The spill, which lost about 14,383 L (3800 gal) of heavy fuel oil, occurred near Gilroy, California. Cleanup and restoration took 20 men 17 days. The oil had a value of about $600 before the spill, but its cleaning cost exceeded $50,000.

4. GENERAL EFFECTS

C-1992-77
CANADA'S TANKER LAWS ARE THE TOUGHEST
Anon. 1977.
Canadian Shipping and Marine Engineering 48(6):20-21.

Tankers, Oil spills, Legislation, Economic effects, Environmental effects, Canada

Tanker disasters that have occurred off the Canadian coasts are discussed. The legal, political, economic and environmental issues surrounding such events are examined.

[from Aquatic Sciences & Fisheries Abstracts 7(8):#7Q10421. 1977]

C-1993-77
PERSISTING OIL SPILL EFFECTS
Anon. 1977.
Mechanical Engineering 99(January):62-63.

Metula spill, Environmental effects, Beaches, Sediments, Strait of Magellan

A recent visit to the area of the 1974 "Metula" supertanker oil spill in the Strait of Magellan shows that the effects of the spill are still dramatically evident on the beaches. Stranded oil has penetrated nearly 20 cm into sand, producing pavement-like surfaces on the beaches. In areas where the beach surface has eroded, soft, fresh oil is evident in the subjacent layers.

NWMAR116797

C-1994-77
OIL SPILLS - AN EDITORIAL
Abelson, P. H. 1977.
Ecolibrium 6(2):15.

Oil spills, Tankers, Environmental effects

Recent tanker spills have resulted in the loss of over 56 million L (15 million gal) of oil into the oceans. The general view is that there are ecological catastrophes which will have serious environmental effects for years. This editorial, originally published in Science [195(4274):137], argues that this generally held view has no factual basis, and that the environmental effects are far less long lived and severe.

C-1995-77
MAN'S IMPACT ON THE NATURAL ENVIRONMENT OF PENINSULAR MALAYSIA: SOME PROBLEMS AND HUMAN CONSEQUENCES
Aiken, S. R., and M. R. Moss. 1976.
Environmental Conservation 3(4):273-283.

Oil spills, Tankers, Environmental effects, Malaysia

Examples are selected to show the degree of man's impact on the natural environment of Malaysia and also the changing relationships between man and his environment. One case study describes the impact of oil spillage from grounded supertankers using the Straits of Malacca and Singapore and illustrates the international implications of a potentially widespread ecological disaster.

[from Applied Ecology Abstracts 3(5):#3D5731. 1977]

C-1996-77
ENVIRONMENTAL EFFECT OF OIL AND THE CHEMICALS USED TO CONTROL IT ON 3) THE SHORE AND SPLASH ZONES
Baker, J. M. 1976.
The Control of Oil Pollution on the Sea and Inland Waters.
J. Wardley-Smith (ed.). London, Graham & Trotman Ltd., 1976.
p.57-71.

Oil spills, Dispersants, Environmental effects, Shorelines, Intertidal zone, Marine organisms, Toxicity

A review is presented on the damage to the shoreline caused by oil pollution. Environmental effects can be documented by post-spill surveys, long-term monitoring schemes, field experiments on rocky, marshy, or sandy shores, and laboratory biological experiments on intertidal species. Parameters that affect shoreline damage include the volume, type, and physical state of the spilled oil, the frequency of oiling, the toxicity of dispersants or cleaning agents, and the shoreline topographic, hydrographic, and climatic conditions.

NWMAR116798

C-1997-77
WARTIME OIL POLLUTION (book review)
Bourne, W. R. P. 1977.
Marine Pollution Bulletin 8(7):167.

Oil spills, Environmental effects, U.S., Atlantic Ocean, *World War II

The book, Impact of Oil Spillage from World War II Tanker Sinkings (Campbell, B., E. Kern, and D. Horn, 1977. MIT Sea Grant Program Report No. 77-4. 85p.), is reviewed. The author criticizes the report for not researching pertinent ornithological literature for important environmental effects, and for the report's implication that current oil pollution risks from offshore developments are over-rated.

C-1998-77
OIL POLLUTION OF THE SEA
Cowell, E. B. 1976.
Marine Pollution. R. Johnston (ed.). London, Academic Press, 1976. p.353-401.

Sources, Contamination, Ships, Exploration, Production, Biological effects, Sea birds, Marine organisms, Fisheries, Spill cleanup, Dispersants

Oil pollution inputs into the marine environment from shipping, oil transfer operations, exploration and production, and other land based sources are reviewed. The effects of oil on seabirds and its acute and chronic effects on various marine communities (salt marshes, rocky shores and sandy to muddy coasts) are summarized. Methods of removing oil from the water or shoreline by mechanical means, absorption, burning, and washing with dispersants are discussed. Possible health hazards to animals and interactions of oil pollution with marine ecosystems are considered.

C-1999-77
SALT MARSHES OF PORT VALDEZ, ALASKA, AND VICINITY: A BASELINE STUDY
Crow, J. H. 1977.
Final report to the U.S. Department of the Interior. 113p.

Oil transport, Environmental effects, Oil spills, Vegetation, Soil, Marshes, Alaska

In 1974 and 1975, 62 baseline locations were selected for intensive study in the salt marshes of Port Valdez and vicinity. The sites are intended to reflect the impact of oil transport activities. Vegetation and soil characteristics were emphasized. Gold Creek and Sawmill Creek appear to be the marshes most susceptible to major oil spill damage, but all the marshes studied are threatened to some degree. An oil spill associated with seasonal high tides or during the winter when freshwater outflow is minimal would increase the potential hazard to the less vulnerable marsh areas.

NWMAR116799

C-2000-77
POLLUTION OF THE OCEANS BY OIL. I - DISTRIBUTION AND EFFECT OF OIL PRODUCTS IN THE MARINE ENVIRONMENT [in French]
Gérard, F. 1976.
La Météorologie, December:53-66.

Contamination, Oceans, Biological effects, Pollution control, Marine organisms, Dispersants

The sources of oil pollution, its biological impact, and the principal means of combatting it are surveyed. Biologically, the effects of dissolved oil must be considered as well as those of oil slicks. Data on lethal concentrations of oil for various types of plant and animal life are given along with data on the lethal effects of oil dispersant chemicals.

[from International Aerospace Abstracts 17(15):#A77-34279. 1977]

C-2001-77
THE ARGO MERCHANT OIL SPILL. A PRELIMINARY SCIENTIFIC REPORT
Grose, P. L., and J. S. Mattson. 1977.
Special report, NOAA-77042007. 338p.

Argo Merchant spill, Distribution, Environmental effects, Coasts, Atlantic Ocean

This report presents the available results from the investigations carried out to date by the many groups involved in the initial assessment of the distribution of the "Argo Merchant" oil spill and its impact. The fortunate aspects of the outcome of the spill are as follows: offshore winds which prevented the oil from coming on the beaches; the low density of the oil which resulted in no sinking of the oil and no bottom contamination; and occurrence of the spill in winter when biological activity and fishing activities are low.

[from Government Reports Announcements 77(16):#PB-267 505/6GA. 1977]

C-2002-77
MARINE POLLUTION
R. Johnston (ed.). 1976.
London, Academic Press, 1976. xiv + 729p.

Oil spills, Refineries, Oil transport, Offshore production, Pollution control, Toxicity, Birds, Fisheries, North Sea

The book is intended as an overview text for those in government, industry, and environmental protection dealing with pollution of the sea by toxic heavy metals, organic poisons, particulates including sewage and dredge spoils, and oil pollution. Eight contributed chapters cover mechanisms of pollution, biological effects of various pollutants with emphasis on fisheries resources and seabirds, pollutant dispersion in estuaries and inland waters, and international and national aspects of pollution control.

NWMAR116800

C-2003-77
MECHANISMS AND PROBLEMS OF MARINE POLLUTION IN RELATION TO COMMERCIAL FISHERIES
Johnston, R. 1976.
Marine Pollution. R. Johnston (ed.). London, Academic Press, 1976. p.3-156.

Crude oil, Aromatic hydrocarbons, Offshore development, Fisheries, North Sea

This chapter presents a synthesis of the major inputs of various marine pollutants, the mechanisms of pollution by different substances, and interactions between pollutants and commercial fish and shellfish resources. A major section deals with the effects of offshore North Sea oil development activities on commercial fisheries and their operations, and assesses the effects of crude oil and aromatic hydrocarbons on commercially important species of fish and mollusks.

C-2004-77
MARINE POLLUTION RESEARCH TITLES
Marine Pollution Information Centre. 1976.
Marine Pollution Research Titles 3(3):1-28.

Detection, Chemical analysis, Spill cleanup

The title publication includes 205 selected references on marine and estuarine pollution divided into a dozen chapters. Oil pollution is covered in detail, especially its detection, analysis, characteristics, and removal.

[from Selected Water Resources Abstracts 10(11):#W77-05383. 1977]

C-2005-77
THE EFFECTS OF PETROLEUM HYDROCARBONS ON MARINE POPULATIONS AND COMMUNITIES
Michael, A. D. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p.129-137. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Hydrocarbons, Environmental effects, Chronic effects, Marine organisms, Contaminants, Oil spills

Recent literature on the effects of petroleum hydrocarbons on marine life and ecosystems is reviewed from the standpoint of assessing the current status of research. Included are the effects of oil spills or chronic contamination on plankton,

NWMAR116801

intertidal and subtidal benthos, fisheries, birds, and mammals. Future research priorities suggested include long-term study of oil spills and chronic contamination, and field and laboratory studies of sublethal effects of pollution.

C-2006-77
PENETRATION OF CRUDE OIL DISTILLATION PRODUCTS THROUGH SOIL AND THEIR EFFECT OF [sic] MICROORGANISMS IN SOIL AND WATER [English summary]
Milkowska-Jankowska, D., J. Maleszewska, and J. Luzak. 1976.
Roczniki Panstwowego Zakladu Higieny 27(6):679-687.

Petroleum products, Lubricating oil, Movement, Soil, Bacteria, Biological effects

"Motor oils Marinol 211D and Lux 5 rapidly passed through soil samples in conjunction with water. Pollution of soils with the oils lowered the organoleptic properties of water passing through them. The oils enhanced the development of N-reducing bacteria in the soil."

[from Chemical Abstracts 86(25):#184188x. 1977]

C-2007-77
ENVIRONMENTAL EFFECTS OF FOSSIL FUELS
Morris, S. C. 1976.
Energy and the Environment: Cost-Benefit Analysis. Proceedings of a Conference, Georgia Institute of Technology, Atlanta, June 23-27, 1975. R. A. Karam, and K. Z. Morgan (eds.). Elmsford, N.Y., Pergamon Press, 1976. p.330-344.

Fuels, Production, Contaminants, Environmental effects

"A review on pollutants associated with fuels and energy-producing processes with 38 references."

[from Chemical Abstracts 87(2):#10533m. 1977]

C-2008-77
MEDICAL-BIOLOGICAL AND ECOLOGICAL ASPECTS OF POLLUTION OF THE OCEANS [English summary]
Ricci, G. C. 1975.
Annali di Medicina Navale 80(3-4):289-406.

Hydrocarbons, Contamination, Oceans, Biological effects, Health hazards, Pollution control

Environmental and medical-biological aspects of ocean contamination by various pollutants including hdyrocarbons are summarized. The

NWMAR116802

interaction of pollutants, the physical, biological and chemical mechanisms of pollution, self-purification of the sea, and anti-pollution measures are also discussed.

[from Chemical Abstracts 87(2):#11172e. 1977]

C-2009-77
ENVIRONMENTAL EFFECT OF OIL AND THE CHEMICALS USED TO CONTROL IT ON 2) FISHERIES
Shelton, R. G. T. 1976.
The Control of Oil Pollution on the Sea and Inland Waters.
J. Wardley-Smith (ed.). London, Graham & Trotman Ltd., 1976.
p.51-56.

Fisheries, *Shellfish, Contamination, Environmental effects

Oil pollution is a potential threat to fish and shellfish resources because: 1) the pollution may directly kill or harm the fish or shellfish stocks; 2) oil contaminants on or in the animals may render them unacceptable for consumption, and 3) spilled oil may physically interfere with fishing operations.

C-2010-77
ENVIRONMENTAL EFFECT OF OIL AND THE CHEMICALS USED TO CONTROL IT ON 1) PLANKTON
Wardley-Smith, J. 1976.
The Control of Oil Pollution on the Sea and Inland Waters.
J. Wardley-Smith (ed.). London, Graham & Trotman Ltd., 1976.
p.47-50.

Oil slicks, Phytoplankton, Environmental effects, Dispersants, Toxicity, *Light reduction, *Photosynthesis

The environmental effects of oil slicks on plankton are threefold: the oil layer reduces photosynthesis in phytoplankton by occluding light; oil interferes with oxygen exchange at the sea surface, and oil and dispersants exert serious toxic effects on plankton.

NWMAR116803

D. EFFECTS OF OIL EXPLORATION AND PRODUCTION

1. BIOLOGICAL EFFECTS

C-2011-77
HEALTH EFFECTS OF OIL SHALE PROCESSING
Coomes, R. M. 1976.
Quarterly of the Colorado School of Mines 71(4):101-123.

Oil shale, Extraction, Carcinogens, Health hazards, *Benzo(a)pyrene

The benzo(a)pyrene content of crude shale oil was found to be the same order of magnitude as that of petroleum products and can be reduced by hydrotreating or upgrading of the shale oil. Processed shale was enriched in benzo(a)pyrene but contained less than many natural materials considered to be noncarcinogenic. Test animals exposed to large quantities of processed shale during their lifetime developed no skin cancers.

[from Chemical Abstracts 87(2):#10803z. 1977]

C-2012-77
FISHING AND NORTH SEA OIL
MacArthur, G.P.S. 1976.
Scottish Fisheries Bulletin 43:27-31.

Fisheries, Oil industry, Offshore development, North Sea, Scotland

This paper describes the current status of the oil exploitation industry and its cooperative interactions with the fishing industry of Scotland. Emphasis is given to oil-related debris and to offshore installations and their future effects, including pollution.

[from Aquatic Sciences & Fisheries Abstracts 7(7):#7Q7842. 1977]

C-2013-77
ENVIRONMENTAL ASSESSMENT OF THE ALASKAN CONTINENTAL SHELF. PRINCIPAL INVESTIGATORS' REPORTS JULY-SEPTEMBER 1976. VOLUME 1: MARINE MAMMALS, MARINE BIRDS
National Oceanic and Atmospheric Administration. 1976. 601p.

Offshore development, Environmental effects, Baseline studies, OCS, Alaska, Mammals, Birds

This volume contains the quarterly reports of baseline studies on the environmental effects related to petroleum development on the Alaska Continental Shelf. The multi-year program is sponsored by the Bureau of Land Management.

[from Selected Water Resources Abstracts 10(14):#W77-06793. 1977]

NWMAR116804

C-2014-77
ENVIRONMENTAL ASSESSMENT OF THE ALASKAN CONTINENTAL SHELF. PRINCIPAL INVESTIGATORS' REPORTS FOR THE YEAR ENDING SEPTEMBER 1976. VOL. 2: FISH, PLANKTON, BENTHOS, LITTORAL
National Oceanic and Atmospheric Administration. 1976. 535p.

Offshore development, Environmental effects, Baseline studies, OCS, Fish, Plankton, Benthos, Alaska

This volume contains the quarterly reports of baseline studies on the environmental effects related to petroleum development on the Alaskan Continental Shelf. The multi-year program is sponsored by the Bureau of Land Management.

[from Selected Water Resources Abstracts 10(14):#W77-06825. 1977]

C-2015-77
SHOREBIRD DEPENDENCE ON ARCTIC LITTORAL HABITATS
Risebrough, R. W., and P. G. Connors. 1976.
Environmental Assessment of the Alaskan Continental Shelf. Principal Investigators' Reports for the Year Ending September 1976. Vol. 1, Marine Mammals, Marine Birds. p.404-408.

Birds, Habitat, Shorelines, Arctic, Offshore development, Environmental effects, Alaska, *Shorebird species

To assess the degree and nature of dependence of each shorebird species on arctic habitats which may be susceptible to disturbance from offshore development, 3 major areas must be investigated: seasonal occurrence of shorebirds by species in several arctic littoral habitats; foraging habitat preferences within the littoral zone by species; and diets of shorebirds in the littoral zone by species. About 500 transect censuses were completed during this period; results are compared to data obtained from the 1975 studies.

[from Selected Water Resources Abstracts 10(14):#W77-06811. 1977]

C-2016-77
AVIFAUNAL UTILIZATION OF THE OFFSHORE ISLAND AREA NEAR PRUDHOE BAY, ALASKA
Schamel, D. 1976.
Environmental Assessment of the Alaskan Continental Shelf. Principal Investigators' Reports for the Year Ending, September 1976. Vol. 1, Marine Mammals, Marine Birds. p.409-447.

Birds, Shorelines, Offshore development, Oil spills, Environmental effects, Baseline studies, Alaska

Changes in numbers and activity patterns of avifauna over time and space were documented. Census work was conducted on Egg

NWMAR116805

Island, a barrier inlet on the Beaufort Sea coast which was found to have the greatest concentration of nesting Eiders in the area. The most numerous birds in the area (Common Eiders, King Eiders, and Oldsquaw) are all highly susceptible to oil spills. Oil development on these islands could interfere with nesting of the Common Eiders and, to a lesser extent, the King Eiders.

[from Selected Water Resources Abstracts 10(14):#W77-06812. 1977]

C-2017-77
EPA RESEARCH PROGRAM ON THE FRESHWATER ECOLOGICAL EFFECTS OF ENERGY DEVELOPMENT AND USE
Yount, J. D. 1976.
National Conference on Health, Environmental Effects, and Control Technology of Energy Use, Washington, D.C., 1976.

Oil transport, Pipelines, Environmental effects, Freshwater, Arctic, EPA

Described is the EPA freshwater ecological effects program which concentrates on coal mining, transport, and energy conversion; and oil transport by pipeline from arctic oil fields.

[from ERDA Energy Research Abstracts 2(11):#26768. 1977]

2. ECONOMIC EFFECTS

C-2018-77
TOUGHER WATER STANDARDS SEEN HIKING CONSUMERS' FUEL COSTS (news brief)
Anon. 1977.
Oil and Gas Journal 77(27):27.

Oil industry, Regulations, U.S., Cost analysis, Water quality, Pollution prevention

Compliance with the proposed 1983 federal water pollution control standards will cost the U.S. oil industry an estimated $4.2 billion, but will do little to improve water qualtiy. A recent Battelle study suggests that a strategy based on preventing new pollution and not only focusing on cleanup efforts might be a more cost effective approach.

NWMAR116806

C-2019-77
THE ECONOMIC IMPACT OF ENVIRONMENTAL REGULATIONS ON THE PETROLEUM INDUSTRY - PHASE II STUDY
Sheppard, W., et al. 1976.
API Report. 357p.

Oil industry, Regulations, Pollution prevention, Economic effects, Cost analysis

Estimates are presented of the cost to the entire oil industry of meeting existing and future (up to 1985) environmental regulations. Annual costs were estimated at $3.2 billion in 1973, and will be $10.3 billion in 1985. Cumulative capital investments, $7.9 billion in 1973, are estimated to be $28.9 billion in 1985. The analysis includes environmental protection costs incurred during exploration and production, transport, refining, distribution, and marketing. The cost-effectiveness of selected pollution abatement technologies is assessed.

[from Energy Information Abstracts 2(2):#77-21485. 1977]

3. GENERAL EFFECTS

C-2020-77
EKOFISK BRAVO BLOWOUT - THE MILLION BARREL WARNING
Anon. 1977.
Noroil 5(5):45,47-49.

Ekofisk blowout, Offshore development, North Sea, Environmental protection, Safety, Regulations

The widely publicized Ekofisk Bravo platform blowout in the North Sea is expected to have serious repercussions, and offshore development in the North Sea will undergo intense and critical scrutiny from both governments and the public. The long and bitter debate over oil development vs. environmental protection is renewed, and, with certainty, tough new safety regulations will go into effect.

[from Petroleum Abstracts 17(28):#235,494. 1977]

NWMAR116807

C-2021-77
MINERAL RESOURCE MANAGEMENT OF THE OUTER CONTINENTAL SHELF
Adams, M. V., C. B. John, R. F. Kelley, A. E. laPointe, and R. W. Meurer. 1976.
U.S. Geological Survey, Circ-720. 37p.

Environmental management, OCS, Offshore drilling, Fossil fuels, Regulations, Pollution control

OCS oil and gas production represents an increasing percentage of total U.S. production, as onshore production has declined and offshore production has increased. Improved technology and enforcement of more stringent regulations have made offshore operations safer, but it is unrealistic to believe that completely accident-free operations can ever be achieved. Management of OCS mineral resources will become an increasingly significant function.

[from Government Reports Announcements 77(15):#N76-76745/8GA. 1977]

C-2022-77
SOCIAL AND ECONOMIC IMPACT ASSESSMENT OF ALASKA OUTER CONTINENTAL SHELF PETROLEUM DEVELOPMENT
Alaska University,College. Sea Grant Program. 1975.
Study plan report, Sea Grant-75-15, NOAA-76050604; Contract DI-AA550-CT6-2. 100p.

Offshore drilling, Socio-economic effects, OCS, Crude oil, Alaska, *Sea Grant program, *Energy policy

Physical, economic, social, individual human, and political effects and interrelations are considered in this report. The study is organized in geographic units - the state of Alaska, regions specific to the oil and gas development, and local communities within the regions.

[from Government Reports Announcements 76(18):#PB-254 669. 1977]

C-2023-77
ENVIRONMENTAL CONSIDERATIONS OF SELECTED ENERGY CONSERVING MANUFACTURING PROCESS OPTIONS: VOLUME IV. PETROLEUM REFINING INDUSTRY REPORT
Arthur D. Little, Inc. 1976.
Final report, EPA/600/7-76/034d; Contract EPA-68-03-2198. 193p.

Oil industry, Refining, Environmental effects, Pollution control, *Technology assessment

Volume IV assesses the likelihood of new process technology in the petroleum refining industry and explores the environmental impact of such changes. Five options are examined in terms of process economics and environmental energy consequences: 1) direct combustion of asphalt in process heaters and boilers; 2) hydrocracking of vacuum bottoms; 3) flexicoking of vacuum bottoms; 4) internal electrical power generation; and 5) hydrogen generation by partial oxidation.

NWMAR116808

C-2024-77
PROPOSED 1976 OUTER CONTINENTAL SHELF OIL AND GAS LEASE SALE, GULF OF MEXICO: OCS SALE 44. FINAL ENVIRONMENTAL IMPACT STATEMENT. VOLUME 1
Berklund, C. 1976.
Washington, D.C., Bureau of Land Management, 1976. 405p.

Oil-gas leasing, OCS, Environmental effects, EIS, Gulf of Mexico

Sixty-one tracts of 102,991 ha (254,488 acres) of OCS land located offshore Texas and Louisiana have been proposed for leasing action. If implemented, the sale was tentatively scheduled to be held in November, 1976. All tracts pose some degree of pollution risk to the environment. Methods used to evaluate the environmental impacts of the proposed leasing, exploration, and production are described and alternatives to the proposed action are considered.

[from ERDA Energy Research Abstracts 2(10):#24923. 1977]

C-2025-77
PROPOSED 1976 OUTER CONTINENTAL SHELF OIL AND GAS LEASE SALE, GULF OF MEXICO: OCS SALE 44. FINAL ENVIRONMENTAL IMPACT STATEMENT. VOLUME 2
Berklund, C. 1976.
Washington, D.C., Bureau of Land Management, 1976.

Oil-gas leasing, OCS, Environmental effects, EIS, Gulf of Mexico

Maps of tracts of 102,991 ha (254,488 acres) proposed for leasing in the Gulf of Mexico are in the packet. Other information given includes: lease status, recreation, historic and archeological resources, geologic and geomorphic features, and endangered wildlife and natural vegetation.

[from ERDA Energy Research Abstracts 2(10):#24924. 1977]

C-2026-77
PETROCHEMICAL INDUSTRY - A CHALLENGE FOR ANALYTICAL CHEMISTS [English summary]
Boeler, J. B. 1975.
Kjemi 35(7):4-5.

Petrochemicals, Chemical analysis, Wastewater treatment, Pollution control, Norway

Pollution problems of the Norwegian petrochemical industry are reviewed.

[from Chemical Abstracts 86(26):#192111g. 1977]

NWMAR116809

C-2027-77
GULF OF ALASKA AND BERING SEA OCS STUDIES - AN OVERVIEW
Bruce, H. E. 1976.
Oceans '76 Conference, Washington, D.C., 1976. p.23A-26A.

Offshore exploration, Oil-gas leasing, Environmental effects, OCS, Gulf of Alaska, Bering Sea

Activities and results of the first two years of an environmental assessment program involving the Gulf of Alaska and Bering Sea are described. The study includes environmental evaluations of nine potential petroleum lease areas extending from the Gulf of Alaska to the Beaufort Sea.

[from Environment Abstracts 7(5/6):#77-03177. 1977]

C-2028-77
FINAL ENVIRONMENTAL STATEMENT. VOL. I, PROPOSED 1975 OUTER CONTINENTAL SHELF OIL AND GAS LEASE SALE OFFSHORE SOUTHERN CALIFORNIA (O.C.S. SALE NO. 35)
Bureau of Land Management. 1975. 709p.

Oil-gas leasing, EIS, Environmental effects, Baseline studies, Southern California

In Volume I, a description of the proposed lease region is followed by a description of the environment in this part of the offshore area of Southern California. The proposed federal action under consideration is the leasing of 297 tracts in this region.

[from Selected Water Resources Abstracts 10(11):#W77-05536. 1977]

C-2029-77
FINAL ENVIRONMENTAL STATEMENT. VOL. 2, PROPOSED 1975 OUTER CONTINENTAL SHELF OIL AND GAS GENERAL LEASE SALE OFFSHORE SOUTHERN CALIFORNIA (O.C.S. SALE NO. 35)
Bureau of Land Management. 1975. 767p.

Oil-gas leasing, EIS, Environmental effects, Offshore development, Baseline studies, Southern California

The general environmental impacts of offshore oil and gas operations are described. Development and production activity could result in a variety of impacts on the natural environment, Channel Island area resources, air and water qualtiy, land use patterns, the social order, and the economy.

[from Selected Water Resources Abstracts 10(11):#W77-05537. 1977]

NWMAR116810

C-2030-77
FINAL ENVIRONMENTAL STATEMENT. VOL. 3, PROPOSED 1975 OUTER CONTINENTAL SHELF OIL AND GAS GENERAL LEASE SALE OFFSHORE SOUTHERN CALIFORNIA (O.C.S. SALE NO. 35)
Bureau of Land Management. 1975. 857p.

Oil-gas leasing, EIS, Environmental effects, Baseline studies, Southern California

Volume 3 contains the documentation dealing with the consultation and coordination with agencies in the preparation of the draft EIS. Also included are the records of various public hearings and the review of the draft EIS leading to the preparation of the final environmental statement.

[from Selected Water Resources Abstracts 10(11):#W77-05538. 1977]

C-2031-77
FINAL ENVIRONMENTAL STATEMENT. VOL. 4, PROPOSED 1975 OUTER CONTINENTAL SHELF OIL AND GAS GENERAL LEASE SALE OFFSHORE SOUTHERN CALIFORNIA (O.C.S. SALE NO. 35)
Bureau of Land Management. 1975. 886p.

Oil-gas leasing, EIS, Environmental effects, Offshore development, Baseline studies, Southern California

This volume comprises 27 appendices of details including summary descriptions of environmental conditions and pollution effects of oil-gas resource development offshore Southern California. It also includes a history of oil and gas operations, summary of regulations concerning hazards to navigation, and a list of significant felt earthquakes in the region.

[from Selected Water Resources Abstracts 10(11):#W77-05539. 1977]

C-2032-77
FINAL ENVIRONMENTAL STATEMENT. VOL. 5, PROPOSED 1975 OUTER CONTINENTAL SHELF OIL AND GAS GENERAL LEASE SALE OFFSHORE SOUTHERN CALIFORNIA (O.C.S. SALE NO. 35)
Bureau of Land Management. 1975. n.p.

Oil-gas leasing, Offshore development, EIS, Environmental effects, Baseline studies, Southern California

The graphics, maps, and charts illustrating the lease sale area offshore Southern California are described and include: potential use conflicts, rare and endangered species, land use, air basins, winds and vegetation, aesthetics, commercial fisheries, sport fishing, marine mammals, shoreline types, geology, tectonics, bottom sediments, and impact potential.

[from Selected Water Resources Abstracts 10(11):#W77-05540. 1977]

NWMAR116811

C-2033-77
FINAL ENVIRONMENTAL STATEMENT: PROPOSED 1976 OUTER CONTINENTAL SHELF OIL AND GAS LEASE SALE, LOWER COOK INLET
Bureau of Land Management. 1976.
Vol. 1-2. 1405p.

Oil-gas leasing, OCS, EIS, Environmental effects, Socio-economic effects, Alaska

About 360,000 ha (0.9 million acres) of OCS tracts, situated in 35-80 m water depths, are tentatively scheduled for oil-gas leasing in 1977. The environmental risks from chronic oil pollution or accidental spills are assessed, and socio-economic impacts of offshore development are projected. Although some risks can be mitigated, some impacts are considered unavoidable.

[from Energy Information Abstracts 2(2):#77-21486. 1977]

C-2034-77
OIL UNDER ICE (book review)
Casey, S. 1977.
Alternatives 6(4):35.

Offshore exploration, Offshore development, Environmental effects, Canada, Arctic, Ice, Oil industry

The publication, Oil Under Ice (Pimlott, D., D. Brown, and K. Sam. Ottawa, Canadian Arctic Resources Committee, 1976. 161p.), is reviewed as a serious, well-documented indictment of Canada's "energy-industry first" exploration policies. The book details the physical environment of the Beaufort Sea, Arctic Archipelago, Hudson's Bay, and Lancaster Sound, and critically examines Canada's environmental assessment programs and offshore exploration and development policies.

C-2035-77
POSSIBLE CONTAMINATION OF GROUND WATERS BY OIL AND GAS-WELL DRILLING AND COMPLETION FLUIDS
Collins, A. G. 1975.
Environmental Aspects of Chemical Use in Well-drilling Operations, Houston, 1975. 37p.

Contamination, Groundwater, Drilling, Oil wells, *Drilling fluids, *Well completion

Chemicals used in the drilling fluids and in well completion and treatment are listed; several of them are quite capable of polluting water and land. The compositions of some oilfield brines and crude oils which can be used to prepare drilling fluids are listed. Possible ways in which drilling fluids and

NWMAR116812

well operations may contaminate ground water are outlined, and methods for rehabilitating a contaminated aquifer are discussed.

[from ERDA Energy Research Abstracts 2(11):#25906. 1977]

C-2036-77
THE ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
Falk, M. R. 1976.
Canadian Society of Environmental Biologists Meeting , 17th, Ottawa, Canada, 1976. p.40-43.

Tar sands, Development, Extraction, Environmental protection, Canada, *Alberta

"The Alberta Oil Sands Environmental Research Program will undertake a 10 year, $40 million investigation into the Athabasca oil sands area to ensure acceptable environmental quality during and after development. The programs, the nature of oil sands, and mining and processing methods are described."

[from Environment Abstracts 7(5/6):#77-03006. 1977]

C-2037-77
MORBIDITY AND MORTALITY OF MARINE MAMMALS
Fay, F. H. 1976.
Environmental Assessment of the Alaskan Continental Shelf. Principal Investigators' Reports for the Quarter Ending September, 1976. Vol. 1, Marine Mammals, Marine Birds. p.43-47.

Offshore development, Biological effects, Marine mammals, OCS, Alaska, *Mortality

In a survey for dead or moribund marine mammals on the coast of Kotzebue Sound from Bering Strait to Point Hope, a total of 166 dead mammals were sighted, 92 of which were old weathered remains of previous years. Findings suggest that 2 pathologic conditions, dermatomycosis and streptococcosis, occur frequently and that their rate of occurrence and the potential aggravation by the stresses of oil development activities merit further investigation.

[from Selected Water Resources Abstracts 10(15):#W77-07405. 1977]

NWMAR116813

C-2038-77
MID-ATLANTIC OUTER CONTINENTAL SHELF BENCHMARK STUDIES
Jacobson, J. P., and M. P. Lynch. 1976.
Oceans '76 Conference, Washington, D.C., 1976. p.18B-23B.

Baseline studies, OCS, Atlantic coast, Offshore development, Hydrocarbons, Chemical analysis

A multidisciplinary environmental baseline studies program was undertaken for the OCS area off the coast of New Jersey, Delaware, Maryland, and Virginia in order to determine pre-drilling environmental conditions, and to assess possible impacts of oil-gas development. Hydrocarbon analyses of sediments, benthos, zooplankton, and suspended matter were conducted, and supportive physical, chemical, and geological data were gathered.

[from Environment Abstracts 7(5/6):#77-03175. 1977]

C-2039-77
MONITORING ENVIRONMENTAL IMPACTS OF THE COAL AND OIL SHALE INDUSTRIES: RESEARCH AND DEVELOPMENT NEEDS
Jones, D. C., W. S. Clark, W. F. Holland, J. C. Lacy, and E. D. Sethness. 1977.
Final report, EPA/600/7-77/015; Contract EPA-68-02-1319. 207p.

Oil shale, Industries, Environmental effects, Monitoring, *R & D needs

Presented are recommendations for the monitoring and predictive technology for the coal and oil shale industries. Information is based upon a literature survey of the emissions and potential impacts of these industries.

[from Government Reports Announcements 77(15):#PB-266 292/2GA. 1977]

C-2040-77
PROTECTING THE ENVIRONMENT
McCormack, M. M. 1976.
Encyclopedia of Energy. New York, McGraw-Hill Book Co., 1976. p.49-55.

Production, Fossil fuels, Oil shale, Tar sands, Environmental effects

The environmental impacts of producing and utilizing fossil and nuclear fuels are investigated. The effects of producing coal, oil, natural gas, uranium, oil shale, tar sands, and geothermal energy are specifically examined.

[from Petroleum Abstracts 17(32):#236,706. 1977]

NWMAR116814

C-2041-77
UPTAKE IN MARINE LIFE: CHEMICAL STUDIES OF OFFSHORE OIL PLATFORMS
McDermott-Ehrlich, D., and G. A. Alexander. 1976.
Coastal Water Research Project: Annual Report for the Year Ended 30 June 1976. El Segundo, CA, Southern California Coastal Water Research Project, 1976. p.129-135.

Offshore drilling, Platforms, Uptake, Marine organisms, Sediments, Southern California

Levels of copper, zinc, hexane extractable materials, and volatile solids in sediments around oil platforms were similar to average coastal background levels and well below levels observed in sediments contaminated by the largest municipal wastewater discharges in Southern California. In the sediments, only weathered oils were detected, indicating no recent spills.

[from Aquatic Sciences & Fisheries Abstracts 7(6):#7Q7516. 1977]

C-2042-77
COASTAL OCEANOGRAPHIC PROCESSES
Manowitz, B. 1975.
Conference on Computer Support of Environmental Science and Analysis, Albuquerque, 1975.

Offshore drilling, Environmental effects, Contaminants, Coasts, Fish

The impact on coastal zones by offshore nuclear reactors and oil well drilling related activities, especially to the eggs and larvae of dominant fish species, is discussed. The transport and diffusion of potentially released contaminants, particularly in the near shore zone, are also covered.

[from ERDA Energy Research Abstracts 2(12):#30858. 1977]

C-2043-77
THE BUREAU OF LAND MANAGEMENT OCS ENVIRONMENTAL STUDIES PROGRAM - A DECISION MAKING ORIENTATION
Monastero, F. C. 1976.
Oceans '76 Conference, Washington, D.C., 1976. p.18A-20A.

Environmental effects, OCS, BLM, Offshore development

The objectives and the rationale behind the design and implementation of the title program and related BLM studies are explained and discussed.

[from Environment Abstracts 7(5/6):#77-03174. 1977]

NWMAR116815

C-2044-77
THE IMPACTS OF OUTER CONTINENTAL SHELF DEVELOPMENT ON LAFOURCHE PARISH
Mumphrey, A. J., Jr., F. W. Wagner, G. D. Carlucci, Jr., M. J. Landry, and J. C. Miller, Jr. 1976.
NOAA-77021610. 391p.

Oil industry, Offshore drilling, Environmental effects, Economic effects, OCS, Louisiana

This study deals with the impacts of OCS mining activity on Lafourche Parish in terms of employment, income, job types, environmental effects, and supporting facilities and services.

[from Government Reports Announcements 77(11):#PB-264 992/9GA. 1977]

C-2045-77
PROGRAM DEVELOPMENT PLAN. ENVIRONMENTAL ASSESSMENT OF THE ALASKAN CONTINENTAL SHELF
National Oceanic and Atmospheric Administration. 1976.
NOAA-77032913. 269p.

Offshore development, Crude oil, OCS, Environmental effects, Oil-gas leasing, Alaska

This plan was developed by the interdisciplinary staff of the NOAA Outer Continental Shelf Environmental Assessment Program Office with input from the Bureau of Land Management, State of Alaska, and Users Panel composed of representatives from several federal and state agencies and private environmental groups.

[from Government Reports Announcements 77(15):#PB-266 337/5GA. 1977]

C-2046-77
WHO'S MINDING THE SHORE. A CITIZENS' GUIDE TO COASTAL MANAGEMENT
Natural Resources Defense Council. 1976.
Report to NOAA, Office of Coastal Zone Management. 56p.

Offshore development, Environmental management, Coasts, Guidelines, *CZM

Coastal zone management is described and a catalog of what people can do to become actively involved in their state's program is given. The requirements of an effective program are considered, and the natural conditions existing in the the coastal ecosystems and the areas which are vital to their preservation are outlined. Two of the most serious development pressures in the coastal zone - offshore oil production and residential subdivisions - are considered with their problems for the design of a management program.

[from Selected Water Resources Abstracts 10(14):#W77-06935. 1977]

NWMAR116816

C-2047-77
COASTAL EFFECTS OF OFFSHORE ENERGY SYSTEMS
Office of Technology Assessment. 1976.
U.S. Congress Office of Technology Assessment report. Vol. 1. 306p.

Offshore development, Ports, Atlantic coast, Environmental deterioration

The construction and operation of offshore energy systems are analyzed for adverse effects on the Mid-Atlantic U.S. coastal region. Included in the assessment are floating nuclear power plants, offshore oil-gas development, and supertanker deepwater ports. No significant environmental degradation is expected to result from the presently anticipated magnitude of oil-gas development and supertanker port construction.

[from Energy Information Abstracts 2(2):#77-21487. 1977]

C-2048-77
WORKING PAPERS, COASTAL EFFECTS OF OFFSHORE ENERGY SYSTEMS, AN ASSESSMENT OF OIL AND GAS SYSTEMS, DEEPWATER PORTS AND COAST OF NEW JERSEY AND DELAWARE
Office of Technology Assessment. 1976.
U.S. Congress Office of Technology Assessment report. Vol. 2. 865p.

Offshore development, Ports, Environmental effects, Fisheries, Atlantic coast, New Jersey, Delaware

Offshore oil-gas development and the siting of deepwater ports and floating nuclear power plants off the coast of Delaware and New Jersey are assessed for environmental effects. Biological repercussions of offshore drilling were surveyed. Commercial fishing was found to be unaffected by the presence of oil rigs, and ecosystem impacts were relatively minor.

[from Energy Information Abstracts 2(2):#77-21488. 1977]

C-2049-77
OUR COASTAL WATERS: AN ENDANGERED ZONE
Pearce, J. B. 1976.
The Science Teacher 43(9). 4p.

Contamination, Coasts, Estuaries, Development, Oil industry

Discussed are the phenomenon of "coastal congestion", brought about by the development and increased population of the coastal and estuarine environments, and the threat to these areas caused by pollution from sewage and sludge, petroleum and power plants, and by mineral resource development.

NWMAR116817

C-2050-77
INDUSTRIAL PROCESS PROFILES FOR ENVIRONMENTAL USE: CHAPTER 5. BASIC PETROCHEMICALS INDUSTRY
Radian Corp. 1977.
Report for August 75-November 76, EPA/600/2-77/023e; Contract EPA-68-02-1319. 155p.

Oil industry, Petrochemicals, Environmental effects, Refineries

This catalog was developed to aid in defining the environmental impacts of U.S. industrial activity. Entries for each industry form separate chapters of the catalog. The petroleum industry includes companies that treat hydrocarbon streams from the oil refining industry, as well as natural gas liquids from the oil and gas production industry. From these raw materials, materials are produced for the organic chemicals industry.

[from Government Reports Announcements 77(15):#PB-266 224/5GA. 1977]

C-2051-77
MINING TECHNOLOGY FOR OFFSHORE HYDROCARBON DEVELOPMENT
Snyder, H. L. 1977.
CIM Bulletin 70(778):62-69.

Offshore development, OCS, Ice, Safety, Labrador Sea, *Mining technology

Current technology is not adequate for safeguarding offshore oil-gas production on the Labrador continental shelf, as the area is infested with icebergs and pack ice. The author believes that mining beneath the ocean floor, as practiced at Bell Island and Cape Breton, may utilize the technology which would also allow for safe, economical, and reliable oil production.

[from The Engineering Index Monthly 15(6):#042590. 1977]

C-2052-77
EFFECTS OF OFFSHORE OIL & NATURAL GAS DEVELOPMENT ON THE COASTAL ZONE
U.S. Library of Congress. Congressional Research Service. 1976.
Washington, D.C., U.S. Government Printing Office, 1976. 396p.

Offshore development, OCS, Coasts, Onshore impacts, Environmental effects, Pollution prevention

This comprehensive government study evaluates the U.S. offshore oil & gas resources, including projected environmental and socio-economic effects of onshore and offshore petroleum development. It also covers current OCS development regulations, congressional actions for changing regulations, and compensation to the coastal

NWMAR116818

states. There are chapters concerning environmental impacts offshore, in the coastal zone, and on the fishing industry, including blowout and spill prevention technology, probabilities of oil spills and blowouts, and containment and cleanup technology.

C-2053-77
THE OIL INDUSTRY AND COASTAL ZONE MANAGEMENT IN LOUISIANA
Van Lopik, J. R. 1976.
26th Annual Gulf Coast Association Geological Societies Meeting Transactions 26:349-353. Held at Shreveport, Louisiana, October 13-15, 1976.

Oil industry, Environmental management, Coasts, Louisiana, Legislation, U.S.

The Federal Coastal Zone Management Act of 1972 provides incentives for states to plan and implement management programs to guide the use of lands and waters in the coastal zone. Several coastal zone bills have been prepared for consideration by the Louisiana legislature during the 1976 session. In these guidelines, a comprehensive assessment of techniques will be required to mitigate the effects of such activities as brine disposal, pipelaying, spoil disposal, and the construction and operation of processing plants, storage facilities, and refineries.

[from Petroleum Abstracts 17(31):#236,384. 1977]

C-2054-77
OCS ENVIRONMENTAL RESEARCH TECHNOLOGY IN ICE-COVERED WATERS
Weller, G. 1976.
Oceans '76 Conference, Washington D.C., 1976. p.23D-25D.

Offshore development, Arctic, Ice, Environmental effects, *Ice-covered water, *Research technology

Offshore development-related environmental assessment programs in the Arctic must deal with ice-infested or ice-covered waters for nine to ten months each year. This paper describes technological developments and specially developed methods and equipment which have made it possible to conduct research in the coastal arctic marine environment year round.

[from Environment Abstracts 7(5/6):#77-03179. 1977]

NWMAR116819

C-2055-77
STATE INFORMATION NEEDS RELATED TO ONSHORE AND NEARSHORE EFFECTS OF OCS PETROLEUM DEVELOPMENT
Williams, D. C., P. R. Stang, and B. Hyde. 1977.
Report NOAA-77031402. 191p.

Offshore development, OCS, Coasts, U.S., Environmental effects, Socio-economic effects, State governments

In response to widespread OCS development along U.S. coasts, this report identifies the environmental, social, and economic impacts of oil development and attendant oil pollution, and discusses state policies, organization and planning approaches, and major concerns.

[from Government Reports Announcements 77(13):#PB-266 001/7GA. 1977]

C-2056-77
FATE OF DRILL CUTTINGS IN THE MARINE ENVIRONMENT
Zingula, R. P., and D. W. Larson. 1977.
SPE of AIME Offshore Technology Conference, 9th, Houston, 1977.
No. OTC-3040. p.553-556.

Drilling, *Drill cuttings, Fate, Biological effects, Oceans

By use of sidescan sonar, scuba, and underwater photography, studies have revealed that adverse effects are minimal and short-lived, and in some instances the accumulation of cuttings from offshore wells may be beneficial. Modification of normal mud and cuttings discharge procedures would be needed only in unusual circumstances.

[from Petroleum Abstracts 17(27):#235,276. 1977]

NWMAR116820

E. FATE OF OIL IN THE ENVIRONMENT

1. BIODEGRADATION

C-2057-77
ARCTIC HYDROCARBON DEGRADATION
Arhelger, S. D., B. R. Robertson, and D. K. Button. 1977. Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 270-275. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Biodegradation, Microorganisms, Arctic Ocean, *^{14}C-dodecane oxidation, *Port Valdez

Supplemented sterile seawater was inoculated with raw seawater samples and examined for oil related microbial activity. Microbial populations of 10^3 to 10^5/L were indicated. In situ ^{14}C-dodecane oxidation rates based on $^{14}CO_2$ recovery were: Port Valdez, 0.7 g/L day; Chukchi Sea, 0.05 g/L day; and Arctic Ocean, 0.001 g/L day.

C-2058-77
STUDIES ON PETROLEUM BIODEGRADATION IN THE ARCTIC
Atlas, R. M. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 261-269. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Biodegradation, Crude oil, Microorganisms, Arctic, Beaufort Sea

Oil-degrading microorganisms were widely distributed in the Beaufort and Chukchi Seas, but constituted only a low percentage of the indigenous microbial populations. Concentrations of hydrocarbon-utilizing microorganisms were lower in ice than in water or sediment. Rates of biodegradation were found to be limited by temperature and available nitrogen and phosphorus. Biodegradation of all oil component classes apparently proceeded at similar rates.

C-2059-77
PROCESS AND APPARATUS FOR THE MICROBIAL DEGRADATION OF CRUDE OIL, OF CRUDE FRACTIONS AND OF VARIOUS ORGANIC CONTAMINANTS
Azarowicz, E. N. 1977.
French Patent 2,320,912.

Biodegradation, Crude oil, Petroleum products, Bacteria, Patent, *Nutrient addition

NWMAR116821

A suitable nutrient is added to the contaminated water along with at least one of the following microorganisms: Candida parapsilosis ATCC 20246, C. tropicalis ATCC 20247, C. utilis ATCC 20248, C. lipolytica ATCC 20255, 20362, 20363, and 20364, Penicillium sp. 20339, or one of their mutants. After agitation and aeration of the mixture, it is then fed to a final degradation basin and a new charge of one of the above microorganisms is added together with a new charge of nutrient.

[from Petroleum Abstracts 17(30):#235,877. 1977]

C-2060-77
EMULSIFICATION OF HYDROCARBONS BY BACTERIA FROM FRESHWATER ECOSYSTEMS
Broderick, L. S., and J. J. Cooney. 1977.
American Society for Microbiology Annual Meeting, 77th, New Orleans, 1977. Paper no. N63. Abstract.

Biodegradation, Hydrocarbons, Bacteria, Emulsification, Freshwater, *Kerosene

Bacteria which utilize hydrocarbons as a sole carbon source were studied for their ability to form stable emulsions of kerosene and water. All of the organisms which grew on kerosene also emulsified kerosene. However, there was no correlation between the observed emulsifying activity and the history of hydrocarbon pollution of the ecosystems from which the organismswere isolated.

C-2061-77
ENRICHMENT FOR ESTUARINE PETROLEUM-DEGRADING BACTERIA USING LIQUID AND SOLID MEDIA
Calomiris, J. J., B. Austin, J. D. Walker, and R. R. Colwell. 1977.
Journal of Bacteriology 42:135-144.

Biodegradation, Bacteria, Estuaries, *Enrichment techniques

Bacteria in oil-contaminated and oil-free estuarine water and sediment were isolated on solid and in liquid petroleum media. A greater variety of bacteria was noted when direct plating techniques were employed, compared with liquid enrichment. Strains isolated by liquid enrichment were found more frequently to be capable of utilizing model petroleum in vitro, compared with isolates obtained by direct plating.

NWMAR116822

C-2062-77
INTERACTIONS OF ARABIAN CRUDE OIL WITH BEACH SEDIMENT BACTERIA
Colwell, R. R., J. D. Walker, B. F. Conrad, and P. A. Seesman. 1977.
Final report, EPA Grant No. 68-01-3284. 78 p.

Biodegradation, Hydrocarbons, Bacteria, Sediment, Beaches, Strait of Magellan, Metula spill

Beach sediment samples collected in the Straits of Magellan were examined for petroleum hydrocarbons and found to contain significant amounts of oil, with the concentration of oil related to degree of exposure to the "Metula" spill. The total number of viable, aerobic, heterotrophic microorganisms in the samples was found to decrease with increasing oil concentration. More rapid glucose uptake and mineralization by microorganisms were observed in clean sediment samples. Good growth in Arabian crude oil medium was obtained for most samples; however, the extent of degradation varied considerably with rate of removal of the major components of the oil. High concentrations of oil appeared to affect biodegradation adversely.

C-2063-77
EFFECT OF CHLORINATED AND AROMATIC HYDROCARBONS ON HEXADECANE METABOLISM BY SURFACE SLICK MICROORGANISMS
Crow, S. A., P. I. Bowman, and D. G. Ahearn. 1977.
American Society for Microbiology Annual Meeting, 77th, New Orleans, 1977. Paper no. N92. Abstract.

Biodegradation, Hydrocarbons, Yeasts, Bacteria, Oil slicks, Aromatic hydrocarbons, *Chlorinated hydrocarbons

Hydrocarbonoclastic bacteria were found to constitute less than 1.0% of the total heterotrophic bacteria isolated from estuarine surface slicks; however, over 90% of hexadecane was utilized in 48 hr in samples taken. Some chlorinated and aromatic hydrocarbons, which were found to accumulate from underlying waters in model hexadecane surface films, reduced hexadecane utilization by bacteria and yeasts. Observations suggest that the mode of action of these compounds on hexadecane metabolism may not be a simple mechanism and may differ from species to species.

C-2064-77
OPTIMIZATION STUDIES ON OIL SLUDGE DISPOSAL IN SOIL
Dibble, J. T., and R. Bartha. 1977.
American Society for Microbiology Annual Meeting, 77th, New Orleans, 1977. Paper no. Q84. Abstract.

Biodegradation, Sludge, Soil, Disposal, Waste oil, Refineries

NWMAR116823

Parameters which affect the biodegradation of oil sludge in soil were studied in order to optimize this method for disposing of oil storage and refinery wastes. The greatest positive effect on the rate and extent of oil sludge degradation resulted from a combination of a slightly alkaline soil pH, a moderate loading rate of 10%, and a mesophilic temperature of 28°C. Using this combination, up to 35% of ether extractable hydrocarbons were biodegraded in 100 days.

C-2065-77
MICROBIAL DEGRADATION OF OIL SHALE
Findley, J. E., M. D. Appleman, and T. F. Yen. 1976.
Science and Technology of Oil Shale. T. F. Yen (ed.).
Michigan, Ann Arbor Science, 1976. p. 175-181.

Biodegradation, Oil shale, Bacteria, Hydrocarbons

"The oil shale was treated by bacteria, and the inorganic matrix was dissolved by the H_2SO_4 produced by the microorganisms. A 40% weight loss of the shale was obtained, and 98% of the dolomite and calcite were removed. Microorganisms capable of degrading hydrocarbons did affect the kerogen mols."

[from Chemical Abstracts 86(22):#158032x. 1977]

C-2066-77
BACTERIAL DEGRADATION OF HYDROCARBONS; I. TAXONOMIC STUDY OF THE BACTERIA WHICH ATTACK HYDROCARBONS [English summary]
Frieyro, O. 1975.
Sociedad Espanola de Historia Natural (Real), Boletin, Seccion Biologica 72:43-53.

Biodegradation, Hydrocarbons, Bacteria, *Taxonomy

Some techniques were developed for isolating hydrocarbon-metabolizing bacteria and, as a result, 40 bacterial strains from 9 different genera were isolated. This report is a systematic study of the bacteria, the types of hydrocarbons they biodegrade, and their capacity and rate of biodegradation.

C-2067-77
QUANTITATIVE STUDIES ON MARINE BIODEGRADATION OF OIL; II. EFFECT OF TEMPERATURE
Gibbs, C. F., K. B. Pugh, and A. R. Andrews. 1975.
Proceedings of the Royal Society of London 188(1090):83-94.

Biodegradation, Crude oil, Oxidation, Uptake, *Temperature effects

NWMAR116824

This paper examines the biodegradation of crude oil residues in seawater at different temperatures and with low concentrations of nitrogen and phosphorus. After studying oxygen uptake and nutrient absorption, it was suggested that the rate of breakdown of a low concentration of oil depends on the rate of oil and water mixing.

C-2068-77
BIODEGRADATION OF AROMATIC PETROLEUM HYDROCARBONS
Gibson, D. T. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 36-46. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Biodegradation, Aromatic hydrocarbons, Microorganisms, Sources

The following topics are discussed: origin of hydrocarbons in the environment; degradation of aromatic hydrocarbons by eucaryotic organisms; and degradation of aromatic hydrocarbons by procaryotic microorganisms.

C-2069-77
DEGRADATION OF MODEL RECALCITRANT HYDROCARBONS BY MICROORGANISMS FROM FRESHWATER ECOSYSTEMS
Griffin, W. M., and J. J. Cooney. 1977.
American Society for Microbiology Annual Meeting, 77th, New Orleans, 1977. Paper no. RT37. Abstract.

Biodegradation, Hydrocarbons, Bacteria, Fungi, Freshwater, Sediments

Data are presented from a study examining the degradation of pristane and 1, 13-tetradecane by 22 bacteria and 15 fungi in freshwater and sediment cultures.

C-2070-77
CONTINUOUS OPEN FLOW-THROUGH SYSTEM AS A MODEL FOR OIL DEGRADATION IN THE ARCTIC OCEAN
Horowitz, A., and R. M. Atlas. 1977.
Applied and Environmental Microbiology 33(3):647-653.

Biodegradation, Oil slicks, Microorganisms, Arctic Ocean, *Continuous flow-through system

The microbial community underlying oil slicks increased and showed a population shift to a greater percentage of hydrocarbon-utilizing microorganisms. Microbial populations and oil biodegradation were increased by nitrogen and phosphorus addition. Chromatographic and spectrometric analyses showed

NWMAR116825

that residual oils contained similar percentages of individual hydrocarbon components, regardless of the amount of degradation, indicating that most components were being degraded at similar rates.

C-2071-77
INTERACTIONS OF MICROORGANISMS AND HYDROCARBONS FOLLOWING AN ACCIDENTAL LEAKAGE OF GASOLINE INTO A FRESHWATER LAKE AT BARROW, ALASKA
Horowitz, A., and R. M. Atlas. 1977.
American Society for Microbiology Annual Meeting, 77th, New Orleans, 1977. Paper no. Q82. Abstract.

Biodegradation, Hydrocarbons, Microorganisms, Gasoline, Lakes, Sediments, Alaska

After a 190,000 L (50,000 gal) leakage of gasoline into an arctic lake, changes in microbial communities in surface waters and sediments were monitored, and their ability to degrade hydrocarbons was determined in situ. Initially, the heterotrophic bacteria decreased in number, then increased to 10 times their original number. Their physical distribution paralleled the spread of gasoline contamination in the lake and sediments. About 99% of the hydrocarbons in the sediments were lost by natural weathering and biodegradation within 5 weeks.

C-2072-77
RESPONSE OF MICROORGANISMS TO AN ACCIDENTAL GASOLINE SPILLAGE IN AN ARCTIC FRESHWATER ECOSYSTEM
Horowitz, A., and R. M. Atlas. 1977.
Applied and Environmental Microbiology 33(6):1252-1258.

Biodegradation, Gasoline, Biological effects, Microorganisms, Lakes, Arctic

The effects on microorganisms of a 208,175 L (55,000 gal) spill of leaded gasoline into an arctic freshwater lake were studied. "Shifts in microbial populations were detected after the spillage, reflecting the migration pattern of the gasoline enrichment for hydrocarbon utilizers, and selection for leaded-gasoline-tolerant microorganisms... Nutrient addition and bacterial inoculation resulted in enhanced biodegradative losses, significantly reducing the amount of residual hydrocarbons."

NWMAR116826

C-2073-77
BACTERIAL DEGRADATION OF CRUDE OIL
Hughes, D. E., and S. Stafford. 1976.
The Control of Oil Pollution on the Sea and Inland Waters.
J. Wardley-Smith (ed.). London, Graham & Trotman Ltd.,
1976. p. 39-46.

Biodegradation, Crude oil, Bacteria, Dispersants

A brief review with 40 references is presented on the microbial degradation of oil. Discussed are the relative rates of biodegradation, the types and numbers of microbial species that utilize oil, the numerous factors governing oil degradation, the effects of dispersants on bacteria, and results of field experiments.

C-2074-77
UTILIZATION OF AROMATIC HYDROCARBONS BY STRAINS OF ACINETOBACTER
Kunz, D. A., and P. J. Chapman. 1977.
American Society for Microbiology Annual Meeting, 77th,
New Orleans, 1977. Paper no. Q85. Abstract.
Biodegradation, Aromatic hydrocarbons, Bacteria, *Acinetobacter

Aromatic hydrocarbon degradation by microorganisms can be attributed in part to their ability to elaborate enzymes of the catechol ortho and meta-fission pathways. Two distinct modes of substrate degradation which can be correlated with the enzymology of catabolic pathways used by Acinetobacter are detailed, based on patterns of hydrocarbon utilization, rates of oxidation by intact cells, and enzyme assays. Results show that members of the genus Acinetobacter exhibit varying abilities to elaborate enzymes of the catechol meta-fission route as is the case in genus Pseudomonas.

C-2075-77
MICROBIAL CONTRIBUTION TO WASTE OIL DECOMPOSITION IN SOIL IN AN ARID SITE
McDonald, S., and J. Skujins. 1977.
American Society for Microbiology Annual Meeting, 77th, New Orleans,
1977. Paper no. Q46. Abstract.

Biodegradation, Waste oil, Soil, Monitoring, Bacteria, Fungi, *Arid site

Microbial aspects of the degradation of oil under arid conditions were monitored for 3 years and correlated with biochemical changes in soil, disappearance of the oil, climate, addition of N, P, and Ca nutrients, and response in vegetation. Biodegradation was achieved primarily by greatly enlarged populations of lipolytic bacteria aided by some fungi; it occurred best under aerobic

NWMAR116827

conditions, elevated temperatures, and availability of water and nitrogen. About 80% of the oil was degraded in 3 years, leaving a humus-like organic fraction in the soil.

C-2076-77
BIOTRANSFORMATION OF PETROLEUM HYDROCARBONS IN MARINE ORGANISMS INDIGENOUS TO THE ARCTIC AND SUBARCTIC
Malins, D. C. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 47-49. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Biodegradation, Marine organisms, Hydrocarbons, Arctic, Subarctic regions, Toxicity

A review is given of the recent literature dealing with the biotransformation of aromatic hydrocarbons in arctic and subarctic species. Deficiencies in the existing knowledge are assessed and the need for further studies is addressed.

C-2077-77
USE OF ^{14}C RADIOLABELLED HYDROCARBON SPIKED CRUDE OIL TO ASSESS OIL BIODEGRADATION POTENTIAL IN THE BEAUFORT SEA
Roubal, G., and R. M. Atlas. 1977.
American Society for Microbiology Annual Meeting, 77th, New Orleans, 1977. Paper no. Q83. Abstract.

Biodegradation, Hydrocarbons, Crude oil, Ice, Sediments, Seawater, Beaufort Sea

Ice, water, and sediment samples from the Beaufort Sea were collected in winter and in summer and incubated with Prudhoe crude oil spiked with ^{14}C radiolabelled hydrocarbons. Hydrocarbon biodegradation potentials in summer were found to be an unexpected 80% lower than biodegradation rates from comparable sediment and water samples taken in winter. Surface ice samples had biodegradation potentials that averaged 75% less than water and sediment samples.

C-2078-77
BIODEGRADATION OF EKOFISK OIL, AND THE EFFECTS OF WATER-SOLUBLE METABOLIC PRODUCTS ON THE FERTILIZATION AND DEVELOPMENT OF SEA URCHIN EGGS. [in Norwegian, occas. English]
NORDFORSK, Miljoevardssekretariatet, Publikation. (2, Organiska Miljoegifter i Vatten, Nordiska Symposiet om Vattenforskning, 12th):295-298.

NWMAR116828

Biodegradation, Crude oil, Toxicity, Echinoderms, *Ekofisk oil

Experiments show that biodegradation is not a suitable method for decontamination of sea water. Water-soluble toxic compounds were released and inhibited the fertilization and development of three species of sea urchins.

[from Chemical Abstracts 87(8):#57948r. 1977]

C-2079-77
MATERIAL FOR BIOLOGICAL DEGRADATION OF PETROLEUM
Townsley, P. M. 1976.
Canadian Patent 997,290.

Biodegradation, Oil spills, Patent, *Nutrient addition

Oil spill biodegradation in seawater is fostered by the addition of nutrient particles which have been treated so that they are lipophilic, hydrophobic, and float at the oil-water interface. The nutrient particles are coated with magnesium stearate which acts to release the nutrients slowly and also serves as a nutrient. The coated nutrient particles are dispersed over the oil spill by aerodusting or similar means.

[from Chemical Abstracts 86(26):#194681s. 1977]

C-2080-77
MODELING OF THE MICROBIAL OXIDATION OF PETROLEUM AND DIESEL FUEL [in Russian]
Tsuban, A. V., A. N. Zubekina, V. V. Il' inskii, S. P. Barinova, and T. O. Skakun. 1975.
Materialy Vsesoyuznogo Simpoziuma "Okeanograficheskie Aspekty Okhrany Vod ot Khimicheskikh Zagrya znenii," 1st, 1974.
Chernyshov, V. I. (ed.). Moscow, USSR, Akademiya Nauk, SSSR, Okeanograficheskaya Komissiya, 1975. p. 191-194.

Biodegradation, Fuel oil, Petroleum products, Oxidation, Bacteria, Caspian Sea

The authors studied separate strains of hydrocarbon-oxidizing bacteria isolated from open waters of the Caspian Sea and from the mouth of the Lena River. The bacteria assimilated petroleum and diesel fuel and oxidized xylene.

[from Chemical Abstracts 87(8):#55314g. 1977]

NWMAR116829

C-2081-77
NUTRIENT LIMITATION OF OIL BIODEGRADATION IN LAKES OF VARYING WATER QUALITY IN VILAS COUNTY
Ward, D. M., and T. D. Brock. 1976.
Transactions of the Wisconsin Academy of Sciences, Arts and Letters No.64:240-249.

Biodegradation, Hydrocarbons, Bacteria, Lakes, Water quality, Wisconsin, *Nutrient limitation

The hydrocarbon oxidation potential of 25 lakes differing in nutrient content was studied. Oil-degrading bacteria generally comprised a small percentage of heterotrophic bacterial populations except in areas near boat landings where selective enrichment occurs. Rates of hydrocarbon oxidation were very low in all lakes but were stimulated by the addition of P and N nutrients.

[from Chemical Abstracts 86(26):#194831r. 1977]

C-2082-77
BIODEGRADABILITY OF NORTHERN CRUDE OILS
Westlake, D. W. S., and F.D . Cook. 1975.
Report ALUR 74-75-81. 21 p.

Biodegradation, Crude oil, Bacteria, Hydrocarbons, Soil, Canada, *Nutrient addition

Laboratory and field studies were conducted on the biodegradation of crude oils under northwestern Canadian conditions. Test plots were oiled and treated with fertilizer and/or oil-degrading bacteria. Fertilizers aided primarily in the microbial utilization of alkanes. The number of Clostridia was found to increase in the soil and water under oil spills.

[from Chemical Abstracts 87(1):#4621x. 1977]

2. PHYSICAL CHANGES OF OIL

C-2083-77
DETERMINATION OF THE SIZE DISTRIBUTION FUNCTION OF THE OIL PARTICLES DISPERSED IN SEAWATER ON THE BASIS OF MULTIFACTOR EXPERIMENT [English summary]
Akhmetov, A. Sh., V. I. Belyaev, and O. G. Mironov. 1976.
Dopovidi Akademii Nauk Ukrains'koi RSR, Ser. A No.8:705-707.

NWMAR116830

Distribution, *Oil particles, Seawater

"The size distribution function of the oil particles in seawater is logarithmically normal. In this contribution the parameters of distribution are determined as linear functions of the water temperature, time of mixing, energy dissipation and oil viscosity."

[from ERDA Energy Research Abstracts 2(11):#25909. 1977]

C-2084-77
THE STABILITY OF EMULSIFIED CRUDE OILS AS AFFECTED BY SUSPENDED PARTICLES
Huang, C. P., and H. A. Elliott. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 413-420. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Emulsions, Crude oil, Physical effects, *Suspended solids, *Stability

The primary objective of this research is to investigate the effect of various inorganic solids on the stability of crude oil emulsions. Interfacial reactions between emulsion and solid are influenced by the physical and chemical properties of both kinds of particles involved as well as the chemical characteristics of the aqueous phase.

C-2085-77
EVAPORATION AND SOLUTION OF C_2 TO C_{10} HYDROCARBONS FROM CRUDE OILS ON THE SEA SURFACE
McAuliffe, C. D. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 363-372. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Hydrocarbons, Oil spills, Fate, Evaporation, Solution, Weathering

Evaporation and solution of C_2 to C_{10} hydrocarbons were measured from 4 ocean spills of 2 crude oils (24° and 39° API gravities). Experimental data are presented. These studies indicate that dissolution of hydrocarbons into the water column from crude oil slicks, followed by evaporation, resulted in immeasurably low concentrations (<1 µg/L) of dissolved C_2 to C_{10} hydrocarbons 15 min after each spill.

NWMAR116831

C-2086-77
SEA ICE TOPOGRAPHY IN THE BEAUFORT SEA AND ITS EFFECTS ON OIL CONTAINMENT
Wadhams, P. 1976.
AIDJEX Bulletin No.33:1-52.

Oil spills, Spreading, Ice, Beaufort Sea, *Under-ice spill

The topography of the Beaufort Sea ice cover was examined by airborne laser profiling methods and the data analyzed in order to give a quantitative description of pressure ridge and keel distributions. The distributions are used as a basis for a discussion of the extent to which sea ice deformation features help or hinder the long-term spreading of oil under ice after an under-ice blowout.

C-2087-77
MODELING OF OIL EVAPORATION IN AN AQUEOUS ENVIRONMENT. RESEARCH ON THE EFFECTS OF CRUDE OIL TRANSFER AND UPSTREAM REFINERIES ON DELAWARE BAY
Wang, H., W. C. Yang, and C. P. Huang. 1976.
Delaware University, College of Marine Studies report, CMS-RANN-5-76, NSF/RA-760478; Grant NSF-GI-41896. 49 p.

Oil spills, Models, Weathering, Evaporation, Oil transfer, Delaware Bay

The weathering of oil during early stages of a spill was investigated using computerized simulation of the evaporative changes in oil characteristics, specific gravity, and residues by weight and volume. The numerical results support laboratory findings which indicate that the effect of temperature on oil weathering is most significant at the early stages of weathering and diminishes with time. Wind speed has a more uniform effect throughout the time tested.

[from Government Reports Announcements 77(13):#PB-264 968/9GA. 1977]

3. CHEMICAL CHANGES OF OIL

C-2088-77
PHOTOOXIDATION OF N-HEXADECANE SENSITIZED BY XANTHONE
Gesser, H. D. 1977.
Environmental Science and Technology 11(6):605-608.

NWMAR116832

Models, Oil spills, Oxidation, Fate, *n-Hexadecane, *Photo-oxidation

"The photosensitized oxidation of hexadecane on water is studied as a model for the solar dissipation of oil spills." Experimental results are presented and discussed.

[from the UDS Water Quality Control Digest 8(4):III-30, #7F-28. 1977]

C-2089-77
FORMATION OF TOXIC PRODUCTS FROM A #2 FUEL OIL BY PHOTOOXIDATION
Larson, R. A., L. L. Hunt, and D. W. Blankenship. 1977.
Environmental Science and Technology 11(5):492-496.

Fuel oil, Toxicity, Yeasts, Oxidation, *UV irradiation

Simulated environmental levels of UV irradiation of a No. 2 fuel oil resulted in oxygenated compounds that were relatively soluble in water and toxic to baker's yeast. Maximum toxicity was reached within 24 hr and appeared to be due primarily to reactive peroxides. Addition of a mild reducing agent eliminated much of the light-induced toxicity. Continued irradiation produced other classes of compounds including phenols and carbonyls.

[from Chemical Abstracts 86(25):#184194w. 1977]

4. GENERAL FATE OF OIL

C-2090-77
SCIENTIFIC STUDY OF MAJOR OIL SPILL OFF THE UNITED STATES
Anon. 1977.
Petroleum Times 81(2049):76.

Argo Merchant spill, Monitoring, Environmental effects, Behavior, Movement, Sampling

The grounding of the Liberian tanker, "Argo Merchant," presented an opportunity for scientists to conduct studies on the properties, behavior, and detailed ecological impact of oil spills. A coordinated program of monitoring and tracking of the spill movement and behavior was provided by aircraft, while ground-based missions collected water, oil, and biological samples.

[from Petroleum Abstracts 17(28):#235,533. 1977]

NWMAR116833

C-2091-77
THE FATE OF PETROLEUM HYDROCARBONS FROM A NO. 2 FUEL OIL SPILL IN A SEMINATURAL ESTUARINE ENVIRONMENT
Bieri, R. H., and V. C. Stamoudis. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 332-344. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Hydrocarbons, Fuel oil, Sediments, Marine organisms, Estuaries, Virginia

Experimental spills of No. 2 fuel oil were conducted in a York River, Virginia, estuarine area. The fate of oil components over time was investigated by repeated sampling of water sediments, oysters, and clams from the spill area and analysis by gas chromatography and computerized gas chromatography-mass spectrometry.

C-2092-77
DISTINCTIVE FEATURES OF THE SELF-PURIFICATION OF WATER AND BOTTOM DEPOSITS IN A SHALLOW SEA (AS EXEMPLIFIED BY THE SEA OF AZOV)
Bronfman, A. M., A. Ya. Aldakimova, G. D. Makarova, and L. I. Tolokonnikova. 1976.
Oceanology 16(1):48-51.

Petroleum products, Surfactants, Fate, Biodegradation, Seawater, Sediments, *Self-purification, *Sea of Azov

Spatial and seasonal variations in processes that rid seawater and bottom sediments of pollutant petroleum products and detergents are discussed with reference to studies conducted in the Sea of Azov. In a direction away from the coastal source of pollution, four distinct zones of self-purification occur, each with a characteristic assemblage of biological agents. The processes of self-purification in the pelagic and benthic zones of the sea are found to be out of phase and less effective than those of shallow waters; thus assuring a steady accumulation of toxic substances in bottom sediments.

C-2093-77
OIL SPILL FROM T/T "DRUPA": STUDIES ON THE OIL, WATER AND FISH [in Norwegian, occas. English]
Grahl-Nielsen, O., T. Neppelberg, K. H. Palmork, K. Westrheim, and S. Wilhelmsen. 1976.
NORDFORSK, Miljoevardssekretariatet Publikation (2, Organiska Miljoegilter i Vatten, Nordiska Symposiet om Vattenforskning, 12th):221-40.

NWMAR116834

Oil spills, Chemical analysis, Weathering, Biodegradation, Biological effects, Aromatic hydrocarbons, Fish, Norway, *T/T "Drupa" spill

Samples of spilled Iranian oil were collected along the Norwegian coast and analyzed by mass fragmentography. The authors estimated the effects of dissolution, emulsification, evaporation, microbial decomposition, and photochemical decay. Water samples were analyzed by gas chromatography and concentrations of aromatic hydrocarbons in fish liver were measured.

[from Chemical Abstract 87(8):#57947g. 1977]

C-2094-77
THE FATE OF OIL IN A MODEL ECOSYSTEM
Hagström, A. 1977.
Ambio 6(4):229-231.

Oil spills, Models, Fate, Biodegradation, Distribution, Baltic Sea, Intertidal zone

A model ecosystem representing the littoral zone of the Baltic Sea was developed for a simulation of the environmental effects of oil spills. Three different types of oil were used, namely, Nigerian crude and medium and light fuel oils. Changes in oil composition and distribution were monitored for 54 days, and bacterial degradation rates were measured. A theoretical model is presented which summarizes the events leading to the disappearance of oil in the sea.

C-2095-77
ALONG-SHORE COHERENCE OF WINDS ALONG THE NORTH ALASKAN COAST FOR OIL SPILL ANALYSIS
Hufford, G. L., J. P. Welsh, I. M. Lissauer, and B. D. Thompson. 1977.
Annual SPE of AIME Offshore Technology Conference, 9th, Houston, 1977. No. OTC-2947. p. 529-532.

Oil spills, Movement, *Coastal winds, Alaska

From analysis of available data, there appear to be 3 wind field regimes along the Alaskan North Slope coast: a western regime, a central regime, and an eastern regime. These regimes must be taken into account in the prediction of oil spill movement during normal conditions. During storm conditions, an existing Coast Guard storm model can be used to predict coastal winds.

[from Petroleum Abstracts 17(26):#235,037. 1977]

NWMAR116835

C-2096-77
SEA ICE THICKNESS PROFILING AND UNDER-ICE OIL ENTRAPMENT
Kovacs, A. 1977.
Annual SPE of AIME Offshore Technology Conference, 9th, Houston, 1977. No. OTC-2949. p. 547-554.

Oil spills, Fate, Ice, Alaska, *Oil-under-ice, *Impulse radar system

Results obtained with a unique dual-antenna impulse radar system used to profile first- and multi-year sea ice near Prudhoe Bay, Alaska, are discussed. A description of the radar system is given along with representative field data.

[from Petroleum Abstracts 17(26):#235,034. 1977]

C-2097-77
FATE AND EFFECTS OF NAPHTHALENES. CONTROLLED ECOSYSTEM POLLUTION EXPERIMENT
Lee, R. F., and J. W. Anderson. 1977.
Bulletin of Marine Science 27(1):127-134.

Fate, Hydrocarbons, Seawater, Ecosystem, Sedimentation, Biodegradation, *Naphthalenes

The amount of naphthalenes which was present in the water of a controlled ecosystem pollution experiment was reduced by 50% one day after addition, and the concentrations gradually decreased to background levels during the following 20 days. Most of the decrease of naphthalenes was due to adsorption by sinking phytoplankton and microbial degradation. Microbial degradation of naphthalene at 5-10 m depth increased from 0.04 µg/L/day at day 0 to 3.3 µg/L/day after 3 days. An immediate decline in the ctenophore population of the systems was observed after addition of the naphthalenes.

C-2098-77
ENVIRONMENTAL RISK OF BEAUFORT SEA OIL SPILLS - A MANAGEMENT TOOL
Lissauer, I. M., J. P. Welsh, and G. L. Hufford. 1977.
Marine Technology Society Journal 11(1):22-25.

Oil spills, Movement, Shorelines, *Spill impact probability, Alaska Coast, Beaufort Sea.

Using available environmental data, this paper develops a technique for oil spill impact assessment of the north Alaskan coastline. Fifteen potential drilling sites are studied and a generalized equation is given for calculating minimum impact time for a spill to reach the shore. Probability of impact ranges from 40 to 96 percent.

NWMAR116836

C-2099-77
DISPERSAL AND ALTERATION OF OIL DISCHARGED ON A WATER SURFACE
McAuliffe, C. D. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 19-35. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Oil spills, Fate, Biological effects, Dispersants

The physical, chemical, and biological fate of oil discharged to a water surface is reviewed briefly, including recent literature. The only significant adverse effects from crude oil spills have been to birds and to some species of intertidal organisms where the oil stranded. Chemical dispersants have the potential for reducing the known adverse effects. This remedy is discussed, along with suggested research to evaluate effects from oil spills.

C-2100-77
ADSORPTION-DESORPTION OF SELECTED HYDROCARBONS IN CRUDE OIL ON SOILS
Nathwani, J. S., and C. R. Phillips. 1977.
Chemosphere 6(4):157-162.

Crude oil, Hydrocarbons, Soil, Adsorption, *Desorption, *Organic matter content

This study investigated the effects of hydrocarbon concentration, soil type, and organic matter content on the adsorption and desorption of selected petroleum hydrocarbons in soil. The organic matter content of soils is very important in both adsorption and desorption of crude oil constituents. The oil-sorbent capacity of soil was found to vary directly with organic matter content.

C-2101-77
HYDROCARBONS IN THE WATER COLUMN
Shaw, D. G. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 8-18. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Hydrocarbons, Seawater, Fate, Marine organisms, *Molecular interactions

The molecular basis of the water-hydrocarbon interaction is reviewed from the perspective of the degree of aggregation of hydrocarbon molecules in water. Some of the ways in which this information can be used when considering the design and interpretation of experiments dealing with the fate and effects of petroleum on marine ecosystems and organisms are presented.

NWMAR116837

C-2102-77
UPTAKE AND RELEASE OF PETROLEUM BY INTERTIDAL SEDIMENTS AT PORT VALDEZ, ALASKA
Shaw, D. G., L. M. Cheek, and A. J. Paul. 1977.
Estuarine and Coastal Marine Science 5(3):429-436.

Uptake, Release, Hydrocarbons, Sediments, Oil slicks, Intertidal zone, Alaska

Two experiments were conducted which simulated the stranding of a light oil slick by spreading oil on sediments daily for 5 days. Hydrocarbon content of the top 1.0 cm of the sediments was monitored for 60 days. In both experiments, the added oil was no longer detectable on the 60th day. Possible reasons for the rapid loss of oil by sediments are discussed.

[from Petroleum Abstracts 17(31):#236,390. 1977]

C-2103-77
DETERMINATION OF THE LEEWAY OF OIL SLICKS
Smith, C. L. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D. A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 351-362. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

Oil slicks, Movement, *Leeway, *Wind drift

The leeway of oil slicks was determined as a function of wind velocity in the range 5-25 kn to enable more precise forecasting of the trajectory of oil spills, and thus aid in effective containment and cleanup operations. Calculation of oil spill leeway is explained.

C-2104-77
A REVIEW AND EVALUATION OF BASIC TECHNIQUES FOR PREDICTING THE BEHAVIOR OF SURFACE OIL SLICKS
Stolzenbach, K. D., O. S. Madsen, E. E. Adams, A. M. Pollack, and C. K. Cooper. 1977.
Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics, Report No. 222. 315 p.

Oil slicks, Behavior, Physical effects, Models, *Wind-current effects

The purpose of the study is to conduct a state-of-the-art review of the basic techniques and knowledge associated with surface oil slick behavior. Results of this review are presented in the following manner : representation and determination of wind fields; treatment of the advection of oil slicks that is brought about by the combined action of currents and wind-waves; the physical phenomena that transform an oil slick as it is being

NWMAR116838

advected; and a review and evaluation of existing models for oil slick behavior. A comprehensive bibliography is included at the end of the report.

C-2105-77
REMOVAL [OF OIL] BY NATURAL CAUSES
Wardley-Smith, J. 1976.
The Control of Oil Pollution on the Sea and Inland Waters. J. Wardley-Smith (ed.). London, Graham & Trotman Ltd., 1976. p. 27-38.

Fate, Contamination, Seawater, Spreading, Evaporation, Oxidation, Solution, Dispersions

Natural processes that remove oil contaminants on and in the sea are considered. These include spreading on water, evaporation, photochemical oxidation, and solution and the formation of dispersions in the water column.

C-2106-77
STUDIES ON THE OIL POLLUTION OF SEDIMENTS IN THE SETO INLAND SEA
Yamada, H., and M. Kayama. 1976.
Bulletin of the Nansei Regional Fisheries Research Laboratory No. 9:19-31.

Petroleum products, Sediments, Movement, Japan, *Seto Inland Sea

The lipid content of the Seto Inland Sea is related to ignition loss. Organic compounds accumulate in the sediments of stagnant areas, and the n-alkanes/pristane and squalene ratio indicates the contributions from petroleum oil. The authors conclude that oil stranded at the southern coast of Harima Nada is moving toward the sediments of the stagnant area.

[from Aquatic Sciences & Fisheries Abstracts 7(7):#7Q8976. 1977]

C-2107-77
ROLE OF PHYSICOCHEMICAL AND MICROBIOLOGICAL FACTORS IN THE DEGRADATION OF HYDROCARBONS OF PETROLEUM ORIGIN [in Russian]
Zubakina, A. N., A. V. Tsyban, S. P. Barinova, and I. M. Mikhalera. 1975.
Materialy Vsesoyuznogo Simpoziuma "Okeanograficheskie Aspecty Okhrany Vod Khimicheskikh Zagryaznenii," 1st, Moscow, 1974. V. I. Chernyshov (ed.). Moscow, Akad. Nauk SSSR, Okeanograficheskie Komissiya, 1975. p. 66-72.

Decomposition, Fuel oil, Microorganisms, Biodegradation, *Physicochemical degradation

NWMAR116839

Microbial oxidation of fuel oil at -0.6° to 22° during 3-30 days was studied with special reference to conditions prevailing in the arctic region of the Pacific Ocean. At -0.3 to -0.6°, where physical and chemical degradation is greatly reduced, the bacterial oxidizing activity reduces the hydrocarbon content 38% at a microorganism count in seawater and ice of 10^4-10^5 colonies/ml. Oxidizing microorganisms degrade the fuel oil at the rate of 100-180 mg/l day, consuming 38-62% of the substrate in 6 days at 22° or 35% in 30 days at 2°. At this low temperature, only 1% is degraded by physical and chemical oxidation.

NWMAR116840

F. OIL POLLUTION REGULATIONS

1. U.S. LEGISLATION

C-2108-77
OIL POLLUTION LIABILITY (HEARINGS ON HR 9294, 10969, 10363, 10756 WHICH PROVIDE A COMPREHENSIVE SYSTEM OF LIABILITY FOR OIL SPILL DAMAGE AND CLEANUP COSTS)
Anon. 1976.
U.S. House of Representatives. Committee on Merchant Marine and Fisheries. Subcommittee on Coast Guard and Navigation. Hearings. October 29, November 4, 12, 18; December 2, 4, 16, 1975; January 29, 1976. Serial no. 94-21. 367 p.

Legislation, U.S., Oil spills, Liability, Compensation, Spill cleanup, *Costs

The proposed bills offer plans for comprehensive coverage for oil pollution damage, including a system of liability and compensation for spill damage and removal costs. This legislation proposes to establish a domestic oil pollution liability fund to provide protection for claimants not otherwise protected by previous conventions. It will provide for complete protection against damages to innocent third parties who will have ready access to compensatory funds.

[from Selected Water Resources Abstracts 10(13):#W77-06555. 1977]

C-2109-77
THE COAST: WHERE ENERGY MEETS THE ENVIRONMENT
Hildreth, R. G. 1976.
San Diego Law Review 13(2):253-305.

Legislation, U.S., OCS, Offshore development, Refineries, Environmental effects, Coasts

The adverse impacts of pollution from OCS development, onshore refineries, and chronic coastal oil pollution are some of the factors that in the long run could outweigh any short-term gains from exploitation of continental shelf resources. As coastal states stand to lose the most from such developments, the Deepwater Port Act and the Coastal Zone Management Act (CZMA) are assessed with the states' interest in mind.

[from Pollution Abstracts 17(29):#235,721. 1977]

NWMAR116841

C-2110-77
OIL TANKER SPILLS - WASHINGTON IS WEIGHING VARIOUS PREVENTIVE MEASURES
Scheibla, S. 1977.
Barrons Feb. 28:9.

Legislation, U.S., State governments, Oil spills, Tankers, Pollution control

Recent tanker-related spills are speeding up the enactment of state and federal legislation designed to prevent or abate oil discharges during tanker and ship operations. Laws being considered by Congress and some states are mentioned, and the effects of past and upcoming legislation upon Tennaco's Newport News dry dock and shipyard facility are assessed.

[from Environment Abstracts 7(5/6): #77-03184. 1977]

C-2111-77
REGULATION FOR TANK VESSELS ENGAGED IN THE CARRIAGE OF OIL IN DOMESTIC TRADE
U.S. Coast Guard. 1975.
Final Environmental Impact Statement, Report no. USCG-M-07-77. 335 p.

Oil transport, Tankers, U.S., Regulations, EIS, Pollution control, Oil discharges

Assessed is the environmental impact of proposed change to the pollution regulations in Title 33, Code of Federal Regulation, by adding conditions governing the design and operation of certain seagoing U.S. tank ships and barges certified to carry oil in U.S. domestic trade. The new regulations require segregated ballast on new tankers over 70,000 dwt, contain cargo tank size limits and improved tank vessel subdivision and stability, and set stringent discharge standards for both new and existing vessels requiring load-on-top or retention-on-board methods to curtail oil discharges to marine waters.

[from Government Reports Announcements 77(11):#AD-A036 719/3GA. 1977]

C-2112-77
REGULATIONS FOR U.S. TANK VESSELS CARRYING OIL IN FOREIGN TRADE AND FOREIGN TANK VESSELS THAT ENTER THE NAVIGABLE WATERS OF THE UNITED STATES
U.S. Coast Guard. 1976.
Final Environmental Impact Statement, Report no. USCG-M-08-77. 141 p.

Oil transport, Tankers, Segregated ballast, Regulations, U.S., EIS, Pollution control, Oil discharges

This statement assesses the environmental impact of changing the pollution prevention regulations in Title 33, Part 157, Code of Federal Regulations, to extend requirements for segregated

NWMAR116842

ballast on new tankers over 70,000 dwt and other design equipment and operating requirements to the title groups of vessels. The purpose of these regulations is to control the discharge of oily mixtures from tank cleaning and deballasting operations and to incorporate construction requirements for new vessels which will reduce the occurrence of oil spills after accidents and improve the survivability of tankers after damage.

[from Government Reports Announcements 77(11):#AD-A036 769/8GA. 1977]

C-2113-77
RULES AND REGULATIONS FOR PROTECTION OF THE MARINE ENVIRONMENT RELATING TO TANK VESSELS CARRYING OIL IN DOMESTIC TRADE
U.S. Coast Guard. 1976.
Federal Register 41(5):1479-1482.

Regulations, Tankers, Segregated ballast, Environmental protection, USCG

These regulations provide for the placement of ballast tanks on oil-carrying vessels of over 70,000 dwt in order to minimize oil loss in the event of an accidental leakage from tankers. While some believe that the cost of segregated ballast is too high, the Coast Guard believes that it is needed to improve the environmental quality of the oceans.

[from Selected Water Resources Abstracts 10(15):#W77-07254. 1977]

C-2114-77
RULES FOR THE PROTECTION OF THE MARINE ENVIRONMENT RELATING TO TANK VESSELS CARRYING OIL IN BULK
U.S. Coast Guard. 1976.
Federal Register 41(240):54177-54180.

Regulations, Tankers, Oil discharges, Wastewaters, USCG

Amendments have been added to the oil vessel pollution regulations imposing design, equipment, and operation requirements for seagoing U.S. flag tank vessels of 150 gross tons or more and equally heavy foreign flag vessels that enter U.S. waters. The requirements are delineated in detail. The amendments also provide the conditions under which clean and segregated ballast may be discharged; they became effective April 1, 1977.

[from Selected Water Resources Abstracts 10(15):#W77-07251. 1977]

NWMAR116843

2. INTERNATIONAL LEGISLATION

C-2115-77
LEGAL ASPECTS OF MARINE POLLUTION CONTROL
Moore, G. 1976.
Marine Pollution. R. Johnston (ed.). London, Academic Press, 1976. p. 589-697.

International agreements, International conventions, Legislation, Pollution control, Oceans, UK, U.S.

In the first part of this chapter, customary international law, and international agreements and conventions concerning marine pollution, especially oil pollution, are examined. Recent trends toward comprehensive antipollution programs on the global and regional scale are discussed. The second part describes and summarizes national pollution control laws, programs, and approaches with numerous examples from the United Kingdom and the United States.

C-2116-77
INTERNATIONAL MARINE POLLUTION CONTROLS
Portmann, J. E. 1977.
Marine Pollution Bulletin 8(6):126-132.

International conventions, Legislation, Pollution control

"The purpose of this article is to attempt to bring some order to the international scene, by describing the aims, coverage, scientific validity and status of the main international pollution regulations, at least so far as they affect European marine interests." In the course of the paper, the author reviews the history of international oil pollution legislation, but the bulk of the article concerns other pollutants and conventions.

3. FOREIGN LEGISLATION

C-2117-77
ENVIRONMENTAL LEGISLATION - ALBERTA PETROLEUM EFFLUENT GUIDELINES (news brief)
Anon. 1977.
Water & Pollution Control 115(2):5.

Guidelines, Environmental protection, Refineries, Wastewater treatment, Canada, *Alberta

NWMAR116844

The Alberta Department of Environment and the petroleum refining industry have developed and reviewed wastewater effluent guidelines that will define minimum acceptable levels of wastewater treatment at refineries, consistent with good operating practices and environmental protection. Permits and licenses will now be issued only when these minimal requirements are met.

C-2118-77
ENVIRONMENTAL LEGISLATION - QUEBEC REFINERS TO MEET NEW EFFLUENT LEVELS (news brief)
Anon. 1977.
Water & Pollution Control 115(6):35.

Regulations, Wastewaters, Refineries, Environmental protection, Economics, Canada, *Quebec

Seven Quebec oil refineries will have to meet tough new effluent quality regulations by 1980. At present these refineries dump about 15,400 kg (34,000 lbs) of contaminants into the St. Lawrence River per day, of which about 3240 kg (7200 lbs) are oil and grease. Implementation of the regulations will cost the industry about $88 million.

C-2119-77
ENFORCEMENT OF OIL POLLUTION LEGISLATION
Brown, M. A. 1976.
The Modern Law Review 39(2):162-168.

Legislation, Law enforcement, Ships, Oil spills, England, Canada

The British oil pollution law is enforced only when there is substantial pollution or when the pollution, however minimal, is caused by substantial negligence. Pollution caused by foreign owned ships also poses serious legal problems. The author examines several methods utilized by the shipping community to pay for oil pollution damages. The Canadian law governing oil polluting incidents is also discussed.

[from Selected Water Resources Abstracts 10(13):#W77-06543. 1977]

NWMAR116845

4. STANDARDS AND GUIDELINES

C-2120-77
THE THREAT TO OUR SHORES
Bernstein, P. J. 1977.
Nation 224(3):73-77.

Regulations, Tankers, Ports, Government agencies, USCG, Safety, Law enforcement

U.S. Government agencies, especially the U.S. Coast Guard, are criticized for their failure to implement and enforce safety standards, such as double bottoms for all oil tankers entering U.S. ports. Unless such safety regulations are required in domestic and foreign registry tankers, a high number of oil spills off U.S. coasts are likely to continue.

[from Environment Abstracts 7(5/6):#77-03157. 1977]

C-2121-77
STATUS REPORT ON ABATEMENT OF WATER POLLUTION FROM THE CANADIAN PETROLEUM REFINING INDUSTRY - 1975
Environmental Protection Service, Ottawa (Ontario). Water Pollution Control Directorate. 1976.
Economic and technical review report, EPS 3-WP-76-11. 54 p.

Regulations, Pollution control, Wastewaters, Contaminants, Refineries, Canada

"Effluent regulations and guidelines to limit the discharge of pollutants from the petroleum refining industry were issued under the Federal Fisheries Act in November 1973. This report presents an assessment of the progress to the end of 1975 in meeting the discharge objectives, and provides projections of the anticipated status through to 1980."

[from Selected Water Resources Abstracts 10(15):#W77-07334. 1977]

C-2122-77
MANUAL ON OIL POLLUTION. SECTION 1 (PREVENTION). OCTOBER 1976.
Inter-Governmental Maritime Consultative Organization. 1976.
London, IMCO, 1976. 27 p.

Manuals, Pollution prevention, Guidelines, Tankers, Contingency planning

Section 1 of the Comprehensive Anti-Pollution Manual details practical information on means of prevention of oil pollution in the sea, especially useful to governments of developing countries. Requirements are given for all ships, with special

NWMAR116846

details concerning tankers. Other sections of the manual address contingency planning, salvage, and methods of dealing with oil spills (published in 1972).

[from Aquatic Sciences & Fisheries Abstracts 7(7):#7Q9059. 1977]

5. AGREEMENTS AND CONVENTIONS

C-2123-77
AID TO THE BEWILDERED
Anon. 1977.
Ship & Boat International 30(5):35.

International conventions, Pollution prevention, EPA, IMCO, Sweden, *Baltic Convention

"Sweden has enacted legislation giving effect to the provisions of the Baltic Convention for the prevention of pollution of the seas." The Convention may serve as a model for similar action elsewhere regulating discharges into 'special waters.' This document differs slightly from the IMCO 1973 draft conventions, and both differ from the EPA regulations, as well as from local restrictions.

[from Aquatic Sciences & Fisheries Abstracts 7(8):7Q10559. 1977]

C-2124-77
NORTH SEA PACT SETS OIL POLLUTION LIABILITY
Anon. 1977.
Chemical and Engineering News 55 (January):15.

International agreements, Liability, Offshore drilling, Oil transfer, Storage, North Sea

An international agreement has been reached between countries adjoining the North Sea which assesses liability for pollution damage resulting from the escape of oil from offshore installations. The term installation covers any fixed or mobile unit involved in offshore oil activity, including platforms, pipelines, and oil transfer and storage structures. A liability of up to $35 million in damages can be assessed against the operator company, regardless of whether the company is at fault in a pollution incident or not.

NWMAR116847

C-2125-77
TOWARD A POLLUTION POLICY
Sandbrook, R. 1977.
Nature 267(5614):745-747.

International conventions, UN, Pollution control, Monitoring, Biological effects, Mediterranean Sea

The progress of a UNEP-sponsored international convention for preventing and controlling pollution in the Mediterranean is discussed. The program involves 16 of the 18 Mediterranean countries and includes provisions for extensive scientific research, monitoring, and integrated planning for the region. Included are regional baseline studies and monitoring of petroleum hydrocarbons, and studies on the effects of oil on marine organisms, populations, and marine communities and coastal ecosystems. Coastal transport of pollutants and water quality problems are also addressed.

C-2126-77
THE 1973 IMCO CONVENTION: TIGHTENING THE CONTROLS ON OPERATIONAL OIL POLLUTION FROM TANKERS
Skocypec, R. J. 1976.
UCLA-Alaska Law Review 5(2):353-380.

International conventions, IMCO, Oil discharges, Tankers, Law enforcement

The set of regulations proposed by the convention to control oil pollution from tankers includes an expanded definition of oil to cover various forms of petroleum, a strengthening of discharge standards, a new discharge monitoring and control system, shoreside treatment facilities, and segregated ballast tanks for new vessels exceeding 70,000 dwt. The major drawback of the new regulations is in enforcement.

[from Selected Water Resources Abstracts 10(15):#W77-07244. 1977]

NWMAR116848

G. BIBLIOGRAPHIES

C-2127-77
EFFECTS OF POLLUTION ON FRESHWATER FISH
Brungs, W. A., J. H. McCormick, T. W. Neiheisel, R. L. Spehar, C. E. Stephan, G. N. Stokes. 1977.
Journal Water Pollution Control Federation 49(6):1425-1493.

Bibliographies, Fish, Freshwater, Biological effects

This bibliographic review covers symposia and reviews, topics on water quality and various pollutants including pesticides, domestic, industrial, radioactive, and other pollutants. There are 464 references cited with nine concerning oil pollution.

C-2128-77
THE BIOLOGICAL EFFECTS OF OIL SPILLS (A BIBLIOGRAPHY WITH ABSTRACTS)
Harrison, E. A. 1977.
Report for 1964-March 1977. 196 p.

Bibliographies, Oil spills, Biological effects, Plants, Animals, Microorganisms

This bibliography contains 191 abstracts, 49 of which are new entries to the previous edition, which cover the biological and ecological effects of oil spills in salt and fresh water. The effects on microorganisms, plants, and animals are studied, along with research on the residues and metabolic products of various oil components.

[from Government Reports Announcements 77(11):#NTIS/PS-77/0200/4GA. 1977]

C-2129-77
OIL SHALE MINING, PROCESSING, USES, AND ENVIRONMENTAL IMPACTS. VOLUME 1. 1970-1975 (CITATIONS FROM THE ENGINEERING INDEX DATA BASE)
Hundemann, A. S. 1977.
Report for 1970-1975. 219 p.

Bibliographies, Oil shale, Development, Extraction, Environmental effects

Research projects on the mining, extraction, environmental impacts, and other topics related to oil shale development are covered. The report contains 212 citations with abstracts.

[from Government Reports Announcements 77(14):#NTIS/PS-77/0386/1GA. 1977]

NWMAR116849

C-2130-77
OIL SHALE MINING, PROCESSING, USES, AND ENVIRONMENTAL IMPACTS. VOLUME 2. 1976-APRIL 1977 (CITATIONS FROM THE ENGINEERING INDEX DATA BASE)
Hundemann, A. S. 1977.
Report for 1976-1977. 138 p.

Bibliographies, Oil shale, Development, Extraction, Environmental effects

Research projects on the mining, extraction, environmental impacts, and other topics related to oil shale development are covered. The report contains 131 citations with abstracts, 112 of which are new entries to the previous edition.

[from Government Reports Announcements 77(14):#NTIS/PS-77/0387/9GA. 1977]

C-2131-77
OIL SHALE MINING, PROCESSING, USES,AND ENVIRONMENTAL IMPACTS. VOLUME 1. 1964-1975. (CITATIONS FROM THE NTIS DATA BASE)
Hundemann, A. S. 1977.
Report for 1964-1975. 200 p.

Bibliographies, Oil shale, Development, Extraction, Environmental effects, Pollution control

Government-funded studies on oil shale are covered, including topics on environmental impacts and air and water pollution control. The report contains 195 citations with abstracts.

[from Government Reports Announcements 77(14):#NTIS/PS-77/0384/6GA. 1977]

C-2132-77
OIL SHALE MINING, PROCESSING, USES, AND ENVIRONMENTAL IMPACTS. VOLUME 2. 1976-APRIL 1977 (CITATIONS FROM THE NTIS DATA BASE)
Hundemann, A. S. 1977.
Report for 1976-April 1977. 153 p.

Bibliographies, Oil shale, Development, Extraction, Environmental effects, Pollution control

Government-funded research projects on oil shale are covered, including reports on environmental impacts and air and water pollution control. The report contains 148 citations with abstracts 120 of which are new entries to the previous edition.

[from Government Reports Announcements 77(14):#NTIS/PS-77/0385/3GA. 1977]

NWMAR116850

C-2133-77
MARINE AND ESTUARINE POLLUTION
Reish, D. J., T. J. Kauwling, A. J. Mearns, P. S. Oshida, and S. S. Rossi. 1977.
Journal Water Pollution Control Federation 49(6):1316-1340.

Bibliographies, Estuaries, Marine organisms, Environmental effects

This bibliographic review covers residues, sludge, dumping and dredging, diseases and abnormalities, complex effluents and environments, oil pollution, microorganisms, and physical and chemical aspects of marine pollution. There are 312 references in all, with 104 on oil pollution.

C-2134-77
INTERNATIONAL AND MARINE POLLUTION
Smith, J. O. and J. L. Jackson. 1977.
Journal Water Pollution Control Federation 49(6):1547-1553.

Bibliographies, Legislation, U.S., Pollution control

The authors review federal and state water pollution control and litigation, as well as sources of water pollution. Eighty references are given, thirty-one of which are court cases, and fourteen referring to oil pollution.

C-2135-77
OIL POLLUTION DETECTION AND SENSING (A BIBLIOGRAPHY WITH ABSTRACTS)
Smith, M. F.. 1976.
NTIS, Report for 1964-July 1976. 239 p.

Bibliographies, Detection, Sampling, Monitoring, Chemical analysis, Remote sensing

This updated bibliography contains 58 new entries to the previous edition, with a total of 234 abstracts. Most of the report deals with oil spills, although research on oil detection in industrial wastes and sewage is also cited. Analytical techniques include chromatography, infrared spectroscopy, light scattering, fluorescence, mass spectroscopy, and remote sensing. Oil and hydrocarbon sampling, monitoring, and instrumentation are covered.

[from ERDA ENergy Research Abstracts 2(14):#33937. 1977]

C-2136-77
SELECTED REGIONAL BIBLIOGRAPHY ON MARINE POLLUTION [IOC/FAO/UNEP INTERNATIONAL WORKSHOP ON MARINE POLLUTION IN THE CARIBBEAN AND ADJACENT REGIONS, TRINIDAD, 1976]
Thomas, S. J., and D. S. Moulder. 1976.
Paris, Intergovernmental Oceanographic Commission. 1976. 59 p.
IOC-FAO-UNEP-IWMPCAR--17.

NWMAR116851

Bibliographies, Contamination, Caribbean Sea, Marine organisms

The bibliography contains 498 references on pollution in marine and brackish waters of the Caribbean and adjacent regions. References are arranged in 13 sections, mainly by pollutant.

[from Aquatic Sciences & Fisheries Abstracts 7(6):#7Q7429. 1977]

NWMAR116852

SECTION II: CURRENT RESEARCH PROJECTS

Title, contract information and a summary of project objectives are provided in each entry. Project notices have been obtained from the Smithsonian Science Information Exchange (SSIE). Current status information and publications resulting from the projects are presented when such information is available from the principal investigators or performing organizations. The source of status information is given at the end of each entry.

Entries are grouped according to subject and then ordered by serial number within each subject division. The serial number designates the original issue of OIL SPILL AND OIL POLLUTION REPORTS in which the research project is listed:

R-001-74 to R-165-74	EPA-670/2-75-003 July 74 to October 74
R-269-74 to R-342-74	EPA-600/2-76-129 May 75 to July 75
R-269-75 to R-304-75	EPA-600/2-76-113 August 75 to October 75
R-124-76 to R-175-76	EPA-600/2-77-037 August 76 to October 76
R-001-77 to R-022-77	EPA-600/2-77-075 November 76 to January 77
R-076-77 to R-096-77	August 77 to October 77

NWMAR116853

A. OIL POLLUTION DETECTION AND EVALUATION

1. MONITORING

R-002-77 (renewal)
SOUTHERN CALIFORNIA BORDERLAND - ENVIRONMENTAL

Principal Investigator:	Greene, H.G.
Performing Organization:	U.S. Department of the Interior, Geological Survey, 345 Middlefield Rd. Menlo Park, CA 94025
Supporting Agency:	U.S. Department of the Interior, Geological Survey, Geologic Division, No. 9460-01650
Period:	10/76 to 9/77
Funds:	$142,000

A study is being conducted to identify, map, and report the geologic hazards and problems that exist in the southern California borderland, specifically in areas where future development may take place. Geological hazards consist of faults, submarine landslides and slumps, hydrocarbon seeps, salt water intrusion sites, contaminant pathways, and areas of anomalous high erosion and sedimentation. Areas to be looked at include the central part of Santa Rosa-Cortes Ridge, San Diego shelf, western Santa Barbara Channel, and miscellaneous OCS areas that lie in water depths shallower than 750 m.

[SSIE No. ZUA-3979-1]

R-076-77
ENVIRONMENTAL SUPPORT TECHNOLOGY - TRACE GASES IN THE MARINE ENVIRONMENT

Principal Investigators:	Swinnerton, J.W., and W.D. Smith
Performing Organizations:	U.S. Navy, Research Laboratory, Washington, D.C. 20375
Supporting Agency:	U.S. Department of Defense, Navy, No. DN620141
Period:	10/76 to 9/77

The objectives of this project are "to develop and utilize shipboard and in situ methods for measuring the concentrations of gases and hydrocarbons in ocean and atmosphere in order to better assess pollution in the marine environment, to minimize underwater corrosion and to determine the relationships of dissolved gases to marine biota."

[SSIE No. ZQN-620141-3]

NWMAR116854

2. SAMPLING

R-077-77
NEW APPROACHES TO THE PRESERVATION OF CONTAMINANTS IN WATER SAMPLES

Principal Investigator:	Saxena, J.
Performing Organization:	Syracuse University Res. Corp., Merrill Lane, University Heights, Syracuse, NY 13210
Supporting Agency:	U.S. Environmental Protection Agency, Office of Research and Development, No. R80460901
Period:	9/76 to 8/77
Funds:	$32,410

This project will test new methods of water sample preservation. Nitrogen and phosphorus series, oil, grease, and organic carbon are the sample parameters that will be stabilized. Four phases of study will encompass the following: 1) evaluation of the effectiveness of the proposed preservation methods in controlling microorganisms; 2) study of the stability of the contaminants in natural waters; 3) study of the effects of storage and transportation parameters on the preservation methods; and 4) simplification of the methods for field application, cost benefit analysis, and comparisons with currently used methods.

[SSIE No. GMA-3256]

3. ANALYSIS

R-022-77 (renewal)
COASTAL SEDIMENTOLOGY

Principal Investigator:	Clifton, H.E.
Performing Organization:	U.S. Department of the Interior, Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025
Supporting Agency:	U.S. Department of the Interior, Geological Survey, Geological Division, No. 9460-00984
Period:	10/76 to 9/77
Funds:	$292,000

Included in the project are facies analysis of estuarine deposits; a study of sand transport in the estuarine system of Willapa Bay, Washington; studies of the hydrodynamic effects of waves on sedimentation and the mechanics of beach sedimentation;

NWMAR116855

research on the distribution of spilled oil in nearshore systems and the physical and chemical changes in oil attendant with beach and nearshore processes; and studies of nearshore sedimentation of the coast of Alaska and the effect of storm surges. The results of coastal reconnaisance of the Bering Sea from the previous year will be analyzed and compiled for publication.

[SSIE No. ZUA-2471-4]

R-078-77
CHEMISTRY OF AQUATIC ORGANIC MATTER
Principal Investigator: Goerlitz, D.F.
Performing Organization: U.S. Department of the Interior, Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025
Supporting Agency: U.S. Department of the Interior, Geological Survey, Water Resources Division, No. WR 00-149
Period: 7/75 to 9/76
Funds: $75,037

This investigation will involve: identification of organic substances brought about by introduction of selected pollutants into the environment; laboratory determination of the equilibrium and kinetics of reactions within the aquatic system and those that occur at the water-mineral interface; and application of the above relationships to the field behavior of the organics.

[SSIE No. ZUA-4131]

R-079-77
NAVY ENVIRONMENT: CHARACTERISTICS AND STABILITY OF COLLOIDAL MATERIAL ACCOMMODATING HYDROCARBONS IN THE OPEN OCEAN
Principal Investigator: Zsolnay, A.
Performing Organization: Bermuda Biological Station for Research, St. Georges, St. Georges West, Bermuda
Supporting Agency: U.S. Department of Defense, Navy, No. DN675124, Contract N00014-76-C-0029
Period: 10/76 to 9/77
Funds: $39,948

This project will study the contributions of organic compounds to the characterization of chemical and biological properties of seawater, their role as an energy source for the benthic community, and their effect on sediment physicochemical properties. The mechanism of transport of this material is emphasized. Seawater samples will be collected from the Sargasso Sea for fractionation of colloids and subsequent removal and chemical analysis of sorbed hydrocarbons.

[SSIE No. GQN-675124]

NWMAR116856

4. SOURCE IDENTIFICATION

R-124-76 (renewal)
LIGHT HYDROCARBONS - OCS

Principal Investigator:	Cline, J.D.
Performing Organization:	U.S. Department of Commerce, Environmental Research Laboratories, Boulder, CO 80302
Supporting Agency:	U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Research Laboratories, No. R7120841
Period:	10/76 to 9/77
Funds:	$65,000

The current objective is to determine the nature of sedimentary hydrocarbon sources in the Tarr Bank - Kayak Island region of the northeast Gulf of Alaska. Seep locations on the Kodiak Shelf are also being identified. All previous survey work on the distribution of low molecular weight hydrocarbons on the Alaskan OCS has been completed and is being compiled for reports.

[SSIE No. GUK-65-2]

NWMAR116857

B. OIL POLLUTION PREVENTION AND CONTROL

1. CONTAINMENT

R-080-77
STRENGTH AND SEAKEEPING ABILITY OF POLLUTION CONTROL BARRIERS
Principal Investigator: Unknown
Performing Organization: Marine Professional Services, Cambridge, MA 02138
Supporting Agency: U.S. Department of Transportation, Office of the Secretary, No. CG59182, Contract CG-61, 803-A
Period: 2/76 to 5/76

"The objective is to determine all the commercially available barriers suitable as candidates for controlling oil in high seas applications including a sea state three or greater."

[SSIE No. GZO-256]

2. OIL TRANSFER AND TRANSPORT

R-081-77
MODIFICATIONS TO FUEL AND BALLAST SYSTEM, R/V ROBERT D. CONRAD
Principal Investigator: Talwani, M.
Performing Organization: Columbia University, Lamont Doherty Geolog. Observ., Palisades, NY 10964
Supporting Agency: U.S. National Science Foundation, Division of Ocean Sciences, No. OCE76-20520
Period: 1/77 to 12/77
Funds: $129,800

Funds will be used to support modifications on this research vessel to end the overboard discharging of oily ballast water during refueling operations.

[SSIE No. CM-285]

NWMAR116858

3. WASTE TREATMENT AND DISPOSAL METHODS

R-082-77
POWDERED CARBON - ACTIVATED SLUDGE - FILTRATION PROCESSES FOR PETROLEUM REFINERY WASTEWATER

Principal Investigator:	Knecht, A.T.
Performing Organization:	Atlantic Richfield Company, 400 E. Sibley Blvd., Harvey, IL 60426
Supporting Agency:	U.S. Environmental Protection Agency, Office of Research and Development, No. R804731 01
Period:	1/77 to 12/77
Funds:	$200,000

The objective of this project is "to determine if direct addition of powdered activated carbon (PAC) to activated sludge units and changes in operating procedures will significantly improve effluent quality and approach Best Available Technology." The role of adsorbents in enhancing biological treatment will be studied, as well as the ultimate fate of sludges disposed by land application.

[SSIE No. GMA-3469]

R-083-77
SORPTION OF RESIDUAL ORGANIC SUBSTANCES IN RETORT WATERS BY SPENT OIL SHALE RESIDUES

Principal Investigator:	Leenheer, J.A.
Performing Organization:	U.S. Department of the Interior, Geological Survey, Denver, CO 80225
Supporting Agency:	U.S. Department of the Interior, Geological Survey, Water Resources Division, No. CR 00-181
Period:	7/75 to 9/76
Funds:	$79,498

The disposal of waste retort water from oil-shale processes onto spent oil-shale residues may result in leaching of organic solutes into ground water or run off into surface water. At present there are no recommendations concerning the disposal capacity of spent oil shale organic substances in retort waters. "A preliminary objective [of this report] will be to develop an organic water quality analytical program such that background concentrations of dissolved and sediment organic materials can be determined and characterized for surface and ground water in regions of oil-shale and coal development. The overall objective is to determine the capacity of spent oil-shale residues to adsorb and immobilize residual organic substances in retort waters."

[SSIE No. BI-76-1]

NWMAR116859

R-084-77

CHEMICAL DEMULSIFIERS SUITABLE FOR LARGE SCALE USE IN SHORE-BASED OILY WASTE TREATMENT PLANTS

Principal Investigator: Little, R.C.
Performing Organization: U.S. Navy, Research Laboratory, Washington, D.C. 20375
Supporting Agency: U.S. Department of Defense, Navy, No. DN580173
Period: 10/76 to 9/77

Non-specific chemical agents for breaking emulsions in Navy bilge waste collection and treatment systems and in the new oily waste treatment plant facilities are being developed and evaluated. These agents will be tested and used under practical working conditions.

[SSIE No. ZQN-580173]

Status: The project has been completed.

Reports and Publications

BREAKING EMULSIONS IN NAVY BILGE COLLECTION AND TREATMENT SYSTEMS
Little, R.C., and R.L. Patterson. 1976.
NRL Memorandum Report 3424.

BREAKING EMULSIONS IN NAVY BILGE COLLECTION AND TREATMENT SYSTEMS
Little, R.C., and R.L. Patterson. 1977.
Submitted to Environmental Science and Technology.

EMULSIFIER AND SURFACE EFFECTS OBSERVED IN LABORATORY FILTER COASLESCER STUDIES OF OIL-WATER SEPARATION
Zakin, J., and R.C. Little. 1977.
Submitted to Environmental Science and Technology.

Information Source: R.C. Little, Surface Chemistry Branch, Naval Research Laboratory, Washington, D.C. 20375

NWMAR116860

4. PREVENTION AND CONTROL MEASURES

R-085-77
NAVY ENVIRONMENT: INFORMATION SYSTEM FOR MANAGEMENT OF ENVIRONMENTAL PROTECTION RESEARCH PROGRAM

Principal Investigator:	Hnat, K.
Performing Organization:	Telcom Incorporated, 2300 S. 9th St., Arlington, VA 22204
Supporting Agency:	U.S. Department of Defense, Navy, No. DN575373, Contract N00014-75-C-0988
Period:	10/76 to 9/77
Funds:	$24,912

This project will develop the information system mentioned in the title with special emphasis on pollution control guidelines. Investigations will be made of current ship pollution control programs and will identify revisions to regulatory and funding requirements.

[SSIE No. GQN-575373-1]

NWMAR116861

C. EFFECTS OF OIL POLLUTION

1. BIOLOGICAL EFFECTS

R-101-74 (renewal)
MARINE PETROLEUM POLLUTION - BIOLOGICAL EFFECTS AND CHEMICAL CHARACTERIZATION
Principal Investigators: Parker, P.L., J.A. Nicol, and C. VanBaalen
Performing Organization: University of Texas, Marine Science Institution, Port Aransas, TX 78373
Supporting Agency: U.S. National Science Foundation, Division of Ocean Sciences, No. OCE76-83913
Period: 2/77 to 7/78
Funds: $71,900

"The overall goal of this final year is to evaluate the significance of demonstrated toxicity by chemically characterized compounds. This will provide, as a guideline for environmental management, the levels of petroleum types which might be safe in the ocean for a variety of marine plants and animals."

[SSIE No. GSN-1146-4]

R-109-74 (renewal)
FATE, SPATIAL AND TEMPORAL DISTRIBUTION OF PETROLEUM DERIVED ORGANIC COMPOUNDS IN THE OCEAN AND THEIR SUBLETHAL EFFECTS ON MARINE ORGANISMS
Principal Investigator: Sackett, W.M.
Performing Organization: Texas A & M University System, School of Geosciences, College Station, TX 77843
Supporting Agency: U.S. National Science Foundation, Division of Ocean Sciences, No. OCE76-81493
Period: 2/77 to 7/78
Funds: $28,200

Environmental concentrations of C5 to C12 hydrocarbons in the Gulf of Mexico will be established, and the levels of these hydrocarbons necessary to inhibit primary producers in laboratory experiments will be confirmed. Prior research in this project has shown that C5-C12 straight chain hydrocarbons are more toxic to phytoplankton than aromatics such as benzene and toluene, a result contrary to previous beliefs.

[SSIE No. GSN-1145-4]

NWMAR116862

Reports and Publications

THE FLUX OF LIGHT HYDROCARBONS INTO THE GULF OF MEXICO VIA RUNOFF
Brooks, J.M. 1977.
Marine Pollutant Transfer. H.L. Windom, and R.A. Duce (eds.). Lexington, MA, Lexington Books, D.C. Heath and Company, 1977. p. 185-200.

Light gaseous hydrocarbons (methane through pentanes) are sensitive indicators of petroleum pollution. Natural processes cannot account for the occurrence of light hydrocarbons in the Gulf of Mexico, and thus they must enter chiefly from man-derived sources, river runoff, and/or across the sea/air or sea/sediment interface. In particular, light hydrocarbons in the Mississippi River originate predominantly from petroleum and petrochemical activities. Significant impacts on coastal waters are evidenced by hydrocarbon anomalies seen from 16-32 km (10-20 mi) off port and up to 80 km (50 mi) off the Mississippi River.

GULF UNDERWATER FLARE EXPERIMENT (GUFEX): EFFECTS OF HYDROCARBONS ON PHYTOPLANKTON
Brooks, J.M., G.A. Fryxell, D.F. Reid, and W.M. Sackett.
Marine Biological Effects of Petroleum Hydrocarbons.
C.S. Giam (ed.). D.C. Heath and Co. In press.

"Carbon-14 uptake, plant pigments, ATP and POC concentrations, the ratio of full to empty cells and species of phytoplankters and standard hydrographic parameters were determined as a function of hydrocarbon concentrations in the vicinity of underwater 'flaring', the venting of non-commercial quantities of natural gases separated from liquid petroleum on offshore petroleum production platforms. Although there were significant covariances between hydrocarbon concentrations and several biomass parameters, the variability was apparently due to up-welling, induced by the rapidly rising jet of gaseous hydrocarbons."

SIGNIFICANCE OF LOW-MOLECULAR-WEIGHT HYDROCARBONS IN MARINE WATERS
Brooks, J.M., and W.M. Sackett. 1977.
Proceedings of the 7th International Meeting on Organic Geochemistry, 1975. R. Campos and J. Gon (eds.).
Madrid, Revista Espanola de Micropaleon., 1977. p. 455-468.

Thousands of determinations of dissolved hydrocarbons in surface water for 5000 miles of cruise tracks in the Gulf of Mexico have been made using a shipboard "sniffer" system. Surface water analyses show up to 6 orders of magnitude higher levels of C_1 to C_5 saturated hydrocarbons than open ocean surface water. In almost all cases these high concentrations are attributable

NWMAR116863

to petroleum production operations as many as 10 miles distant, suggesting that saturated low-molecular-weight hydrocarbons are very sensitive indicators of man-derived petroleum pollution.

Information Source: W.M. Sackett, Texas A & M University, College of Geosciences, College Station, TX 77843

R-086-77

LONG-TERM EFFECTS OF HYDROCARBONS ON SELECTED ECOSYSTEMS AND ASSOCIATED ORGANISMS

Principal Investigators:	Anderson, J.W., and R.M. Bean
Performing Organization:	Battelle Memorial Institute, P.O. Box 999, Richland, WA 99352
Supporting Agency:	U.S. Environmental Protection Agency, Office of Research and Development, Contract EPA-IAG-D6-E681-CF
Period:	7/75 to 6/76
Funds:	$313,000

The main objective of this project is to determine the effects of long-term, low-level petroleum hydrocarbon (PHC) contaminated water on the growth and reproduction of two sensitive crustaceans (amphipods and mysids) exposed for more than one generation. Research will cover exchange of specific PHCs between oil, sediment, water, and organisms from laboratory and field experiments; availability of sediment-sorbed PHCs to deposit-feeding organisms; and alteration of PHCs in and on oiled sediments and the effect of this alteration on recruitment of benthic organisms.

[SSIE No. GMA-2990]

Status: This is a large program involving both biology and analytical chemistry. It is funded through 1978.

Reports and Publications

RESPONSES TO SUBLETHAL LEVELS OF PETROLEUM HYDROCARBONS: ARE THEY SENSITIVE INDICATORS AND DO THEY CORRELATE WITH TISSUE CONTAMINATION?
Anderson, J.W. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D.A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 95-114. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

EFFECTS OF PETROLEUM HYDROCARBONS ON THE RATE OF HEART BEAT AND HATCHING SUCCESS OF ESTUARINE FISH EMBRYOS
Anderson, J.W., D.B. Dixit, G.S. Ward, and R.S. Foster, 1977.
A. Calabrese and F.P. Thurberg (eds.). New York, Academic Press, 1977. p. 241-258.

NWMAR116864

BIOAVAILABILITY OF SEDIMENT-SORBED NAPHTHALENES TO THE SIPUNCULID WORM, PHASCOLOSOMA AGASSIZII
Anderson, J.W., L.J. Moore, J.W. Blaylock, D.L. Woodruff, and S.L. Kiesser. 1977.
Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. D.A. Wolfe (ed.). New York, Pergamon Press, 1977. p. 276-285. Proceedings of a Symposium, Seattle, Washington, November 10-12, 1976.

RECRUITMENT OF BENTHIC ANIMALS AS A FUNCTION OF PETROLEUM HYDROCARBON CONCENTRATIONS IN THE SEDIMENT
Anderson, J.W., R.G. Riley, and R.M. Bean. 1978.
International Symposium on "Recovery of Oiled Northern Marine Environments", Nova Scotia, October, 1977. In press.

LABORATORY AND FIELD STUDIES ON THE EFFECTS OF PETROLEUM HYDROCARBONS ON BENTHIC MARINE INVERTEBRATES
Anderson, J.W., R.G. Riley, R.M. Bean, J.W. Blaylock, and S.L. Kiesser. 1977.
Proceedings of EPA Workshop on the Interagency Marine Research Program Associated with Energy Development, Newport, Rhode Island, March 1-3, 1977. In press.

OIL BIOASSAYS WITH THE AMERICAN OYSTER, CRASSOSTREA VIRGINICA (GMELIN)
Anderson, R.D., and J.W. Anderson. 1976.
Proceedings of the National Shellfisheries Association 65:38-42.

DISTRIBUTION OF NAPHTHALENES WITHIN EXPOSED FUNDULUS SIMILUS AND CORRELATIONS WITH STRESS BEHAVIOR
Dixit, D., and J.W. Anderson. 1977.
1977 Oil Spill Conference (Prevention, Behavior, Control, Cleanup). Washington, D.C., American Petroleum Institute, 1977. p. 633-636. Held in New Orleans, March 8-10, 1977.

EFFECTS OF WATER-SOLUBLE FRACTIONS OF NO. 2 FUEL OIL ON THE DEVELOPMENT OF THE FISH FUNDULUS SIMILUS
Ernst, V., J.M. Neff, and J.W. Anderson. 1977.
Environmental Pollution. In press.

FATE AND EFFECT OF NAPHTHALENES: CONTROLLED ECOSYSTEM POLLUTION EXPERIMENT
Lee, R.F., and J.W. Anderson. 1977.
Bulletin of Marine Science 27:127-134.

EFFECTS OF PETROLEUM ON SURVIVAL, RESPIRATION AND GROWTH OF MARINE ANIMALS
Neff, J.M., J.W. Anderson, B.A. Cox, R.B. Laughlin, Jr., S.S. Rossi, and H.E. Tatem. 1976.
Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment. Arlington, Virginia, American Institute of Biological Sciences, 1976. p. 515-539. Proceedings of the Symposium, Washington, D.C., 9-11 August, 1976.

NWMAR116865

ACCUMULATION AND RELEASE OF PETROLEUM-DERIVED AROMATIC HYDROCARBONS BY FOUR SPECIES OF MARINE ANIMALS
Neff, J.M., B.A. Cox, D. Dixit, and J.W. Anderson. 1976.
Marine Biology 38:279-289.

ACCUMULATION AND RELEASE OF FUEL OIL DERIVED DIAROMATIC HYDROCARBONS BY THE POLYCHAETE, NEANTHES ARENACEODENTATA (MOORE)
Rossi, S.S., and J.W. Anderson. 1977.
Marine Biology 39:51-55

TEMPERATURE, SALINITY AND OIL EFFECTS ON THE INGESTION, EGESTION AND GROWTH OF NEANTHES ARENACEODENTATA (MOORE)
Young, L., and J.W. Anderson. 1976.
American Zoology 16:238. Abstract.

Information Source: J.W. Anderson, Senior Research Scientist, Battelle Pacific Northwest Division, Marine Research Laboratory, Route 5, Box 100, Sequim, WA 93832

R-087-77
ACUTE FISH BIOASSAY

Principal Investigator:	Slonim, A.R.
Performing Organization:	U.S. Air Force, Aerospace Medical Research Laboratory, Wright Patterson A.F.B. Dayton, OH 45433
Supporting Agency:	U.S. Department of Defense, Air Force, No. DF320510
Period:	10/76 to 9/77

This project will determine the water pollution potential of aircraft fuels and lubricants, missile propellants and their exhaust products, and other Air Force materials that could result in significant environmental damage. The acute toxicity of hydrazine, UDMH, aerozine-50, and MMH will be determined using propellant bioassays with the fathead minnow and other fish species. The efficacy of various chemicals will be evaluated relative to reversing or reducing the toxicity to fish life. Results will provide a data base upon which environmental impact statements and assessments can be made as they apply to weapon systems using these chemicals.

[SSIE No. ZQF-320510]

NWMAR116866

R-088-77
ECOLOGICAL, PHYSIOLOGICAL, AND TOXICOLOGICAL EFFECTS OF OIL ON BIRDS
Principal Investigator: Stickel, L.F.
Performing Organization: U.S. Department of the Interior, Fish and Wildlife Service, Laurel, MD 20811
Supporting Agency: U.S. Department of the Interior, Fish and Wildlife Service, Division of Population Reg. Res.; No. 85-830-9285-000
Period: 10/76 to 9/77
Funds: $440,000

The effect of sublethal exposure of birds to oil will be studied by correlating experimental and ecological studies that relate toxicological/physiological effects and kinetics of oil in birds to exposure in the environment. Recommendations will be made for guidelines to levels of oil in the environment that are dangerous to the welfare of wild bird populations.

[SSIE No. ZUV-82]

2. GENERAL EFFECTS

R-089-77
STUDY OF OIL SPILLED FROM THE SUPERTANKER METULA
Principal Investigator: Hann, R.W., Jr.
Performing Organization: Texas A & M University System, Graduate School, College Station, TX 77843
Supporting Agency: U.S. Department of Transportation, Office of the Secretary, No. CG59181, Contract CG-62, 281-A
Period: 12/75 to 12/76

The objectives of this project are threefold: 1) to determine and photograph periodically the remaining oil on the shores of the Strait of Magellan; 2) to collect and ship oil samples to the U.S. Coast Guard Research and Development Center for oil fingerprinting; 3) to visually observe the recurring damage and/or resulting recovery in the affected intertidal zone and estuaries.

[SSIE No. GZO-255]

NWMAR116867

Status: The project is continuing with another site visit to Chile in the winter, 1977-78. In conjunction with this project, the investigators are developing an Oil Spill Technical Assistance Program and preparing a second generation of courses in oil spill cleanup. These courses will expand upon those offered at the Texas A & M Oil Spill Control School in Galveston.

Reports and Publications

OIL POLLUTION FROM THE TANKER "METULA"
Hann, R.W., Jr. 1974.
Texas A & M University Report. 61 p.

The VLCC "Metula" ran aground in the Straits of Magellan in August, 1974, and lost 51,500 tons of oil. The effects of this spill on the shore and the organisms, and the feasibility of cleanup/containment operations are discussed. This spill taught those involved that spills can happen even with superships, that present cleanup methods are for small spills, and that keeping superports offshore helps provide reaction time.

FOLLOW-UP FIELD SURVEY OF THE OIL POLLUTION FROM THE TANKER 'METULA'
Hann, R.W. 1975.
Final report, USCG-D-166-75, Contract DOT-CG-42444-A.
59 p. AD-A017 100/9GA

Most of the 20,000 tons of oil which came ashore is still present; the spill will be a longterm source of water pollution as it leaches and erodes into the water. The intertidal marine life was substantially affected. Marine waterfowl are still suffering from unstabilized oil or mousse at the top of the beach zone and from eating contaminated mussels.

Information Source: H.N. Young, Jr., Texas A & M University, Civil Engineering Department, College Station, TX 77843

R-090-77
DAMAGE ASSESSMENT FOLLOWING ALEXANDRIA BAY OIL SPILL

Principal Investigators:	Tyson, W.E., D. Palm, M. Alexander, D. Behrend, J. Geis, T. Lillesand, and R. Marler
Performing Organization:	St. Lawrence E. Ontario Commission, 317 Washington St., Watertown, NY 13601
Supporting Agency:	U.S. Environmental Protection Agency, Office of Research and Development, No. R805031 01
Period:	11/76 to 10/77
Funds:	$59,745

NWMAR116868

This project is concerned with the environmental and economic impacts of the June 23, 1976 oil spill on the St. Lawrence River. Evaluations will cover the adequacy of the spill clean-up, biological effects on small mammals, water fowl, aquatic and wetland resources, and determination of the levels of petroleum hydrocarbons within the affected ecosystems to assess the extent of contamination and bioaccumulation. Results will provide data for development of policies and procedures dealing with oil transport and spillage in similar areas.

[SSIE No. GMA-3463]

Status: The first year of the two-year study was completed September 23, 1977. An interim report entitled, "Fall 1976 Survey of Residual Contaminants," was issued in January, 1977. No other reports are expected until the end of the granting period, September, 1978.

Reports and Publications

DAMAGE ASSESSMENT STUDIES FOLLOWING ALEXANDRIA BAY OIL SPILL: FALL 1976 FIELD SURVEY OF RESIDUAL CONTAMINANTS
St. Lawrence-Eastern Ontario Commission. 1977.
Interim report, EPA Grant No. R80531010. 22 p.

On June 23, 1976, an estimated 1,166,000 L (308,000 gal) of No. 6 bunker oil were released from a barge after several tanks ruptured as it struck Comfort Shoal upstream of Alexandria Bay. Efforts were undertaken to develop a plan of study to determine the economic and environmental impacts of oil in a riverine environment. The main objective of this study was to determine the effects of time and the elements on residual hydrocarbons. Results are summarized of the fall 1976 field survey.

Information Source: D.J. Palm, Project Manager, St. Lawrence-Eastern Ontario Commission, 317 Washington St., Watertown, NY 13601

NWMAR116869

D. EFFECTS OF OIL EXPLORATION AND PRODUCTION

1. GENERAL EFFECTS

R-333-74 (renewal)
COASTAL WETLANDS MANAGEMENT
Principal Investigator: McIntyre, W.G.
Performing Organization: Louisiana State University, School of Arts and Sciences, University Station, Baton Rouge, LA 70803
Supporting Agency: Ford Foundation
Period: 7/75 to 9/76

Pollution arising from offshore marine transportation, oil and gas development, and the movement of populations to coastal areas endangers coastal wetlands, which constitute one of the most important support systems for the world's fishery resources. A study of coastal wetlands management will be conducted comparing control policies and programs of the Rhone River in France, the Rhine in the Netherlands, the Mississippi in the U.S., and the Thames in England.

[SSIE No. QY-2559-1]

R-091-77
STUDY OF ENVIRONMENTAL BENEFITS OF EFFLUENT STANDARDS FOR THE OFFSHORE OIL AND GAS
Principal Investigators: Shore, R., and J.A. Post
Performing Organization: Energy Resources Company, Inc., 185 Alewife Brook Parkway, Cambridge, MA 02138
Supporting Agency: U.S. Environmental Protection Agency, Office of Research and Development, Contract 68-01-4177
Period: 8/76 to 2/77
Funds: $111,309

The impacts of brine discharge on the marine and estuarine environment will be assessed at 4 sites: a coastal bay in Louisiana; Cook Inlet, Alaska; near offshore Gulf of Mexico; and far offshore Gulf of Mexico. A computerized dispersion model is used to calculate contours of brine concentration levels around the discharge point. Data in the literature of the toxic effects of brine constituents (including oil hydrocarbons) are then used in conjunction with the dispersion model results to estimate impacted areas at the study sites.

[SSIE No. GMA-3399]

NWMAR116870

E. FATE OF OIL IN THE ENVIRONMENT

1. BIODEGRADATION

R-092-77
CONTROLLED ECOSYSTEM POLLUTION EXPERIMENT (CEPEX) - ROLE OF BACTERIA IN POLLUTED MARINE ECOSYSTEM
Principal Investigator: Azam, F.
Performing Organization: University of California, Graduate School, P.O. Box 109, San Diego, CA 92037
Supporting Agency: U.S. National Science Foundation, Division of Ocean Sciences, No. OCE76-22716
Period: 11/76 to 12/77
Funds: $48,100

For this research, natural marine communities contained in large plastic cylinders are subjected to low-level, long-term exposure to heavy metals and petroleum. One of the five studies deals with bacterial breakdown of selected 14C-labeled petroleum hydrocarbons.

[SSIE No. CH-881]

Reports and Publications

EFFECTS OF FOUR OILS ON MARINE BACTERIAL POPULATIONS: CONTROLLED ECOSYSTEM POLLUTION EXPERIMENT
Hodson, R.E., F. Azam, and R.F. Lee. 1977.
Bulletin of Marine Science 27(1):119-126.

The effects of Louisiana and Kuwait crudes, No. 2, and Bunker-C fuel oils were examined on heterotrophic uptake and mineralization of D-glucose by microbial populations from Saanich Inlet, Canada. All oils inhibited uptake and mineralization, with the two processed oils being more toxic than the crude oils. Populations did not acquire tolerance to oil after one month's exposure.

Information Source: F. Azam, University of California, Graduate School, P.O. Box 109, San Diego, CA 92037

R-093-77
DEEP OCEAN ENVIRONMENTAL STUDIES OF MARINE BACTERIA
Principal Investigator: Colwell, R.R.
Performing Organization: University of Maryland, School of Agriculture, College Park, MD 20742
Supporting Agency: U.S. National Science Foundation, Division of Ocean Sciences, No. OCE76-82655
Period: 1/77 to 12/77
Funds: $32,500

NWMAR116871

Second-year research is being conducted to determine the interaction of microorganisms with the deep-ocean environment under in situ conditions. Rates of utilization will be assessed using seawater samples enriched with chitin, cellulose, carbohydrates, urea, and other organic compounds. Biodegradation experiments will use substrates of petroleum, heavy metals, and pesticides. Other studies will cover metabolic activity, genetic experiments concerning geographic distribution, and the ecological significance of plasmids in the deep sea.

[SSIE No. CM-310]

For a list of publications, see Oil Spill and Oil Pollution Reports, May-July 77, p. 271-274.

2. GENERAL FATE OF OIL

R-302-75 (renewal)
ENVIRONMENTAL ORGANIC GEOCHEMISTRY OF OUTER CONTINENTAL SHELVES

Principal Investigator:	Miller, R.E.
Performing Organization:	U.S. Department of the Interior, Geological Survey, 12201 Sunrise Valley Dr., Herndon, VA 22092
Supporting Agency:	U.S. Department of the Interior, Geological Survey, Geologic Division, No. 9450-01543
Period:	10/76 to 9/77
Funds:	$60,000

The principal objectives of this project are to determine quantitatively the low-level baseline concentrations of naturally occurring organic substances in surface shelf and slope sediments, and to distinguish and classify in core sediments those natural organic substances and organo-metallo complexes that are related to specific geological and geochemical processes.

[SSIE No. ZUA-3570-2]

R-094-77
PETROLEUM HYDROCARBONS IN THE SEDIMENTS OF THE BERMUDA PLATFORM

Principal Investigator:	Butler, J.N.
Performing Organization:	Harvard University, School of Arts & Sciences, Cambridge, MA 02138
Supporting Agency:	U.S. National Science Foundation, Division of Ocean Sciences, No. OCE76-19901
Period:	11/76 to 10/77
Funds:	$22,000

NWMAR116872

"This research project will sample sediments on the slope of the Bermuda platform at depths from shallow lagoonal to abyssal, and characterize the hydrocarbons found in these sediments using column chromatography, gas chromatography, and mass spectrometry." It is speculated that one possible fate of petroleum residues in the open ocean is accumulation in the sediments.

[SSIE No. CH-875]

R-095-77
EPA/MASS
Principal Investigator: Galt, J.A.
Performing Organization: U.S. Department of Commerce, Environmental Research Laboratories, Boulder, CO 80302
Supporting Agency: U.S. Environmental Protection Agency, Office of Research and Development, No. B7121231
Period: 10/76 to 9/77
Funds: $80,000

"Develop numerical techniques to model and simulate the marine environment to: 1) aid in the interpretation of observational data, 2) explain dynamic processes controlling the distribution of substances within and on the water, and 3) facilitate the communication and presentation of research results through the development of computer graphics." Modeling and simulation studies are being conducted in support of EPA sponsored pollutant distribution studies.

Status: Initial formulations of oil trajectory models for the Puget Sound region have been constructed.

[SSIE No. GMA-3297]

R-096-77
ENVIRONMENTAL DEGRADATION OF AIR FORCE CHEMICALS IN AIR, WATER AND SOIL
Principal Investigator: Inman, R.C.
Performing Organization: U.S. Air Force, Aerospace Medical Research Laboratory, Wright Patterson A.F.B., Dayton, OH 45433
Supporting Agency: U.S. Department of Defense, Air Force, No. DF320520
Period: 10/76 to 9/77

The degradation of Air Force critical materials introduced into an aquatic or terrestrial environment and the degradation rate kinetics will be studied. Data will be used in compiling environmental impact statements or assessments on weapons systems using these chemicals.

[SSIE No. ZQF-320520]

NWMAR116873

SECTION III: CURRENT CONFERENCES

*Additional information not available at time of publication.

Aug. 20-27 — 9th International Seaweed Symposium and meetings of the International Phycological Society and Phycological Society of America, University of California, Santa Barbara, California, 1977.

Oil Pollution Related Papers

TOXICITY OF CRUDE OILS AND FUEL OILS PRESENTED DIRECTLY TO MICROALGAE
Batterton, J. C., K. Winters, and C. Van Baalen

Fuel oils were much more growth-inhibiting than crude oils for a green alga, a blue-green alga, and a diatom. "Baton Rouge" and "New Jersey" fuel oil samples were toxic but were detoxified by heating. Chemical data suggest that the less water-soluble compounds in the higher boiling aromatic fraction are the cause of toxicity.

SENSITIVITY OF SOME BROWN ALGAL REPRODUCTIVE STAGES TO OIL POLLUTION
Steele, R. L.

The author studied two genera of brown algae, Fucus and Laminaria, to measure oil pollution toxicity in these bioassay organisms. Four kinds of oil were tested and both algae were found to be sensitive at less than 100 ppb. Male reproductive cells were much more sensitive than eggs or female gametophytes.

Proceedings of the Ninth International Seaweed Symposium will be published in 1978 and be available for $25.00 from Science Press, 8 Brookstone Drive, Princeton, NJ 08540

Aug. 28-31 — PACHEC '77, 2nd Pacific Area Chemical Engineering Conference, Denver, Colorado.
Sponsored by the Interamerican Confederation of Chemical Engineers, Asian Pacific Confederation of Chemical Engineering, and American Institute of Chemical Engineers.

The program included environmental and safety aspects of energy, petroleum, and petrochemicals production. Sessions 9, 18, and 27 were entitled Environmental Aspects of Shale Oil Production and Processing; Sessions 38 and 47 dealt with Water Problems Associated with Coal Conversion and Shale Oil Production; and Session 45 was entitled Environmental Aspects of Tar Sands Processing.

Proceedings of the Conference are available for $35.00 from AIChE Publications Department, 345 East 47th St., New York, NY 10007

NWMAR116874

Sept. 12-16 Meeting of the Water Pollution Control Federation of Germany, Essen, Federal Republic of Germany, 1977.

FFI contact Mr. C. H. Plumer, Abwassertechnische Vereinigung, Bertha von Sutter Platz 9, Bonn 53, Federal Republic of Germany

Sept. 13-16 Third Symposium on Environmental Aspects of Fuel Conversion Technology, Hollywood, Florida, 1977.
Sponsored by the U.S. Environmental Protection Agency Industrial Environmental Research Laboratory/RTP.

FFI contact Franklin A. Ayer, Research Triangle Institute, P.O. Box 12194, Research Triangle Park, NC 27709

Sept. 26-28 2nd International Symposium on Aquatic Pollutants, Noordwijkerhout (near Amsterdam), The Netherlands, 1977.
Sponsored by the Commission of European Communities, U.S. Environmental Protection Agency, Netherlands Ministry of Public Health and Environmental Hygiene, and others.

The conference included 30 papers on transport, transformation, and biological effects of aquatic pollutants.

FFI contact George L. Baughman, Environmental Research Laboratory, Environmental Protection Agency, College Station Rd., Athens, GA 30601

Sept. 28-30 2nd International Symposium on Polynuclear Aromatic Hydrocarbons, Battelle Columbus Labs, Columbus, Ohio, 1977.

FFI contact Dr. Peter W. Jones, Battelle Columbus Labs, 505 King Ave., Columbus, OH 43201

Oct. 3-6 1977 Refining Department Autumn Meeting, Atlanta, Georgia, 1977.
Sponsored by the American Petroleum Institute.

FFI contact the Conference Department, API Refining Department, 2101 L St., N.W., Washington, D.C. 20037

Oct. 4-5 ASTM Symposium on Chemical Dispersants for the Control of Oil Spills, Williamsburg, Virginia, 1977.
Sponsored by the American Society for Testing and Materials, Committee F-20 on Spill Control Systems.

NWMAR116875

Oil Pollution Related Papers

Session I

SOME OBSERVATIONS ON THE MECHANISM AND CHEMISTRY ASPECTS OF CHEMICAL DISPERSION
Canevari, G. P.

JOINT US/USSR PROGRAM--DEVELOPMENT OF STANDARD DISPERSANT TESTS
Dorrler, J. S., and L. T. McCarthy, Jr.

TOXICITY TESTING PROCEDURES IN THE UK FOR THE EVALUATION OF OIL SLICK DISPERSANTS
Norton, M. G., F. E. Franklin, and R. A. A. Blackman

A SMALL SCALE LABORATORY DISPERSANT EFFECTIVENESS TEST
Mackay, D., S. Nadeau, and C. Ng

THE ACUTE TOXICITY AND DISPERSING EFFECTIVENESS OF OIL SPILLS DISPERSANTS-RESULTS OF A CANADIAN DISPERSANT TESTING PROGRAM (1973-1977)
Doe, D. G., P. G. Wells, and G. W. Harris

THE FEASIBILITY OF AERIAL APPLICATION OF DISPERSANTS IN THE SOUTHERN BEAUFORT SEA
Ross, C. W.

Session II

DEVELOPMENT OF AN OIL DISPERSANT SPRAYING SYSTEM
Manolio, V. P., Jr., and L. T. McCarthy, Jr.

CHEMICAL CONTROL OF OIL SPILLS AND HAZARDS
Kaufmann, S.

SOME GUIDELINES FOR OIL-SPILL CONTROL IN COASTAL ENVIRONMENTS BASED ON FIELD STUDIES OF THE METULA AND URQUIOLA OIL SPILLS
Hayes, M. O., E. R. Gundlach, A. E. Blount, C. H. Ruby, I. A. Fischer, L. G. Ward, and R. Stein

THE ASSESSMENT PROBLEMS OF WHETHER OR NOT TO TREAT OIL SPILLS
Wilson, M. P., Jr.

OIL SPILL CONTROL CHEMICALS - A CURRENT VIEW
Lindblom, G. P.

Session III

THE PHYSICAL AND CHEMICAL BEHAVIOR OF DISPERSED AND UNDISPERSED OIL SPILLS AT SEA
Johanson, E. E., C. D. McAuliffe, and R. A. Brown

DISPERSANT FIELD TRIALS IN CANADIAN WATER
Gill, S. D.

EVALUATION OF EQUIPMENT FOR AERIAL SPRAYING OF OIL DISPERSANT CHEMICALS
Barker, C. D., G. P. Lindblom, J. C. Jefferies, H. Hawkins, R. J. Fulleylove, J. Nichols, J. H. Arnold, and S. A. Horn

NWMAR116876

EVALUATION OF SELECTED SURFACTANTS FOR THE PROTECTION OF SHORELINES AND SALT MARSHES FROM OIL SPILLS
Foget, C.

EFFECT OF A CHEMICAL DISPERSANT ON MICROBIAL UTILIZATION OF PETROLEUM
Traxler, R. W., and L. S. Bhattacharya

CHEMICAL ANALYSIS OF DISPERSED OIL IN THE WATER COLUMN
Ahmadjian, M., and P. F. Lynch

Session IV

DROP SIZE DISTRIBUTIONS IN A TREATED OIL-WATER SYSTEM
Jasper, W. L., T. J. Kim, and M. P. Wilson

PRACTICAL EXPERIENCE OF DISPERSANT USAGE
Garnett, M. J., and I. C. White

PROMPT USE OF DISPERSANTS CAN CONTROL OFFSHORE OIL SPILLS
Fitzgerald, D. E.

A SYSTEM FOR THE APPLICATION OF DISPERSANTS TO THE PROBLEMS OF OIL SPILL CLEANING
Cormack, D.

EFFECTS OF DISPERSANT USE ON SHORE LIFE
Nelson, A.

Discussion Session

THE USE OF CHEMICALS TO CONTROL SPILLS OF OIL
Laroche, G., J. Kirkland, M. J. Garnett, and E. W. Mertens

FFI contact Conference Chairman, ASTM Symposium on Chemical Dispersants, 1916 Race St., Philadelphia, PA 19103

Oct. 9-12 52nd SPE-AIME Annual Fall Technology Conference and Exhibition, Denver, Colorado, 1977.

Oil Pollution Related Papers

SPE 6835
POLYMER USE IN BLOWOUT CONTROL
Arnwine, L. C., and J. W. Ely

SPE 6903
AN OFFSHORE BLOWOUT AND HOW IT WAS KILLED
Barnett, R. D.

FFI contact Ms. K. Lee, Meetings Secretary, SPE of AIME, 6200 N. Central Expressway, Dallas, TX 75206

NWMAR116877

Oct. 11-14 Long-Term Recovery Potential of Cold-Water Marine Environments after Oil Spills, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, 1977.
Sponsored by the Bedford Institute of Oceanography, Canada Fisheries and Marine Service, Canada Environmental Protection Service, Transport Canada, and The Petroleum Association for the Conservation of the Canadian Environment.

A primary aim of the symposium was to focus on the question of community recovery over time, especially in cold-water environments. Central to the symposium are papers dealing with long-term follow-up studies on four major spills: the 1967 "Torrey Canyon" in the U.K., the 1969 "Florida" in West Falmouth, Mass., the 1970 "Arrow" in Chedabucto Bay, Canada, and the 1974 "Metula" spill in Chile.

Symposium Program

Session 1 - "Long-Term Fate of Petroleum Hydrocarbons after Spills -- Compositional Changes and Microbial Degradation"

BIOTIC AND ABIOTIC CHANGES IN PRUDHOE BAY OIL IN SURFACE AND UNDER-ICE WATERS IN THE ARCTIC
Atlas, R. M.

MICROBIAL ECOLOGY STUDIES OF THE METULA SPILL IN THE STRAITS OF MAGELLAN
Colwell, R. R.

LONG-TERM FATE OF A HEAVY FUEL OIL IN A SPILL-CONTAMINATED B.C. COASTAL BAY
Cretnay, W. J.

GEOCHEMICAL STUDIES OF NO. 2 FUEL OIL SPILLS IN BUZZARDS BAY - 1969 SPILL AND 1974 SPILL
Farrington, J. W.

CHEMICAL AND MICROBIOLOGICAL CHANGES IN THE SAND COLUMN OF A POLLUTED BEACH IN WILHEMSHAVEN
Gassmann, G.

ROLE OF THE BURROWING ANNELID ARENICOLA MARINA IN THE WEATHERING OF OIL IN INTERTIDAL SEDIMENTS
Gordon, D. C., Jr.

ARROW BUNKER C RESIDUES IN SHORE AND BOTTOM SEDIMENTS OF CHEDABUCTO BAY, NOVA SCOTIA
Keizer, P. D., et al

PEABODY CREEK, PORT ANGELES, WASHINGTON - INTERTIDAL SEDIMENT CONTAMINATION AND APPARENT RECOVERY
MacLeod, W. D., et al

BASE-LINE STUDIES OF THE U.K. AND ANTARCTIC COAST
Mackie, P. R.

NWMAR116878

PETROLEUM HYDROCARBONS IN TISSUES AND SEDIMENTS FROM STEADILY WEATHERING OIL SPILLS - SEARSPORT AND CASCO BAY
Mayo, D., and D. Page

RATES OF MECHANICAL DISPERSAL OF OIL STRANDED IN THE LITTORAL ZONE
Owens, E. H.

HYDROCARBON-UTILIZING BACTERIA FROM SHORELINES AND BOTTOM SEDIMENTS OF CHEDABUCTO BAY, NOVA SCOTIA - POTENTIAL FOR SPILL DEGRADATION
Stewart, J.

ANALYSES OF CHANGES IN AROMATICS IN SEVEN YEARS SINCE THE WEST FALMOUTH OIL SPILLS IN WILD HARBOR MARSH SEDIMENTS: 1969-1976
Teal, J.

EARLY DIAGENETIC CHANGES IN PETROLEUM COMPOUNDS BURIED IN SEDIMENTS
Van Vleet, E. S.

Session II - "Physiological Stresses and Response in Chronically Oiled Organisms."

DEMOGRAPHIC CONSEQUENCES OF SHORT - TERM NATURAL SELECTION ON TWO ALLOZYMIC LOCI IN THE OYSTER DRILL UROSALPINX CINEREA FROM W. FALMOUTH
Cole, T. J.

ALTERATIONS IN PHYSIOLOGY, GROWTH, AND POPULATION STRUCTURE IN THE SOFT-SHELL CLAM MYA ARENARIA FROM CHRONICALLY OILED SEDIMENTS: ARROW 1970-1976
Gilfillan, E.

UPTAKE AND DEPURATION OF AROMATIC PETROLEUM HYDROCARBONS IN SEVERAL SPECIES AFTER A 2,000-TON IRANIAN CRUDE SPILL ON THE WEST COAST OF NORWAY
Grahl-Nielsen, O.

EFFECTS OF SEAWATER EXTRACTS OF EKOFISK OIL ON THE HATCHING SUCCESS OF BARENTS SEA CAPELIN
Johannessen, K. I.

LONG-TERM EFFECTS OF THE WEST FALMOUTH SPILL ON CRAB POPULATIONS: 1969-1976
Krebs, C. T.

EFFECTS OF LOW CONCENTRATIONS OF WATER SOLUBLE FRACTION OF NO. 2 FUEL OIL ON EGGS AND LARVAE OF WINTER FLOUNDER AFTER EXPOSURE OF THE ADULTS DURING MATURATION
Kuhnhold, W. W.

EFFECTS OF LONG-TERM EXPOSURE OF FLATFISH TO SEDIMENT CONTAMINATED WITH ALASKAN CRUDE OIL
McCain, B. B.

NWMAR116879

GROWTH AND HISTOPATHOLOGICAL CHANGES IN A MARINE FISH AFTER SIX MONTHS EXPOSURE TO PETROLEUM
Payne, J. F.

EFFECTS OF CHRONIC EXPOSURE TO PETROLEUM UPON THE GROWTH OF MARINE ORGANISMS
Percy, J.

BIO-AVAILABILITY OF HYDROCARBONS IN MARINE SEDIMENTS
Roesijadi, G.

THE EFFECTS OF UPTAKE AND DISCHARGE OF PETROLEUM HYDROCARBONS ON THE RESPIRATION OF THE SOFT-SHELL CLAM MYA ARENARIA
Stainken, D.

CYTOCHROME P-450 AND HYDROCARBON METABOLISM IN FISH FROM THE WILD HARBOR MARSH, WEST FALMOUTH
Stegeman, J. J.

TISSUE ARYL HYDROCARBON HYDROXYLASES IN CHRONICALLY OILED SEDIMENTS FROM CHEDABUCTO BAY, NOVA SCOTIA: ARROW 1970-1976
Vandermeulen, J. H.

Session III - "Long-Term Effects of Oil Spills on Marine Intertidal Communities."

RECRUITMENT OF BENTHIC ANIMALS AS A FUNCTION OF PETROLEUM HYDROCARBON CONCENTRATION IN THE SEDIMENT
Anderson, J. W.

LONG-TERM EFFECTS OF OIL POLLUTION ON SOME BRITISH INTERTIDAL COMMUNITIES
Baker, J. M.

OBSERVATIONS OF A COLD-WATER INTERTIDAL COMMUNITY FIVE YEARS AFTER THE GENERAL M.C. MEIGS SPILL
Clark, R. C., Jr.

BIOLOGICAL EFFECTS OF OIL POLLUTION IN THE BALTIC SEA
Ganning, B., and O. Linden

EFFECTS OF OIL ON SALT MARSH VEGETATION: A QUANTITATIVE TWO-YEAR STUDY OF RECRUITMENT AND GROWTH
Hampson, G. R.

RECOVERY OF BENTHIC MACROFAUNA FROM CHRONIC OIL POLLUTION IN THE SEA AREA OFF A REFINERY PLANT, FINLAND
Leppakoski, E. J.

LONG-TERM EFFECTS OF OIL ON BENTHIC COMMUNITY STRUCTURE AT WEST FALMOUTH
Michael, A. D.

LONG-TERM EFFECTS OF AN OIL SPILL ON FUCUS AND MACROFAUNA IN A SMALL BALTIC BAY
Notini, M.

NWMAR116880

FLORIDA OIL SPILL IMPACT ON THE BUZZARDS BAY BENTHIC FAUNA: WEST FALMOUTH
Sanders, H. L.

RECOLONIZATION OF ROCKY SHORES IN CORNWALL AFTER USE OF TOXIC DETERGENTS TO CLEAN UP THE TORREY CANYON SPILL
Southward, A. J.

INTERTIDAL ECOLOGICAL EFFECTS OF THE METULA OIL SPILL FOR TWO AND A HALF YEARS AFTER THE SPILL
Straughan, D. J.

RECOVERY OF INTERTIDAL FAUNA AND FLORA ON CHRONICALLY OILED SHORES OF CHEDABUCTO BAY: 1970-1977
Thomas, M.

The proceedings of the symposium will be published by the Journal of the Fisheries Research Board of Canada as a special symposium issue. Inquiries should be directed to: Scientific Information and Publications Branch, Fisheries and Marine Service, Department of Fisheries and the Environment, Ottawa, Ontario, Canada K1A 0E6.

Oct. 12-14 9th American Chemical Society Central Regional Meeting, Charleston, West Virginia, 1977.

Oil Pollution Related Papers

Biochemical Program
Symposium on Microbial Transformations of Aromatic Compounds

Paper 16
MICROBIAL OXIDATION OF AROMATIC HYDROCARBONS
Gibson, D. T., R. H. Dodge, and C. E. Cerniglia

Conference abstracts are available from Dr. J. N. Cawse, Union Carbide Corporation, P.O. Box 8361, South Charleston, WV 25303

Oct. 12-14 1977 Pacific Conference on Chemistry and Spectroscopy, Anaheim, California, 1977.
Sponsored by the American Chemical Society and the Society for Applied Spectroscopy.

Oil Pollution Related Papers

Symposium on Practical Applications of Atomic Spectroscopy

Paper 71
APPLICATIONS OF ATOMIC ABSORPTION AND INFRARED SPECTROSCOPY FOR OIL IDENTIFICATION
Coleman, H. J., and P. L. Grizzle

NWMAR116881

FFI contact Mr. M. M. Owens, Cochairman, ARCO, 1801 East Sepulveda Blvd., Carson, CA 90745

Oct. 17-19 OCEANS '77, Los Angeles, California, 1977.
Sponsored by the Marine Technology Society and the Institute of Electrical and Electronic Engineers Council on Oceanic Engineering.

"An International Conference to discuss and explore developing technology and its impact on public policy and education with a focus on the Pacific Rim".

Oil Pollution Related Papers

Public Policy Session 5: The Pacific Basin Community

Paper 5D
Palau: "NATIVE PARADISE" OR PETROLEUM SUPERPORT
Soule, D. F.

Technical Session 13: Port Operations

Paper 13B
THE COAST GUARD'S DEEPWATER PORT RESEARCH AND DEVELOPMENT PROGRAM
Jones, R. G.

Paper 13D
PORT PLANNING TO MINIMIZE RISK TO HAZARDOUS MATERIAL VESSEL MOVEMENT
Lancaster, J. H.

Technical Session 28: Tanker Operations

Paper 28A
TANKERS, THE COAST GUARD AND PUBLIC POLICY
Ide, J. C.

Paper 28B
OIL/WATER SEPARATOR FOR DEBALLASTING APPLICATIONS
Mittleman, J., and M. Jones

Paper 28D
VALDEZ NARROWS TANKER SIMULATIONS
Devlin, W. H.

Technical Session 33: Marine Water Quality

Paper 33D
DEVELOPMENT OF OIL SPILL CLEANUP TECHNOLOGY
Jensen, D. S.

Paper 33E
OIL SPILL RECOVERY WITH MAGNETICALLY RETRIEVABLE SORBENTS
Turbeville, J. E.

NWMAR116882

Technical Session 40: Environmental Aspects of Offshore Petroleum Development

Paper 40A
ENVIRONMENTAL ASPECTS OF DRILLING FLUID AND DRILL CUTTINGS DISPOSAL
Zingula, R.

Paper 40B
ENVIRONMENTAL ASPECTS OF PRODUCED WATER DISPOSAL
Weiss, F. T., and B. Koons

Paper 40C
FATE OF HYDROCARBONS IN MARINE ANIMALS
Lee, R.

Paper 40D
WEATHERING OF SPILLED OIL AND METHODS OF ACCELERATING
McAuliffe, C. D.

Paper 40E
IMPACT OF ALASKAN PETROLEUM TRANSPORT ON THE CALIFORNIA COASTLINE
Stinner, R. J., and S. Wang

Technical Session 43: Safety Aspects of Ship Operations

Paper 43C
TRANS-ALASKA OIL PIPELINE SYSTEM (TAPS) OIL MOVEMENT--MARINE SAFETY CONSIDERATIONS OF MOVEMENT BY SEA
Riedel, W. R.

The OCEANS '77 Conference Record containing the technical papers will be available from IEEE Single Copy Sales, 445 Hoes Lane, Piscataway, NJ 08854

Oct. 17-22 — 8th International Conference on Water Pollution Research, Sydney, Australia.

FFI contact H. R. Eisenhauer, Canada Department of the Environment, Inland Waters Directorate, Ottawa, Ontario K1A 0E7, Canada

Oct. 23-27 — 27th Canadian Chemical Engineering Conference, Calgary, Alberta, 1977.
Sponsored by the Canadian Society for Mechanical Engineering, Canadian Natural Gas Processing Association, Canadian Natural Gas Processing Supply Men's Association, Coal Association of Canada, Petroleum Society of the Canadian Institute of Mining and Metallurgy, Chemical Institute of Canada, and Alberta Sulfur Research Ltd.

NWMAR116883

Theme of the conference is Energy and Development.

Oil Pollution Related Papers

Session 1: Oil Sands Symposium 1

THE ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
Pahl, M. G.

The title program, AOSERP, is a multidisciplinary, intergovernmental applied research effort directed towards the practical solution of social and environmental problems associated with the Athabasca oil sands development. The project, now in its third year, is headed by Alberta Environment and is jointly funded at $4 million per year by the Alberta and Canadian government. Industry is represented through the Oil Sands Environmental Study Group. Research efforts are focused in areas of hydrology, hydrogeology, meteorology, air quality, terrestrial and aquatic fauna, land use and reclamation, vegetation, and human environment.

Session 4: Environmental and Resource Management 1

AN ENVIRONMENTALIST'S PERCEPTION OF THE CANADIAN OIL INDUSTRY
Gallon, G.

A personal viewpoint is presented on the activities of the oil industry in Canada from 1970 to present, addressing major oil company activities including Northern Development, West Coast Oil Port Development, Refining, and media advertisement.

Session 8: Oil Sands Symposium II

SOME ASPECTS OF ATHABASCA OIL SANDS PROCESSING
Moschopedis, S. E., and J. G. Speight

The environmental impact of the gigantic Athabasca oil sands development project has been a cause of some concern, particularly the water-soluble organic materials and dispersed clay that exists in the tailings ponds of oil sands processing plants. The soluble organics are partly aromatic in nature, contain phenolic, carboxylic and sulphonic functions, and act as clay dispersants.

Conference proceedings will be available from the CSChE Publications Department, 906-151 Slater St., Ottawa, Ontario K1P 5H3, Canada.

Oct. 26-28 SPE-AIME Eastern Regional Meeting, Pittsburgh, Pennsylvania, 1977.

Theme of the conference is "Eastern expectations for energy development". The primary aim of the meeting is to clarify what the northeastern U.S. may expect from emerging national energy policies.

NWMAR116884

Oil Pollution Related Papers

SPE 6623
REGULATORY DRILLING PRACTICES IN THE EASTERN UNITED STATES
Dodd, R. L.

The powers and responsibilities of agencies overseeing oil and gas exploration and drilling activities are reviewed for Kentucky, Maryland, Michigan, New York, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia. State oil development policies are compared with state's policies towards other natural resources, industries, and environmental and conservation issues.

FFI contact Ms. K. Lee, Meetings Secretary, SPE of AIME, 6200 North Central Expressway, Dallas, TX 75206

Nov. 1-3 6th International Pollution Engineering Exposition & Congress, Atlanta, Georgia, 1977.

Runs concurrently with the Southern Plant Engineering & Maintenance Show and Conference. Over 300 exhibits by manufacturers of plant operating equipment, maintenance and pollution control products and services are featured, including oil skimmers, adsorbents, and wastewater sampling instrumentation. The conference includes topics in industrial wastewater treatment and disposal, containment of plant spills, and compliance with environmental regulations and standards.

Conference programs are available from Clapp & Poliak, Inc., 245 Park Avenue, New York, NY 10017

Nov. 2-4 SREL Symposium on Energy and Environmental Stress in Aquatic Systems, Augusta, Georgia, 1977.

The symposium includes topics on contamination from fossil fuels and byproducts.

FFI contact Dr. James H. Thorp, Savannah River Ecology Laboratory, Drawer E, Aiken, SC 29801

Nov. 4-5 SPE-AIME Trinidad-Tobago Petroleum Exposition and Conference, Port-of-Spain, 1977.

Oil Pollution Related Papers

SPE 7031
OIL SPILL CONTINGENCY PLANNING
Hinds, H. C., and R. A. Mends

NWMAR116885

SPE 7035
SAFETY AND PROPOSED DRILLING REGULATIONS FOR TRINIDAD
Kin, F. L.

FFI contact Ms. K. Lee, Meetings Secretary, SPE of AIME, 6200 North Central Expressway, Dallas, TX 75206

Nov. 6-11 4th Joint Conference on Sensing of Environmental Pollutants, New Orleans, Louisiana, 1977.
Sponsored by the ACS, AIAA, AIChE, AME, EPA, ERDA, IEEE, Instrument Society of America, NASA, NOAA, U.S. Department of Housing and Urban Development, USGS, U.S. Department of State, U.S. Department of Transportation.

Oil Pollution Related Papers

Session VI-D: New Analytical Techniques for Environmental Sensing and Assessment - I

Paper 165
ANALYSIS OF ENVIRONMENTAL POLLUTANTS USING ION CHROMATOGRAPHY
Long, T. S., and A. L. Reinsvold

Paper 170
DIFFERENTIAL ABSORPTION TECHNIQUES FOR MEASUREMENT OF REACTIVE HYDROCARBONS
Baskins, L. L.

Session VI-E: Sensing of Water and Land Pollution in the Coastal Zone

Paper 175
SIGNATURE EXTRACTION OF OCEAN POLLUTANTS BY EIGENVECTOR TRANSFORMATION OF REMOTE SPECTRA
Crew, G. W.

Paper 176
MARINE POLLUTION MONITORING UTILIZING AN AIRBORNE FRAUNHOFER LINE DISCRIMINATOR
Watson, R. D., M. E. Henry, A. F. Theisen, T. J. Donovan, and W. R. Hemphill

Session VII-E: Remote Sensing of Water and Land Pollution

Paper 207
DEVELOPMENT OF AN AIRBORNE LASER FLUOROSENSOR FOR OIL AND WATER POLLUTION MONITORING
Houston, W. R., W. Morrow, and J. H. Davies

Proceedings are available for $50.00 from Barbara R. Hodsdon, Conference Manager, American Chemical Society, 1155 16th St., N.W., Washington, D.C. 20036

NWMAR116886

Nov. 9-11 SERACS 29 (29th Annual ACS Southeast Regional Meeting), Tampa, Florida, 1977.
Sponsored by the American Chemical Society Florida Section.

Oil Pollution Related Papers

Marine Chemistry Symposium

Paper 300
ANALYSIS OF ACCUMULATED PETROLEUM HYDROCARBONS IN TISSUES OF OIL-EXPOSED MALLARD DUCKS (ANAS PLATYRHYNCHOS)
Lawler, G. C., W.-A. Loong, and J. L. Laseter

FFI contact A. T. Winstead, American Chemical Society, 1155 16th St., N.W., Washington, D.C. 20036

Nov. 10-12 SNAME 1977 Annual Meeting, New York City, New York, 1977.

FFI contact the Society of Naval Architects and Marine Engineers, One World Trade Center, Ste 1369, New York, NY 10048

Nov. 13-17 70th AIChE Annual Meeting, New York City, New York, 1977.

The conference program covers topics on fuels and petrochemicals. Included are two sessions entitled, "Energy, Environment and Cost: a Challenge to Refining and Petrochemical Operations," and a session on environmental aspects of water, industrial wastes, runoff, wastewater treatment and disposal, and wastewater monitoring.

Oil Pollution Related Papers

Session 58: Energy, Environment, and Cost: A Challenge to Refining and Petrochemical Operations

Paper 58c
ENVIRONMENTAL ASPECTS OF LOCATING A GRASS ROOTS REFINERY IN AN ENVIRONMENTALLY SENSITIVE AREA
Rayford, R., and B. Rubin

Features of refinery design and operation which are necessary for adequate environmental protection are discussed. The modification of an existing refinery and the design of a new facility are described, using case examples. Problems of siting refineries in environmentally sensitive areas are considered.

Session 92: Toxic Effluents and Toxic Spills - Safety and Environmental Aspects. Part I

Paper 92a
EPA REGULATIONS ON TOXIC SPILLS AND TOXIC POLLUTANTS
Jennings, A.

NWMAR116887

Present and proposed EPA regulations regarding toxic oil and chemical spills are discussed and their key features are detailed.

Paper 92b
CHEMICAL INDUSTRY VIEWPOINTS ON TOXIC SPILLS AND TOXIC POLLUTANTS
Ladd, E. C., and R. L. Pellissier

The chemical industry's perspective on the problem of toxic oil and chemical spills is presented, and the effects of present and proposed regulations on plant operation costs and methods are discussed.

Paper 92c
SAFETY ASPECTS OF TOXIC SPILLS AND TOXIC POLLUTANTS
Wood, W. S.

The safety aspects of toxic oil and chemical spills are presented, including the potential of fires, explosions and hazards to life and property. Safety measures in the chemical industry are featured.

Paper 92d
MODELING AND MONITORING OF TOXIC SPILLS AND TOXIC EFFLUENTS
Kenson, R. E.

Problems of monitoring and modeling toxic oil and chemical spills are discussed, and suitable standard methods are proposed. State-of-the-art techniques are reviewed.

Paper 92e
BIOLOGICAL ASPECTS OF TOXIC SPILLS AND TOXIC POLLUTANTS
Nadeau, R.

The effects of toxic oil and chemical spills on biological systems are reviewed. Most data available deal with aquatic organisms, however some data on effects of spills on terrestrial organisms are recorded.

Paper 92f
TECHNICAL ASPECTS OF TOXIC SPILLS/TOXIC POLLUTANTS CLEANUP
Larkman, D. F. G.

Responsibilities of the chemical industry for cleaning up toxic oil and chemical spills are discussed, and a review of currently available technology is presented.

Session 101: Land Application Technology For Industrial Wastes. Part 1

Paper 101b
BIODEGRADATION OF POLYNUCLEAR AROMATIC HYDROCARBON POLLUTANTS BY SOIL AND WATER MICROORGANISMS
Mc Kenna, E. J.

NWMAR116888

This study delineated the biodegradability of polynuclear aromatic hydrocarbons (PNA) by soil and water organisms, and determined the persistence of selected PNA components by measuring residual hydrocarbons in microbial cultures as a function of time.

Paper 101d
ELECTROLYTIC TREATMENT OF DILUTE EMULSIFIED OILY WASTEWATERS
Weintraub, M. H.

Electrolytic treatment of emulsified oil in dilute oily wastewater is described, and design and economic considerations for treatment facilities are discussed.

Paper 116d
SOIL DISPOSAL OF PETROCHEMICAL WASTE EFFLUENTS
Brown, K. W., and L. E. Deuel

The feasibility of using land disposal for petrochemical wastewaters was investigated. The toxicity of the wastewaters was evaluated for three plant species, and the toxic effects were reduced by dilution and rinsing after application. Nitrates in wastes were not found to dissipate into groundwater.

FFI contact W. H. McCarty, Mobil Chemical Co. Research and Development Laboratories, P.O. Box 240, Edison, NJ 08817

Nov. 14-15 Annual Meeting of the American Petroleum Institute, Houston, Texas, 1977.

FFI contact the Conference Department, American Petroleum Institute, 2101 L St., N.W., Washington, D.C. 20037

NWMAR116889

S: See
SA: See also

Absorption
Activated sludge
Acute effects
Adriatic Sea
Adsorption
Aegean Sea
Africa
Alabama
Alaska
Alaska coast
Alaska, Gulf of
Algae ... SA: Phytoplankton
Analytical techniques ...
  SA: Chemical analysis; Source identification
Animals
Annelida ... SA: Polychaetes
Antarctica
API
Arabian Sea
Arctic
Arctic Ocean
Argentina
Argo Merchant Spill
Aromatic hydrocarbons ...
  SA: Hydrocarbons; PAH
Asia
Atlantic coast
Atlantic Ocean
Australia
Bacteria
Bahamas
Ballast
Baltic Sea
Bantry Bay
Barent Sea
Baseline studies
Beaches
Beaufort Sea
Behavior
Belgium
Bengal, Bay of
Benthos
Bering Sea
Bermuda coast
Bibliographies
Bilges
Biodegradation
Biological effects ... SA:
  Toxicity; Acute effects;
  Chronic effects
Biomass
Birds
Biscay, Bay of
Black Sea
BLM
Blowout prevention
Blowouts
Booms
Brazil
California
California coast
California, Southern
Canada
Carcinogens ... SA: Health hazards; PAH
Caribbean Sea
Caspian Sea
Chedabucto Bay
Chemical analysis ... SA: Analytical techniques; Source identification
Chemical effects
Chesapeake Bay
Chile
China
Chromatography
Chronic effects
Coagulation
Coalescence
Coasts
Colorado
Compensation
Connecticut
Conservation
Containment
Contaminants
Contamination
Contingency planning
Coral reefs
Cost analysis
Crankcase oil
Crude oil
Crustaceans
Decomposition
Delaware

NWMAR116890

Delaware Bay
Denmark
Design and engineering
Detection ... SA: Monitoring; Chemical analysis
Development ... SA: Offshore development
Dispersants
Dispersions
Disposal ... SA: Waste oil disposal; Wastewater disposal
Distillation
Distribution
Drift ... SA: Movement; Spreading
Drilling ... SA: Offshore drilling; Oil wells
East China Sea
Echinoderms
Economic effects
Economics
Ecosystems
Ecuador
Effluent treatment ... S: Wastewater treatment
EIS
Ekofisk blowout
Emulsification
Emulsifiers
Emulsions
Engineering ... S: Design and engineering
England
English Channel
Environmental deterioration
Environmental effects
Environmental Impact Statement ... S: EIS
Environmental management
Environmental protection
EPA
ERDA
Europe
Evaporation
Exploration ... SA: Offshore exploration; Production
Extraction
Fate
FEA
Filtration ... SA: Flocculation
Finland
Fish
Fisheries
Flocculation ... SA: Filtration
Florida
Florida coast
Flotation
Food web
Foreign governments
Fossil fuels
France
Freshwater
Fuel oil
Fuels
Fungi
Gas, liquid chromatography ... S: Chromatography
Gasoline
Georgia
Germany, East
Germany, West
Gibraltar, Strait of
Government agencies ... SA: U.S. Government, State governments
Great Lakes
Groundwater
Guidelines ... SA: Manuals
Habitat
Harbors
Health hazards ... SA: Carcinogens
Hydrocarbons ... SA: Aromatic hydrocarbons; Crude oil, PAH
Ice
IMCO
Incineration
India
Indian Ocean
Indonesia
Industries ... SA: Oil industry
Information systems
Infrared spectroscopy ... S: Spectroscopy
Inland
Insurance
International agreements
International conventions ... SA: Regulations; Legislation
Intertidal zone
Invertebrates
Iran
Iraq

NWMAR116891

Ireland
Israel
Italy
Japan
Japan, Sea of
Kentucky
Korea
Kuwait
Labrador Sea
Lakes ... SA: Great Lakes
Latin America
Law enforcement
Leakage
Legislation ... SA: Regulations; International conventions
Liability
Louisiana
Lubricating oil
Magellan, Strait of
Maine
Malaysia
Manuals ... SA: Guidelines
Marine mammals
Marine organisms
Marshes
Maryland
Massachusetts
Mass spectroscopy ... S: Spectroscopy
Mediterranean Sea
Metabolism
Metula spill
Mexico
Mexico, Gulf of
Michigan
Microorganisms ... SA: Algae; Bacteria; Fungi; Yeasts
Middle East
Mississippi
Mississippi River
Models
Mollusks
Monitoring ... SA: Detection; Remote sensing; Sampling
Movement ... SA: Spreading; Drift
Narraganset Bay
Natural seepage
Netherlands
Neuston
New Hampshire
New Jersey
New Mexico
New York
Niche
North Carolina
North Sea
North Vietnam
Norway
Norwegian Sea
Oceans
OCS
Offshore development
Offshore drilling
Offshore exploration
Offshore pipelines
Offshore production
Ohio
Oil ... S: Crude oil; Fuel oil; Lubricating oil; Crankcase oil; Waste oil
Oil discharges
Oil fields ... SA: Production
Oil-gas leasing
Oil industry
Oil shale
Oil slicks
Oil spills
Oil tanks
Oil transfer
Oil transport
Oil-water separation ... SA: Wastewater treatment
Oil wells ... SA: Drilling; Production; Offshore drilling; Offshore production
Okhotsk, Sea of
Onshore impacts
Oregon
Oxidation ... SA: Biodegradation; Weathering
Pacific Ocean
PAH
Patent
Pennsylvania
Personnel training
Petroleum ... S: Crude oil
Petroleum products
Petrochemicals
Petroleum industry ... S: Oil industry
pH control
Philippines
Physical effects

NWMAR116892

Phytoplankton
Pipelines ... SA: Offshore pipelines
Plankton ... SA: Phytoplankton; Zooplankton
Plants
Platforms
Poland
Pollution control
Pollution prevention ... SA: Environmental protection; Contingency planning
Polychaetes
Ports
Portugal
Precipitation
Production ... SA: Offshore production; Drilling; Offshore drilling
Prudhoe Bay
Puerto Rico
Puget Sound
Reclamation ... SA: Recycling; Reuse
Recycling ... SA: Reclamation; Reuse
Red Sea
Refineries
Refining
Regulations ... SA: Legislation; International conventions
Release
Remote Sensing ... SA: Monitoring; Detection
Resource management
Restoration
Reuse ... SA: Reclamation; Recycling
Rhine River
Rhode Island
Rivers
Ross Sea
Safety
Sampling ... SA: Monitoring; Detection
San Francisco Bay
Santa Barbara Channel
Sargasso Sea
Saudi Arabia
Scotland
Seawater
Sedimentation
Sediments
Segregated ballast
Ships ... SA: Tankers
Shorelines
Sinking agents
Skimmers
Sludge
Social effects
Socio-economic effects
Soil
Solid wastes
Solubility
Solution
Solvents
Source identification
Sources
South Africa
South Carolina
South China Sea
Spain
Spectrometry
Spectroscopy
Spill cleanup
Spill disposal
Spill recovery
Spreading ... SA: Movement; Drift
St. Lawrence River
Standing Crop
State Governments ... SA: U.S. Government; Government agencies
Statistical analysis
Statistics
Storage
Streams
Subarctic regions
Superports ... S: Ports
Supertankers ... S: Tankers
Surfactants
Surveillance
Sweden
Syria
Tankers ... SA: Ships
Tar
Tar sands
Texas
Torrey Canyon
Toxicity ... SA: Biological effects
Tropical regions
Turkey
UK
Uptake
U.S.
USCG

NWMAR116893

U.S. Government ... SA: State
governments;
Government agencies
USGS
USSR
Vegetation
Venezuela
Vietnam
Virginia
Virgin Islands
Wales
Washington
Waste oil
Waste oil disposal ...
SA: Disposal
Waste oil treatment
Wastewaters
Wastewater disposal ...
SA: Disposal
Wastewater treatment
Water quality
Weathering
Weddell Sea
West Indies
Wildlife
Yeasts
Yugoslavia
Zooplankton

NWMAR116894

SUBJECT INDEX

THE SUBJECT INDEX IS A PERMUTED INDEX THAT LISTS ALPHABETICALLY THE KEYWORDS AND CORRESPONDING CITATION NUMBER ASSIGNED TO EACH ABSTRACT IN SECTION I (EACH INDEX NUMBER APPEARS IN THE FORM C-____-77 IN SECTION I). KEYWORDS ARE SELECTED FROM THE MASTER LIST, P.224. FREE LANGUAGE TERMS WHICH ARE INCLUDED TO GIVE MORE SPECIFIC INFORMATION ABOUT AN ENTRY ARE PRECEDED BY A * SIGN IN THE SUBJECT INDEX.

1711 ABSORPTION, ANALYTICAL TECHNIQUES, HYDROCARBONS, SEAWATER, BEACHES, SPECTROSCOPY, CHROMATOGRAPHY,
1743 ABSORPTION, SPILL RECOVERY, DESIGN-ENGINEERING, USN, *FOAM CHIPS,
1750 ABSORPTION, SPILL RECOVERY, SKIMMERS, BOOMS, SHIPS,
1760 ABSORPTION, SPILL CLEANUP, SPILL CONTAINMENT, *POLYURETHANE FOAMS,
1763 ABSORPTION, CONTAMINANTS, PATENT, *OIL-ABSORBENT COMPOUND,
1765 ABSORPTION, CONTAMINATION, OIL TANKS, PATENT, *CLEANUP ,
1769 ABSORPTION, SPILL RECOVERY, COST ANALYSIS, *SORBENTS, *PERFORMANCE EVALUATION,
1771 ABSORPTION, SPILL CLEANUP, PETROLEUM PRODUCTS, SOIL, SOURCES, BIODEGRADATION, OXIDATION,
1776 ABSORPTION, SPILL RECOVERY, INCINERATION, PATENT, *ABSORBENT FIBERS,
1778 ABSORPTION, SPILL CLEANUP, OCEANS, *POLYURETHANE FOAMS,
1781 ABSORPTION, SPILL RECOVERY, SURFACTANTS, *SORBENT WOOD CHIPS,
1782 ABSORPTION, OIL SLICKS, SPILL RECOVERY, PATENT,
1790 ABSORPTION, SPILL CLEANUP, INCINERATION, *GELLING AGENTS,
1791 ABSORPTION, SPILL CLEANUP, DISPERSANTS, DISPOSAL , COASTS, MARSHES, BEACHES, SEAWATER, FRESHWATER,
1853 ABSORPTION, WASTEWATER TREATMENT, SPILL RECOVERY, OIL-WATER SEPARATION, PATENT, *SORBENT MATERIAL,
1866 ABSORPTION, WASTEWATER TREATMENT, PETROLEUM PRODUCTS, PATENT, *ABSORBENT POLYOLEFIN,
1620 ACTIVATED SLUDGE , WASTEWATER TREATMENT, BIODEGRADATION, REFINERIES,
1726 ADSORPTION, PETROLEUM PRODUCTS, HYDROCARBONS, SEAWATER, SURFACTANTS, CHEMICAL ANALYSIS, *ELECTROANALYSIS ,
1759 ADSORPTION, FUEL OIL, CONTAMINATION, FRESHWATER, *ACTIVATED CARBON, *WATER SUPPLY,
1777 ADSORPTION, SPILL RECOVERY, FUEL OIL, PATENT, *SAWDUST,
1787 ADSORPTION, SPILL CLEANUP, GASOLINE, FUEL OIL, PATENT,
1602 ADSORPTION, OIL TRANSPORT, GROUNDWATER, *LIME, *CLAY, *SOIL COMPONENTS,
1632 ADSORPTION, WASTEWATER TREATMENT, EMULSIONS, OIL-WATER SEPARATION, OXIDATION, PATENT,
1850 ADSORPTION, WASTEWATER TREATMENT, EMULSIFIERS, SLUDGE, FLOTATION, PATENT,
1872 ADSORPTION, WASTEWATER TREATMENT, EMULSIONS, FILTRATION, POLAND, *CELLULOSE, *DIATOMACEOUS EARTH,
2100 ADSORPTION, CRUDE OIL, HYDROCARBONS, SOIL, *DESORPTION, *ORGANIC MATTER CONTENT,
1939 AEGEAN SEA, CONTAMINATION, CHRONIC EFFECTS, PHYTOPLANKTON,
1651 ALASKA, OIL SPILLS, PIPELINES, CRUDE OIL, *PUMP STATION ACCIDENT,
1653 ALASKA, OIL SPILLS, CRUDE OIL, PIPELINES, *PUMP STATION ACCIDENT,
1657 ALASKA, OIL SPILLS, OCEANS, STATISTICS, COASTS,
1673 ALASKA, MONITORING, FATE, CRUDE OIL, MOVEMENT, BIOLOGICAL EFFECTS, MICROORGANISMS, CHEMICAL EFFECTS, *PERMAFROST TERRAIN,
1797 ALASKA, OIL TRANSPORT, PIPELINES, TEXAS, EIS, CRUDE OIL, OIL SPILLS,
1989 ALASKA, OIL SPILLS, LIABILITY, REGULATIONS, TANKERS, OIL TRANSFER, PORTS, *OIL SPILL FUND,
1999 ALASKA, OIL TRANSPORT, ENVIRONMENTAL EFFECTS, OIL SPILLS, VEGETATION, SOIL, MARSHES,
2013 ALASKA, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, BASELINE STUDIES, OCS, MARINE MAMMALS, BIRDS,
2014 ALASKA, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, BASELINE STUDIES, OCS, FISH, PLANKTON , BENTHOS,
2015 ALASKA, BIRDS, HABITAT, SHORELINES, ARCTIC, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, *SHOREBIRD SPECIES,
2016 ALASKA, BIRDS, SHORELINES, OFFSHORE DEVELOPMENT, OIL SPILLS, ENVIRONMENTAL EFFECTS, BASELINE STUDIES,
2022 ALASKA, OFFSHORE DRILLING, SOCIO-ECONOMIC EFFECTS, OCS, CRUDE OIL, *SEA GRANT PROGRAM, *ENERGY POLICY,
2033 ALASKA, OIL-GAS LEASING, OCS, EIS, ENVIRONMENTAL EFFECTS, SOCIO-ECONOMIC EFFECTS,
2037 ALASKA, OFFSHORE DEVELOPMENT, BIOLOGICAL EFFECTS, MARINE MAMMALS, OCS, *MORTALITY,
2045 ALASKA, OFFSHORE DEVELOPMENT, CRUDE OIL, OCS, ENVIRONMENTAL EFFECTS, OIL-GAS LEASING,
2071 ALASKA, BIODEGRADATION, HYDROCARBONS, MICROORGANISMS, GASOLINE, LAKES, SEDIMENTS,
2095 ALASKA, OIL SPILLS, MOVEMENT, *COASTAL WINDS,
2096 ALASKA, OIL SPILLS, FATE, ICE, *OIL-UNDER-ICE , *IMPULSE RADAR SYSTEM,
2102 ALASKA, UPTAKE, RELEASE, HYDROCARBONS, SEDIMENTS, OIL SLICKS, INTERTIDAL ZONE,
1676 ALASKA COAST, MONITORING, BASELINE STUDIES, ENVIRONMENTAL EFFECTS, OFFSHORE DEVELOPMENT, OCS, INFORMATION SYSTEMS, NOAA, BLM,
2098 ALASKA COAST, OIL SPILLS, MOVEMENT, SHORELINES, *SPILL IMPACT PROBABILITY, BEAUFORT SEA,

NWMAR116895

1700 ALASKA/GULF OF, SAMPLING, TAR, *PLASTICS, DISTRIBUTION, BERING SEA,
2027 ALASKA/GULF OF, OFFSHORE EXPLORATION, OIL-GAS LEASING, ENVIRONMENTAL EFFECTS, OCS, BERING SEA,
1794 ALGAE, RESTORATION, SHORELINES, OIL SPILLS, BIOLOGICAL EFFECTS, MOLLUSKS, *ROCKY SHORES, ENGLAND,
1914 ALGAE, TOXICITY, CRUDE OIL, FUEL OIL,
1955 ALGAE, CRUDE OIL, PETROLEUM PRODUCTS, GASOLINE, BIODEGRADATION, TOXICITY, BACTERIA, FRESHWATER, *PHOTOSYNTHESIS,
1969 ALGAE, PETROLEUM PRODUCTS, FUELS, CRUDE OIL, BIOLOGICAL EFFECTS, *GROWTH, *REPRODUCTION, *FUCUS EDENTATUS DE LA PYL,
1970 ALGAE, TOXICITY, *REPRODUCTION,
1978 ALGAE, TOXICITY, SURFACTANTS, EMULSIFIERS, *SEAWEED, *GROWTH RATES,
1667 ANALYTICAL TECHNIQUES, MONITORING, CONTAMINANTS, SAMPLING,
1701 ANALYTICAL TECHNIQUES, OIL-WATER SEPARATION, DETECTION, PATENT, *OIL-IN-WATER, *FLUORESCENCE,
1706 ANALYTICAL TECHNIQUES, WASTEWATERS, REFINERIES, FOSSIL FUELS ,
1711 ANALYTICAL TECHNIQUES, ABSORPTION, HYDROCARBONS, SEAWATER, BEACHES, SPECTROSCOPY, CHROMATOGRAPHY,
1713 ANALYTICAL TECHNIQUES, SAMPLING, HYDROCARBONS, SEDIMENTS, INTERTIDAL ZONE, WASHINGTON,
1716 ANALYTICAL TECHNIQUES, PETROLEUM PRODUCTS, SEAWATER, *GRAVIMETRIC ANALYSIS, *SPECTROPHOTOMETRY,
1720 ANALYTICAL TECHNIQUES, CONTAMINATION, *OPTICAL EMISSION, CASPIAN SEA, *SEA SURFACE,
1724 ANALYTICAL TECHNIQUES, CRUDE OIL, FUEL OIL, *OIL-GREASE DETERMINATION,
1725 ANALYTICAL TECHNIQUES, HYDROCARBONS, SEDIMENTS, CHROMATOGRAPHY, SPECTROSCOPY, *INTERCALIBRATION,
1727 ANALYTICAL TECHNIQUES, SOURCE IDENTIFICATION, CRUDE OIL, FUEL OIL, PETROLEUM PRODUCTS, SPECTROSCOPY,
1728 ANALYTICAL TECHNIQUES, SOURCE IDENTIFICATION, OIL SPILLS,
1913 ANALYTICAL TECHNIQUES, TOXICITY, HYDROCARBONS, MARINE ORGANISMS, METABOLISM, BEHAVIOR, *SUBLETHAL LEVELS,
1936 ANALYTICAL TECHNIQUES, FISH, BIOLOGICAL EFFECTS, HYDROCARBONS, *TISSUES, *MORPHOLOGICAL CHANGES,
2128 ANIMALS, BIBLIOGRAPHIES, OIL SPILLS, BIOLOGICAL EFFECTS, PLANTS, MICROORGANISMS,
1912 ANNELIDS, HYDROCARBONS, SEDIMENT, UPTAKE, RELEASE, *PHASCOLOSOMA AGASSIZII, *NAPHTHALENES,
1987 API, REGULATIONS, OIL INDUSTRY, POLLUTION CONTROL, WASTEWATER TREATMENT, REFINERIES, COST ANALYSIS,
1990 API, REGULATIONS, OIL INDUSTRY, POLLUTION CONTROL, ECONOMIC EFFECTS, COST ANALYSIS, EPA,
1891 ARCTIC, OFFSHORE DRILLING, SAFETY, POLLUTION PREVENTION, *ICEBERGS, GREENLAND,
1905 ARCTIC, OIL SPILLS, POLLUTION CONTROL, BEAUFORT SEA, *SPILL COUNTERMEASURES,
1951 ARCTIC, HYDROCARBONS, BIOLOGICAL EFFECTS, MARINE ORGANISMS, ECOSYSTEMS, SUBARCTIC REGIONS,
1980 ARCTIC, CRUDE OIL, TOXICITY, PHYTOPLANKTON, FRESHWATER, *PRIMARY PRODUCTION,
2015 ARCTIC, ALASKA, BIRDS, HABITAT, SHORELINES, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, *SHOREBIRD SPECIES,
2017 ARCTIC, OIL TRANSPORT, PIPELINES, ENVIRONMENTAL EFFECTS, FRESHWATER, EPA,
2034 ARCTIC, OFFSHORE EXPLORATION, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, CANADA, ICE, OIL INDUSTRY,
2054 ARCTIC, OFFSHORE DEVELOPMENT, ICE, ENVIRONMENTAL EFFECTS, *ICE COVERED WATERS, *RESEARCH TECHNOLOGY,
2058 ARCTIC, BIODEGRADATION, CRUDE OIL, MICROORGANISMS, BEAUFORT SEA,
2072 ARCTIC, BIODEGRADATION, GASOLINE, BIOLOGICAL EFFECTS, MICROORGANISMS, LAKES,
2076 ARCTIC, BIODEGRADATION, HYDROCARBONS, METABOLISM, MARINE ORGANISMS, SUBARCTIC REGIONS, TOXICITY,
1638 ARCTIC OCEAN, ENVIRONMENTAL PROTECTION, CONTINGENCY PLANNING, CANADA,
2057 ARCTIC OCEAN, BIODEGRADATION, MICROORGANISMS, *14C-DODECANE OXIDATION , *PORT VALDEZ,
2070 ARCTIC OCEAN, BIODEGRADATION, OIL SLICKS, MICROORGANISMS, *CONTINUOUS FLOW-THROUGH SYSTEM,
1941 ARGENTINA, BIRDS, CONTAMINATION, COASTS, *TIERRA DEL FUEGO, *PENGUINS, *MORTALITY,
1640 ARGO MERCHANT SPILL, TANKERS, LIABILITY, SPILL CLEANUP,
1641 ARGO MERCHANT SPILL, MONITORING, MOVEMENT, POLLUTION PREVENTION, TANKERS, USGS,
1668 ARGO MERCHANT SPILL, MONITORING, CHESAPEAKE BAY,
1922 ARGO MERCHANT SPILL, BIOLOGICAL EFFECTS, INVERTEBRATES, FISH, FOOD WEB,
2001 ARGO MERCHANT SPILL, DISTRIBUTION, ENVIRONMENTAL EFFECTS, COASTS, ATLANTIC OCEAN,
2090 ARGO MERCHANT SPILL, MONITORING, ENVIRONMENTAL EFFECTS, BEHAVIOR, MOVEMENT, SAMPLING,
1707 AROMATIC HYDROCARBONS , CHEMICAL ANALYSIS, SEAWATER, *ELECTROCHEMICAL ANALYSIS ,
1717 AROMATIC HYDROCARBONS , CHEMICAL ANALYSIS, CHROMATOGRAPHY, HYDROCARBONS, MONITORING, SEDIMENTS, *GLASS CAPILLARY COLUMNS,
1915 AROMATIC HYDROCARBONS , CRUSTACEANS, BIOLOGICAL EFFECTS, ESTUARIES, *COPEPOD,
1920 AROMATIC HYDROCARBONS , CRUDE OIL, TOXICITY, CRUSTACEANS, *LARVAL DEVELOPMENT, *CANCER MAGISTER,
2003 AROMATIC HYDROCARBONS , CRUDE OIL, OFFSHORE DEVELOPMENT, FISHERIES, NORTH SEA,
2063 AROMATIC HYDROCARBONS , BIODEGRADATION, HYDROCARBONS, YEASTS, BACTERIA, OIL SLICKS, *CHLORINATED HYDROCARBONS ,

NWMAR116896

2068 AROMATIC HYDROCARBONS , BIODEGRADATION, MICROORGANISMS, SOURCES,
2074 AROMATIC HYDROCARBONS , BIODEGRADATION, BACTERIA, *ACINETOBACTER,
2093 AROMATIC HYDROCARBONS , OIL SPILLS, CHEMICAL ANALYSIS, WEATHERING, BIODEGRADATION, BIOLOGICAL EFFECTS, FISH, NORWAY, *T/T "DRUPA" SPILL,
1706 ATLANTIC COAST, HYDROCARBONS, CHEMICAL ANALYSIS, CHROMATOGRAPHY, SPECTROSCOPY, DETECTION, CANADA,
1967 ATLANTIC COAST, OIL DISCHARGES, HYDROCARBONS, CONTAMINATION, PHYTOPLANKTON, OCS,
2038 ATLANTIC COAST, BASELINE STUDIES, OCS, OFFSHORE DEVELOPMENT, HYDROCARBONS, CHEMICAL ANALYSIS,
2047 ATLANTIC COAST, OFFSHORE DEVELOPMENT, PORTS, ENVIRONMENTAL DETERIORATION,
2048 ATLANTIC COAST, OFFSHORE DEVELOPMENT, PORTS, ENVIRONMENTAL EFFECTS, FISHERIES, NEW JERSEY, DELAWARE,
1648 ATLANTIC OCEAN, TAR, OCEANS, DISTRIBUTION, CANADA, SARGASSO SEA,
1997 ATLANTIC OCEAN, OIL SPILLS, ENVIRONMENTAL EFFECTS, US, *WORLD WAR II,
2001 ATLANTIC OCEAN, ARGO MERCHANT SPILL, DISTRIBUTION, ENVIRONMENTAL EFFECTS, COASTS,
1672 AUSTRALIA, MONITORING, HYDROCARBONS, SOURCES, DISTRIBUTION, CHRONIC EFFECTS, *MYTILUS EDULIS, *INDICATOR SPECIES,
1919 BACTERIA, CRUDE OIL, BIOLOGICAL EFFECTS, FUNGI, ICE, FRESHWATER, *OIL-UNDER-ICE ,
1955 BACTERIA, ALGAE, CRUDE OIL, PETROLEUM PRODUCTS, GASOLINE, BIODEGRADATION, TOXICITY, FRESHWATER, *PHOTOSYNTHESIS,
1957 BACTERIA, BIOLOGICAL EFFECTS, BIOMASS, SEDIMENTS, MICROORGANISMS, INTERTIDAL ZONE,
2006 BACTERIA, PETROLEUM PRODUCTS, LUBRICATING OIL, MOVEMENT, SOIL, BIOLOGICAL EFFECTS,
2059 BACTERIA, BIODEGRADATION, CRUDE OIL, PETROLEUM PRODUCTS, PATENT, *NUTRIENT ADDITION,
2060 BACTERIA, BIODEGRADATION, HYDROCARBONS, EMULSIFICATION, FRESHWATER, *KEROSENE,
2061 BACTERIA, BIODEGRADATION, ESTUARIES, *ENRICHMENT TECHNIQUES,
2062 BACTERIA, BIODEGRADATION, HYDROCARBONS, SEDIMENT, BEACHES, MAGELLAN/STRAIT OF, METULA SPILL,
2063 BACTERIA, AROMATIC HYDROCARBONS , BIODEGRADATION, HYDROCARBONS, YEASTS, OIL SLICKS, *CHLORINATED HYDROCARBONS ,
2065 BACTERIA, BIODEGRADATION, OIL SHALE, HYDROCARBONS,
2066 BACTERIA, BIODEGRADATION, HYDROCARBONS, *TAXONOMY,
2069 BACTERIA, BIODEGRADATION, HYDROCARBONS, FUNGI, FRESHWATER, SEDIMENTS,
2073 BACTERIA, BIODEGRADATION, CRUDE OIL, DISPERSANTS,
2074 BACTERIA, AROMATIC HYDROCARBONS , BIODEGRADATION, *ACINETOBACTER,
2075 BACTERIA, BIODEGRADATION, WASTE OIL, SOIL, MONITORING, FUNGI, *ARID SITE,
2080 BACTERIA, BIODEGRADATION, FUEL OIL, PETROLEUM PRODUCTS, OXIDATION, CASPIAN SEA,
2081 BACTERIA, BIODEGRADATION, HYDROCARBONS, LAKES, WATER QUALITY, WISCONSIN, *NUTRIENT LIMITATION,
2082 BACTERIA, BIODEGRADATION, CRUDE OIL, HYDROCARBONS, SOIL, CANADA, *NUTRIENT ADDITION,
1950 BALTIC SEA, INTERTIDAL ZONE, BIOLOGICAL EFFECTS, SPILL CLEANUP,
1982 BALTIC SEA, CONTAMINATION, BIOLOGICAL EFFECTS,
2094 BALTIC SEA, OIL SPILLS, MODELS, FATE, BIODEGRADATION, DISTRIBUTION, INTERTIDAL ZONE,
1676 BASELINE STUDIES, ALASKA COAST, MONITORING, ENVIRONMENTAL EFFECTS, OFFSHORE DEVELOPMENT, OCS, INFORMATION SYSTEMS, NOAA, BLM,
1714 BASELINE STUDIES, CHEMICAL ANALYSIS, CHROMATOGRAPHY, SPECTROSCOPY, DETECTION, HYDROCARBONS, MARINE ORGANISMS,
2013 BASELINE STUDIES, ALASKA, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, OCS, MARINE MAMMALS, BIRDS,
2014 BASELINE STUDIES, ALASKA, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, OCS, FISH, PLANKTON , BENTHOS,
2016 BASELINE STUDIES, ALASKA, BIRDS, SHORELINES, OFFSHORE DEVELOPMENT, OIL SPILLS, ENVIRONMENTAL EFFECTS,
2028 BASELINE STUDIES, OIL-GAS LEASING, EIS, ENVIRONMENTAL EFFECTS, CALIFORNIA/SOUTHERN,
2029 BASELINE STUDIES, OIL-GAS LEASING, EIS, ENVIRONMENTAL EFFECTS, OFFSHORE DEVELOPMENT, CALIFORNIA/SOUTHERN,
2030 BASELINE STUDIES, OIL-GAS LEASING, EIS, ENVIRONMENTAL EFFECTS, CALIFORNIA/SOUTHERN,
2031 BASELINE STUDIES, OIL-GAS LEASING, EIS, ENVIRONMENTAL EFFECTS, OFFSHORE DEVELOPMENT, CALIFORNIA/SOUTHERN,
2032 BASELINE STUDIES, OIL-GAS LEASING, OFFSHORE DEVELOPMENT, EIS, ENVIRONMENTAL EFFECTS, CALIFORNIA/SOUTHERN,
2038 BASELINE STUDIES, ATLANTIC COAST, OCS, OFFSHORE DEVELOPMENT, HYDROCARBONS, CHEMICAL ANALYSIS,
1711 BEACHES, ANALYTICAL TECHNIQUES, ABSORPTION, HYDROCARBONS, SEAWATER, SPECTROSCOPY, CHROMATOGRAPHY,
1783 BEACHES, SPILL RECOVERY, DISPERSANTS, SURFACTANTS, PATENT,
1791 BEACHES, ABSORPTION, SPILL CLEANUP, DISPERSANTS, DISPOSAL , COASTS, MARSHES, SEAWATER, FRESHWATER,
1993 BEACHES, METULA SPILL, ENVIRONMENTAL EFFECTS, SEDIMENTS, MAGELLAN/STRAIT OF,
2062 BEACHES, BACTERIA, BIODEGRADATION, HYDROCARBONS, SEDIMENT, MAGELLAN/STRAIT OF, METULA SPILL,
1905 BEAUFORT SEA, ARCTIC, OIL SPILLS, POLLUTION CONTROL, *SPILL COUNTERMEASURES,
1924 BEAUFORT SEA, BIOLOGICAL EFFECTS, HYDROCARBONS, CRUDE OIL, UPTAKE, MARINE MAMMALS, *RINGED SEAL,
2056 BEAUFORT SEA, ARCTIC, BIODEGRADATION, CRUDE OIL, MICROORGANISMS,
2077 BEAUFORT SEA, BIODEGRADATION, HYDROCARBONS, CRUDE OIL, ICE, SEDIMENTS, SEAWATER,

NWMAR116897

2066 BEAUFORT SEA, OIL SPILLS, SPREADING, ICE, *UNDER-ICE SPILL,
2098 BEAUFORT SEA, ALASKA COAST, OIL SPILLS, MOVEMENT, SHORELINES, *SPILL IMPACT PROBABILITY,
1664 BEHAVIOR, OIL SPILLS, FATE, ENVIRONMENTAL EFFECTS, SPILL CLEANUP, MONITORING, *1977 OIL SPILL CONFERENCE,
1738 BEHAVIOR, SPILL CONTAINMENT, BOOMS, OIL SLICKS, *SLICK DROPLET FORMATION, *ENTRAINMENT FAILURE,
1913 BEHAVIOR, ANALYTICAL TECHNIQUES, TOXICITY, HYDROCARBONS, MARINE ORGANISMS, METABOLISM, *SUBLETHAL LEVELS,
2090 BEHAVIOR, ARGO MERCHANT SPILL, MONITORING, ENVIRONMENTAL EFFECTS, MOVEMENT, SAMPLING,
2104 BEHAVIOR, OIL SLICKS, PHYSICAL EFFECTS, MODELS, *WIND-CURRENT EFFECTS,
1940 BENTHOS, CRUDE OIL, TOXICITY, PLANKTON , OCS, *NEW YORK BIGHT, NEW YORK,
1961 BENTHOS, POLLUTION CONTROL, BIOLOGICAL EFFECTS, COASTS, *PELAGIC ORGANISMS,
2014 BENTHOS, BASELINE STUDIES, ALASKA, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, OCS, FISH, PLANKTON ,
1700 BERING SEA, ALASKA/GULF OF, SAMPLING, TAR, *PLASTICS, DISTRIBUTION,
2027 BERING SEA, ALASKA/GULF OF, OFFSHORE EXPLORATION, OIL-GAS LEASING, ENVIRONMENTAL EFFECTS, OCS,
1697 BIBLIOGRAPHIES, REMOTE SENSING, OIL SLICKS, OCEANS, *RADAR, *SEA SURFACE,
1965 BIBLIOGRAPHIES, HYDROCARBONS, CRUDE OIL, TOXICITY, MOLLUSKS, SURFACTANTS, EMULSIFIERS, *MUSSELS,
2127 BIBLIOGRAPHIES, FISH, FRESHWATER, BIOLOGICAL EFFECTS,
2128 BIBLIOGRAPHIES, ANIMALS, OIL SPILLS, BIOLOGICAL EFFECTS, PLANTS, MICROORGANISMS,
2129 BIBLIOGRAPHIES, OIL SHALE, DEVELOPMENT , EXTRACTION, ENVIRONMENTAL EFFECTS,
2130 BIBLIOGRAPHIES, OIL SHALE, DEVELOPMENT , EXTRACTION, ENVIRONMENTAL EFFECTS,
2131 BIBLIOGRAPHIES, OIL SHALE, DEVELOPMENT , EXTRACTION, ENVIRONMENTAL EFFECTS, POLLUTION CONTROL,
2132 BIBLIOGRAPHIES, OIL SHALE, DEVELOPMENT , EXTRACTION, ENVIRONMENTAL EFFECTS, POLLUTION CONTROL,
2133 BIBLIOGRAPHIES, ESTUARIES, MARINE ORGANISMS, ENVIRONMENTAL EFFECTS,
2134 BIBLIOGRAPHIES, LEGISLATION, US, POLLUTION CONTROL,
2135 BIBLIOGRAPHIES, DETECTION, SAMPLING, MONITORING, CHEMICAL ANALYSIS, REMOTE SENSING,
2136 BIBLIOGRAPHIES, CONTAMINATION, CARIBBEAN SEA, MARINE ORGANISMS,
1684 BILGES, MONITORING, SHIPS, DESIGN-ENGINEERING, DETECTION,
1685 BILGES, MONITORING, DESIGN-ENGINEERING, *TOTAL ORGANIC CARBON DETERMINATION,
1722 BIODEGRADATION, CHEMICAL ANALYSIS, NATURAL SEEPAGE, WEATHERING, CHROMATOGRAPHY, SPECTROMETRY, SANTA BARBARA CHANNEL, CALIFORNIA/SOUTHERN,
1771 BIODEGRADATION, ABSORPTION, SPILL CLEANUP, PETROLEUM PRODUCTS, SOIL, SOURCES, OXIDATION,
1820 BIODEGRADATION, ACTIVATED SLUDGE , WASTEWATER TREATMENT, REFINERIES,
1821 BIODEGRADATION, WASTEWATERS, SPILL CLEANUP, PATENT, *H2O2,
1925 BIODEGRADATION, HYDROCARBONS, FUEL OIL, BIOLOGICAL EFFECTS, MICROORGANISMS, MARSHES, *SALTMARSH,
1955 BIODEGRADATION, BACTERIA, ALGAE, CRUDE OIL, PETROLEUM PRODUCTS, GASOLINE, TOXICITY, FRESHWATER, *PHOTOSYNTHESIS,
2057 BIODEGRADATION, ARCTIC OCEAN, MICROORGANISMS, *14C-DODECANE OXIDATION , *PORT VALDEZ,
2058 BIODEGRADATION, BEAUFORT SEA, ARCTIC, CRUDE OIL, MICROORGANISMS,
2059 BIODEGRADATION, BACTERIA, CRUDE OIL, PETROLEUM PRODUCTS, PATENT, *NUTRIENT ADDITION,
2060 BIODEGRADATION, BACTERIA, HYDROCARBONS, EMULSIFICATION, FRESHWATER, *KEROSENE,
2061 BIODEGRADATION, BACTERIA, ESTUARIES, *ENRICHMENT TECHNIQUES,
2062 BIODEGRADATION, BEACHES, BACTERIA, HYDROCARBONS, SEDIMENT, MAGELLAN/STRAIT OF, METULA SPILL,
2063 BIODEGRADATION, BACTERIA, AROMATIC HYDROCARBONS , HYDROCARBONS, YEASTS, OIL SLICKS, *CHLORINATED HYDROCARBONS ,
2064 BIODEGRADATION, SLUDGE, SOIL, DISPOSAL , WASTE OIL, REFINERIES,
2065 BIODEGRADATION, BACTERIA, OIL SHALE, HYDROCARBONS,
2066 BIODEGRADATION, BACTERIA, HYDROCARBONS, *TAXONOMY,
2067 BIODEGRADATION, CRUDE OIL, OXIDATION, UPTAKE, *TEMPERATURE EFFECTS,
2068 BIODEGRADATION, AROMATIC HYDROCARBONS , MICROORGANISMS, SOURCES,
2069 BIODEGRADATION, BACTERIA, HYDROCARBONS, FUNGI, FRESHWATER, SEDIMENTS,
2070 BIODEGRADATION, ARCTIC OCEAN, OIL SLICKS, MICROORGANISMS, *CONTINUOUS FLOW-THROUGH SYSTEM,
2071 BIODEGRADATION, ALASKA, HYDROCARBONS, MICROORGANISMS, GASOLINE, LAKES, SEDIMENTS,
2072 BIODEGRADATION, ARCTIC, GASOLINE, BIOLOGICAL EFFECTS, MICROORGANISMS, LAKES,
2073 BIODEGRADATION, BACTERIA, CRUDE OIL, DISPERSANTS,
2074 BIODEGRADATION, BACTERIA, AROMATIC HYDROCARBONS , *ACINETOBACTER,
2075 BIODEGRADATION, BACTERIA, WASTE OIL, SOIL, MONITORING, FUNGI, *ARID SITE,
2076 BIODEGRADATION, ARCTIC, HYDROCARBONS, METABOLISM, MARINE ORGANISMS, SUBARCTIC REGIONS, TOXICITY,
2077 BIODEGRADATION, BEAUFORT SEA, HYDROCARBONS, CRUDE OIL, ICE, SEDIMENTS, SEAWATER,
2078 BIODEGRADATION, CRUDE OIL, TOXICITY, ECHINODERMS, *EKOFISK OIL,
2079 BIODEGRADATION, OIL SPILLS, PATENT, *NUTRIENT ADDITION,
2080 BIODEGRADATION, BACTERIA, FUEL OIL, PETROLEUM PRODUCTS, OXIDATION, CASPIAN SEA,
2081 BIODEGRADATION, BACTERIA, HYDROCARBONS, LAKES, WATER QUALITY, WISCONSIN, *NUTRIENT LIMITATION,

NWMAR116898

2082 BIODEGRADATION, BACTERIA, CRUDE OIL, HYDROCARBONS, SOIL, CANADA, *NUTRIENT ADDITION,
2092 BIODEGRADATION, PETROLEUM PRODUCTS, SURFACTANTS, FATE, SEAWATER, SEDIMENTS, *SELF-PURIFICATION, *SEA OF AZOV,
2093 BIODEGRADATION, AROMATIC HYDROCARBONS , OIL SPILLS, CHEMICAL ANALYSIS, WEATHERING, BIOLOGICAL EFFECTS, FISH, NORWAY, *T/T "DRUPA" SPILL,
2094 BIODEGRADATION, BALTIC SEA, OIL SPILLS, MODELS, FATE, DISTRIBUTION, INTERTIDAL ZONE,
2097 BIODEGRADATION, FATE, HYDROCARBONS, SEAWATER, ECOSYSTEM, SEDIMENTATION, *NAPHTHALENES,
2107 BIODEGRADATION, DECOMPOSITION, FUEL OIL, MICROORGANISMS, *PHYSICOCHEMICAL DEGRADATION,
1639 BIOLOGICAL EFFECTS, OIL SPILLS, REGULATIONS, OIL TRANSFER, BIRDS, SCOTLAND,
1673 BIOLOGICAL EFFECTS, ALASKA, MONITORING, FATE, CRUDE OIL, MOVEMENT, MICROORGANISMS, CHEMICAL EFFECTS, *PERMAFROST TERRAIN,
1794 BIOLOGICAL EFFECTS, ALGAE, RESTORATION, SHORELINES, OIL SPILLS, MOLLUSKS, *ROCKY SHORES, ENGLAND,
1911 BIOLOGICAL EFFECTS, FUEL OIL, BIRDS, *HATCHABILITY, *MALLARD DUCK EGGS,
1915 BIOLOGICAL EFFECTS, AROMATIC HYDROCARBONS , CRUSTACEANS, ESTUARIES, *COPEPOD,
1917 BIOLOGICAL EFFECTS, BIRDS, *SEABIRDS, OIL SPILLS, RESTORATION,
1918 BIOLOGICAL EFFECTS, BIRDS, *SEABIRDS, OIL SPILLS, OIL SLICKS, CHRONIC EFFECTS,
1919 BIOLOGICAL EFFECTS, BACTERIA, CRUDE OIL, FUNGI, ICE, FRESHWATER, *OIL-UNDER-ICE ,
1922 BIOLOGICAL EFFECTS, ARGO MERCHANT SPILL, INVERTEBRATES, FISH, FOOD WEB,
1923 BIOLOGICAL EFFECTS, MICROORGANISMS, CRUDE OIL, FUEL OIL, CANADA, *GEORGIA STRAIT, *HETEROTROPHIC POTENTIAL, *PRODUCTIVITY,
1924 BIOLOGICAL EFFECTS, BEAUFORT SEA, HYDROCARBONS, CRUDE OIL, UPTAKE, MARINE MAMMALS, *RINGED SEAL,
1925 BIOLOGICAL EFFECTS, BIODEGRADATION, HYDROCARBONS, FUEL OIL, MICROORGANISMS, MARSHES, *SALTMARSH,
1927 BIOLOGICAL EFFECTS, OIL SPILLS, ENVIRONMENTAL EFFECTS, MARINE ORGANISMS, BIRDS, SANTA BARBARA CHANNEL,
1928 BIOLOGICAL EFFECTS, MOLLUSKS, *PHENOL, *CYTOLOGY, *MERCENARIA MERCENARIA,
1931 BIOLOGICAL EFFECTS, CRUDE OIL, FISH, *FIN ROT, *MUGIL CEPHALUS,
1932 BIOLOGICAL EFFECTS, DISPERSANTS, SURFACTANTS, FISH, TOXICITY,
1936 BIOLOGICAL EFFECTS, ANALYTICAL TECHNIQUES, FISH, HYDROCARBONS, *TISSUES, *MORPHOLOGICAL CHANGES,
1937 BIOLOGICAL EFFECTS, OIL SPILLS, MARSHES, MARINE ORGANISMS, BIRDS, MOLLUSKS, CHESAPEAKE BAY, *MARSH GRASSES,
1944 BIOLOGICAL EFFECTS, FUEL OIL, OIL SPILLS, CONTAMINATION, MARSHES, CRUSTACEANS, MASSACHUSETTS, *UCA PUGNAX,
1945 BIOLOGICAL EFFECTS, FUEL OIL, METABOLISM, CRUSTACEANS, *TEMPERATURE, *SALINITY, *LIMULUS POLYPHEMUS,
1950 BIOLOGICAL EFFECTS, CORAL REEFS, CONTAMINATION, RED SEA, ISRAEL, *SUCCESSION, *RECOLONIZATION,
1951 BIOLOGICAL EFFECTS, ARCTIC, HYDROCARBONS, MARINE ORGANISMS, ECOSYSTEMS, SUBARCTIC REGIONS,
1952 BIOLOGICAL EFFECTS, OIL SPILLS, FUEL OIL, INVERTEBRATES, FISH, STREAMS, VIRGINIA,
1953 BIOLOGICAL EFFECTS, CRUDE OIL, CRUSTACEANS, *WATER-SOLUBLE FRACTION, *MOLTING LARVAE,
1956 BIOLOGICAL EFFECTS, BALTIC SEA, INTERTIDAL ZONE, SPILL CLEANUP,
1957 BIOLOGICAL EFFECTS, BACTERIA, BIOMASS, SEDIMENTS, MICROORGANISMS, INTERTIDAL ZONE,
1956 BIOLOGICAL EFFECTS, PHYTOPLANKTON, HYDROCARBONS, METABOLISM, *PLANT GROWTH, *PHOTOSYNTHESIS,
1960 BIOLOGICAL EFFECTS, CRUDE OIL, DISPERSIONS, METABOLISM, CRUSTACEANS, *SUBLETHAL EFFECTS, *ARCTIC AMPHIPOD,
1961 BIOLOGICAL EFFECTS, BENTHOS, POLLUTION CONTROL, COASTS, *PELAGIC ORGANISMS,
1966 BIOLOGICAL EFFECTS, CRUDE OIL, *INSECTS, CANADA, *CHIRONOMID LARVAE,
1969 BIOLOGICAL EFFECTS, ALGAE, PETROLEUM PRODUCTS, FUELS, CRUDE OIL, *GROWTH, *REPRODUCTION, *FUCUS EDENTATUS DE LA PYL,
1971 BIOLOGICAL EFFECTS, METULA SPILL, MARINE ORGANISMS, INTERTIDAL ZONE, MAGELLAN/STRAIT OF,
1973 BIOLOGICAL EFFECTS, FUEL OIL, BIRDS, *HATCHABILITY, *COMMON EIDER EGGS,
1975 BIOLOGICAL EFFECTS, CRUDE OIL, SEAWATER, SEDIMENTS, MOLLUSKS, *WATER-SOLUBLE FRACTION, *OIL-TREATED SEDIMENT, *MACOMA BALTHICA,
1982 BIOLOGICAL EFFECTS, BALTIC SEA, CONTAMINATION,
1983 BIOLOGICAL EFFECTS, DISPERSANTS, FISH, SPILL CLEANUP, *EMBRYO DEVELOPMENT,
1984 BIOLOGICAL EFFECTS, OIL SPILLS, MOLLUSKS, MAINE, *GONADAL NEOPLASMS, *MYA ARENARIA,
1986 BIOLOGICAL EFFECTS, MARINE MAMMALS, CRUDE OIL, *THERMAL CONDUCTANCE, *SEA OTTERS, *PINNIPEDS,
1998 BIOLOGICAL EFFECTS, SOURCES, CONTAMINATION, SHIPS, EXPLORATION , PRODUCTION , SEABIRDS, MARINE ORGANISMS, FISHERIES, SPILL CLEANUP, DISPERSANTS,
2000 BIOLOGICAL EFFECTS, CONTAMINATION, OCEANS, SOURCES, POLLUTION CONTROL, MARINE ORGANISMS, DISPERSANTS,
2006 BIOLOGICAL EFFECTS, BACTERIA, PETROLEUM PRODUCTS, LUBRICATING OIL, MOVEMENT, SOIL,
2008 BIOLOGICAL EFFECTS, HYDROCARBONS, CONTAMINATION, OCEANS, HEALTH HAZARDS, POLLUTION CONTROL,
2037 BIOLOGICAL EFFECTS, ALASKA, OFFSHORE DEVELOPMENT, MARINE MAMMALS, OCS, *MORTALITY,
2056 BIOLOGICAL EFFECTS, DRILLING , *DRILL CUTTINGS, FATE, OCEANS,
2072 BIOLOGICAL EFFECTS, BIODEGRADATION, ARCTIC, GASOLINE, MICROORGANISMS, LAKES,
2093 BIOLOGICAL EFFECTS, BIODEGRADATION, AROMATIC HYDROCARBONS , OIL SPILLS, CHEMICAL

NWMAR116899

ANALYSIS, WEATHERING, FISH, NORWAY, *T/T "DRUPA" SPILL,
2099 BIOLOGICAL EFFECTS, OIL SPILLS, FATE, DISPERSANTS,
2125 BIOLOGICAL EFFECTS, INTERNATIONAL CONVENTIONS, UN, POLLUTION CONTROL, MONITORING, MEDITERRANEAN SEA,
2127 BIOLOGICAL EFFECTS, BIBLIOGRAPHIES, FISH, FRESHWATER,
2128 BIOLOGICAL EFFECTS, BIBLIOGRAPHIES, ANIMALS, OIL SPILLS, PLANTS, MICROORGANISMS,
1957 BIOMASS, BIOLOGICAL EFFECTS, BACTERIA, SEDIMENTS, MICROORGANISMS, INTERTIDAL ZONE,
1639 BIRDS, BIOLOGICAL EFFECTS, OIL SPILLS, REGULATIONS, OIL TRANSFER, SCOTLAND,
1660 BIRDS, TANKERS, OLYMPIC GAMES SPILL, SPILL CLEANUP, DELAWARE, *DELAWARE RIVER,
1911 BIRDS, BIOLOGICAL EFFECTS, FUEL OIL, *HATCHABILITY, *MALLARD DUCK EGGS,
1917 BIRDS, BIOLOGICAL EFFECTS, *SEABIRDS, OIL SPILLS, RESTORATION,
1916 BIRDS, BIOLOGICAL EFFECTS, *SEABIRDS, OIL SPILLS, OIL SLICKS, CHRONIC EFFECTS,
1927 BIRDS, BIOLOGICAL EFFECTS, OIL SPILLS, ENVIRONMENTAL EFFECTS, MARINE ORGANISMS, SANTA BARBARA CHANNEL,
1937 BIRDS, BIOLOGICAL EFFECTS, OIL SPILLS, MARSHES, MARINE ORGANISMS, MOLLUSKS, CHESAPEAKE BAY, *MARSH GRASSES,
1941 BIRDS, ARGENTINA, CONTAMINATION, COASTS, *TIERRA DEL FUEGO, *PENGUINS, *MORTALITY,
1973 BIRDS, BIOLOGICAL EFFECTS, FUEL OIL, *HATCHABILITY, *COMMON EIDER EGGS,
2002 BIRDS, OIL SPILLS, REFINERIES, OIL TRANSPORT, OFFSHORE PRODUCTION, POLLUTION CONTROL, TOXICITY, FISHERIES, NORTH SEA,
2013 BIRDS, BASELINE STUDIES, ALASKA, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, OCS, MARINE MAMMALS,
2015 BIRDS, ARCTIC, ALASKA, HABITAT, SHORELINES, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, *SHOREBIRD SPECIES,
2016 BIRDS, BASELINE STUDIES, ALASKA, SHORELINES, OFFSHORE DEVELOPMENT, OIL SPILLS, ENVIRONMENTAL EFFECTS,
1676 BLM, BASELINE STUDIES, ALASKA COAST, MONITORING, ENVIRONMENTAL EFFECTS, OFFSHORE DEVELOPMENT, OCS, INFORMATION SYSTEMS, NOAA,
2043 BLM, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, OCS,
1652 BLOWOUT PREVENTION, NORTH SEA, NORWAY, *RED ADAIR CO.,
1864 BLOWOUT PREVENTION, PERSONNEL TRAINING, *BLOWOUT SCHOOL,
1893 BLOWOUT PREVENTION, DRILLING , DESIGN-ENGINEERING, PATENT,
1897 BLOWOUT PREVENTION, POLLUTION CONTROL, *SLIP RINGS, *EQUIPMENT,
1642 BLOWOUTS, POLLUTION CONTROL, NORTH SEA, NORWAY, *EMERGENCY VESSEL,
1644 BLOWOUTS, OIL WELLS, LOUISIANA, *GAS-WELLS,
1645 BLOWOUTS, OIL SPILLS, NORWAY, *PREDICTION,
1744 BLOWOUTS, SPILL RECOVERY, BOOMS, NORTH SEA, NORWAY,
1904 BLOWOUTS, STATISTICAL ANALYSIS, ENVIRONMENTAL PROTECTION, ECONOMIC EFFECTS, NORTH SEA,
1732 BOOMS, SPILL CONTAINMENT, HARBORS, INLAND, *PRODUCT INFORMATION,
1733 BOOMS, SPILL CONTAINMENT, DESIGN-ENGINEERING, *OILFENCE,
1735 BOOMS, SPILL CONTAINMENT, DESIGN-ENGINEERING, *PRODUCT INFORMATION,
1736 BOOMS, SPILL CONTAINMENT, DESIGN-ENGINEERING, PATENT, *CONNECTOR HINGE,
1737 BOOMS, SPILL CONTAINMENT, SKIMMERS, DESIGN-ENGINEERING, PATENT,
1738 BOOMS, BEHAVIOR, SPILL CONTAINMENT, OIL SLICKS, *SLICK DROPLET FORMATION, *ENTRAINMENT FAILURE,
1739 BOOMS, SPILL CONTAINMENT, DESIGN-ENGINEERING, FRESHWATER, OCEANS,
1740 BOOMS, SPILL CONTAINMENT, DESIGN-ENGINEERING, PATENT,
1741 BOOMS, SPILL CONTAINMENT, DESIGN-ENGINEERING, *SEABOOM,
1744 BOOMS, BLOWOUTS, SPILL RECOVERY, NORTH SEA, NORWAY,
1750 BOOMS, ABSORPTION, SPILL RECOVERY, SKIMMERS, SHIPS,
1752 BOOMS, DISPERSANTS, OIL SLICKS, SPILL CLEANUP, *PUMPS,
1774 BOOMS, SPILL RECOVERY, PATENT,
1786 BOOMS, SPILL RECOVERY, SKIMMERS, DESIGN-ENGINEERING, PATENT,
1991 CALIFORNIA, OIL SPILLS, INLAND, ECONOMICS, SPILL CLEANUP, RESTORATION,
1722 CALIFORNIA/SOUTHERN, BIODEGRADATION, CHEMICAL ANALYSIS, NATURAL SEEPAGE, WEATHERING, CHROMATOGRAPHY, SPECTROMETRY, SANTA BARBARA CHANNEL,
1685 CALIFORNIA/SOUTHERN, CONTINGENCY PLANNING, OIL INDUSTRY, OIL-GAS LEASING, OCS,
2028 CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING, EIS, ENVIRONMENTAL EFFECTS,
2029 CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING, EIS, ENVIRONMENTAL EFFECTS, OFFSHORE DEVELOPMENT,
2030 CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING, EIS, ENVIRONMENTAL EFFECTS,
2031 CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING, EIS, ENVIRONMENTAL EFFECTS, OFFSHORE DEVELOPMENT,
2032 CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING, OFFSHORE DEVELOPMENT, EIS, ENVIRONMENTAL EFFECTS,
2041 CALIFORNIA/SOUTHERN, OFFSHORE DRILLING, PLATFORMS, UPTAKE, MARINE ORGANISMS, SEDIMENTS,
1638 CANADA, ARCTIC OCEAN, ENVIRONMENTAL PROTECTION, CONTINGENCY PLANNING,
1646 CANADA, ATLANTIC OCEAN, TAR, OCEANS, DISTRIBUTION, SARGASSO SEA,
1708 CANADA, ATLANTIC COAST, HYDROCARBONS, CHEMICAL ANALYSIS, CHROMATOGRAPHY, SPECTROSCOPY, DETECTION,
1754 CANADA, SPILL CLEANUP, SPILL CONTAINMENT, *EQUIPMENT LOCATER SYSTEM,
1630 CANADA, WASTEWATER TREATMENT, INDUSTRIES, OIL-WATER SEPARATION, RECLAMATION, REUSE,
1634 CANADA, WASTEWATER TREATMENT, OIL-WATER SEPARATION, FILTRATION, REFINERIES, *DUAL-MEDIA FILTERS,
1923 CANADA, BIOLOGICAL EFFECTS, MICROORGANISMS, CRUDE OIL, FUEL OIL, *GEORGIA STRAIT,

NWMAR116900

*HETEROTROPHIC POTENTIAL, *PRODUCTIVITY,
1959 CANADA, HYDROCARBONS, METABOLISM, DETECTION, MONITORING, MARINE ORGANISMS, *ENZYME ACTIVITY,
1966 CANADA, BIOLOGICAL EFFECTS, CRUDE OIL, *INSECTS, *CHIRONOMID LARVAE,
1977 CANADA, OIL SPILLS, TOXICITY, MARINE ORGANISMS, INTERTIDAL ZONE, CHEDABUCTO BAY, *MORTALITIES,
1992 CANADA, TANKERS, OIL SPILLS, LEGISLATION, ECONOMIC EFFECTS, ENVIRONMENTAL EFFECTS,
2034 CANADA, ARCTIC, OFFSHORE EXPLORATION, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, ICE, OIL INDUSTRY,
2036 CANADA, TAR SANDS, DEVELOPMENT , EXTRACTION, ENVIRONMENTAL PROTECTION, *ALBERTA,
2082 CANADA, BIODEGRADATION, BACTERIA, CRUDE OIL, HYDROCARBONS, SOIL, *NUTRIENT ADDITION,
2117 CANADA, GUIDELINES, ENVIRONMENTAL PROTECTION, REFINERIES, WASTEWATER TREATMENT, *ALBERTA,
2118 CANADA, REGULATIONS, WASTEWATERS, REFINERIES, ENVIRONMENTAL PROTECTION, ECONOMICS, *QUEBEC,
2119 CANADA, LEGISLATION, LAW ENFORCEMENT, SHIPS, OIL SPILLS, ENGLAND,
2121 CANADA, REGULATIONS, POLLUTION CONTROL, WASTEWATERS, CONTAMINANTS, REFINERIES,
1699 CARCINOGENS, SAMPLING, PAH, DETECTION, MOLLUSKS, ESTUARIES, OREGON, *BIVALVES,
2011 CARCINOGENS, OIL SHALE, EXTRACTION, HEALTH HAZARDS, *BENZO(A)PYRENE,
2136 CARIBBEAN SEA, BIBLIOGRAPHIES, CONTAMINATION, MARINE ORGANISMS,
1720 CASPIAN SEA, ANALYTICAL TECHNIQUES, CONTAMINATION, *OPTICAL EMISSION, *SEA SURFACE,
2060 CASPIAN SEA, BIODEGRADATION, BACTERIA, FUEL OIL, PETROLEUM PRODUCTS, OXIDATION,
1977 CHEDABUCTO BAY, CANADA, OIL SPILLS, TOXICITY, MARINE ORGANISMS, INTERTIDAL ZONE, *MORTALITIES,
1070 CHEMICAL ANALYSIS, MONITORING, OIL SPILLS, WASTE OIL, *IR ABSORPTION ,
1090 CHEMICAL ANALYSIS, REMOTE SENSING, PETROLEUM PRODUCTS, DETECTION, SPECTROSCOPY, *COMPUTERIZED RAMAN SPECTROSCOPY ,
1698 CHEMICAL ANALYSIS, SAMPLING, HYDROCARBONS, SEAWATER, OIL-GAS LEASING, MEXICO/GULF OF, *SEASONAL VARIATIONS, *MAFLA LEASE AREA,
1703 CHEMICAL ANALYSIS, OIL SLICKS, PETROLEUM PRODUCTS, SEAWATER, *SORBENTS,
1704 CHEMICAL ANALYSIS, SEDIMENTS, OFFSHORE PRODUCTION, VENEZUELA, STATISTICAL ANALYSIS,
1705 CHEMICAL ANALYSIS, HYDROCARBONS, FUEL OIL, SEAWATER, CHROMATOGRAPHY, *WATER-SOLUBLE FRACTION,
1707 CHEMICAL ANALYSIS, AROMATIC HYDROCARBONS , SEAWATER, *ELECTROCHEMICAL ANALYSIS ,
1708 CHEMICAL ANALYSIS, CANADA, ATLANTIC COAST, HYDROCARBONS, CHROMATOGRAPHY, SPECTROSCOPY, DETECTION,
1709 CHEMICAL ANALYSIS, HYDROCARBONS, SURFACTANTS, DETECTION, CONTAMINANTS, ENVIRONMENTAL PROTECTION,
1710 CHEMICAL ANALYSIS, HYDROCARBONS, CHROMATOGRAPHY, SPECTROMETRY, ZOOPLANKTON, CRUSTACEANS, SEDIMENTS,
1712 CHEMICAL ANALYSIS, SOURCES, CONTAMINATION, FISH, PETROLEUM PRODUCTS, GREAT LAKES ,
1714 CHEMICAL ANALYSIS, BASELINE STUDIES, CHROMATOGRAPHY, SPECTROSCOPY, DETECTION, HYDROCARBONS, MARINE ORGANISMS,
1715 CHEMICAL ANALYSIS, SOURCES, HYDROCARBONS, MARINE ORGANISMS, CHROMATOGRAPHY, SPECTROSCOPY, SPECTROMETRY,
1717 CHEMICAL ANALYSIS, AROMATIC HYDROCARBONS , CHROMATOGRAPHY, HYDROCARBONS, MONITORING, SEDIMENTS, *GLASS CAPILLARY COLUMNS,
1718 CHEMICAL ANALYSIS, *OIL IN WATER ,
1719 CHEMICAL ANALYSIS, DISPERSANTS, SURFACTANTS,
1721 CHEMICAL ANALYSIS, PETROLEUM PRODUCTS, SOIL,
1722 CHEMICAL ANALYSIS, CALIFORNIA/SOUTHERN, BIODEGRADATION, NATURAL SEEPAGE, WEATHERING, CHROMATOGRAPHY, SPECTROMETRY, SANTA BARBARA CHANNEL,
1723 CHEMICAL ANALYSIS, OIL SPILLS, SOURCE IDENTIFICATION,
1726 CHEMICAL ANALYSIS, ADSORPTION, PETROLEUM PRODUCTS, HYDROCARBONS, SEAWATER, SURFACTANTS, *ELECTROANALYSIS ,
1846 CHEMICAL ANALYSIS, WASTEWATER TREATMENT, REFINERIES, EPA, *ANALYTICAL VARIABILITY,
2004 CHEMICAL ANALYSIS, DETECTION, SPILL CLEANUP,
2026 CHEMICAL ANALYSIS, PETROCHEMICALS, WASTEWATER TREATMENT, POLLUTION CONTROL, NORWAY,
2038 CHEMICAL ANALYSIS, BASELINE STUDIES, ATLANTIC COAST, OCS, OFFSHORE DEVELOPMENT, HYDROCARBONS,
2093 CHEMICAL ANALYSIS, BIOLOGICAL EFFECTS, BIODEGRADATION, AROMATIC HYDROCARBONS , OIL SPILLS, WEATHERING, FISH, NORWAY, *T/T "DRUPA" SPILL,
2135 CHEMICAL ANALYSIS, BIBLIOGRAPHIES, DETECTION, SAMPLING, MONITORING, REMOTE SENSING,
1673 CHEMICAL EFFECTS, BIOLOGICAL EFFECTS, ALASKA, MONITORING, FATE, CRUDE OIL, MOVEMENT, MICROORGANISMS, *PERMAFROST TERRAIN,
1660 CHESAPEAKE BAY, ARGO MERCHANT SPILL, MONITORING,
1937 CHESAPEAKE BAY, BIRDS, BIOLOGICAL EFFECTS, OIL SPILLS, MARSHES, MARINE ORGANISMS, MOLLUSKS, *MARSH GRASSES,
1677 CHROMATOGRAPHY, MONITORING, SOURCE IDENTIFICATION, DESIGN-ENGINEERING, *INSTRUMENT SURVEY,
1705 CHROMATOGRAPHY, CHEMICAL ANALYSIS, HYDROCARBONS, FUEL OIL, SEAWATER, *WATER-SOLUBLE FRACTION,
1708 CHROMATOGRAPHY, CHEMICAL ANALYSIS, CANADA, ATLANTIC COAST, HYDROCARBONS, SPECTROSCOPY, DETECTION,
1710 CHROMATOGRAPHY, CHEMICAL ANALYSIS, HYDROCARBONS, SPECTROMETRY, ZOOPLANKTON,

NWMAR116901

CRUSTACEANS, SEDIMENTS,
1711 CHROMATOGRAPHY, BEACHES, ANALYTICAL TECHNIQUES, ABSORPTION, HYDROCARBONS, SEAWATER, SPECTROSCOPY,
1714 CHROMATOGRAPHY, CHEMICAL ANALYSIS, BASELINE STUDIES, SPECTROSCOPY, DETECTION, HYDROCARBONS, MARINE ORGANISMS,
1715 CHROMATOGRAPHY, CHEMICAL ANALYSIS, SOURCES, HYDROCARBONS, MARINE ORGANISMS, SPECTROSCOPY, SPECTROMETRY,
1717 CHROMATOGRAPHY, CHEMICAL ANALYSIS, AROMATIC HYDROCARBONS , HYDROCARBONS, MONITORING, SEDIMENTS, *GLASS CAPILLARY COLUMNS,
1722 CHROMATOGRAPHY, CHEMICAL ANALYSIS, CALIFORNIA/SOUTHERN, BIODEGRADATION, NATURAL SEEPAGE, WEATHERING, SPECTROMETRY, SANTA BARBARA CHANNEL,
1725 CHROMATOGRAPHY, ANALYTICAL TECHNIQUES, HYDROCARBONS, SEDIMENTS, SPECTROSCOPY, *INTERCALIBRATION,
1672 CHRONIC EFFECTS, AUSTRALIA, MONITORING, HYDROCARBONS, SOURCES, DISTRIBUTION, *MYTILUS EDULIS, *INDICATOR SPECIES,
1918 CHRONIC EFFECTS, BIRDS, BIOLOGICAL EFFECTS, *SEABIRDS, OIL SPILLS, OIL SLICKS,
1938 CHRONIC EFFECTS, CRUDE OIL, TOXICITY, FISH, *TROUT REPRODUCTION,
1939 CHRONIC EFFECTS, AEGEAN SEA, CONTAMINATION, PHYTOPLANKTON,
1949 CHRONIC EFFECTS, TOXICITY, FISH, FRESHWATER, LUBRICATING OIL, *SYNTHETIC OIL,
2005 CHRONIC EFFECTS, HYDROCARBONS, ENVIRONMENTAL EFFECTS, MARINE ORGANISMS, CONTAMINATION, OIL SPILLS,
1814 COALESCENCE, WASTEWATER TREATMENT, EMULSIONS, WASTE OIL,
1815 COALESCENCE, OIL-WATER SEPARATION, SHIPS, FLOTATION, DESIGN-ENGINEERING, PATENT,
1826 COALESCENCE, OIL-WATER SEPARATION, EMULSIONS, PATENT, *CELLULOSE PULP,
1838 COALESCENCE, OIL-WATER SEPARATION, PATENT, *ULTRASONICS,
1839 COALESCENCE, WASTEWATER TREATMENT, OIL-WATER SEPARATION, DESIGN-ENGINEERING,
1841 COALESCENCE, OIL-WATER SEPARATION, WASTEWATER TREATMENT, DESIGN-ENGINEERING, *GRAVITY SEPARATION ,
1002 COALESCENCE, WASTEWATER TREATMENT, OIL-WATER SEPARATION, WASTEWATERS,
1071 COALESCENCE, WASTEWATER TREATMENT, EMULSIONS, OIL-WATER SEPARATION,
1073 COALESCENCE, WASTE OIL, LUBRICATING OIL, RECYCLING, FILTRATION,
1056 COASTS, URQUIOLA SPILL, FATE, POLLUTION CONTROL, SPILL CLEANUP, SPAIN,
1057 COASTS, ALASKA, OIL SPILLS, OCEANS, STATISTICS,
1091 COASTS, REMOTE SENSING, OIL SLICKS, DETECTION, MONITORING, NATURAL SEEPAGE, *LANDSAT DATA,
1095 COASTS, REMOTE SENSING, OIL SLICKS, MOVEMENT, WASTEWATERS, *CURRENT CIRCULATION, *SATELLITE-AIRCRAFT-DROGUE STUDIES,
1791 COASTS, BEACHES, ABSORPTION, SPILL CLEANUP, DISPERSANTS, DISPOSAL , MARSHES, SEAWATER, FRESHWATER,
1941 COASTS, BIRDS, ARGENTINA, CONTAMINATION, *TIERRA DEL FUEGO, *PENGUINS, *MORTALITY,
1961 COASTS, BIOLOGICAL EFFECTS, BENTHOS, POLLUTION CONTROL, *PELAGIC ORGANISMS,
2001 COASTS, ATLANTIC OCEAN, ARGO MERCHANT SPILL, DISTRIBUTION, ENVIRONMENTAL EFFECTS,
2042 COASTS, OFFSHORE DRILLING, ENVIRONMENTAL EFFECTS, CONTAMINANTS, FISH,
2046 COASTS, OFFSHORE DEVELOPMENT, ENVIRONMENTAL MANAGEMENT, GUIDELINES, *CZM,
2049 COASTS, CONTAMINATION, ESTUARIES, DEVELOPMENT , OIL INDUSTRY,
2052 COASTS, OFFSHORE DEVELOPMENT, OCS, ONSHORE IMPACTS, ENVIRONMENTAL EFFECTS, POLLUTION PREVENTION,
2053 COASTS, OIL INDUSTRY, ENVIRONMENTAL MANAGEMENT, LOUISIANA, LEGISLATION, US,
2055 COASTS, OFFSHORE DEVELOPMENT, OCS, US, ENVIRONMENTAL EFFECTS, SOCIO-ECONOMIC EFFECTS, STATE GOVERNMENTS,
2109 COASTS, LEGISLATION, US, OCS, OFFSHORE DEVELOPMENT, REFINERIES, ENVIRONMENTAL EFFECTS,
1059 COMPENSATION, LEGISLATION, NEW JERSEY, SPILL CLEANUP, OIL INDUSTRY, *SPILL FUND,
1908 COMPENSATION, LEGISLATION, LIABILITY, TANKERS, OIL SPILLS, OIL INDUSTRY, *SPILL SUPERFUNDS,
2108 COMPENSATION, LEGISLATION, US, OIL SPILLS, LIABILITY, SPILL CLEANUP, *COSTS,
1667 CONTAMINANTS, ANALYTICAL TECHNIQUES, MONITORING, SAMPLING,
1692 CONTAMINANTS, REMOTE SENSING, ENVIRONMENTAL EFFECTS, MONITORING, OIL SPILLS,
1709 CONTAMINANTS, CHEMICAL ANALYSIS, HYDROCARBONS, SURFACTANTS, DETECTION, ENVIRONMENTAL PROTECTION,
1763 CONTAMINANTS, ABSORPTION, PATENT, *OIL-ABSORBENT COMPOUND,
1816 CONTAMINANTS, WASTEWATER TREATMENT, REFINERIES, EXTRACTION, SOLVENTS,
1813 CONTAMINANTS, CRUDE OIL, INDUSTRIES, DISPOSAL , GROUNDWATER, ENVIRONMENTAL EFFECTS,
1855 CONTAMINANTS, REFINERIES, WASTEWATERS, SOLID WASTES, DISPOSAL , INLAND, *WASTE DISPOSAL PRACTICES, *LANDFILLS,
2007 CONTAMINANTS, FUELS, PRODUCTION , ENVIRONMENTAL EFFECTS,
2042 CONTAMINANTS, COASTS, OFFSHORE DRILLING, ENVIRONMENTAL EFFECTS, FISH,
2121 CONTAMINANTS, CANADA, REGULATIONS, POLLUTION CONTROL, WASTEWATERS, REFINERIES,
1702 CONTAMINATION, OCEANS, PETROLEUM PRODUCTS, *LASER RADAR, *SEA SURFACE,
1712 CONTAMINATION, CHEMICAL ANALYSIS, SOURCES, FISH, PETROLEUM PRODUCTS, GREAT LAKES ,
1720 CONTAMINATION, CASPIAN SEA, ANALYTICAL TECHNIQUES, *OPTICAL EMISSION, *SEA SURFACE,
1729 CONTAMINATION, SOURCE IDENTIFICATION, GROUNDWATER, OIL WELLS, PRODUCTION . WASTEWATERS, *BRINE DISPOSAL,
1759 CONTAMINATION, ADSORPTION, FUEL OIL, FRESHWATER, *ACTIVATED CARBON, *WATER SUPPLY,
1765 CONTAMINATION, ABSORPTION, OIL TANKS, PATENT, *CLEANUP ,
1793 CONTAMINATION, RESTORATION, VEGETATION, MARSHES, WASTEWATERS, REFINERIES, ENGLAND,

NWMAR116902

*SALT MARSH,
1930 CONTAMINATION, PLANTS, CRUDE OIL, TOXICITY, *OLNEY BULRUSH, *MARSHHAY CORDGRASS,
1939 CONTAMINATION, CHRONIC EFFECTS, AEGEAN SEA, PHYTOPLANKTON,
1941 CONTAMINATION, COASTS, BIRDS, ARGENTINA, *TIERRA DEL FUEGO, *PENGUINS, *MORTALITY,
1944 CONTAMINATION, BIOLOGICAL EFFECTS, FUEL OIL, OIL SPILLS, MARSHES, CRUSTACEANS, MASSACHUSETTS, *UCA PUGNAX,
1950 CONTAMINATION, BIOLOGICAL EFFECTS, CORAL REEFS, RED SEA, ISRAEL, *SUCCESSION, *RECOLONIZATION,
1954 CONTAMINATION, FISH, CRUDE OIL, ESTUARIES, *FIN ROT, *MULLET,
1967 CONTAMINATION, ATLANTIC COAST, OIL DISCHARGES, HYDROCARBONS, PHYTOPLANKTON, OCS,
1982 CONTAMINATION, BIOLOGICAL EFFECTS, BALTIC SEA,
1998 CONTAMINATION, BIOLOGICAL EFFECTS, SOURCES, SHIPS, EXPLORATION , PRODUCTION , SEABIRDS, MARINE ORGANISMS, FISHERIES, SPILL CLEANUP, DISPERSANTS,
2000 CONTAMINATION, BIOLOGICAL EFFECTS, OCEANS, SOURCES, POLLUTION CONTROL, MARINE ORGANISMS, DISPERSANTS,
2005 CONTAMINATION, CHRONIC EFFECTS, HYDROCARBONS, ENVIRONMENTAL EFFECTS, MARINE ORGANISMS, OIL SPILLS,
2008 CONTAMINATION, BIOLOGICAL EFFECTS, HYDROCARBONS, OCEANS, HEALTH HAZARDS, POLLUTION CONTROL,
2009 CONTAMINATION, FISHERIES, *SHELLFISH , ENVIRONMENTAL EFFECTS,
2035 CONTAMINATION, GROUNDWATER, DRILLING , OIL WELLS, *DRILLING FLUIDS, *WELL COMPLETION,
2049 CONTAMINATION, COASTS, ESTUARIES, DEVELOPMENT , OIL INDUSTRY,
2105 CONTAMINATION, FATE, SEAWATER, SPREADING, EVAPORATION, OXIDATION, SOLUTION, DISPERSIONS,
2136 CONTAMINATION, CARIBBEAN SEA, BIBLIOGRAPHIES, MARINE ORGANISMS,
1638 CONTINGENCY PLANNING, CANADA, ARCTIC OCEAN, ENVIRONMENTAL PROTECTION,
1757 CONTINGENCY PLANNING, SPILL RECOVERY, *RESPONSE TEAMS, US,
1883 CONTINGENCY PLANNING, PERSONNEL TRAINING, OIL SPILLS, POLLUTION CONTROL, *OIL SPILL CONTROL COURSE,
1885 CONTINGENCY PLANNING, CALIFORNIA/SOUTHERN, OIL INDUSTRY, OIL-GAS LEASING, OCS,
1886 CONTINGENCY PLANNING, SPILL CLEANUP, USCG, EPA,
1887 CONTINGENCY PLANNING, SPILL CLEANUP, PERSONNEL TRAINING, UK, US, EUROPE,
1898 CONTINGENCY PLANNING, SPILL CLEANUP, PUGET SOUND, OIL INDUSTRY, *OIL SPILL COOPERATIVE,
2122 CONTINGENCY PLANNING, MANUALS, POLLUTION PREVENTION, GUIDELINES, TANKERS,
1950 CORAL REEFS, CONTAMINATION, BIOLOGICAL EFFECTS, RED SEA, ISRAEL, *SUCCESSION, *RECOLONIZATION,
1635 COST ANALYSIS, EKOFISK BLOWOUT, OFFSHORE DRILLING, OFFSHORE EXPLORATION, NORWAY,
1769 COST ANALYSIS, ABSORPTION, SPILL RECOVERY, *SORBENTS, *PERFORMANCE EVALUATION,
1861 COST ANALYSIS, WASTEWATER TREATMENT, CRUDE OIL, REFINERIES, ECONOMICS, USSR,
1987 COST ANALYSIS, API, REGULATIONS, OIL INDUSTRY, POLLUTION CONTROL, WASTEWATER TREATMENT, REFINERIES,
1990 COST ANALYSIS, API, REGULATIONS, OIL INDUSTRY, POLLUTION CONTROL, ECONOMIC EFFECTS, EPA,
2018 COST ANALYSIS, OIL INDUSTRY, REGULATIONS, US, WATER QUALITY, POLLUTION PREVENTION,
2019 COST ANALYSIS, OIL INDUSTRY, REGULATIONS, POLLUTION PREVENTION, ECONOMIC EFFECTS,
1634 CRUDE OIL, OIL SPILLS, FATE, EKOFISK BLOWOUT,
1651 CRUDE OIL, ALASKA, OIL SPILLS, PIPELINES, *PUMP STATION ACCIDENT,
1653 CRUDE OIL, ALASKA, OIL SPILLS, PIPELINES, *PUMP STATION ACCIDENT,
1673 CRUDE OIL, CHEMICAL EFFECTS, BIOLOGICAL EFFECTS, ALASKA, MONITORING, FATE, MOVEMENT, MICROORGANISMS, *PERMAFROST TERRAIN,
1693 CRUDE OIL, REMOTE SENSING, PETROLEUM PRODUCTS, DETECTION, *SEA SURFACE, *RADAR,
1724 CRUDE OIL, ANALYTICAL TECHNIQUES, FUEL OIL, *OIL-GREASE DETERMINATION,
1727 CRUDE OIL, ANALYTICAL TECHNIQUES, SOURCE IDENTIFICATION, FUEL OIL, PETROLEUM PRODUCTS, SPECTROSCOPY,
1795 CRUDE OIL, TANKERS, STORAGE, ENVIRONMENTAL PROTECTION, FEA,
1797 CRUDE OIL, ALASKA, OIL TRANSPORT, PIPELINES, TEXAS, EIS, OIL SPILLS,
1798 CRUDE OIL, STORAGE, ENVIRONMENTAL EFFECTS, EIS, *SALT DOMES, OIL TANKS, *STRATEGIC PETROLEUM RESERVE,
1799 CRUDE OIL, STORAGE, ENVIRONMENTAL EFFECTS, EIS, *SALT DOMES, *MINES, *STRATEGIC PETROLEUM RESERVE,
1800 CRUDE OIL, STORAGE, ENVIRONMENTAL EFFECTS, EIS, LOUISIANA, *BAYOU CHOCTAW SALT DOME,
1818 CRUDE OIL, CONTAMINANTS, INDUSTRIES, DISPOSAL , GROUNDWATER, ENVIRONMENTAL EFFECTS,
1824 CRUDE OIL, OIL-WATER SEPARATION, EMULSIONS, PATENT,
1831 CRUDE OIL, EMULSIONS, OIL-WATER SEPARATION, PATENT,
1852 CRUDE OIL, EMULSIONS, OIL-WATER SEPARATION,
1861 CRUDE OIL, COST ANALYSIS, WASTEWATER TREATMENT, REFINERIES, ECONOMICS, USSR,
1875 CRUDE OIL, SPILL RECOVERY, WASTEWATER TREATMENT, OIL-WATER SEPARATION, FUELS,
1914 CRUDE OIL, ALGAE, TOXICITY, FUEL OIL,
1919 CRUDE OIL, BIOLOGICAL EFFECTS, BACTERIA, FUNGI, ICE, FRESHWATER, *OIL-UNDER-ICE ,
1920 CRUDE OIL, AROMATIC HYDROCARBONS , TOXICITY, CRUSTACEANS, *LARVAL DEVELOPMENT, *CANCER MAGISTER,
1921 CRUDE OIL, FUEL OIL, TOXICITY, POLYCHAETES, *REPRODUCTION,
1923 CRUDE OIL, CANADA, BIOLOGICAL EFFECTS, MICROORGANISMS, FUEL OIL, *GEORGIA STRAIT, *HETEROTROPHIC POTENTIAL, *PRODUCTIVITY,
1924 CRUDE OIL, BIOLOGICAL EFFECTS, BEAUFORT SEA, HYDROCARBONS, UPTAKE, MARINE MAMMALS,

NWMAR116903

*RINGED SEAL,
1926 CRUDE OIL, TOXICITY, CRUSTACEANS, *MISSISSIPPI SOUND, *COPEPODS,
1929 CRUDE OIL, UPTAKE, RELEASE, MOLLUSKS, *NAPHTHALENES, *RANGEA CUNEATA, *PROTOTHACA STAMINEA,
1930 CRUDE OIL, CONTAMINATION, PLANTS, TOXICITY, *OLNEY BULRUSH, *MARSHHAY CORDGRASS,
1931 CRUDE OIL, BIOLOGICAL EFFECTS, FISH, *FIN ROT, *MUGIL CEPHALUS,
1938 CRUDE OIL, CHRONIC EFFECTS, TOXICITY, FISH, *TROUT REPRODUCTION,
1940 CRUDE OIL, BENTHOS, TOXICITY, PLANKTON , OCS, *NEW YORK BIGHT, NEW YORK,
1948 CRUDE OIL, TOXICITY, PHYTOPLANKTON, ESTUARIES, *KUWAIT CRUDE,
1953 CRUDE OIL, BIOLOGICAL EFFECTS, CRUSTACEANS, *WATER-SOLUBLE FRACTION, *MOLTING LARVAE,
1954 CRUDE OIL, CONTAMINATION, FISH, ESTUARIES, *FIN ROT, *MULLET,
1955 CRUDE OIL, BIODEGRADATION, BACTERIA, ALGAE, PETROLEUM PRODUCTS, GASOLINE, TOXICITY, FRESHWATER, *PHOTOSYNTHESIS,
1960 CRUDE OIL, BIOLOGICAL EFFECTS, DISPERSIONS, METABOLISM, CRUSTACEANS, *SUBLETHAL EFFECTS, *ARCTIC AMPHIPOD,
1962 CRUDE OIL, FUEL OIL, TOXICITY, UPTAKE, RELEASE, MARINE ORGANISMS,
1963 CRUDE OIL, FUEL OIL, TOXICITY, HYDROCARBONS, METABOLISM, FISH,*RESPIRATION, *ONCORHYNCHUS GORBUSCHA,
1964 CRUDE OIL, TOXICITY, MARINE ORGANISMS, PETROLEUM PRODUCTS, *COMPARATIVE TOXICITY , *BIOASSAY,
1965 CRUDE OIL, BIBLIOGRAPHIES, HYDROCARBONS, TOXICITY, MOLLUSKS, SURFACTANTS, EMULSIFIERS, *MUSSELS,
1966 CRUDE OIL, CANADA, BIOLOGICAL EFFECTS, *INSECTS, *CHIRONOMID LARVAE,
1969 CRUDE OIL, BIOLOGICAL EFFECTS, ALGAE, PETROLEUM PRODUCTS, FUELS, *GROWTH, *REPRODUCTION, *FUCUS EDENTATUS DE LA PYL,
1973 CRUDE OIL, BIOLOGICAL EFFECTS, SEAWATER, SEDIMENTS, MOLLUSKS, *WATER-SOLUBLE FRACTION, *OIL-TREATED SEDIMENT, *MACOMA BALTHICA,
1980 CRUDE OIL, ARCTIC, TOXICITY, PHYTOPLANKTON, FRESHWATER, *PRIMARY PRODUCTION,
1986 CRUDE OIL, BIOLOGICAL EFFECTS, MARINE MAMMALS, *THERMAL CONDUCTANCE, *SEA OTTERS, *PINNIPEDS,
2005 CRUDE OIL, AROMATIC HYDROCARBONS , OFFSHORE DEVELOPMENT, FISHERIES, NORTH SEA,
2022 CRUDE OIL, ALASKA, OFFSHORE DRILLING, SOCIO-ECONOMIC EFFECTS, OCS, *SEA GRANT PROGRAM, *ENERGY POLICY,
2045 CRUDE OIL, ALASKA, OFFSHORE DEVELOPMENT, OCS, ENVIRONMENTAL EFFECTS, OIL-GAS LEASING,
2058 CRUDE OIL, BIODEGRADATION, BEAUFORT SEA, ARCTIC, MICROORGANISMS,
2059 CRUDE OIL, BIODEGRADATION, BACTERIA, PETROLEUM PRODUCTS, PATENT, *NUTRIENT ADDITION,
2067 CRUDE OIL, BIODEGRADATION, OXIDATION, UPTAKE, *TEMPERATURE EFFECTS,
2073 CRUDE OIL, BIODEGRADATION, BACTERIA, DISPERSANTS,
2077 CRUDE OIL, BIODEGRADATION, BEAUFORT SEA, HYDROCARBONS, ICE, SEDIMENTS, SEAWATER,
2078 CRUDE OIL, BIODEGRADATION, TOXICITY, ECHINODERMS, *EKOFISK OIL,
2082 CRUDE OIL, CANADA, BIODEGRADATION, BACTERIA, HYDROCARBONS, SOIL, *NUTRIENT ADDITION,
2084 CRUDE OIL, EMULSIONS, PHYSICAL EFFECTS, *SUSPENDED SOLIDS, *STABILITY,
2100 CRUDE OIL, ADSORPTION, HYDROCARBONS, SOIL, *DESORPTION, *ORGANIC MATTER CONTENT,
1710 CRUSTACEANS, CHROMATOGRAPHY, CHEMICAL ANALYSIS, HYDROCARBONS, SPECTROMETRY, ZOOPLANKTON, SEDIMENTS,
1915 CRUSTACEANS, BIOLOGICAL EFFECTS, AROMATIC HYDROCARBONS , ESTUARIES, *COPEPOD,
1920 CRUSTACEANS, CRUDE OIL, AROMATIC HYDROCARBONS , TOXICITY, *LARVAL DEVELOPMENT, *CANCER MAGISTER,
1926 CRUSTACEANS, CRUDE OIL, TOXICITY, *MISSISSIPPI SOUND, *COPEPODS,
1935 CRUSTACEANS, HYDROCARBONS, PLANKTON , UPTAKE, RELEASE, *14C-1-NAPHTHALENE, *COPEPODS,
1944 CRUSTACEANS, CONTAMINATION, BIOLOGICAL EFFECTS, FUEL OIL, OIL SPILLS, MARSHES, MASSACHUSETTS, *UCA PUGNAX,
1945 CRUSTACEANS, BIOLOGICAL EFFECTS, FUEL OIL, METABOLISM, *TEMPERATURE, *SALINITY, *LIMULUS POLYPHEMUS,
1953 CRUSTACEANS, CRUDE OIL, BIOLOGICAL EFFECTS, *WATER-SOLUBLE FRACTION, *MOLTING LARVAE,
1960 CRUSTACEANS, CRUDE OIL, BIOLOGICAL EFFECTS, DISPERSIONS, METABOLISM, *SUBLETHAL EFFECTS, *ARCTIC AMPHIPOD,
1974 CRUSTACEANS, HYDROCARBONS, FUEL OIL, UPTAKE, METABOLISM, *NAPHTHALENES, *HATCHING, *LARVAL GROWTH, *GRASS SHRIMP,
2107 DECOMPOSITION, BIODEGRADATION, FUEL OIL, MICROORGANISMS, *PHYSICOCHEMICAL DEGRADATION,
1660 DELAWARE, BIRDS, TANKERS, OLYMPIC GAMES SPILL, SPILL CLEANUP, *DELAWARE RIVER,
2048 DELAWARE, ATLANTIC COAST, OFFSHORE DEVELOPMENT, PORTS, ENVIRONMENTAL EFFECTS, FISHERIES, NEW JERSEY,
2087 DELAWARE BAY, OIL SPILLS, MODELS, WEATHERING, EVAPORATION, OIL TRANSFER,
1669 DESIGN-ENGINEERING, MONITORING, POLLUTION CONTROL,
1674 DESIGN-ENGINEERING, MONITORING, OIL SPILLS, DETECTION, *BUOYS, *GAS SENSORS,
1677 DESIGN-ENGINEERING, CHROMATOGRAPHY, MONITORING, SOURCE IDENTIFICATION, *INSTRUMENT SURVEY,
1680 DESIGN-ENGINEERING, MONITORING, OIL DISCHARGES, TANKERS, REGULATIONS, PATENT,
1684 DESIGN-ENGINEERING, BILGES, MONITORING, SHIPS, DETECTION,
1685 DESIGN-ENGINEERING, BILGES, MONITORING, *TOTAL ORGANIC CARBON DETERMINATION,
1733 DESIGN-ENGINEERING, BOOMS, SPILL CONTAINMENT, *OILFENCE,
1735 DESIGN-ENGINEERING, BOOMS, SPILL CONTAINMENT, *PRODUCT INFORMATION,
1736 DESIGN-ENGINEERING, BOOMS, SPILL CONTAINMENT, PATENT, *CONNECTOR HINGE,
1737 DESIGN-ENGINEERING, BOOMS, SPILL CONTAINMENT, SKIMMERS, PATENT,

NWMAR116904

1739 DESIGN-ENGINEERING, BOOMS, SPILL CONTAINMENT, FRESHWATER, OCEANS,
1740 DESIGN-ENGINEERING, BOOMS, SPILL CONTAINMENT, PATENT,
1741 DESIGN-ENGINEERING, BOOMS, SPILL CONTAINMENT, *SEABOOM,
1742 DESIGN-ENGINEERING, SPILL RECOVERY, OIL TRANSPORT, *DRACONE BARGE,
1743 DESIGN-ENGINEERING, ABSORPTION, SPILL RECOVERY, USN, *FOAM CHIPS,
1747 DESIGN-ENGINEERING, SPILL RECOVERY, RECLAMATION,
1748 DESIGN-ENGINEERING, SKIMMERS, SPILL RECOVERY,
1751 DESIGN-ENGINEERING, SPILL RECOVERY, NORTH SEA, *OIL COLLECTION SYSTEMS,
1753 DESIGN-ENGINEERING, SPILL CLEANUP, *OIL-SPILL PUMP,
1755 DESIGN-ENGINEERING, SPILL RECOVERY, SKIMMERS, *SKIMJET,
1756 DESIGN-ENGINEERING, SKIMMERS, SPILL RECOVERY,
1758 DESIGN-ENGINEERING, SPILL RECOVERY, SKIMMERS, *SEAWARD INTERNATIONAL,
1761 DESIGN-ENGINEERING, SPILL RECOVERY, SKIMMERS, *FAST CURRENT OIL RECOVERY ,
1762 DESIGN-ENGINEERING, SPILL RECOVERY, PATENT,
1767 DESIGN-ENGINEERING, SPILL RECOVERY, *LOCKHEED DISC-DRUM DEVICE, *PERFORMANCE,
1772 DESIGN-ENGINEERING, DISPERSIONS, OIL-WATER SEPARATION, SPILL CLEANUP, PATENT,
1775 DESIGN-ENGINEERING, SPILL RECOVERY, SKIMMERS,
1779 DESIGN-ENGINEERING, OIL SLICKS, DISPERSANTS, SPILL CLEANUP, PATENT,
1785 DESIGN-ENGINEERING, OIL SLICKS, SPILL RECOVERY, PATENT,
1786 DESIGN-ENGINEERING, BOOMS, SPILL RECOVERY, SKIMMERS, PATENT,
1788 DESIGN-ENGINEERING, OIL SLICKS, SPILL RECOVERY, SKIMMERS, SHIPS, PATENT,
1796 DESIGN-ENGINEERING, STORAGE, TANKERS, PATENT, *OIL STORAGE TANK,
1805 DESIGN-ENGINEERING, WASTEWATER TREATMENT, OIL-WATER SEPARATION, EMULSIONS, FLOTATION,
1809 DESIGN-ENGINEERING, WASTEWATER TREATMENT, WASTE OIL, PATENT, *COLLECTION RESERVOIR,
1815 DESIGN-ENGINEERING, COALESCENCE, OIL-WATER SEPARATION, SHIPS, FLOTATION, PATENT,
1827 DESIGN-ENGINEERING, OIL-WATER SEPARATION, SLUDGE, GASOLINE, WASTEWATERS, PATENT,
1839 DESIGN-ENGINEERING, COALESCENCE, WASTEWATER TREATMENT, OIL-WATER SEPARATION,
1841 DESIGN-ENGINEERING, COALESCENCE, OIL-WATER SEPARATION, WASTEWATER TREATMENT, *GRAVITY SEPARATION ,
1844 DESIGN-ENGINEERING, WASTEWATER TREATMENT, REFINERIES, FILTRATION, SOLID WASTES, OHIO, *UPFLOW SAND FILTERS,
1845 DESIGN-ENGINEERING, OIL-WATER SEPARATION, SKIMMERS, FLOTATION, PATENT,
1860 DESIGN-ENGINEERING, WASTE OIL TREATMENT, EMULSIONS, REFINERIES,
1868 DESIGN-ENGINEERING, POLLUTION PREVENTION, OFFSHORE DRILLING, EMULSIONS, *DRILLING MUDS,
1893 DESIGN-ENGINEERING, BLOWOUT PREVENTION, DRILLING , PATENT,
1895 DESIGN-ENGINEERING, PIPELINES, LEAKAGE, POLLUTION PREVENTION, PATENT,
1901 DESIGN-ENGINEERING, LEAKAGE, PIPELINES, DETECTION, PATENT,
1674 DETECTION, DESIGN-ENGINEERING, MONITORING, OIL SPILLS, *BUOYS, *GAS SENSORS,
1683 DETECTION, MONITORING, DISPERSIONS, PATENT, *OIL SOLUBLE DYE,
1684 DETECTION, DESIGN-ENGINEERING, BILGES, MONITORING, SHIPS,
1686 DETECTION, MONITORING, LEAKAGE, PIPELINES,
1690 DETECTION, CHEMICAL ANALYSIS, REMOTE SENSING, PETROLEUM PRODUCTS, SPECTROSCOPY, *COMPUTERIZED RAMAN SPECTROSCOPY ,
1691 DETECTION, COASTS, REMOTE SENSING, OIL SLICKS, MONITORING, NATURAL SEEPAGE, *LANDSAT DATA,
1693 DETECTION, CRUDE OIL, REMOTE SENSING, PETROLEUM PRODUCTS, *SEA SURFACE, *RADAR,
1694 DETECTION, REMOTE SENSING, OIL SLICKS, SURVEILLANCE, NATURAL SEEPAGE, SANTA BARBARA CHANNEL, *COASTAL ZONE COLOR SCANNER,
1699 DETECTION, CARCINOGENS, SAMPLING, PAH, MOLLUSKS, ESTUARIES, OREGON, *BIVALVES,
1701 DETECTION, ANALYTICAL TECHNIQUES, OIL-WATER SEPARATION, PATENT, *OIL-IN-WATER, *FLUORESCENCE,
1708 DETECTION, CHROMATOGRAPHY, CHEMICAL ANALYSIS, CANADA, ATLANTIC COAST, HYDROCARBONS, SPECTROSCOPY,
1709 DETECTION, CONTAMINANTS, CHEMICAL ANALYSIS, HYDROCARBONS, SURFACTANTS, ENVIRONMENTAL PROTECTION,
1714 DETECTION, CHROMATOGRAPHY, CHEMICAL ANALYSIS, BASELINE STUDIES, SPECTROSCOPY, HYDROCARBONS, MARINE ORGANISMS,
1894 DETECTION, LEAKAGE, PIPELINES, PATENT,
1899 DETECTION, PRODUCTION , POLLUTION PREVENTION, OIL SPILLS, LEAKAGE, PIPELINES,
1901 DETECTION, DESIGN-ENGINEERING, LEAKAGE, PIPELINES, PATENT,
1959 DETECTION, CANADA, HYDROCARBONS, METABOLISM, MONITORING, MARINE ORGANISMS, *ENZYME ACTIVITY,
2004 DETECTION, CHEMICAL ANALYSIS, SPILL CLEANUP,
2135 DETECTION, CHEMICAL ANALYSIS, BIBLIOGRAPHIES, SAMPLING, MONITORING, REMOTE SENSING,
2036 DEVELOPMENT , CANADA, TAR SANDS, EXTRACTION, ENVIRONMENTAL PROTECTION, *ALBERTA,
2049 DEVELOPMENT , CONTAMINATION, COASTS, ESTUARIES, OIL INDUSTRY,
2129 DEVELOPMENT , BIBLIOGRAPHIES, OIL SHALE, EXTRACTION, ENVIRONMENTAL EFFECTS,
2130 DEVELOPMENT , BIBLIOGRAPHIES, OIL SHALE, EXTRACTION, ENVIRONMENTAL EFFECTS,
2131 DEVELOPMENT , BIBLIOGRAPHIES, OIL SHALE, EXTRACTION, ENVIRONMENTAL EFFECTS, POLLUTION CONTROL,
2132 DEVELOPMENT , BIBLIOGRAPHIES, OIL SHALE, EXTRACTION, ENVIRONMENTAL EFFECTS, POLLUTION CONTROL,
1650 DISPERSANTS, SPILL CLEANUP, UK, *OIL SPILL POLICY,
1666 DISPERSANTS, FISH, TOXICITY, TROPICAL REGIONS, JAPAN, *WARREN SPRINGS LABORATORY, *HONG KONG,

NWMAR116905

1719 DISPERSANTS, CHEMICAL ANALYSIS, SURFACTANTS,
1746 DISPERSANTS, SPILL CLEANUP, EMULSIFIERS, SOLUTION, TOXICITY,
1752 DISPERSANTS, BOOMS, OIL SLICKS, SPILL CLEANUP, *PUMPS,
1770 DISPERSANTS, SPILL CLEANUP, TOXICITY, SINKING AGENTS,
1773 DISPERSANTS, SPILL CLEANUP, PATENT, *MAGNETIC POWDER,
1779 DISPERSANTS, DESIGN-ENGINEERING, OIL SLICKS, SPILL CLEANUP, PATENT,
1783 DISPERSANTS, BEACHES, SPILL RECOVERY, SURFACTANTS, PATENT,
1791 DISPERSANTS, COASTS, BEACHES, ABSORPTION, SPILL CLEANUP, DISPOSAL , MARSHES, SEAWATER, FRESHWATER,
1907 DISPERSANTS, SPILL CLEANUP, ENVIRONMENTAL EFFECTS, POLLUTION CONTROL,
1916 DISPERSANTS, SPILL CLEANUP, OIL DISCHARGES, TOXICITY, MARINE ORGANISMS,
1932 DISPERSANTS, BIOLOGICAL EFFECTS, SURFACTANTS, FISH, TOXICITY,
1934 DISPERSANTS, TOXICITY, ECHINODERMS, *ESSO COREXIT 9527, *FERTILIZATION,
1963 DISPERSANTS, BIOLOGICAL EFFECTS, FISH, SPILL CLEANUP, *EMBRYO DEVELOPMENT,
1990 DISPERSANTS, OIL SPILLS, ENVIRONMENTAL EFFECTS, SHORELINES, INTERTIDAL ZONE, MARINE ORGANISMS, TOXICITY,
1998 DISPERSANTS, CONTAMINATION, BIOLOGICAL EFFECTS, SOURCES, SHIPS, EXPLORATION , PRODUCTION , SEABIRDS, MARINE ORGANISMS, FISHERIES, SPILL CLEANUP,
2000 DISPERSANTS, CONTAMINATION, BIOLOGICAL EFFECTS, OCEANS, SOURCES, POLLUTION CONTROL, MARINE ORGANISMS,
2010 DISPERSANTS, OIL SLICKS, PHYTOPLANKTON, ENVIRONMENTAL EFFECTS, TOXICITY, *LIGHT REDUCTION, *PHOTOSYNTHESIS,
2073 DISPERSANTS, CRUDE OIL, BIODEGRADATION, BACTERIA,
2099 DISPERSANTS, BIOLOGICAL EFFECTS, OIL SPILLS, FATE,
1883 DISPERSIONS, DETECTION, MONITORING, PATENT, *OIL SOLUBLE DYE,
1772 DISPERSIONS, DESIGN-ENGINEERING, OIL-WATER SEPARATION, SPILL CLEANUP, PATENT,
1960 DISPERSIONS, CRUSTACEANS, CRUDE OIL, BIOLOGICAL EFFECTS, METABOLISM, *SUBLETHAL EFFECTS, *ARCTIC AMPHIPOD,
2105 DISPERSIONS, CONTAMINATION, FATE, SEAWATER, SPREADING, EVAPORATION, OXIDATION, SOLUTION,
1791 DISPOSAL , DISPERSANTS, COASTS, BEACHES, ABSORPTION, SPILL CLEANUP, MARSHES, SEAWATER, FRESHWATER,
1818 DISPOSAL , CRUDE OIL, CONTAMINANTS, INDUSTRIES, GROUNDWATER, ENVIRONMENTAL EFFECTS,
1855 DISPOSAL , CONTAMINANTS, REFINERIES, WASTEWATERS, SOLID WASTES, INLAND, *WASTE DISPOSAL PRACTICES, *LANDFILLS,
1863 DISPOSAL , WASTEWATER TREATMENT, REFINERIES, *BIOLOGICAL TREATMENT, *UNDERGROUND WASTE INJECTION,
2004 DISPOSAL , BIODEGRADATION, SLUDGE, SOIL, WASTE OIL, REFINERIES,
1836 DISTILLATION, POLLUTION CONTROL, OIL-WATER SEPARATION, OIL DISCHARGES, USSR,
1640 DISTRIBUTION, CANADA, ATLANTIC OCEAN, TAR, OCEANS, SARGASSO SEA,
1672 DISTRIBUTION, CHRONIC EFFECTS, AUSTRALIA, MONITORING, HYDROCARBONS, SOURCES, *MYTILUS EDULIS, *INDICATOR SPECIES,
1700 DISTRIBUTION, BERING SEA, ALASKA/GULF OF, SAMPLING, TAR, *PLASTICS,
2001 DISTRIBUTION, COASTS, ATLANTIC OCEAN, ARGO MERCHANT SPILL, ENVIRONMENTAL EFFECTS,
2085 DISTRIBUTION, *OIL PARTICLES, SEAWATER,
2094 DISTRIBUTION, BIODEGRADATION, BALTIC SEA, OIL SPILLS, MODELS, FATE, INTERTIDAL ZONE,
1893 DRILLING , DESIGN-ENGINEERING, BLOWOUT PREVENTION, PATENT,
2035 DRILLING , CONTAMINATION, GROUNDWATER, OIL WELLS, *DRILLING FLUIDS, *WELL COMPLETION,
2056 DRILLING , BIOLOGICAL EFFECTS, *DRILL CUTTINGS, FATE, OCEANS,
1934 ECHINODERMS, DISPERSANTS, TOXICITY, *ESSO COREXIT 9527, *FERTILIZATION,
2070 ECHINODERMS, CRUDE OIL, BIODEGRADATION, TOXICITY, *EKOFISK OIL,
1904 ECONOMIC EFFECTS, BLOWOUTS, STATISTICAL ANALYSIS, ENVIRONMENTAL PROTECTION, NORTH SEA,
1990 ECONOMIC EFFECTS, COST ANALYSIS, API, REGULATIONS, OIL INDUSTRY, POLLUTION CONTROL, EPA,
1992 ECONOMIC EFFECTS, CANADA, TANKERS, OIL SPILLS, LEGISLATION, ENVIRONMENTAL EFFECTS,
2019 ECONOMIC EFFECTS, COST ANALYSIS, OIL INDUSTRY, REGULATIONS, POLLUTION PREVENTION,
2044 ECONOMIC EFFECTS, OIL INDUSTRY, OFFSHORE DRILLING, ENVIRONMENTAL EFFECTS, OCS, LOUISIANA,
1640 ECONOMICS, TANKERS, OIL SPILLS, SAFETY, *LIBERIAN REGISTRY,
1804 ECONOMICS, WASTE OIL DISPOSAL, STORAGE, UK,
1861 ECONOMICS, CRUDE OIL, COST ANALYSIS, WASTEWATER TREATMENT, REFINERIES, USSR,
1876 ECONOMICS, WASTE OIL, RECLAMATION, REUSE,
1991 ECONOMICS, CALIFORNIA, OIL SPILLS, INLAND, SPILL CLEANUP, RESTORATION,
2116 ECONOMICS, CANADA, REGULATIONS, WASTEWATERS, REFINERIES, ENVIRONMENTAL PROTECTION, *QUEBEC,
1951 ECOSYSTEMS, BIOLOGICAL EFFECTS, ARCTIC, HYDROCARBONS, MARINE ORGANISMS, SUBARCTIC REGIONS,
1797 EIS, CRUDE OIL, ALASKA, OIL TRANSPORT, PIPELINES, TEXAS, OIL SPILLS,
1796 EIS, CRUDE OIL, STORAGE, ENVIRONMENTAL EFFECTS, *SALT DOMES, OIL TANKS, *STRATEGIC PETROLEUM RESERVE,
1799 EIS, CRUDE OIL, STORAGE, ENVIRONMENTAL EFFECTS, *SALT DOMES, *MINES, *STRATEGIC PETROLEUM RESERVE,
1800 EIS, CRUDE OIL, STORAGE, ENVIRONMENTAL EFFECTS, LOUISIANA, *BAYOU CHOCTAW SALT DOME,
2024 EIS, OIL-GAS LEASING, OCS, ENVIRONMENTAL EFFECTS, MEXICO/GULF OF,
2025 EIS, OIL-GAS LEASING, OCS, ENVIRONMENTAL EFFECTS, MEXICO/GULF OF,

NWMAR116906

2028 EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING, ENVIRONMENTAL EFFECTS,
2029 EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING, ENVIRONMENTAL EFFECTS, OFFSHORE DEVELOPMENT,
2030 EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING, ENVIRONMENTAL EFFECTS,
2031 EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING, ENVIRONMENTAL EFFECTS, OFFSHORE DEVELOPMENT,
2032 EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS,
2033 EIS, ALASKA, OIL-GAS LEASING, OCS, ENVIRONMENTAL EFFECTS, SOCIO-ECONOMIC EFFECTS,
2111 EIS, OIL TRANSPORT, TANKERS, US, REGULATIONS, POLLUTION CONTROL, OIL DISCHARGES,
2112 EIS, OIL TRANSPORT, TANKERS, SEGREGATED BALLAST , REGULATIONS, US, POLLUTION CONTROL, OIL DISCHARGES,
1634 EKOFISK BLOWOUT, CRUDE OIL, OIL SPILLS, FATE,
1635 EKOFISK BLOWOUT, COST ANALYSIS, OFFSHORE DRILLING, OFFSHORE EXPLORATION, NORWAY,
1643 EKOFISK BLOWOUT, ENVIRONMENTAL EFFECTS, PRODUCTION , NORTH SEA,
1647 EKOFISK BLOWOUT, OIL SPILLS, FISH, NORTH SEA,
1654 EKOFISK BLOWOUT, OIL SPILLS, SPILL CLEANUP, POLLUTION CONTROL, NORTH SEA,
1656 EKOFISK BLOWOUT, ENVIRONMENTAL PROTECTION, WILDLIFE, NORTH SEA,
1665 EKOFISK BLOWOUT, NORTH SEA, POLLUTION CONTROL,
2020 EKOFISK BLOWOUT, OFFSHORE DEVELOPMENT, NORTH SEA, ENVIRONMENTAL PROTECTION, SAFETY, REGULATIONS,
2060 EMULSIFICATION, BIODEGRADATION, BACTERIA, HYDROCARBONS, FRESHWATER, *KEROSENE,
1746 EMULSIFIERS, DISPERSANTS, SPILL CLEANUP, SOLUTION, TOXICITY,
1650 EMULSIFIERS, ADSORPTION, WASTEWATER TREATMENT, SLUDGE, FLOTATION, PATENT,
1965 EMULSIFIERS, CRUDE OIL, BIBLIOGRAPHIES, HYDROCARBONS, TOXICITY, MOLLUSKS, SURFACTANTS, *MUSSELS,
1978 EMULSIFIERS, ALGAE, TOXICITY, SURFACTANTS, *SEAWEED, *GROWTH RATES,
1768 EMULSIONS, FILTRATION, EVAPORATION, INCINERATION, *OIL REMOVAL,
1784 EMULSIONS, OIL-WATER SEPARATION, SEAWATER, PETROLEUM PRODUCTS, FLOTATION,
1805 EMULSIONS, DESIGN-ENGINEERING, WASTEWATER TREATMENT, OIL-WATER SEPARATION, FLOTATION,
1806 EMULSIONS, OIL-WATER SEPARATION, PATENT, *AMINE ADDITION,
1807 EMULSIONS, WASTE OIL TREATMENT, FILTRATION, *ULTRAFILTRATION ,
1808 EMULSIONS, WASTEWATER TREATMENT, INDUSTRIES, FILTRATION, OIL-WATER SEPARATION, *ULTRAFILTRATION ,
1811 EMULSIONS, OIL-WATER SEPARATION, FILTRATION, PATENT, *ULTRAFILTRATION ,
1814 EMULSIONS, COALESCENCE, WASTEWATER TREATMENT, WASTE OIL,
1824 EMULSIONS, CRUDE OIL, OIL-WATER SEPARATION, PATENT,
1826 EMULSIONS, COALESCENCE, OIL-WATER SEPARATION, PATENT, *CELLULOSE PULP,
1831 EMULSIONS, CRUDE OIL, OIL-WATER SEPARATION, PATENT,
1832 EMULSIONS, ADSORPTION, WASTEWATER TREATMENT, OIL-WATER SEPARATION, OXIDATION, PATENT,
1852 EMULSIONS, CRUDE OIL, OIL-WATER SEPARATION,
1854 EMULSIONS, WASTEWATER TREATMENT, OIL-WATER SEPARATION, FLOTATION, PATENT, *CATIONIC POLYMERS,
1860 EMULSIONS, DESIGN-ENGINEERING, WASTE OIL TREATMENT, REFINERIES,
1864 EMULSIONS, WASTEWATER TREATMENT, OIL-WATER SEPARATION, FLOTATION,
1869 EMULSIONS, WASTEWATER TREATMENT, OIL-WATER SEPARATION, FILTRATION, PATENT, *ULTRAFILTRATION ,
1871 EMULSIONS, COALESCENCE, WASTEWATER TREATMENT, OIL-WATER SEPARATION,
1872 EMULSIONS, ADSORPTION, WASTEWATER TREATMENT, FILTRATION, POLAND, *CELLULOSE, *DIATOMACEOUS EARTH,
1888 EMULSIONS, DESIGN-ENGINEERING, POLLUTION PREVENTION, OFFSHORE DRILLING, *DRILLING MUDS,
1968 EMULSIONS, FUEL OIL, MOLLUSKS, UPTAKE, RELEASE, *MYA ARENARIA L.,
2084 EMULSIONS, CRUDE OIL, PHYSICAL EFFECTS, *SUSPENDED SOLIDS, *STABILITY,
1793 ENGLAND, CONTAMINATION, RESTORATION, VEGETATION, MARSHES, WASTEWATERS, REFINERIES, *SALT MARSH,
1794 ENGLAND, BIOLOGICAL EFFECTS, ALGAE, RESTORATION, SHORELINES, OIL SPILLS, MOLLUSKS, *ROCKY SHORES,
2119 ENGLAND, CANADA, LEGISLATION, LAW ENFORCEMENT, SHIPS, OIL SPILLS,
2047 ENVIRONMENTAL DETERIORATION, ATLANTIC COAST, OFFSHORE DEVELOPMENT, PORTS,
1643 ENVIRONMENTAL EFFECTS, EKOFISK BLOWOUT, PRODUCTION , NORTH SEA,
1664 ENVIRONMENTAL EFFECTS, BEHAVIOR, OIL SPILLS, FATE, SPILL CLEANUP, MONITORING, *1977 OIL SPILL CONFERENCE,
1676 ENVIRONMENTAL EFFECTS, BLM, BASELINE STUDIES, ALASKA COAST, MONITORING, OFFSHORE DEVELOPMENT, OCS, INFORMATION SYSTEMS, NOAA,
1679 ENVIRONMENTAL EFFECTS, MONITORING, HYDROCARBONS, OIL TRANSPORT, PIPELINES, REFINERIES, PUGET SOUND,
1692 ENVIRONMENTAL EFFECTS, CONTAMINANTS, REMOTE SENSING, MONITORING, OIL SPILLS,
1798 ENVIRONMENTAL EFFECTS, EIS, CRUDE OIL, STORAGE, *SALT DOMES, OIL TANKS, *STRATEGIC PETROLEUM RESERVE,
1799 ENVIRONMENTAL EFFECTS, EIS, CRUDE OIL, STORAGE, *SALT DOMES, *MINES, *STRATEGIC PETROLEUM RESERVE,
1800 ENVIRONMENTAL EFFECTS, EIS, CRUDE OIL, STORAGE, LOUISIANA, *BAYOU CHOCTAW SALT DOME,
1618 ENVIRONMENTAL EFFECTS, DISPOSAL , CRUDE OIL, CONTAMINANTS, INDUSTRIES, GROUNDWATER,
1640 ENVIRONMENTAL EFFECTS, WASTEWATERS, OIL DISCHARGES, FUEL OIL, GASOLINE, LUBRICATING OIL, MONITORING, *DISSOLVED ORGANICS,

NWMAR116907

1906 ENVIRONMENTAL EFFECTS, POLLUTION CONTROL, OIL SPILLS, OCEANS, INLAND, SPILL CLEANUP,
1907 ENVIRONMENTAL EFFECTS, DISPERSANTS, SPILL CLEANUP, POLLUTION CONTROL,
1910 ENVIRONMENTAL EFFECTS, OIL SPILLS, TOXICITY, MARINE ORGANISMS,
1927 ENVIRONMENTAL EFFECTS, BIRDS, BIOLOGICAL EFFECTS, OIL SPILLS, MARINE ORGANISMS, SANTA BARBARA CHANNEL,
1992 ENVIRONMENTAL EFFECTS, ECONOMIC EFFECTS, CANADA, TANKERS, OIL SPILLS, LEGISLATION,
1993 ENVIRONMENTAL EFFECTS, BEACHES, METULA SPILL, SEDIMENTS, MAGELLAN/STRAIT OF,
1994 ENVIRONMENTAL EFFECTS, TANKERS, OIL SPILLS,
1995 ENVIRONMENTAL EFFECTS, OIL SPILLS, TANKERS, MALAYSIA,
1996 ENVIRONMENTAL EFFECTS, DISPERSANTS, OIL SPILLS, SHORELINES, INTERTIDAL ZONE, MARINE ORGANISMS, TOXICITY,
1997 ENVIRONMENTAL EFFECTS, ATLANTIC OCEAN, OIL SPILLS, US, *WORLD WAR II,
1999 ENVIRONMENTAL EFFECTS, ALASKA, OIL TRANSPORT, OIL SPILLS, VEGETATION, SOIL, MARSHES,
2001 ENVIRONMENTAL EFFECTS, DISTRIBUTION, COASTS, ATLANTIC OCEAN, ARGO MERCHANT SPILL,
2005 ENVIRONMENTAL EFFECTS, CONTAMINATION, CHRONIC EFFECTS, HYDROCARBONS, MARINE ORGANISMS, OIL SPILLS,
2007 ENVIRONMENTAL EFFECTS, CONTAMINANTS, FUELS, PRODUCTION ,
2009 ENVIRONMENTAL EFFECTS, CONTAMINATION, FISHERIES, *SHELLFISH ,
2010 ENVIRONMENTAL EFFECTS, DISPERSANTS, OIL SLICKS, PHYTOPLANKTON, TOXICITY, *LIGHT REDUCTION, *PHOTOSYNTHESIS,
2013 ENVIRONMENTAL EFFECTS, BIRDS, BASELINE STUDIES, ALASKA, OFFSHORE DEVELOPMENT, OCS, MARINE MAMMALS,
2014 ENVIRONMENTAL EFFECTS, BENTHOS, BASELINE STUDIES, ALASKA, OFFSHORE DEVELOPMENT, OCS, FISH, PLANKTON ,
2015 ENVIRONMENTAL EFFECTS, BIRDS, ARCTIC, ALASKA, HABITAT,'SHORELINES, OFFSHORE DEVELOPMENT, *SHOREBIRD SPECIES,
2016 ENVIRONMENTAL EFFECTS, BIRDS, BASELINE STUDIES, ALASKA, SHORELINES, OFFSHORE DEVELOPMENT, OIL SPILLS,
2017 ENVIRONMENTAL EFFECTS, ARCTIC, OIL TRANSPORT, PIPELINES, FRESHWATER, EPA,
2023 ENVIRONMENTAL EFFECTS, OIL INDUSTRY, REFINING, POLLUTION CONTROL, *TECHNOLOGY ASSESSMENT,
2024 ENVIRONMENTAL EFFECTS, EIS, OIL-GAS LEASING, OCS, MEXICO/GULF OF,
2025 ENVIRONMENTAL EFFECTS, EIS, OIL-GAS LEASING, OCS, MEXICO/GULF OF,
2027 ENVIRONMENTAL EFFECTS, BERING SEA, ALASKA/GULF OF, OFFSHORE EXPLORATION, OIL-GAS LEASING, OCS,
2028 ENVIRONMENTAL EFFECTS, EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING,
2029 ENVIRONMENTAL EFFECTS, EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING, OFFSHORE DEVELOPMENT,
2030 ENVIRONMENTAL EFFECTS, EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING,
2031 ENVIRONMENTAL EFFECTS, EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING, OFFSHORE DEVELOPMENT,
2032 ENVIRONMENTAL EFFECTS, EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING, OFFSHORE DEVELOPMENT,
2033 ENVIRONMENTAL EFFECTS, EIS, ALASKA, OIL-GAS LEASING, OCS, SOCIO-ECONOMIC EFFECTS,
2034 ENVIRONMENTAL EFFECTS, CANADA, ARCTIC, OFFSHORE EXPLORATION, OFFSHORE DEVELOPMENT, ICE, OIL INDUSTRY,
2039 ENVIRONMENTAL EFFECTS, OIL SHALE, INDUSTRIES, MONITORING, *R & D NEEDS,
2040 ENVIRONMENTAL EFFECTS, PRODUCTION , FOSSIL FUELS , OIL SHALE, TAR SANDS,
2042 ENVIRONMENTAL EFFECTS, CONTAMINANTS, COASTS, OFFSHORE DRILLING, FISH,
2043 ENVIRONMENTAL EFFECTS, BLM, OFFSHORE DEVELOPMENT, OCS,
2044 ENVIRONMENTAL EFFECTS, ECONOMIC EFFECTS, OIL INDUSTRY, OFFSHORE DRILLING, OCS, LOUISIANA,
2045 ENVIRONMENTAL EFFECTS, CRUDE OIL, ALASKA, OFFSHORE DEVELOPMENT, OCS, OIL-GAS LEASING,
2046 ENVIRONMENTAL EFFECTS, DELAWARE, ATLANTIC COAST, OFFSHORE DEVELOPMENT, PORTS, FISHERIES, NEW JERSEY,
2050 ENVIRONMENTAL EFFECTS, OIL INDUSTRY, PETROCHEMICALS, REFINERIES,
2052 ENVIRONMENTAL EFFECTS, COASTS, OFFSHORE DEVELOPMENT, OCS, ONSHORE IMPACTS, POLLUTION PREVENTION,
2054 ENVIRONMENTAL EFFECTS, ARCTIC, OFFSHORE DEVELOPMENT, ICE, *ICE COVERED WATERS, *RESEARCH TECHNOLOGY,
2055 ENVIRONMENTAL EFFECTS, COASTS, OFFSHORE DEVELOPMENT, OCS, US, SOCIO-ECONOMIC EFFECTS, STATE GOVERNMENTS,
2090 ENVIRONMENTAL EFFECTS, BEHAVIOR, ARGO MERCHANT SPILL, MONITORING, MOVEMENT, SAMPLING,
2109 ENVIRONMENTAL EFFECTS, COASTS, LEGISLATION, US, OCS, OFFSHORE DEVELOPMENT, REFINERIES,
2129 ENVIRONMENTAL EFFECTS, DEVELOPMENT , BIBLIOGRAPHIES, OIL SHALE, EXTRACTION,
2130 ENVIRONMENTAL EFFECTS, DEVELOPMENT , BIBLIOGRAPHIES, OIL SHALE, EXTRACTION,
2131 ENVIRONMENTAL EFFECTS, DEVELOPMENT , BIBLIOGRAPHIES, OIL SHALE, EXTRACTION, POLLUTION CONTROL,
2132 ENVIRONMENTAL EFFECTS, DEVELOPMENT , BIBLIOGRAPHIES, OIL SHALE, EXTRACTION, POLLUTION CONTROL,
2133 ENVIRONMENTAL EFFECTS, BIBLIOGRAPHIES, ESTUARIES, MARINE ORGANISMS,
2021 ENVIRONMENTAL MANAGEMENT, OCS, OFFSHORE DRILLING, FOSSIL FUELS , REGULATIONS, POLLUTION CONTROL,
2046 ENVIRONMENTAL MANAGEMENT, COASTS, OFFSHORE DEVELOPMENT, GUIDELINES, *CZM,
2053 ENVIRONMENTAL MANAGEMENT, COASTS, OIL INDUSTRY, LOUISIANA, LEGISLATION, US,

NWMAR116908

1638 ENVIRONMENTAL PROTECTION, CONTINGENCY PLANNING, CANADA, ARCTIC OCEAN,
1655 ENVIRONMENTAL PROTECTION, OIL SPILLS, OIL TRANSFER, TANKERS, SURVEILLANCE, NORTH SEA,
1658 ENVIRONMENTAL PROTECTION, EKOFISK BLOWOUT, WILDLIFE, NORTH SEA,
1709 ENVIRONMENTAL PROTECTION, DETECTION, CONTAMINANTS, CHEMICAL ANALYSIS, HYDROCARBONS, SURFACTANTS,
1795 ENVIRONMENTAL PROTECTION, CRUDE OIL, TANKERS, STORAGE, FEA,
1904 ENVIRONMENTAL PROTECTION, ECONOMIC EFFECTS, BLOWOUTS, STATISTICAL ANALYSIS, NORTH SEA,
2020 ENVIRONMENTAL PROTECTION, EKOFISK BLOWOUT, OFFSHORE DEVELOPMENT, NORTH SEA, SAFETY, REGULATIONS,
2036 ENVIRONMENTAL PROTECTION, DEVELOPMENT , CANADA, TAR SANDS, EXTRACTION, *ALBERTA,
2113 ENVIRONMENTAL PROTECTION, REGULATIONS, TANKERS, SEGREGATED BALLAST , USCG,
2117 ENVIRONMENTAL PROTECTION, CANADA, GUIDELINES, REFINERIES, WASTEWATER TREATMENT, *ALBERTA,
2118 ENVIRONMENTAL PROTECTION, ECONOMICS, CANADA, REGULATIONS, WASTEWATERS, REFINERIES, *QUEBEC,
1846 EPA, CHEMICAL ANALYSIS, WASTEWATER TREATMENT, REFINERIES, *ANALYTICAL VARIABILITY,
1886 EPA, CONTINGENCY PLANNING, SPILL CLEANUP, USCG,
1990 EPA, ECONOMIC EFFECTS, COST ANALYSIS, API, REGULATIONS, OIL INDUSTRY, POLLUTION CONTROL,
2017 EPA, ENVIRONMENTAL EFFECTS, ARCTIC, OIL TRANSPORT, PIPELINES, FRESHWATER,
2123 EPA, INTERNATIONAL CONVENTIONS, POLLUTION PREVENTION, IMCO, SWEDEN, *BALTIC CONVENTION,
1699 ESTUARIES, DETECTION, CARCINOGENS, SAMPLING, PAH, MOLLUSKS, OREGON, *BIVALVES,
1900 ESTUARIES, POLLUTION CONTROL, *CONFERENCE,
1915 ESTUARIES, CRUSTACEANS, BIOLOGICAL EFFECTS, AROMATIC HYDROCARBONS , *COPEPOD,
1948 ESTUARIES, CRUDE OIL, TOXICITY, PHYTOPLANKTON, *KUWAIT CRUDE,
1954 ESTUARIES, CRUDE OIL, CONTAMINATION, FISH, *FIN ROT, *MULLET,
2049 ESTUARIES, DEVELOPMENT , CONTAMINATION, COASTS, OIL INDUSTRY,
2061 ESTUARIES, BIODEGRADATION, BACTERIA, *ENRICHMENT TECHNIQUES,
2091 ESTUARIES, HYDROCARBONS, FUEL OIL, SEDIMENTS, MARINE ORGANISMS, VIRGINIA,
2133 ESTUARIES, ENVIRONMENTAL EFFECTS, BIBLIOGRAPHIES, MARINE ORGANISMS,
1663 EUROPE, OIL SPILLS, OIL TRANSPORT, PIPELINES, SPILL CLEANUP, *CROSS COUNTRY PIPELINES ,
1887 EUROPE, CONTINGENCY PLANNING, SPILL CLEANUP, PERSONNEL TRAINING, UK, US,
1768 EVAPORATION, EMULSIONS, FILTRATION, INCINERATION, *OIL REMOVAL,
1803 EVAPORATION, WASTEWATER TREATMENT, REFINERIES, INCINERATION, PATENT, *THERMAL OXIDATION ,
2065 EVAPORATION, HYDROCARBONS, OIL SPILLS, FATE, SOLUTION, WEATHERING,
2087 EVAPORATION, DELAWARE BAY, OIL SPILLS, MODELS, WEATHERING, OIL TRANSFER,
2105 EVAPORATION, DISPERSIONS, CONTAMINATION, FATE, SEAWATER, SPREADING, OXIDATION, SOLUTION,
1998 EXPLORATION , DISPERSANTS, CONTAMINATION, BIOLOGICAL EFFECTS, SOURCES, SHIPS, PRODUCTION , SEABIRDS, MARINE ORGANISMS, FISHERIES, SPILL CLEANUP,
1816 EXTRACTION, CONTAMINANTS, WASTEWATER TREATMENT, REFINERIES, SOLVENTS,
2011 EXTRACTION, CARCINOGENS, OIL SHALE, HEALTH HAZARDS, *BENZO(A)PYRENE,
2036 EXTRACTION, ENVIRONMENTAL PROTECTION, DEVELOPMENT , CANADA, TAR SANDS, *ALBERTA,
2129 EXTRACTION, ENVIRONMENTAL EFFECTS, DEVELOPMENT , BIBLIOGRAPHIES, OIL SHALE,
2130 EXTRACTION, ENVIRONMENTAL EFFECTS, DEVELOPMENT , BIBLIOGRAPHIES, OIL SHALE,
2131 EXTRACTION, ENVIRONMENTAL EFFECTS, DEVELOPMENT , BIBLIOGRAPHIES, OIL SHALE, POLLUTION CONTROL,
2132 EXTRACTION, ENVIRONMENTAL EFFECTS, DEVELOPMENT , BIBLIOGRAPHIES, OIL SHALE, POLLUTION CONTROL,
1634 FATE, EKOFISK BLOWOUT, CRUDE OIL, OIL SPILLS,
1656 FATE, COASTS, URQUIOLA SPILL, POLLUTION CONTROL, SPILL CLEANUP, SPAIN,
1664 FATE, ENVIRONMENTAL EFFECTS, BEHAVIOR, OIL SPILLS, SPILL CLEANUP, MONITORING, *1977 OIL SPILL CONFERENCE,
1673 FATE, CRUDE OIL, CHEMICAL EFFECTS, BIOLOGICAL EFFECTS, ALASKA, MONITORING, MOVEMENT, MICROORGANISMS, *PERMAFROST TERRAIN,
2056 FATE, DRILLING , BIOLOGICAL EFFECTS, *DRILL CUTTINGS, OCEANS,
2085 FATE, EVAPORATION, HYDROCARBONS, OIL SPILLS, SOLUTION, WEATHERING,
2088 FATE, MODELS, OIL SPILLS, OXIDATION, *N-HEXADECANE, *PHOTOOXIDATION ,
2092 FATE, BIODEGRADATION, PETROLEUM PRODUCTS, SURFACTANTS, SEAWATER, SEDIMENTS, *SELF-PURIFICATION, *SEA OF AZOV,
2094 FATE, DISTRIBUTION, BIODEGRADATION, BALTIC SEA, OIL SPILLS, MODELS, INTERTIDAL ZONE,
2096 FATE, ALASKA, OIL SPILLS, ICE, *OIL-UNDER-ICE , *IMPULSE RADAR SYSTEM,
2097 FATE, BIODEGRADATION, HYDROCARBONS, SEAWATER, ECOSYSTEM, SEDIMENTATION, *NAPHTHALENES,
2099 FATE, DISPERSANTS, BIOLOGICAL EFFECTS, OIL SPILLS,
2101 FATE, HYDROCARBONS, SEAWATER, MARINE ORGANISMS, *MOLECULAR INTERACTIONS,
2105 FATE, EVAPORATION, DISPERSIONS, CONTAMINATION, SEAWATER, SPREADING, OXIDATION, SOLUTION,
1795 FEA, ENVIRONMENTAL PROTECTION, CRUDE OIL, TANKERS, STORAGE,
1768 FILTRATION, EVAPORATION, EMULSIONS, INCINERATION, *OIL REMOVAL,
1807 FILTRATION, EMULSIONS, WASTE OIL TREATMENT, *ULTRAFILTRATION ,
1808 FILTRATION, EMULSIONS, WASTEWATER TREATMENT, INDUSTRIES, OIL-WATER SEPARATION, *ULTRAFILTRATION ,
1810 FILTRATION, WASTEWATER TREATMENT, OIL-WATER SEPARATION, PATENT,
1811 FILTRATION, EMULSIONS, OIL-WATER SEPARATION, PATENT, *ULTRAFILTRATION ,

NWMAR116909

1813 FILTRATION, WASTEWATER TREATMENT, OIL-WATER SEPARATION, REFINERIES, PENNSYLVANIA, *SAND FILTERS,
1822 FILTRATION, WASTEWATER TREATMENT, REFINERIES,
1834 FILTRATION, CANADA, WASTEWATER TREATMENT, OIL-WATER SEPARATION, REFINERIES, *DUAL-MEDIA FILTERS,
1844 FILTRATION, DESIGN-ENGINEERING, WASTEWATER TREATMENT, REFINERIES, SOLID WASTES, OHIO, *UPFLOW SAND FILTERS,
1857 FILTRATION, REFINERIES, WASTEWATER TREATMENT, WATER QUALITY, *ONTARIO,
1869 FILTRATION, EMULSIONS, WASTEWATER TREATMENT, OIL-WATER SEPARATION, PATENT, *ULTRAFILTRATION ,
1872 FILTRATION, EMULSIONS, ADSORPTION, WASTEWATER TREATMENT, POLAND, *CELLULOSE, *DIATOMACEOUS EARTH,
1873 FILTRATION, COALESCENCE, WASTE OIL, LUBRICATING OIL, RECYCLING,
1877 FILTRATION, WASTE OIL, LUBRICATING OIL, RECLAMATION, OIL-WATER SEPARATION, FUELS, *USCG POWER PLANTS,
1647 FISH, EKOFISK BLOWOUT, OIL SPILLS, NORTH SEA,
1666 FISH, DISPERSANTS, TOXICITY, TROPICAL REGIONS, JAPAN, *WARREN SPRINGS LABORATORY, *HONG KONG,
1712 FISH, CONTAMINATION, CHEMICAL ANALYSIS, SOURCES, PETROLEUM PRODUCTS, GREAT LAKES ,
1922 FISH, BIOLOGICAL EFFECTS, ARGO MERCHANT SPILL, INVERTEBRATES, FOOD WEB,
1931 FISH, CRUDE OIL, BIOLOGICAL EFFECTS, *FIN ROT, *MUGIL CEPHALUS,
1932 FISH, DISPERSANTS, BIOLOGICAL EFFECTS, SURFACTANTS, TOXICITY,
1933 FISH, HYDROCARBONS, UPTAKE, RELEASE, *COHO AND CHINOOK SALMON, *CHLORINATED BIPHENYLS, *ENZYME ACTIVITY,
1936 FISH, BIOLOGICAL EFFECTS, ANALYTICAL TECHNIQUES, HYDROCARBONS, *TISSUES, *MORPHOLOGICAL CHANGES,
1938 FISH, CRUDE OIL, CHRONIC EFFECTS, TOXICITY, *TROUT REPRODUCTION,
1942 FISH, PETROLEUM PRODUCTS, TOXICITY, METABOLISM, *SPICARA SMARIS, *SOLEA LASCARIS NASUTA,
1943 FISH, PETROLEUM PRODUCTS, TOXICITY, *HEMATOLOGICAL CHANGES,
1949 FISH, CHRONIC EFFECTS, TOXICITY, FRESHWATER, LUBRICATING OIL, *SYNTHETIC OIL,
1952 FISH, BIOLOGICAL EFFECTS, OIL SPILLS, FUEL OIL, INVERTEBRATES, STREAMS, VIRGINIA,
1954 FISH, ESTUARIES, CRUDE OIL, CONTAMINATION, *FIN ROT, *MULLET,
1963 FISH, CRUDE OIL, FUEL OIL, TOXICITY, HYDROCARBONS, METABOLISM,*RESPIRATION, *ONCORHYNCHUS GORBUSCHA,
1972 FISH, TOXICITY, HYDROCARBONS, *BENZENE, *REPRODUCTION, *CLUPEA HARENGUS PALLASI,
1983 FISH, DISPERSANTS, BIOLOGICAL EFFECTS, SPILL CLEANUP, *EMBRYO DEVELOPMENT,
2014 FISH, ENVIRONMENTAL EFFECTS, BENTHOS, BASELINE STUDIES, ALASKA, OFFSHORE DEVELOPMENT, OCS, PLANKTON ,
2042 FISH, ENVIRONMENTAL EFFECTS, CONTAMINANTS, COASTS, OFFSHORE DRILLING,
2093 FISH, CHEMICAL ANALYSIS, BIOLOGICAL EFFECTS, BIODEGRADATION, AROMATIC HYDROCARBONS , OIL SPILLS, WEATHERING, NORWAY, *T/T "DRUPA" SPILL,
2127 FISH, BIOLOGICAL EFFECTS, BIBLIOGRAPHIES, FRESHWATER,
1998 FISHERIES, EXPLORATION , DISPERSANTS, CONTAMINATION, BIOLOGICAL EFFECTS, SOURCES, SHIPS, PRODUCTION , SEABIRDS, MARINE ORGANISMS, SPILL CLEANUP,
2002 FISHERIES, BIRDS, OIL SPILLS, REFINERIES, OIL TRANSPORT, OFFSHORE PRODUCTION, POLLUTION CONTROL, TOXICITY, NORTH SEA,
2003 FISHERIES, CRUDE OIL, AROMATIC HYDROCARBONS , OFFSHORE DEVELOPMENT, NORTH SEA,
2009 FISHERIES, ENVIRONMENTAL EFFECTS, CONTAMINATION, *SHELLFISH ,
2012 FISHERIES, OIL INDUSTRY, OFFSHORE DEVELOPMENT, NORTH SEA, SCOTLAND,
2048 FISHERIES, ENVIRONMENTAL EFFECTS, DELAWARE, ATLANTIC COAST, OFFSHORE DEVELOPMENT, PORTS, NEW JERSEY,
1780 FLOCCULATION, SPILL RECOVERY, SEAWATER, RIVERS, SOLVENTS, COAGULATION, PATENT,
1623 FLOCCULATION, WASTEWATER TREATMENT, PETROLEUM PRODUCTS, OIL-WATER SEPARATION, PATENT,
1846 FLOCCULATION, WASTEWATER TREATMENT, OIL-WATER SEPARATION, PATENT,
1849 FLOCCULATION, WASTEWATER TREATMENT, OIL-WATER SEPARATION, PATENT,
1858 FLOCCULATION, WASTEWATER TREATMENT, SOLVENTS, OIL-WATER SEPARATION, PATENT, *SOLVENT RECOVERY ,
1859 FLOCCULATION, WASTEWATER TREATMENT, SOLVENTS, OIL-WATER SEPARATION, PATENT, *SOLVENT RECOVERY ,
1867 FLOCCULATION, WASTEWATER TREATMENT, SURFACTANTS, OIL-WATER SEPARATION, PATENT,
1870 FLOCCULATION, PETROLEUM PRODUCTS, WASTEWATER TREATMENT,
1784 FLOTATION, EMULSIONS, OIL-WATER SEPARATION, SEAWATER, PETROLEUM PRODUCTS,
1805 FLOTATION, EMULSIONS, DESIGN-ENGINEERING, WASTEWATER TREATMENT, OIL-WATER SEPARATION,
1815 FLOTATION, DESIGN-ENGINEERING, COALESCENCE, OIL-WATER SEPARATION, SHIPS, PATENT,
1835 FLOTATION, WASTEWATER TREATMENT, PATENT, *TETRAETHYLEAD REMOVAL,
1845 FLOTATION, DESIGN-ENGINEERING, OIL-WATER SEPARATION, SKIMMERS, PATENT,
1850 FLOTATION, EMULSIFIERS, ADSORPTION, WASTEWATER TREATMENT, SLUDGE, PATENT,
1854 FLOTATION, EMULSIONS, WASTEWATER TREATMENT, OIL-WATER SEPARATION, PATENT, *CATIONIC POLYMERS,
1864 FLOTATION, EMULSIONS, WASTEWATER TREATMENT, OIL-WATER SEPARATION,
1922 FOOD WEB, FISH, BIOLOGICAL EFFECTS, ARGO MERCHANT SPILL, INVERTEBRATES,
1976 FOOD WEB, HYDROCARBONS, UPTAKE, RELEASE, OCEANS, *FOOD CHAIN TRANSFER,
1706 FOSSIL FUELS , ANALYTICAL TECHNIQUES, WASTEWATERS, REFINERIES,
2021 FOSSIL FUELS , ENVIRONMENTAL MANAGEMENT, OCS, OFFSHORE DRILLING, REGULATIONS,

NWMAR116910

POLLUTION CONTROL,
2040 FOSSIL FUELS , ENVIRONMENTAL EFFECTS, PRODUCTION , OIL SHALE, TAR SANDS,
1739 FRESHWATER, DESIGN-ENGINEERING, BOOMS, SPILL CONTAINMENT, OCEANS,
1759 FRESHWATER, CONTAMINATION, ADSORPTION, FUEL OIL, *ACTIVATED CARBON, *WATER SUPPLY,
1791 FRESHWATER, DISPOSAL , DISPERSANTS, COASTS, BEACHES, ABSORPTION, SPILL CLEANUP, MARSHES, SEAWATER,
1919 FRESHWATER, CRUDE OIL, BIOLOGICAL EFFECTS, BACTERIA, FUNGI, ICE, *OIL-UNDER-ICE ,
1946 FRESHWATER, REFINERIES, TOXICITY, WASTEWATERS, MONITORING, INVERTEBRATES, *DAPHNIA PULEX, *BIOASSAY,
1949 FRESHWATER, FISH, CHRONIC EFFECTS, TOXICITY, LUBRICATING OIL, *SYNTHETIC OIL,
1955 FRESHWATER, CRUDE OIL, BIODEGRADATION, BACTERIA, ALGAE, PETROLEUM PRODUCTS, GASOLINE, TOXICITY, *PHOTOSYNTHESIS,
1980 FRESHWATER, CRUDE OIL, ARCTIC, TOXICITY, PHYTOPLANKTON, *PRIMARY PRODUCTION,
2017 FRESHWATER, EPA, ENVIRONMENTAL EFFECTS, ARCTIC, OIL TRANSPORT, PIPELINES,
2060 FRESHWATER, EMULSIFICATION, BIODEGRADATION, BACTERIA, HYDROCARBONS, *KEROSENE,
2069 FRESHWATER, BIODEGRADATION, BACTERIA, HYDROCARBONS, FUNGI, SEDIMENTS,
2127 FRESHWATER, FISH, BIOLOGICAL EFFECTS, BIBLIOGRAPHIES,
1705 FUEL OIL, CHROMATOGRAPHY, CHEMICAL ANALYSIS, HYDROCARBONS, SEAWATER, *WATER-SOLUBLE FRACTION,
1724 FUEL OIL, CRUDE OIL, ANALYTICAL TECHNIQUES, *OIL-GREASE DETERMINATION,
1727 FUEL OIL, CRUDE OIL, ANALYTICAL TECHNIQUES, SOURCE IDENTIFICATION, PETROLEUM PRODUCTS, SPECTROSCOPY,
1759 FUEL OIL, FRESHWATER, CONTAMINATION, ADSORPTION, *ACTIVATED CARBON, *WATER SUPPLY,
1777 FUEL OIL, ADSORPTION, SPILL RECOVERY, PATENT, *SAWDUST,
1787 FUEL OIL, ADSORPTION, SPILL CLEANUP, GASOLINE, PATENT,
1840 FUEL OIL, ENVIRONMENTAL EFFECTS, WASTEWATERS, OIL DISCHARGES, GASOLINE, LUBRICATING OIL, MONITORING, *DISSOLVED ORGANICS,
1911 FUEL OIL, BIRDS, BIOLOGICAL EFFECTS, *HATCHABILITY, *MALLARD DUCK EGGS,
1914 FUEL OIL, CRUDE OIL, ALGAE, TOXICITY,
1921 FUEL OIL, CRUDE OIL, TOXICITY, POLYCHAETES, *REPRODUCTION,
1923 FUEL OIL, CRUDE OIL, CANADA, BIOLOGICAL EFFECTS, MICROORGANISMS, *GEORGIA STRAIT, *HETEROTROPHIC POTENTIAL, *PRODUCTIVITY,
1925 FUEL OIL, BIOLOGICAL EFFECTS, BIODEGRADATION, HYDROCARBONS, MICROORGANISMS, MARSHES, *SALTMARSH,
1944 FUEL OIL, CRUSTACEANS, CONTAMINATION, BIOLOGICAL EFFECTS, OIL SPILLS, MARSHES, MASSACHUSETTS, *UCA PUGNAX,
1945 FUEL OIL, CRUSTACEANS, BIOLOGICAL EFFECTS, METABOLISM, *TEMPERATURE, *SALINITY, *LIMULUS POLYPHEMUS,
1952 FUEL OIL, FISH, BIOLOGICAL EFFECTS, OIL SPILLS, INVERTEBRATES, STREAMS, VIRGINIA,
1962 FUEL OIL, CRUDE OIL, TOXICITY, UPTAKE, RELEASE, MARINE ORGANISMS,
1963 FUEL OIL, FISH, CRUDE OIL, TOXICITY, HYDROCARBONS, METABOLISM,*RESPIRATION, *ONCORHYNCHUS GORBUSCHA,
1968 FUEL OIL, EMULSIONS, MOLLUSKS, UPTAKE, RELEASE, *MYA ARENARIA L.,
1973 FUEL OIL, BIRDS, BIOLOGICAL EFFECTS, *HATCHABILITY, *COMMON EIDER EGGS,
1974 FUEL OIL, CRUSTACEANS, HYDROCARBONS, UPTAKE, METABOLISM, *NAPHTHALENES, *HATCHING, *LARVAL GROWTH, *GRASS SHRIMP,
2080 FUEL OIL, CASPIAN SEA, BIODEGRADATION, BACTERIA, PETROLEUM PRODUCTS, OXIDATION,
2089 FUEL OIL, TOXICITY, YEASTS, OXIDATION, *UV IRRADIATION,
2091 FUEL OIL, ESTUARIES, HYDROCARBONS, SEDIMENTS, MARINE ORGANISMS, VIRGINIA,
2107 FUEL OIL, DECOMPOSITION, BIODEGRADATION, MICROORGANISMS, *PHYSICOCHEMICAL DEGRADATION,
1847 FUELS, WASTEWATER DISPOSAL, WASTE OIL, RECLAMATION, *LAND DISPOSAL, *SPRAY IRRIGATION,
1875 FUELS, CRUDE OIL, SPILL RECOVERY, WASTEWATER TREATMENT, OIL-WATER SEPARATION,
1877 FUELS, FILTRATION, WASTE OIL, LUBRICATING OIL, RECLAMATION, OIL-WATER SEPARATION, *USCG POWER PLANTS,
1969 FUELS, CRUDE OIL, BIOLOGICAL EFFECTS, ALGAE, PETROLEUM PRODUCTS, *GROWTH, *REPRODUCTION, *FUCUS EDENTATUS DE LA PYL,
2007 FUELS, ENVIRONMENTAL EFFECTS, CONTAMINANTS, PRODUCTION ,
1919 FUNGI, FRESHWATER, CRUDE OIL, BIOLOGICAL EFFECTS, BACTERIA, ICE, *OIL-UNDER-ICE ,
2069 FUNGI, FRESHWATER, BIODEGRADATION, BACTERIA, HYDROCARBONS, SEDIMENTS,
2075 FUNGI, BIODEGRADATION, BACTERIA, WASTE OIL, SOIL, MONITORING, *ARID SITE,
1787 GASOLINE, FUEL OIL, ADSORPTION, SPILL CLEANUP, PATENT,
1827 GASOLINE, DESIGN-ENGINEERING, OIL-WATER SEPARATION, SLUDGE, WASTEWATERS, PATENT,
1840 GASOLINE, FUEL OIL, ENVIRONMENTAL EFFECTS, WASTEWATERS, OIL DISCHARGES, LUBRICATING OIL, MONITORING, *DISSOLVED ORGANICS,
1955 GASOLINE, FRESHWATER, CRUDE OIL, BIODEGRADATION, BACTERIA, ALGAE, PETROLEUM PRODUCTS, TOXICITY, *PHOTOSYNTHESIS,
2071 GASOLINE, BIODEGRADATION, ALASKA, HYDROCARBONS, MICROORGANISMS, LAKES, SEDIMENTS,
2072 GASOLINE, BIOLOGICAL EFFECTS, BIODEGRADATION, ARCTIC, MICROORGANISMS, LAKES,
1837 GERMANY, EAST, REFINERIES, OIL INDUSTRY, PETROCHEMICALS, WASTEWATER TREATMENT,
2120 GOVERNMENT AGENCIES, REGULATIONS, TANKERS, PORTS, USCG, SAFETY, LAW ENFORCEMENT,
1712 GREAT LAKES, PETROLEUM PRODUCTS, FISH, CONTAMINATION, CHEMICAL ANALYSIS, SOURCES,
1891 GREENLAND, ARCTIC, OFFSHORE DRILLING, SAFETY, POLLUTION PREVENTION, *ICEBERGS,
1729 GROUNDWATER, CONTAMINATION, SOURCE IDENTIFICATION, OIL WELLS, PRODUCTION , WASTEWATERS, *BRINE DISPOSAL,
1802 GROUNDWATER, ADSORPTION, OIL TRANSPORT, *LIME, *CLAY, *SOIL COMPONENTS,

NWMAR116911

1818 GROUNDWATER, ENVIRONMENTAL EFFECTS, DISPOSAL , CRUDE OIL, CONTAMINANTS, INDUSTRIES,
2035 GROUNDWATER, DRILLING , CONTAMINATION, OIL WELLS, *DRILLING FLUIDS, *WELL COMPLETION,
2046 GUIDELINES, ENVIRONMENTAL MANAGEMENT, COASTS, OFFSHORE DEVELOPMENT, *CZM,
2117 GUIDELINES, ENVIRONMENTAL PROTECTION, CANADA, REFINERIES, WASTEWATER TREATMENT, *ALBERTA,
2122 GUIDELINES, CONTINGENCY PLANNING, MANUALS, POLLUTION PREVENTION, TANKERS,
2015 HABITAT, ENVIRONMENTAL EFFECTS, BIRDS, ARCTIC, ALASKA, SHORELINES, OFFSHORE DEVELOPMENT, *SHOREBIRD SPECIES,
1732 HARBORS, BOOMS, SPILL CONTAINMENT, INLAND, *PRODUCT INFORMATION,
2008 HEALTH HAZARDS, CONTAMINATION, BIOLOGICAL EFFECTS, HYDROCARBONS, OCEANS, POLLUTION CONTROL,
2011 HEALTH HAZARDS, EXTRACTION, CARCINOGENS, OIL SHALE, *BENZO(A)PYRENE,
1671 HYDROCARBONS, MONITORING, SOURCES, PLATFORMS, MEXICO/GULF OF, *GAS VENTING, *BRINE DISCHARGE,
1672 HYDROCARBONS, DISTRIBUTION, CHRONIC EFFECTS, AUSTRALIA, MONITORING, SOURCES, *MYTILUS EDULIS, *INDICATOR SPECIES,
1678 HYDROCARBONS, MONITORING, SEDIMENTS, SOURCES, MEXICO/GULF OF, *CONTINENTAL SHELF,
1679 HYDROCARBONS, ENVIRONMENTAL EFFECTS, MONITORING, OIL TRANSPORT, PIPELINES, REFINERIES, PUGET SOUND,
1698 HYDROCARBONS, CHEMICAL ANALYSIS, SAMPLING, SEAWATER, OIL-GAS LEASING, MEXICO/GULF OF, *SEASONAL VARIATIONS, *MAFLA LEASE AREA,
1705 HYDROCARBONS, FUEL OIL, CHROMATOGRAPHY, CHEMICAL ANALYSIS, SEAWATER, *WATER-SOLUBLE FRACTION,
1708 HYDROCARBONS, DETECTION, CHROMATOGRAPHY, CHEMICAL ANALYSIS, CANADA, ATLANTIC COAST, SPECTROSCOPY,
1709 HYDROCARBONS, ENVIRONMENTAL PROTECTION, DETECTION, CONTAMINANTS, CHEMICAL ANALYSIS, SURFACTANTS,
1710 HYDROCARBONS, CRUSTACEANS, CHROMATOGRAPHY, CHEMICAL ANALYSIS, SPECTROMETRY, ZOOPLANKTON, SEDIMENTS,
1711 HYDROCARBONS, CHROMATOGRAPHY, BEACHES, ANALYTICAL TECHNIQUES, ABSORPTION, SEAWATER, SPECTROSCOPY,
1713 HYDROCARBONS, ANALYTICAL TECHNIQUES, SAMPLING, SEDIMENTS, INTERTIDAL ZONE, WASHINGTON,
1714 HYDROCARBONS, DETECTION, CHROMATOGRAPHY, CHEMICAL ANALYSIS, BASELINE STUDIES, SPECTROSCOPY, MARINE ORGANISMS,
1715 HYDROCARBONS, CHROMATOGRAPHY, CHEMICAL ANALYSIS, SOURCES, MARINE ORGANISMS, SPECTROSCOPY, SPECTROMETRY,
1717 HYDROCARBONS, CHROMATOGRAPHY, CHEMICAL ANALYSIS, AROMATIC HYDROCARBONS , MONITORING, SEDIMENTS, *GLASS CAPILLARY COLUMNS,
1725 HYDROCARBONS, CHROMATOGRAPHY, ANALYTICAL TECHNIQUES, SEDIMENTS, SPECTROSCOPY, *INTERCALIBRATION,
1726 HYDROCARBONS, CHEMICAL ANALYSIS, ADSORPTION, PETROLEUM PRODUCTS, SEAWATER, SURFACTANTS, *ELECTROANALYSIS ,
1730 HYDROCARBONS, SOURCE IDENTIFICATION, SEDIMENTS, LAKES,
1617 HYDROCARBONS, WASTEWATER TREATMENT, REFINERIES, PETROCHEMICALS, *SOLVENT EXTRACTION ,
1912 HYDROCARBONS, ANNELIDS, SEDIMENT, UPTAKE, RELEASE, *PHASCOLOSOMA AGASSIZII, *NAPHTHALENES,
1913 HYDROCARBONS, BEHAVIOR, ANALYTICAL TECHNIQUES, TOXICITY, MARINE ORGANISMS, METABOLISM, *SUBLETHAL LEVELS,
1924 HYDROCARBONS, CRUDE OIL, BIOLOGICAL EFFECTS, BEAUFORT SEA, UPTAKE, MARINE MAMMALS, *RINGED SEAL,
1925 HYDROCARBONS, FUEL OIL, BIOLOGICAL EFFECTS, BIODEGRADATION, MICROORGANISMS, MARSHES, *SALTMARSH,
1933 HYDROCARBONS, FISH, UPTAKE, RELEASE, *COHO AND CHINOOK SALMON, *CHLORINATED BIPHENYLS, *ENZYME ACTIVITY,
1935 HYDROCARBONS, CRUSTACEANS, PLANKTON , UPTAKE, RELEASE, *14C-1-NAPHTHALENE, *COPEPODS,
1936 HYDROCARBONS, FISH, BIOLOGICAL EFFECTS, ANALYTICAL TECHNIQUES, *TISSUES, *MORPHOLOGICAL CHANGES,
1947 HYDROCARBONS, UPTAKE, STORAGE, RELEASE, MARINE ORGANISMS,
1951 HYDROCARBONS, ECOSYSTEMS, BIOLOGICAL EFFECTS, ARCTIC, MARINE ORGANISMS, SUBARCTIC REGIONS,
1956 HYDROCARBONS, BIOLOGICAL EFFECTS, PHYTOPLANKTON, METABOLISM, *PLANT GROWTH, *PHOTOSYNTHESIS,
1959 HYDROCARBONS, DETECTION, CANADA, METABOLISM, MONITORING, MARINE ORGANISMS, *ENZYME ACTIVITY,
1963 HYDROCARBONS, FUEL OIL, FISH, CRUDE OIL, TOXICITY, METABOLISM,*RESPIRATION, *ONCORHYNCHUS GORBUSCHA,
1965 HYDROCARBONS, EMULSIFIERS, CRUDE OIL, BIBLIOGRAPHIES, TOXICITY, MOLLUSKS, SURFACTANTS, *MUSSELS,
1967 HYDROCARBONS, CONTAMINATION, ATLANTIC COAST, OIL DISCHARGES, PHYTOPLANKTON, OCS,
1972 HYDROCARBONS, FISH, TOXICITY, *BENZENE, *REPRODUCTION, *CLUPEA HARENGUS PALLASI,
1974 HYDROCARBONS, FUEL OIL, CRUSTACEANS, UPTAKE, METABOLISM, *NAPHTHALENES, *HATCHING, *LARVAL GROWTH, *GRASS SHRIMP,
1976 HYDROCARBONS, FOOD WEB, UPTAKE, RELEASE, OCEANS, *FOOD CHAIN TRANSFER,
2005 HYDROCARBONS, ENVIRONMENTAL EFFECTS, CONTAMINATION, CHRONIC EFFECTS, MARINE ORGANISMS, OIL SPILLS,

NWMAR116912

2008 HYDROCARBONS, HEALTH HAZARDS, CONTAMINATION, BIOLOGICAL EFFECTS, OCEANS, POLLUTION CONTROL,
2038 HYDROCARBONS, CHEMICAL ANALYSIS, BASELINE STUDIES, ATLANTIC COAST, OCS, OFFSHORE DEVELOPMENT,
2060 HYDROCARBONS, FRESHWATER, EMULSIFICATION, BIODEGRADATION, BACTERIA, *KEROSENE,
2062 HYDROCARBONS, BIODEGRADATION, BEACHES, BACTERIA, SEDIMENT, MAGELLAN/STRAIT OF, METULA SPILL,
2063 HYDROCARBONS, BIODEGRADATION, BACTERIA, AROMATIC HYDROCARBONS , YEASTS, OIL SLICKS, *CHLORINATED HYDROCARBONS ,
2065 HYDROCARBONS, BIODEGRADATION, BACTERIA, OIL SHALE,
2066 HYDROCARBONS, BIODEGRADATION, BACTERIA, *TAXONOMY,
2069 HYDROCARBONS, FUNGI, FRESHWATER, BIODEGRADATION, BACTERIA, SEDIMENTS,
2071 HYDROCARBONS, GASOLINE, BIODEGRADATION, ALASKA, MICROORGANISMS, LAKES, SEDIMENTS,
2076 HYDROCARBONS, BIODEGRADATION, ARCTIC, METABOLISM, MARINE ORGANISMS, SUBARCTIC REGIONS, TOXICITY,
2077 HYDROCARBONS, CRUDE OIL, BIODEGRADATION, BEAUFORT SEA, ICE, SEDIMENTS, SEAWATER,
2081 HYDROCARBONS, BIODEGRADATION, BACTERIA, LAKES, WATER QUALITY, WISCONSIN, *NUTRIENT LIMITATION,
2082 HYDROCARBONS, CRUDE OIL, CANADA, BIODEGRADATION, BACTERIA, SOIL, *NUTRIENT ADDITION,
2085 HYDROCARBONS, FATE, EVAPORATION, OIL SPILLS, SOLUTION, WEATHERING,
2091 HYDROCARBONS, FUEL OIL, ESTUARIES, SEDIMENTS, MARINE ORGANISMS, VIRGINIA,
2097 HYDROCARBONS, FATE, BIODEGRADATION, SEAWATER, ECOSYSTEM, SEDIMENTATION, *NAPHTHALENES,
2100 HYDROCARBONS, CRUDE OIL, ADSORPTION, SOIL, *DESORPTION, *ORGANIC MATTER CONTENT,
2101 HYDROCARBONS, FATE, SEAWATER, MARINE ORGANISMS, *MOLECULAR INTERACTIONS,
2102 HYDROCARBONS, ALASKA, UPTAKE, RELEASE, SEDIMENTS, OIL SLICKS, INTERTIDAL ZONE,
1919 ICE, FUNGI, FRESHWATER, CRUDE OIL, BIOLOGICAL EFFECTS, BACTERIA, *OIL-UNDER-ICE ,
2034 ICE, ENVIRONMENTAL EFFECTS, CANADA, ARCTIC, OFFSHORE EXPLORATION, OFFSHORE DEVELOPMENT, OIL INDUSTRY,
2051 ICE, OFFSHORE DEVELOPMENT, OCS, SAFETY, LABRADOR SEA, *MINING TECHNOLOGY,
2054 ICE, ENVIRONMENTAL EFFECTS, ARCTIC, OFFSHORE DEVELOPMENT, *ICE COVERED WATERS, *RESEARCH TECHNOLOGY,
2077 ICE, HYDROCARBONS, CRUDE OIL, BIODEGRADATION, BEAUFORT SEA, SEDIMENTS, SEAWATER,
2086 ICE, BEAUFORT SEA, OIL SPILLS, SPREADING, *UNDER-ICE SPILL,
2096 ICE, FATE, ALASKA, OIL SPILLS, *OIL-UNDER-ICE , *IMPULSE RADAR SYSTEM,
2123 IMCO, EPA, INTERNATIONAL CONVENTIONS, POLLUTION PREVENTION, SWEDEN, *BALTIC CONVENTION,
2126 IMCO, INTERNATIONAL CONVENTIONS, OIL DISCHARGES, TANKERS, LAW ENFORCEMENT,
1768 INCINERATION, FILTRATION, EVAPORATION, EMULSIONS, *OIL REMOVAL,
1776 INCINERATION, ABSORPTION, SPILL RECOVERY, PATENT, *ABSORBENT FIBERS,
1790 INCINERATION, ABSORPTION, SPILL CLEANUP, *GELLING AGENTS,
1803 INCINERATION, EVAPORATION, WASTEWATER TREATMENT, REFINERIES, PATENT, *THERMAL OXIDATION ,
1812 INCINERATION, WASTEWATER DISPOSAL, SLUDGE, REFINERIES, *FLUID BEDS,
1678 INDIA, INDUSTRIES, REFINERIES, WASTEWATERS, RECLAMATION, REUSE,
1806 INDUSTRIES, FILTRATION, EMULSIONS, WASTEWATER TREATMENT, OIL-WATER SEPARATION, *ULTRAFILTRATION ,
1818 INDUSTRIES, GROUNDWATER, ENVIRONMENTAL EFFECTS, DISPOSAL , CRUDE OIL, CONTAMINANTS,
1830 INDUSTRIES, CANADA, WASTEWATER TREATMENT, OIL-WATER SEPARATION, RECLAMATION, REUSE,
1678 INDUSTRIES, INDIA, REFINERIES, WASTEWATERS, RECLAMATION, REUSE,
2039 INDUSTRIES, ENVIRONMENTAL EFFECTS, OIL SHALE, MONITORING, *R & D NEEDS,
1649 INFORMATION SYSTEMS, STATISTICS, POLLUTION CONTROL, OFFSHORE DEVELOPMENT, *DATA BANK, UK,
1676 INFORMATION SYSTEMS, ENVIRONMENTAL EFFECTS, BLM, BASELINE STUDIES, ALASKA COAST, MONITORING, OFFSHORE DEVELOPMENT, OCS, NOAA,
1732 INLAND, HARBORS, BOOMS, SPILL CONTAINMENT, *PRODUCT INFORMATION,
1855 INLAND, DISPOSAL , CONTAMINANTS, REFINERIES, WASTEWATERS, SOLID WASTES, *WASTE DISPOSAL PRACTICES, *LANDFILLS,
1906 INLAND, ENVIRONMENTAL EFFECTS, POLLUTION CONTROL, OIL SPILLS, OCEANS, SPILL CLEANUP,
1991 INLAND, ECONOMICS, CALIFORNIA, OIL SPILLS, SPILL CLEANUP, RESTORATION,
1731 INTERNATIONAL AGREEMENTS, SOURCE IDENTIFICATION, OIL DISCHARGES, NATURAL SEEPAGE, OIL SPILLS, OFFSHORE DEVELOPMENT, TANKERS,
2115 INTERNATIONAL AGREEMENTS, INTERNATIONAL CONVENTIONS, LEGISLATION, POLLUTION CONTROL, OCEANS, UK, US,
2124 INTERNATIONAL AGREEMENTS, LIABILITY, OFFSHORE DRILLING, OIL TRANSFER, STORAGE, NORTH SEA,
1902 INTERNATIONAL CONVENTIONS, OIL SPILLS, TANKERS, OIL DISCHARGES, SAFETY, POLLUTION CONTROL, LIABILITY,
2115 INTERNATIONAL CONVENTIONS, INTERNATIONAL AGREEMENTS, LEGISLATION, POLLUTION CONTROL, OCEANS, UK, US,
2116 INTERNATIONAL CONVENTIONS, LEGISLATION, POLLUTION CONTROL,
2123 INTERNATIONAL CONVENTIONS, IMCO, EPA, POLLUTION PREVENTION, SWEDEN, *BALTIC CONVENTION,
2125 INTERNATIONAL CONVENTIONS, BIOLOGICAL EFFECTS, UN, POLLUTION CONTROL, MONITORING, MEDITERRANEAN SEA,
2126 INTERNATIONAL CONVENTIONS, IMCO, OIL DISCHARGES. TANKERS, LAW ENFORCEMENT,
1713 INTERTIDAL ZONE, HYDROCARBONS, ANALYTICAL TECHNIQUES, SAMPLING, SEDIMENTS, WASHINGTON,
1956 INTERTIDAL ZONE, BIOLOGICAL EFFECTS, BALTIC SEA, SPILL CLEANUP,

NWMAR116913

1957 INTERTIDAL ZONE, BIOMASS, BIOLOGICAL EFFECTS, BACTERIA, SEDIMENTS, MICROORGANISMS,
1971 INTERTIDAL ZONE, BIOLOGICAL EFFECTS, METULA SPILL, MARINE ORGANISMS, MAGELLAN/STRAIT OF,
1977 INTERTIDAL ZONE, CHEDABUCTO BAY, CANADA, OIL SPILLS, TOXICITY, MARINE ORGANISMS, *MORTALITIES,
1996 INTERTIDAL ZONE, ENVIRONMENTAL EFFECTS, DISPERSANTS, OIL SPILLS, SHORELINES, MARINE ORGANISMS, TOXICITY,
2094 INTERTIDAL ZONE, FATE, DISTRIBUTION, BIODEGRADATION, BALTIC SEA, OIL SPILLS, MODELS,
2102 INTERTIDAL ZONE, HYDROCARBONS, ALASKA, UPTAKE, RELEASE, SEDIMENTS, OIL SLICKS,
1922 INVERTEBRATES, FOOD WEB, FISH, BIOLOGICAL EFFECTS, ARGO MERCHANT SPILL,
1946 INVERTEBRATES, FRESHWATER, REFINERIES, TOXICITY, WASTEWATERS, MONITORING, *DAPHNIA PULEX, *BIOASSAY,
1952 INVERTEBRATES, FUEL OIL, FISH, BIOLOGICAL EFFECTS, OIL SPILLS, STREAMS, VIRGINIA,
1950 ISRAEL, CORAL REEFS, CONTAMINATION, BIOLOGICAL EFFECTS, RED SEA, *SUCCESSION, *RECOLONIZATION,
1666 JAPAN, FISH, DISPERSANTS, TOXICITY, TROPICAL REGIONS, *WARREN SPRINGS LABORATORY, *HONG KONG,
2106 JAPAN, PETROLEUM PRODUCTS, SEDIMENTS, MOVEMENT, *SETO INLAND SEA,
2051 LABRADOR SEA, ICE, OFFSHORE DEVELOPMENT, OCS, SAFETY, *MINING TECHNOLOGY,
1730 LAKES, HYDROCARBONS, SOURCE IDENTIFICATION, SEDIMENTS,
2071 LAKES, HYDROCARBONS, GASOLINE, BIODEGRADATION, ALASKA, MICROORGANISMS, SEDIMENTS,
2072 LAKES, GASOLINE, BIOLOGICAL EFFECTS, BIODEGRADATION, ARCTIC, MICROORGANISMS,
2081 LAKES, HYDROCARBONS, BIODEGRADATION, BACTERIA, WATER QUALITY, WISCONSIN, *NUTRIENT LIMITATION,
1906 LAW ENFORCEMENT, LEGISLATION, POLLUTION PREVENTION, OIL SPILLS, USCG,
2119 LAW ENFORCEMENT, ENGLAND, CANADA, LEGISLATION, SHIPS, OIL SPILLS,
2120 LAW ENFORCEMENT, GOVERNMENT AGENCIES, REGULATIONS, TANKERS, PORTS, USCG, SAFETY,
2126 LAW ENFORCEMENT, INTERNATIONAL CONVENTIONS, IMCO, OIL DISCHARGES, TANKERS,
1686 LEAKAGE, DETECTION, MONITORING, PIPELINES,
1766 LEAKAGE, TANKERS, SPILL CLEANUP, PATENT, *OIL SOLIDIFICATION,
1890 LEAKAGE, SHIPS, POLLUTION PREVENTION, *STERNGEAR SEAL SYSTEM,
1894 LEAKAGE, DETECTION, PIPELINES, PATENT,
1895 LEAKAGE, DESIGN-ENGINEERING, PIPELINES, POLLUTION PREVENTION, PATENT,
1899 LEAKAGE, DETECTION, PRODUCTION , POLLUTION PREVENTION, OIL SPILLS, PIPELINES,
1901 LEAKAGE, DETECTION, DESIGN-ENGINEERING, PIPELINES, PATENT,
1909 LEAKAGE, POLLUTION PREVENTION, SHIPS, OIL DISCHARGES, OIL SPILLS,
1659 LEGISLATION, COMPENSATION, NEW JERSEY, SPILL CLEANUP, OIL INDUSTRY, *SPILL FUND,
1908 LEGISLATION, LAW ENFORCEMENT, POLLUTION PREVENTION, OIL SPILLS, USCG,
1988 LEGISLATION, COMPENSATION, LIABILITY, TANKERS, OIL SPILLS, OIL INDUSTRY, *SPILL SUPERFUNDS,
1992 LEGISLATION, ENVIRONMENTAL EFFECTS, ECONOMIC EFFECTS, CANADA, TANKERS, OIL SPILLS,
2053 LEGISLATION, ENVIRONMENTAL MANAGEMENT, COASTS, OIL INDUSTRY, LOUISIANA, US,
2108 LEGISLATION, COMPENSATION, US, OIL SPILLS, LIABILITY, SPILL CLEANUP, *COSTS,
2109 LEGISLATION, ENVIRONMENTAL EFFECTS, COASTS, US, OCS, OFFSHORE DEVELOPMENT, REFINERIES,
2110 LEGISLATION, US, STATE GOVERNMENTS, OIL SPILLS, TANKERS, POLLUTION CONTROL,
2115 LEGISLATION, INTERNATIONAL CONVENTIONS, INTERNATIONAL AGREEMENTS, POLLUTION CONTROL, OCEANS, UK, US,
2116 LEGISLATION, INTERNATIONAL CONVENTIONS, POLLUTION CONTROL,
2119 LEGISLATION, LAW ENFORCEMENT, ENGLAND, CANADA, SHIPS, OIL SPILLS,
2134 LEGISLATION, BIBLIOGRAPHIES, US, POLLUTION CONTROL,
1640 LIABILITY, ARGO MERCHANT SPILL, TANKERS, SPILL CLEANUP,
1902 LIABILITY, INTERNATIONAL CONVENTIONS, OIL SPILLS, TANKERS, OIL DISCHARGES, SAFETY, POLLUTION CONTROL,
1988 LIABILITY, LEGISLATION, COMPENSATION, TANKERS, OIL SPILLS, OIL INDUSTRY, *SPILL SUPERFUNDS,
1969 LIABILITY, ALASKA, OIL SPILLS, REGULATIONS, TANKERS, OIL TRANSFER, PORTS, *OIL SPILL FUND,
2108 LIABILITY, LEGISLATION, COMPENSATION, US, OIL SPILLS, SPILL CLEANUP, *COSTS,
2124 LIABILITY, INTERNATIONAL AGREEMENTS, OFFSHORE DRILLING, OIL TRANSFER, STORAGE, NORTH SEA,
1644 LOUISIANA, BLOWOUTS, OIL WELLS, *GAS-WELLS,
1800 LOUISIANA, ENVIRONMENTAL EFFECTS, EIS, CRUDE OIL, STORAGE, *BAYOU CHOCTAW SALT DOME,
2044 LOUISIANA, ENVIRONMENTAL EFFECTS, ECONOMIC EFFECTS, OIL INDUSTRY, OFFSHORE DRILLING, OCS,
2053 LOUISIANA, LEGISLATION, ENVIRONMENTAL MANAGEMENT, COASTS, OIL INDUSTRY, US,
1840 LUBRICATING OIL, GASOLINE, FUEL OIL, ENVIRONMENTAL EFFECTS, WASTEWATERS, OIL DISCHARGES, MONITORING, *DISSOLVED ORGANICS,
1873 LUBRICATING OIL, FILTRATION, COALESCENCE, WASTE OIL, RECYCLING,
1874 LUBRICATING OIL, RECLAMATION, WASTE OILS, *IFP PROCESS,
1877 LUBRICATING OIL, FUELS, FILTRATION, WASTE OIL, RECLAMATION, OIL-WATER SEPARATION, *USCG POWER PLANTS,
1949 LUBRICATING OIL, FRESHWATER, FISH, CHRONIC EFFECTS, TOXICITY, *SYNTHETIC OIL,
2006 LUBRICATING OIL, BIOLOGICAL EFFECTS, BACTERIA, PETROLEUM PRODUCTS, MOVEMENT, SOIL,
1971 MAGELLAN/STRAIT OF, INTERTIDAL ZONE, BIOLOGICAL EFFECTS, METULA SPILL, MARINE ORGANISMS,

NWMAR116914

1993 MAGELLAN/STRAIT OF, ENVIRONMENTAL EFFECTS, BEACHES, METULA SPILL, SEDIMENTS,
2062 MAGELLAN/STRAIT OF, HYDROCARBONS, BIODEGRADATION, BEACHES, BACTERIA, SEDIMENT, METULA SPILL,
1984 MAINE, BIOLOGICAL EFFECTS, OIL SPILLS, MOLLUSKS, *GONADAL NEOPLASMS, *MYA ARENARIA,
1995 MALAYSIA, ENVIRONMENTAL EFFECTS, OIL SPILLS, TANKERS,
2122 MANUALS, GUIDELINES, CONTINGENCY PLANNING, POLLUTION PREVENTION, TANKERS,
2013 MARINE MAMMALS, OFFSHORE DEVELOPMENT, OCS, ENVIRONMENTAL EFFECTS, BIRDS, BASELINE STUDIES, ALASKA,
1924 MARINE MAMMALS, HYDROCARBONS, CRUDE OIL, BIOLOGICAL EFFECTS, BEAUFORT SEA, UPTAKE, *RINGED SEAL,
1986 MARINE MAMMALS, CRUDE OIL, BIOLOGICAL EFFECTS, *THERMAL CONDUCTANCE, *SEA OTTERS, *PINNIPEDS,
2037 MARINE MAMMALS, BIOLOGICAL EFFECTS, ALASKA, OFFSHORE DEVELOPMENT, OCS, *MORTALITY,
1714 MARINE ORGANISMS, HYDROCARBONS, DETECTION, CHROMATOGRAPHY, CHEMICAL ANALYSIS, BASELINE STUDIES, SPECTROSCOPY,
1715 MARINE ORGANISMS, HYDROCARBONS, CHROMATOGRAPHY, CHEMICAL ANALYSIS, SOURCES, SPECTROSCOPY, SPECTROMETRY,
1910 MARINE ORGANISMS, ENVIRONMENTAL EFFECTS, OIL SPILLS, TOXICITY,
1913 MARINE ORGANISMS, HYDROCARBONS, BEHAVIOR, ANALYTICAL TECHNIQUES, TOXICITY, METABOLISM, *SUBLETHAL LEVELS,
1916 MARINE ORGANISMS, DISPERSANTS, SPILL CLEANUP, OIL DISCHARGES, TOXICITY,
1927 MARINE ORGANISMS, ENVIRONMENTAL EFFECTS, BIRDS, BIOLOGICAL EFFECTS, OIL SPILLS, SANTA BARBARA CHANNEL,
1937 MARINE ORGANISMS, CHESAPEAKE BAY, BIRDS, BIOLOGICAL EFFECTS, OIL SPILLS, MARSHES, MOLLUSKS, *MARSH GRASSES,
1947 MARINE ORGANISMS, HYDROCARBONS, UPTAKE, STORAGE, RELEASE,
1951 MARINE ORGANISMS, HYDROCARBONS, ECOSYSTEMS, BIOLOGICAL EFFECTS, ARCTIC, SUBARCTIC REGIONS,
1959 MARINE ORGANISMS, HYDROCARBONS, DETECTION, CANADA, METABOLISM, MONITORING, *ENZYME ACTIVITY,
1962 MARINE ORGANISMS, FUEL OIL, CRUDE OIL, TOXICITY, UPTAKE, RELEASE,
1964 MARINE ORGANISMS, CRUDE OIL, TOXICITY, PETROLEUM PRODUCTS, *COMPARATIVE TOXICITY , *BIOASSAY,
1971 MARINE ORGANISMS, MAGELLAN/STRAIT OF, INTERTIDAL ZONE, BIOLOGICAL EFFECTS, METULA SPILL,
1977 MARINE ORGANISMS, INTERTIDAL ZONE, CHEDABUCTO BAY, CANADA, OIL SPILLS, TOXICITY, *MORTALITIES,
1996 MARINE ORGANISMS, INTERTIDAL ZONE, ENVIRONMENTAL EFFECTS, DISPERSANTS, OIL SPILLS, SHORELINES, TOXICITY,
1998 MARINE ORGANISMS, FISHERIES, EXPLORATION , DISPERSANTS, CONTAMINATION, BIOLOGICAL EFFECTS, SOURCES, SHIPS, PRODUCTION , SEABIRDS, SPILL CLEANUP,
2000 MARINE ORGANISMS, DISPERSANTS, CONTAMINATION, BIOLOGICAL EFFECTS, OCEANS, SOURCES, POLLUTION CONTROL,
2005 MARINE ORGANISMS, HYDROCARBONS, ENVIRONMENTAL EFFECTS, CONTAMINATION, CHRONIC EFFECTS, OIL SPILLS,
2041 MARINE ORGANISMS, CALIFORNIA/SOUTHERN, OFFSHORE DRILLING, PLATFORMS, UPTAKE, SEDIMENTS,
2076 MARINE ORGANISMS, HYDROCARBONS, BIODEGRADATION, ARCTIC, METABOLISM, SUBARCTIC REGIONS, TOXICITY,
2091 MARINE ORGANISMS, HYDROCARBONS, FUEL OIL, ESTUARIES, SEDIMENTS, VIRGINIA,
2101 MARINE ORGANISMS, HYDROCARBONS, FATE, SEAWATER, *MOLECULAR INTERACTIONS,
2133 MARINE ORGANISMS, ESTUARIES, ENVIRONMENTAL EFFECTS, BIBLIOGRAPHIES,
2136 MARINE ORGANISMS, CONTAMINATION, CARIBBEAN SEA, BIBLIOGRAPHIES,
1791 MARSHES, FRESHWATER, DISPOSAL , DISPERSANTS, COASTS, BEACHES, ABSORPTION, SPILL CLEANUP, SEAWATER,
1793 MARSHES, ENGLAND, CONTAMINATION, RESTORATION, VEGETATION, WASTEWATERS, REFINERIES, *SALT MARSH,
1925 MARSHES, HYDROCARBONS, FUEL OIL, BIOLOGICAL EFFECTS, BIODEGRADATION, MICROORGANISMS, *SALTMARSH,
1937 MARSHES, MARINE ORGANISMS, CHESAPEAKE BAY, BIRDS, BIOLOGICAL EFFECTS, OIL SPILLS, MOLLUSKS, *MARSH GRASSES,
1944 MARSHES, FUEL OIL, CRUSTACEANS, CONTAMINATION, BIOLOGICAL EFFECTS, OIL SPILLS, MASSACHUSETTS, *UCA PUGNAX,
1999 MARSHES, ENVIRONMENTAL EFFECTS, ALASKA, OIL TRANSPORT, OIL SPILLS, VEGETATION, SOIL,
1944 MASSACHUSETTS, MARSHES, FUEL OIL, CRUSTACEANS, CONTAMINATION, BIOLOGICAL EFFECTS, OIL SPILLS, *UCA PUGNAX,
2125 MEDITERRANEAN SEA, INTERNATIONAL CONVENTIONS, BIOLOGICAL EFFECTS, UN, POLLUTION CONTROL, MONITORING,
1913 METABOLISM, MARINE ORGANISMS, HYDROCARBONS, BEHAVIOR, ANALYTICAL TECHNIQUES, TOXICITY, *SUBLETHAL LEVELS,
1942 METABOLISM, FISH, PETROLEUM PRODUCTS, TOXICITY, *SPICARA SMARIS, *SOLEA LASCARIS NASUTA,
1945 METABOLISM, FUEL OIL, CRUSTACEANS, BIOLOGICAL EFFECTS, *TEMPERATURE, *SALINITY, *LIMULUS POLYPHEMUS,
1956 METABOLISM, HYDROCARBONS, BIOLOGICAL EFFECTS, PHYTOPLANKTON, *PLANT GROWTH, *PHOTOSYNTHESIS,

NWMAR116915

1959 METABOLISM, MARINE ORGANISMS, HYDROCARBONS, DETECTION, CANADA, MONITORING, *ENZYME ACTIVITY,
1960 METABOLISM, DISPERSIONS, CRUSTACEANS, CRUDE OIL, BIOLOGICAL EFFECTS, *SUBLETHAL EFFECTS, *ARCTIC AMPHIPOD,
1963 METABOLISM, HYDROCARBONS, FUEL OIL, FISH, CRUDE OIL, TOXICITY,*RESPIRATION, *ONCORHYNCHUS GORBUSCHA,
1974 METABOLISM, HYDROCARBONS, FUEL OIL, CRUSTACEANS, UPTAKE, *NAPHTHALENES, *HATCHING, *LARVAL GROWTH, *GRASS SHRIMP,
2076 METABOLISM, MARINE ORGANISMS, HYDROCARBONS, BIODEGRADATION, ARCTIC, SUBARCTIC REGIONS, TOXICITY,
1971 METULA SPILL, MARINE ORGANISMS, MAGELLAN/STRAIT OF, INTERTIDAL ZONE, BIOLOGICAL EFFECTS,
1993 METULA SPILL, MAGELLAN/STRAIT OF, ENVIRONMENTAL EFFECTS, BEACHES, SEDIMENTS,
2062 METULA SPILL, MAGELLAN/STRAIT OF, HYDROCARBONS, BIODEGRADATION, BEACHES, BACTERIA, SEDIMENT,
1671 MEXICO/GULF OF, HYDROCARBONS, MONITORING, SOURCES, PLATFORMS, *GAS VENTING, *BRINE SCHARGE,
1678 MEXICO/GULF OF, HYDROCARBONS, MONITORING, SEDIMENTS, SOURCES, *CONTINENTAL SHELF,
1698 MEXICO/GULF OF, HYDROCARBONS, CHEMICAL ANALYSIS, SAMPLING, SEAWATER, OIL-GAS LEASING, *SEASONAL VARIATIONS, *MAFLA LEASE AREA,
2024 MEXICO/GULF OF, ENVIRONMENTAL EFFECTS, EIS, OIL-GAS LEASING, OCS,
2025 MEXICO/GULF OF, ENVIRONMENTAL EFFECTS, EIS, OIL-GAS LEASING, OCS,
1673 MICROORGANISMS, FATE, CRUDE OIL, CHEMICAL EFFECTS, BIOLOGICAL EFFECTS, ALASKA, MONITORING, MOVEMENT, *PERMAFROST TERRAIN,
1923 MICROORGANISMS, FUEL OIL, CRUDE OIL, CANADA, BIOLOGICAL EFFECTS, *GEORGIA STRAIT, *HETEROTROPHIC POTENTIAL, *PRODUCTIVITY,
1925 MICROORGANISMS, MARSHES, HYDROCARBONS, FUEL OIL, BIOLOGICAL EFFECTS, BIODEGRADATION, *SALTMARSH,
1957 MICROORGANISMS, INTERTIDAL ZONE, BIOMASS, BIOLOGICAL EFFECTS, BACTERIA, SEDIMENTS,
2057 MICROORGANISMS, BIODEGRADATION, ARCTIC OCEAN, *14C-DODECANE OXIDATION , *PORT VALDEZ,
2058 MICROORGANISMS, CRUDE OIL, BIODEGRADATION, BEAUFORT SEA, ARCTIC,
2068 MICROORGANISMS, BIODEGRADATION, AROMATIC HYDROCARBONS , SOURCES,
2070 MICROORGANISMS, BIODEGRADATION, ARCTIC OCEAN, OIL SLICKS, *CONTINUOUS FLOW-THROUGH YSTEM,
2071 MICROORGANISMS, LAKES, HYDROCARBONS, GASOLINE, BIODEGRADATION, ALASKA, SEDIMENTS,
2072 MICROORGANISMS, LAKES, GASOLINE, BIOLOGICAL EFFECTS, BIODEGRADATION, ARCTIC,
2107 MICROORGANISMS, FUEL OIL, DECOMPOSITION, BIODEGRADATION, *PHYSICOCHEMICAL DEGRADATION,
2128 MICROORGANISMS, BIOLOGICAL EFFECTS, BIBLIOGRAPHIES, ANIMALS, OIL SPILLS, PLANTS,
2087 MODELS, EVAPORATION, DELAWARE BAY, OIL SPILLS, WEATHERING, OIL TRANSFER,
2088 MODELS, FATE, OIL SPILLS, OXIDATION, *N-HEXADECANE, *PHOTOOXIDATION ,
2094 MODELS, INTERTIDAL ZONE, FATE, DISTRIBUTION, BIODEGRADATION, BALTIC SEA, OIL SPILLS, ..ODELS, BEHAVIOR, OIL SLICKS, PHYSICAL EFFECTS, *WIND-CURRENT EFFECTS,
1699 MOLLUSKS, ESTUARIES, DETECTION, CARCINOGENS, SAMPLING, PAH, OREGON, *BIVALVES,
1794 MOLLUSKS, ENGLAND, BIOLOGICAL EFFECTS, ALGAE, RESTORATION, SHORELINES, OIL SPILLS, *ROCKY SHORES,
1928 MOLLUSKS, BIOLOGICAL EFFECTS, *PHENOL, *CYTOLOGY, *MERCENARIA MERCENARIA,
1929 MOLLUSKS, CRUDE OIL, UPTAKE, RELEASE, *NAPHTHALENES, *RANGEA CUNEATA, *PROTOTHACA .MINEA,
1937 MOLLUSKS, MARSHES, MARINE ORGANISMS, CHESAPEAKE BAY, BIRDS, BIOLOGICAL EFFECTS, OIL SPILLS, *MARSH GRASSES,
1965 MOLLUSKS, HYDROCARBONS, EMULSIFIERS, CRUDE OIL, BIBLIOGRAPHIES, TOXICITY, SURFACTANTS, *MUSSELS,
1968 MOLLUSKS, FUEL OIL, EMULSIONS, UPTAKE, RELEASE, *MYA ARENARIA L.,
1975 MOLLUSKS, CRUDE OIL, BIOLOGICAL EFFECTS, SEAWATER, SEDIMENTS, *WATER-SOLUBLE FRACTION, *OIL-TREATED SEDIMENT, *MACOMA BALTHICA,
1979 MOLLUSKS, TOXICITY, UPTAKE, RELEASE, *OIL DROPLETS, *MORTALITY, *CRASSOSTREA GIGAS, *MYTILUS SPP.,
1981 MOLLUSKS, UPTAKE, PETROLEUM PRODUCTS, SEAWATER, *WATER PURIFICATION, *MYTILUS EDULIS,
1984 MOLLUSKS, MAINE, BIOLOGICAL EFFECTS, OIL SPILLS, *GONADAL NEOPLASMS, *MYA ARENARIA,
1641 MONITORING, ARGO MERCHANT SPILL, MOVEMENT, POLLUTION PREVENTION, TANKERS, USGS,
1664 MONITORING, FATE, ENVIRONMENTAL EFFECTS, BEHAVIOR, OIL SPILLS, SPILL CLEANUP, *1977 OIL SPILL CONFERENCE,
1667 MONITORING, CONTAMINANTS, ANALYTICAL TECHNIQUES, SAMPLING,
1668 MONITORING, CHESAPEAKE BAY, ARGO MERCHANT SPILL,
1669 MONITORING, DESIGN-ENGINEERING, POLLUTION CONTROL,
1670 MONITORING, CHEMICAL ANALYSIS, OIL SPILLS, WASTE OIL, *IR ABSORPTION ,
1671 MONITORING, MEXICO/GULF OF, HYDROCARBONS, SOURCES, PLATFORMS, *GAS VENTING, *BRINE DISCHARGE,
1672 MONITORING, HYDROCARBONS, DISTRIBUTION, CHRONIC EFFECTS, AUSTRALIA, SOURCES, *MYTILUS EDULIS, *INDICATOR SPECIES,
1673 MONITORING, MICROORGANISMS, FATE, CRUDE OIL, CHEMICAL EFFECTS, BIOLOGICAL EFFECTS, ALASKA, MOVEMENT, *PERMAFROST TERRAIN,
1674 MONITORING, DETECTION, DESIGN-ENGINEERING, OIL SPILLS, *BUOYS, *GAS SENSORS,
1675 MONITORING, POLLUTION CONTROL, OIL-WATER SEPARATION, SHIPS, *ULTRASONIC MONITOR,
1676 MONITORING, INFORMATION SYSTEMS, ENVIRONMENTAL EFFECTS, BLM, BASELINE STUDIES, ALASKA

NWMAR116916

COAST, OFFSHORE DEVELOPMENT, OCS, NOAA,
1677 MONITORING, DESIGN-ENGINEERING, CHROMATOGRAPHY, SOURCE IDENTIFICATION, *INSTRUMENT SURVEY,
1678 MONITORING, MEXICO/GULF OF, HYDROCARBONS, SEDIMENTS, SOURCES, *CONTINENTAL SHELF,
1679 MONITORING, HYDROCARBONS, ENVIRONMENTAL EFFECTS, OIL TRANSPORT, PIPELINES, REFINERIES, PUGET SOUND,
1680 MONITORING, DESIGN-ENGINEERING, OIL DISCHARGES, TANKERS, REGULATIONS, PATENT,
1681 MONITORING, STREAMS, SEDIMENTS, WASTEWATERS, REFINERIES, SAMPLING, *HEAVY METALS,
1682 MONITORING, PETROLEUM PRODUCTS, OXIDATION, SEAWATER, *CHEMILUMINESCENCE,
1683 MONITORING, DISPERSIONS, DETECTION, PATENT, *OIL SOLUBLE DYE,
1684 MONITORING, DETECTION, DESIGN-ENGINEERING, BILGES, SHIPS,
1685 MONITORING, DESIGN-ENGINEERING, BILGES, *TOTAL ORGANIC CARBON DETERMINATION,
1686 MONITORING, LEAKAGE, DETECTION, PIPELINES,
1688 MONITORING, REMOTE SENSING, OIL SLICKS, POLLUTION CONTROL, *LANDSAT,
1691 MONITORING, DETECTION, COASTS, REMOTE SENSING, OIL SLICKS, NATURAL SEEPAGE, *LANDSAT DATA,
1692 MONITORING, ENVIRONMENTAL EFFECTS, CONTAMINANTS, REMOTE SENSING, OIL SPILLS,
1717 MONITORING, HYDROCARBONS, CHROMATOGRAPHY, CHEMICAL ANALYSIS, AROMATIC HYDROCARBONS , SEDIMENTS, *GLASS CAPILLARY COLUMNS,
1840 MONITORING, LUBRICATING OIL, GASOLINE, FUEL OIL, ENVIRONMENTAL EFFECTS, WASTEWATERS, OIL DISCHARGES, *DISSOLVED ORGANICS,
1946 MONITORING, INVERTEBRATES, FRESHWATER, REFINERIES, TOXICITY, WASTEWATERS, *DAPHNIA PULEX, *BIOASSAY,
1959 MONITORING, METABOLISM, MARINE ORGANISMS, HYDROCARBONS, DETECTION, CANADA, *ENZYME ACTIVITY,
2039 MONITORING, INDUSTRIES, ENVIRONMENTAL EFFECTS, OIL SHALE, *R & D NEEDS,
2075 MONITORING, FUNGI, BIODEGRADATION, BACTERIA, WASTE OIL, SOIL, *ARID SITE,
2090 MONITORING, ENVIRONMENTAL EFFECTS, BEHAVIOR, ARGO MERCHANT SPILL, MOVEMENT, SAMPLING,
2125 MONITORING, MEDITERRANEAN SEA, INTERNATIONAL CONVENTIONS, BIOLOGICAL EFFECTS, UN, POLLUTION CONTROL,
2135 MONITORING, DETECTION, CHEMICAL ANALYSIS, BIBLIOGRAPHIES, SAMPLING, REMOTE SENSING,
1641 MOVEMENT, MONITORING, ARGO MERCHANT SPILL, POLLUTION PREVENTION, TANKERS, USGS,
1673 MOVEMENT, MONITORING, MICROORGANISMS, FATE, CRUDE OIL, CHEMICAL EFFECTS, BIOLOGICAL EFFECTS, ALASKA, *PERMAFROST TERRAIN,
1695 MOVEMENT, COASTS, REMOTE SENSING, OIL SLICKS, WASTEWATERS, *CURRENT CIRCULATION, *SATELLITE-AIRCRAFT-DROGUE STUDIES,
2006 MOVEMENT, LUBRICATING OIL, BIOLOGICAL EFFECTS, BACTERIA, PETROLEUM PRODUCTS, SOIL,
2090 MOVEMENT, MONITORING, ENVIRONMENTAL EFFECTS, BEHAVIOR, ARGO MERCHANT SPILL, SAMPLING,
2095 MOVEMENT, ALASKA, OIL SPILLS, *COASTAL WINDS,
2096 MOVEMENT, BEAUFORT SEA, ALASKA COAST, OIL SPILLS, SHORELINES, *SPILL IMPACT PROBABILITY,
2103 MOVEMENT, OIL SLICKS, *LEEWAY, *WIND DRIFT,
2106 MOVEMENT, JAPAN, PETROLEUM PRODUCTS, SEDIMENTS, *SETO INLAND SEA,
1687 NATURAL SEEPAGE, REMOTE SENSING, OIL SLICKS, POLLUTION CONTROL, *LANDSAT,
1691 NATURAL SEEPAGE, MONITORING, DETECTION, COASTS, REMOTE SENSING, OIL SLICKS, *LANDSAT DATA,
1694 NATURAL SEEPAGE, DETECTION, REMOTE SENSING, OIL SLICKS, SURVEILLANCE, SANTA BARBARA CHANNEL, *COASTAL ZONE COLOR SCANNER,
1722 NATURAL SEEPAGE, CHROMATOGRAPHY, CHEMICAL ANALYSIS, CALIFORNIA/SOUTHERN, BIODEGRADATION, WEATHERING, SPECTROMETRY, SANTA BARBARA CHANNEL,
1731 NATURAL SEEPAGE, INTERNATIONAL AGREEMENTS, SOURCE IDENTIFICATION, OIL DISCHARGES, OIL SPILLS, OFFSHORE DEVELOPMENT, TANKERS,
1659 NEW JERSEY, LEGISLATION, COMPENSATION, SPILL CLEANUP, OIL INDUSTRY, *SPILL FUND,
2048 NEW JERSEY, FISHERIES, ENVIRONMENTAL EFFECTS, DELAWARE, ATLANTIC COAST, OFFSHORE DEVELOPMENT, PORTS,
1940 NEW YORK, CRUDE OIL, BENTHOS, TOXICITY, PLANKTON , OCS, *NEW YORK BIGHT,
1676 NOAA, MONITORING, INFORMATION SYSTEMS, ENVIRONMENTAL EFFECTS, BLM, BASELINE STUDIES, ALASKA COAST, OFFSHORE DEVELOPMENT, OCS,
1637 NORTH SEA, OIL SPILLS, STATISTICS, SOURCES, UK,
1642 NORTH SEA, BLOWOUTS, POLLUTION CONTROL, NORWAY, *EMERGENCY VESSEL,
1643 NORTH SEA, ENVIRONMENTAL EFFECTS, EKOFISK BLOWOUT, PRODUCTION ,
1647 NORTH SEA, FISH, EKOFISK BLOWOUT, OIL SPILLS,
1652 NORTH SEA, BLOWOUT PREVENTION, NORWAY, *RED ADAIR CO.,
1654 NORTH SEA, EKOFISK BLOWOUT, OIL SPILLS, SPILL CLEANUP, POLLUTION CONTROL,
1655 NORTH SEA, ENVIRONMENTAL PROTECTION, OIL SPILLS, OIL TRANSFER, TANKERS, SURVEILLANCE,
1658 NORTH SEA, ENVIRONMENTAL PROTECTION, EKOFISK BLOWOUT, WILDLIFE,
1665 NORTH SEA, EKOFISK BLOWOUT, POLLUTION CONTROL,
1744 NORTH SEA, BOOMS, BLOWOUTS, SPILL RECOVERY, NORWAY,
1751 NORTH SEA, DESIGN-ENGINEERING, SPILL RECOVERY, *OIL COLLECTION SYSTEMS,
1904 NORTH SEA, ENVIRONMENTAL PROTECTION, ECONOMIC EFFECTS, BLOWOUTS, STATISTICAL ANALYSIS,
2002 NORTH SEA, FISHERIES, BIRDS, OIL SPILLS, REFINERIES, OIL TRANSPORT, OFFSHORE PRODUCTION, POLLUTION CONTROL, TOXICITY,
2003 NORTH SEA, FISHERIES, CRUDE OIL, AROMATIC HYDROCARBONS , OFFSHORE DEVELOPMENT,
2012 NORTH SEA, FISHERIES, OIL INDUSTRY, OFFSHORE DEVELOPMENT, SCOTLAND,
2020 NORTH SEA, ENVIRONMENTAL PROTECTION, EKOFISK BLOWOUT, OFFSHORE DEVELOPMENT, SAFETY,

NWMAR116917

REGULATIONS,
2124 NORTH SEA, LIABILITY, INTERNATIONAL AGREEMENTS, OFFSHORE DRILLING, OIL TRANSFER, STORAGE,
1635 NORWAY, EKOFISK BLOWOUT, COST ANALYSIS, OFFSHORE DRILLING, OFFSHORE EXPLORATION,
1642 NORWAY, NORTH SEA, BLOWOUTS, POLLUTION CONTROL, *EMERGENCY VESSEL,
1645 NORWAY, BLOWOUTS, OIL SPILLS, *PREDICTION,
1652 NORWAY, NORTH SEA, BLOWOUT PREVENTION, *RED ADAIR CO.,
1744 NORWAY, NORTH SEA, BOOMS, BLOWOUTS, SPILL RECOVERY,
2026 NORWAY, CHEMICAL ANALYSIS, PETROCHEMICALS, WASTEWATER TREATMENT, POLLUTION CONTROL,
2093 NORWAY, FISH, CHEMICAL ANALYSIS, BIOLOGICAL EFFECTS, BIODEGRADATION, AROMATIC HYDROCARBONS , OIL SPILLS, WEATHERING, *T/T "DRUPA" SPILL,
1648 OCEANS, DISTRIBUTION, CANADA, ATLANTIC OCEAN, TAR, SARGASSO SEA,
1657 OCEANS, COASTS, ALASKA, OIL SPILLS, STATISTICS,
1662 OCEANS, OIL SPILLS, TANKERS, STATISTICS, *TANKER ACCIDENTS,
1689 OCEANS, REMOTE SENSING, OIL SLICKS, SURVEILLANCE, *DYS/SLICK SEAMARKING DEVICE,
1696 OCEANS, REMOTE SENSING, OIL SLICKS, *WAVE DAMPING, *OIL PROPERTIES,
1697 OCEANS, BIBLIOGRAPHIES, REMOTE SENSING, OIL SLICKS, *RADAR, *SEA SURFACE,
1702 OCEANS, CONTAMINATION, PETROLEUM PRODUCTS, *LASER RADAR, *SEA SURFACE,
1739 OCEANS, FRESHWATER, DESIGN-ENGINEERING, BOOMS, SPILL CONTAINMENT,
1778 OCEANS, ABSORPTION, SPILL CLEANUP, *POLYURETHANE FOAMS,
1906 OCEANS, INLAND, ENVIRONMENTAL EFFECTS, POLLUTION CONTROL, OIL SPILLS, SPILL CLEANUP,
1976 OCEANS, HYDROCARBONS, FOOD WEB, UPTAKE, RELEASE, *FOOD CHAIN TRANSFER,
2000 OCEANS, MARINE ORGANISMS, DISPERSANTS, CONTAMINATION, BIOLOGICAL EFFECTS, SOURCES, POLLUTION CONTROL,
2008 OCEANS, HYDROCARBONS, HEALTH HAZARDS, CONTAMINATION, BIOLOGICAL EFFECTS, POLLUTION CONTROL,
2056 OCEANS, FATE, DRILLING , BIOLOGICAL EFFECTS, *DRILL CUTTINGS,
2115 OCEANS, LEGISLATION, INTERNATIONAL CONVENTIONS, INTERNATIONAL AGREEMENTS, POLLUTION CONTROL, UK, US,
1676 OCS, NOAA, MONITORING, INFORMATION SYSTEMS, ENVIRONMENTAL EFFECTS, BLM, BASELINE STUDIES, ALASKA COAST, OFFSHORE DEVELOPMENT,
1865 OCS, CONTINGENCY PLANNING, CALIFORNIA/SOUTHERN, OIL INDUSTRY, OIL-GAS LEASING,
1940 OCS, NEW YORK, CRUDE OIL, BENTHOS, TOXICITY, PLANKTON , *NEW YORK BIGHT,
1967 OCS, HYDROCARBONS, CONTAMINATION, ATLANTIC COAST, OIL DISCHARGES, PHYTOPLANKTON,
2013 OCS, ENVIRONMENTAL EFFECTS, BIRDS, BASELINE STUDIES, ALASKA, OFFSHORE DEVELOPMENT, MARINE MAMMALS,
2014 OCS, FISH, ENVIRONMENTAL EFFECTS, BENTHOS, BASELINE STUDIES, ALASKA, OFFSHORE DEVELOPMENT, PLANKTON ,
2021 OCS, FOSSIL FUELS , ENVIRONMENTAL MANAGEMENT, OFFSHORE DRILLING, REGULATIONS, POLLUTION CONTROL,
2022 OCS, CRUDE OIL, ALASKA, OFFSHORE DRILLING, SOCIO-ECONOMIC EFFECTS, *SEA GRANT PROGRAM, *ENERGY POLICY,
2024 OCS, MEXICO/GULF OF, ENVIRONMENTAL EFFECTS, EIS, OIL-GAS LEASING,
2025 OCS, MEXICO/GULF OF, ENVIRONMENTAL EFFECTS, EIS, OIL-GAS LEASING,
2027 OCS, ENVIRONMENTAL EFFECTS, BERING SEA, ALASKA/GULF OF, OFFSHORE EXPLORATION, OIL-GAS LEASING,
2033 OCS, ENVIRONMENTAL EFFECTS, EIS, ALASKA, OIL-GAS LEASING, SOCIO-ECONOMIC EFFECTS,
2037 OCS, MARINE MAMMALS, BIOLOGICAL EFFECTS, ALASKA, OFFSHORE DEVELOPMENT, *MORTALITY,
2038 OCS, HYDROCARBONS, CHEMICAL ANALYSIS, BASELINE STUDIES, ATLANTIC COAST, OFFSHORE DEVELOPMENT,
2043 OCS, ENVIRONMENTAL EFFECTS, BLM, OFFSHORE DEVELOPMENT,
2044 OCS, LOUISIANA, ENVIRONMENTAL EFFECTS, ECONOMIC EFFECTS, OIL INDUSTRY, OFFSHORE DRILLING,
2045 OCS, ENVIRONMENTAL EFFECTS, CRUDE OIL, ALASKA, OFFSHORE DEVELOPMENT, OIL-GAS LEASING,
2051 OCS, LABRADOR SEA, ICE, OFFSHORE DEVELOPMENT, SAFETY, *MINING TECHNOLOGY,
2052 OCS, ENVIRONMENTAL EFFECTS, COASTS, OFFSHORE DEVELOPMENT, ONSHORE IMPACTS, POLLUTION PREVENTION,
2055 OCS, ENVIRONMENTAL EFFECTS, COASTS, OFFSHORE DEVELOPMENT, US, SOCIO-ECONOMIC EFFECTS, STATE GOVERNMENTS,
2109 OCS, LEGISLATION, ENVIRONMENTAL EFFECTS, COASTS, US, OFFSHORE DEVELOPMENT, REFINERIES,
1649 OFFSHORE DEVELOPMENT, INFORMATION SYSTEMS, STATISTICS, POLLUTION CONTROL, *DATA BANK, UK,
1676 OFFSHORE DEVELOPMENT, OCS, NOAA, MONITORING, INFORMATION SYSTEMS, ENVIRONMENTAL EFFECTS, BLM, BASELINE STUDIES, ALASKA COAST,
1731 OFFSHORE DEVELOPMENT, NATURAL SEEPAGE, INTERNATIONAL AGREEMENTS, SOURCE IDENTIFICATION, OIL DISCHARGES, OIL SPILLS, TANKERS,
2003 OFFSHORE DEVELOPMENT, NORTH SEA, FISHERIES, CRUDE OIL, AROMATIC HYDROCARBONS ,
2012 OFFSHORE DEVELOPMENT, NORTH SEA, FISHERIES, OIL INDUSTRY, SCOTLAND,
2013 OFFSHORE DEVELOPMENT, OCS, ENVIRONMENTAL EFFECTS, BIRDS, BASELINE STUDIES, ALASKA, MARINE MAMMALS,
2014 OFFSHORE DEVELOPMENT, OCS, FISH, ENVIRONMENTAL EFFECTS, BENTHOS, BASELINE STUDIES, ALASKA, PLANKTON ,
2015 OFFSHORE DEVELOPMENT, HABITAT, ENVIRONMENTAL EFFECTS, BIRDS, ARCTIC, ALASKA, SHORELINES, *SHOREBIRD SPECIES,
2016 OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, BIRDS, BASELINE STUDIES, ALASKA,

NWMAR116918

SHORELINES, OIL SPILLS,
2020 OFFSHORE DEVELOPMENT, NORTH SEA, ENVIRONMENTAL PROTECTION, EKOFISK BLOWOUT, SAFETY, REGULATIONS,
2029 OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING,
2031 OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING,
2032 OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES, OIL-GAS LEASING,
2034 OFFSHORE DEVELOPMENT, ICE, ENVIRONMENTAL EFFECTS, CANADA, ARCTIC, OFFSHORE EXPLORATION, OIL INDUSTRY,
2037 OFFSHORE DEVELOPMENT, OCS, MARINE MAMMALS, BIOLOGICAL EFFECTS, ALASKA, *MORTALITY,
2038 OFFSHORE DEVELOPMENT, OCS, HYDROCARBONS, CHEMICAL ANALYSIS, BASELINE STUDIES, ATLANTIC COAST,
2043 OFFSHORE DEVELOPMENT, OCS, ENVIRONMENTAL EFFECTS, BLM,
2045 OFFSHORE DEVELOPMENT, OCS, ENVIRONMENTAL EFFECTS, CRUDE OIL, ALASKA, OIL-GAS LEASING,
2046 OFFSHORE DEVELOPMENT, GUIDELINES, ENVIRONMENTAL MANAGEMENT, COASTS, *CZM,
2047 OFFSHORE DEVELOPMENT, ENVIRONMENTAL DETERIORATION, ATLANTIC COAST, PORTS,
2048 OFFSHORE DEVELOPMENT, NEW JERSEY, FISHERIES, ENVIRONMENTAL EFFECTS, DELAWARE, ATLANTIC COAST, PORTS,
2051 OFFSHORE DEVELOPMENT, OCS, LABRADOR SEA, ICE, SAFETY, *MINING TECHNOLOGY,
2052 OFFSHORE DEVELOPMENT, OCS, ENVIRONMENTAL EFFECTS, COASTS, ONSHORE IMPACTS, POLLUTION PREVENTION,
2054 OFFSHORE DEVELOPMENT, ICE, ENVIRONMENTAL EFFECTS, ARCTIC, *ICE COVERED WATERS, *RESEARCH TECHNOLOGY,
2055 OFFSHORE DEVELOPMENT, OCS, ENVIRONMENTAL EFFECTS, COASTS, US, SOCIO-ECONOMIC EFFECTS, STATE GOVERNMENTS,
2109 OFFSHORE DEVELOPMENT, OCS, LEGISLATION, ENVIRONMENTAL EFFECTS, COASTS, US, REFINERIES,
1635 OFFSHORE DRILLING, NORWAY, EKOFISK BLOWOUT, COST ANALYSIS, OFFSHORE EXPLORATION,
1688 OFFSHORE DRILLING, EMULSIONS, DESIGN-ENGINEERING, POLLUTION PREVENTION, *DRILLING MUDS,
1691 OFFSHORE DRILLING, GREENLAND, ARCTIC, SAFETY, POLLUTION PREVENTION, *ICEBERGS,
2021 OFFSHORE DRILLING, OCS, FOSSIL FUELS , ENVIRONMENTAL MANAGEMENT, REGULATIONS, POLLUTION CONTROL,
2022 OFFSHORE DRILLING, OCS, CRUDE OIL, ALASKA, SOCIO-ECONOMIC EFFECTS, *SEA GRANT PROGRAM, *ENERGY POLICY,
2041 OFFSHORE DRILLING, MARINE ORGANISMS, CALIFORNIA/SOUTHERN, PLATFORMS, UPTAKE, SEDIMENTS,
2042 OFFSHORE DRILLING, FISH, ENVIRONMENTAL EFFECTS, CONTAMINANTS, COASTS,
2044 OFFSHORE DRILLING, OCS, LOUISIANA, ENVIRONMENTAL EFFECTS, ECONOMIC EFFECTS, OIL INDUSTRY,
2124 OFFSHORE DRILLING, NORTH SEA, LIABILITY, INTERNATIONAL AGREEMENTS, OIL TRANSFER, STORAGE,
1635 OFFSHORE EXPLORATION, OFFSHORE DRILLING, NORWAY, EKOFISK BLOWOUT, COST ANALYSIS,
2027 OFFSHORE EXPLORATION, OCS, ENVIRONMENTAL EFFECTS, BERING SEA, ALASKA/GULF OF, OIL-GAS LEASING,
2034 OFFSHORE EXPLORATION, OFFSHORE DEVELOPMENT, ICE, ENVIRONMENTAL EFFECTS, CANADA, ARCTIC, OIL INDUSTRY,
1704 OFFSHORE PRODUCTION, CHEMICAL ANALYSIS, SEDIMENTS, VENEZUELA, STATISTICAL ANALYSIS,
2002 OFFSHORE PRODUCTION, NORTH SEA, FISHERIES, BIRDS, OIL SPILLS, REFINERIES, OIL TRANSPORT, POLLUTION CONTROL, TOXICITY,
1844 OHIO, FILTRATION, DESIGN-ENGINEERING, WASTEWATER TREATMENT, REFINERIES, SOLID WASTES, *UPFLOW SAND FILTERS,
1636 OIL DISCHARGES, DISTILLATION, POLLUTION CONTROL, OIL-WATER SEPARATION, USSR,
1680 OIL DISCHARGES, MONITORING, DESIGN-ENGINEERING, TANKERS, REGULATIONS, PATENT,
1731 OIL DISCHARGES, OFFSHORE DEVELOPMENT, NATURAL SEEPAGE, INTERNATIONAL AGREEMENTS, SOURCE IDENTIFICATION, OIL SPILLS, TANKERS,
1840 OIL DISCHARGES, MONITORING, LUBRICATING OIL, GASOLINE, FUEL OIL, ENVIRONMENTAL EFFECTS, WASTEWATERS, *DISSOLVED ORGANICS,
1902 OIL DISCHARGES, LIABILITY, INTERNATIONAL CONVENTIONS, OIL SPILLS, TANKERS, SAFETY, POLLUTION CONTROL,
1909 OIL DISCHARGES, LEAKAGE, POLLUTION PREVENTION, SHIPS, OIL SPILLS,
1916 OIL DISCHARGES, MARINE ORGANISMS, DISPERSANTS, SPILL CLEANUP, TOXICITY,
1967 OIL DISCHARGES, OCS, HYDROCARBONS, CONTAMINATION, ATLANTIC COAST, PHYTOPLANKTON,
2111 OIL DISCHARGES, EIS, OIL TRANSPORT, TANKERS, US, REGULATIONS, POLLUTION CONTROL,
2112 OIL DISCHARGES, EIS, OIL TRANSPORT, TANKERS, SEGREGATED BALLAST , REGULATIONS, US, POLLUTION CONTROL,
2114 OIL DISCHARGES, REGULATIONS, TANKERS, WASTEWATERS, USCG,
2126 OIL DISCHARGES, LAW ENFORCEMENT, INTERNATIONAL CONVENTIONS, IMCO, TANKERS,
1698 OIL-GAS LEASING, MEXICO/GULF OF, HYDROCARBONS, CHEMICAL ANALYSIS, SAMPLING, SEAWATER, *SEASONAL VARIATIONS, *MAFLA LEASE AREA,
1885 OIL-GAS LEASING, OCS, CONTINGENCY PLANNING, CALIFORNIA/SOUTHERN, OIL INDUSTRY,
2024 OIL-GAS LEASING, OCS, MEXICO/GULF OF, ENVIRONMENTAL EFFECTS, EIS,
2025 OIL-GAS LEASING, OCS, MEXICO/GULF OF, ENVIRONMENTAL EFFECTS, EIS,
2027 OIL-GAS LEASING, OFFSHORE EXPLORATION, OCS, ENVIRONMENTAL EFFECTS, BERING SEA, ALASKA/GULF OF,
2028 OIL-GAS LEASING, ENVIRONMENTAL EFFECTS, EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES,

NWMAR116919

2029 OIL-GAS LEASING, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES,
2030 OIL-GAS LEASING, ENVIRONMENTAL EFFECTS, EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES,
2031 OIL-GAS LEASING, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES,
2032 OIL-GAS LEASING, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, EIS, CALIFORNIA/SOUTHERN, BASELINE STUDIES,
2033 OIL-GAS LEASING, OCS, ENVIRONMENTAL EFFECTS, EIS, ALASKA, SOCIO-ECONOMIC EFFECTS,
2045 OIL-GAS LEASING, OFFSHORE DEVELOPMENT, OCS, ENVIRONMENTAL EFFECTS, CRUDE OIL, ALASKA,
1659 OIL INDUSTRY, NEW JERSEY, LEGISLATION, COMPENSATION, SPILL CLEANUP, *SPILL FUND,
1837 OIL INDUSTRY, GERMANY, EAST, REFINERIES, PETROCHEMICALS, WASTEWATER TREATMENT,
1865 OIL INDUSTRY, WASTEWATER TREATMENT, OXIDATION,
1885 OIL INDUSTRY, OIL-GAS LEASING, OCS, CONTINGENCY PLANNING, CALIFORNIA/SOUTHERN,
1898 OIL INDUSTRY, CONTINGENCY PLANNING, SPILL CLEANUP, PUGET SOUND, *OIL SPILL COOPERATIVE,
1987 OIL INDUSTRY, COST ANALYSIS, API, REGULATIONS, POLLUTION CONTROL, WASTEWATER TREATMENT, REFINERIES,
1988 OIL INDUSTRY, LIABILITY, LEGISLATION, COMPENSATION, TANKERS, OIL SPILLS, *SPILL SUPERFUNDS,
1990 OIL INDUSTRY, EPA, ECONOMIC EFFECTS, COST ANALYSIS, API, REGULATIONS, POLLUTION CONTROL,
2012 OIL INDUSTRY, OFFSHORE DEVELOPMENT, NORTH SEA, FISHERIES, SCOTLAND,
2018 OIL INDUSTRY, COST ANALYSIS, REGULATIONS, US, WATER QUALITY, POLLUTION PREVENTION,
2019 OIL INDUSTRY, ECONOMIC EFFECTS, COST ANALYSIS, REGULATIONS, POLLUTION PREVENTION,
2023 OIL INDUSTRY, ENVIRONMENTAL EFFECTS, REFINING, POLLUTION CONTROL, *TECHNOLOGY ASSESSMENT,
2034 OIL INDUSTRY, OFFSHORE EXPLORATION, OFFSHORE DEVELOPMENT, ICE, ENVIRONMENTAL EFFECTS, CANADA, ARCTIC,
2044 OIL INDUSTRY, OFFSHORE DRILLING, OCS, LOUISIANA, ENVIRONMENTAL EFFECTS, ECONOMIC EFFECTS,
2049 OIL INDUSTRY, ESTUARIES, DEVELOPMENT , CONTAMINATION, COASTS,
2050 OIL INDUSTRY, ENVIRONMENTAL EFFECTS, PETROCHEMICALS, REFINERIES,
2053 OIL INDUSTRY, LOUISIANA, LEGISLATION, ENVIRONMENTAL MANAGEMENT, COASTS, US,
2011 OIL SHALE, HEALTH HAZARDS, EXTRACTION, CARCINOGENS, *BENZO(A)PYRENE,
2039 OIL SHALE, MONITORING, INDUSTRIES, ENVIRONMENTAL EFFECTS, *R & D NEEDS,
2040 OIL SHALE, FOSSIL FUELS , ENVIRONMENTAL EFFECTS, PRODUCTION , TAR SANDS,
2065 OIL SHALE, HYDROCARBONS, BIODEGRADATION, BACTERIA,
2129 OIL SHALE, EXTRACTION, ENVIRONMENTAL EFFECTS, DEVELOPMENT , BIBLIOGRAPHIES,
2130 OIL SHALE, EXTRACTION, ENVIRONMENTAL EFFECTS, DEVELOPMENT , BIBLIOGRAPHIES,
2131 OIL SHALE, EXTRACTION, ENVIRONMENTAL EFFECTS, DEVELOPMENT , BIBLIOGRAPHIES, POLLUTION CONTROL,
2132 OIL SHALE, EXTRACTION, ENVIRONMENTAL EFFECTS, DEVELOPMENT , BIBLIOGRAPHIES, POLLUTION CONTROL,
1687 OIL SLICKS, NATURAL SEEPAGE, REMOTE SENSING, POLLUTION CONTROL, *LANDSAT,
1688 OIL SLICKS, MONITORING, REMOTE SENSING, POLLUTION CONTROL, *LANDSAT,
1689 OIL SLICKS, OCEANS, REMOTE SENSING, SURVEILLANCE, *DYS/SLICK SEAMARKING DEVICE,
1691 OIL SLICKS, NATURAL SEEPAGE, MONITORING, DETECTION, COASTS, REMOTE SENSING, *LANDSAT DATA,
1694 OIL SLICKS, NATURAL SEEPAGE, DETECTION, REMOTE SENSING, SURVEILLANCE, SANTA BARBARA CHANNEL, *COASTAL ZONE COLOR SCANNER,
1695 OIL SLICKS, MOVEMENT, COASTS, REMOTE SENSING, WASTEWATERS, *CURRENT CIRCULATION, *SATELLITE-AIRCRAFT-DROGUE STUDIES,
1696 OIL SLICKS, OCEANS, REMOTE SENSING, *WAVE DAMPING, *OIL PROPERTIES,
1697 OIL SLICKS, OCEANS, BIBLIOGRAPHIES, REMOTE SENSING, *RADAR, *SEA SURFACE,
1703 OIL SLICKS, CHEMICAL ANALYSIS, PETROLEUM PRODUCTS, SEAWATER, *SORBENTS,
1738 OIL SLICKS, BOOMS, BEHAVIOR, SPILL CONTAINMENT, *SLICK DROPLET FORMATION, *ENTRAINMENT FAILURE,
1752 OIL SLICKS, DISPERSANTS, BOOMS, SPILL CLEANUP, *PUMPS,
1779 OIL SLICKS, DISPERSANTS, DESIGN-ENGINEERING, SPILL CLEANUP, PATENT,
1782 OIL SLICKS, ABSORPTION, SPILL RECOVERY, PATENT,
1785 OIL SLICKS, DESIGN-ENGINEERING, SPILL RECOVERY, PATENT,
1788 OIL SLICKS, DESIGN-ENGINEERING, SPILL RECOVERY, SKIMMERS, SHIPS, PATENT,
1918 OIL SLICKS, CHRONIC EFFECTS, BIRDS, BIOLOGICAL EFFECTS, *SEABIRDS, OIL SPILLS,
1985 OIL SLICKS, *DETERGENTS, PHYSICAL EFFECTS, SEAWATER, *SEA SPRAY FORMATION,
2010 OIL SLICKS, ENVIRONMENTAL EFFECTS, DISPERSANTS, PHYTOPLANKTON, TOXICITY, *LIGHT REDUCTION, *PHOTOSYNTHESIS,
2063 OIL SLICKS, HYDROCARBONS, BIODEGRADATION, BACTERIA, AROMATIC HYDROCARBONS , YEASTS, *CHLORINATED HYDROCARBONS ,
2070 OIL SLICKS, MICROORGANISMS, BIODEGRADATION, ARCTIC OCEAN, *CONTINUOUS FLOW-THROUGH SYSTEM,
2102 OIL SLICKS, INTERTIDAL ZONE, HYDROCARBONS, ALASKA, UPTAKE, RELEASE, SEDIMENTS,
2103 OIL SLICKS, MOVEMENT, *LEEWAY, *WIND DRIFT,
2104 OIL SLICKS, MODELS, BEHAVIOR, PHYSICAL EFFECTS, *WIND-CURRENT EFFECTS,
1634 OIL SPILLS, FATE, EKOFISK BLOWOUT, CRUDE OIL,
1637 OIL SPILLS, NORTH SEA, STATISTICS, SOURCES, UK,
1639 OIL SPILLS, BIRDS, BIOLOGICAL EFFECTS, REGULATIONS, OIL TRANSFER, SCOTLAND,

NWMAR116920

1645 OIL SPILLS, NORWAY, BLOWOUTS, *PREDICTION,
1646 OIL SPILLS, ECONOMICS, TANKERS, SAFETY, *LIBERIAN REGISTRY,
1647 OIL SPILLS, NORTH SEA, FISH, EKOFISK BLOWOUT,
1651 OIL SPILLS, CRUDE OIL, ALASKA, PIPELINES, *PUMP STATION ACCIDENT,
1653 OIL SPILLS, CRUDE OIL, ALASKA, PIPELINES, *PUMP STATION ACCIDENT,
1654 OIL SPILLS, NORTH SEA, EKOFISK BLOWOUT, SPILL CLEANUP, POLLUTION CONTROL,
1655 OIL SPILLS, NORTH SEA, ENVIRONMENTAL PROTECTION, OIL TRANSFER, TANKERS, SURVEILLANCE,
1657 OIL SPILLS, OCEANS, COASTS, ALASKA, STATISTICS,
1661 OIL SPILLS, TANKERS, *LIBERIAN REGISTRY, *FLAGS OF CONVENIENCE,
1662 OIL SPILLS, OCEANS, TANKERS, STATISTICS, *TANKER ACCIDENTS,
1663 OIL SPILLS, EUROPE, OIL TRANSPORT, PIPELINES, SPILL CLEANUP, *CROSS COUNTRY PIPELINES
1664 OIL SPILLS, MONITORING, FATE, ENVIRONMENTAL EFFECTS, BEHAVIOR, SPILL CLEANUP, *1977 OIL SPILL CONFERENCE,
1670 OIL SPILLS, MONITORING, CHEMICAL ANALYSIS, WASTE OIL, *IR ABSORPTION ,
1674 OIL SPILLS, MONITORING, DETECTION, DESIGN-ENGINEERING, *BUOYS, *GAS SENSORS,
1692 OIL SPILLS, MONITORING, ENVIRONMENTAL EFFECTS, CONTAMINANTS, REMOTE SENSING,
1723 OIL SPILLS, CHEMICAL ANALYSIS, SOURCE IDENTIFICATION,
1728 OIL SPILLS, ANALYTICAL TECHNIQUES, SOURCE IDENTIFICATION,
1731 OIL SPILLS, OIL DISCHARGES, OFFSHORE DEVELOPMENT, NATURAL SEEPAGE, INTERNATIONAL AGREEMENTS, SOURCE IDENTIFICATION, TANKERS,
1792 OIL SPILLS, RESTORATION, WILDLIFE, SURFACTANTS, SOLVENTS, TOXICITY,
1794 OIL SPILLS, MOLLUSKS, ENGLAND, BIOLOGICAL EFFECTS, ALGAE, RESTORATION, SHORELINES, *ROCKY SHORES,
1797 OIL SPILLS, EIS, CRUDE OIL, ALASKA, OIL TRANSPORT, PIPELINES, TEXAS,
1883 OIL SPILLS, CONTINGENCY PLANNING, PERSONNEL TRAINING, POLLUTION CONTROL, *OIL SPILL CONTROL COURSE,
1889 OIL SPILLS, POLLUTION PREVENTION, TANKERS, OIL TANKS, *TIN CAN CONTAINERS,
1892 OIL SPILLS, POLLUTION CONTROL, USCG,
1899 OIL SPILLS, LEAKAGE, DETECTION, PRODUCTION , POLLUTION PREVENTION, PIPELINES,
1902 OIL SPILLS, OIL DISCHARGES, LIABILITY, INTERNATIONAL CONVENTIONS, TANKERS, SAFETY, POLLUTION CONTROL,
1905 OIL SPILLS, BEAUFORT SEA, ARCTIC, POLLUTION CONTROL, *SPILL COUNTERMEASURES,
1906 OIL SPILLS, OCEANS, INLAND, ENVIRONMENTAL EFFECTS, POLLUTION CONTROL, SPILL CLEANUP,
1908 OIL SPILLS, LEGISLATION, LAW ENFORCEMENT, POLLUTION PREVENTION, USCG,
1909 OIL SPILLS, OIL DISCHARGES, LEAKAGE, POLLUTION PREVENTION, SHIPS,
1910 OIL SPILLS, MARINE ORGANISMS, ENVIRONMENTAL EFFECTS, TOXICITY,
1917 OIL SPILLS, BIRDS, BIOLOGICAL EFFECTS, *SEABIRDS, RESTORATION,
1918 OIL SPILLS, OIL SLICKS, CHRONIC EFFECTS, BIRDS, BIOLOGICAL EFFECTS, *SEABIRDS,
1927 OIL SPILLS, MARINE ORGANISMS, ENVIRONMENTAL EFFECTS, BIRDS, BIOLOGICAL EFFECTS, SANTA BARBARA CHANNEL,
1937 OIL SPILLS, MOLLUSKS, MARSHES, MARINE ORGANISMS, CHESAPEAKE BAY, BIRDS, BIOLOGICAL EFFECTS, *MARSH GRASSES,
1944 OIL SPILLS, MASSACHUSETTS, MARSHES, FUEL OIL, CRUSTACEANS, CONTAMINATION, BIOLOGICAL EFFECTS, *UCA PUGNAX,
1952 OIL SPILLS, INVERTEBRATES, FUEL OIL, FISH, BIOLOGICAL EFFECTS, STREAMS, VIRGINIA,
1977 OIL SPILLS, MARINE ORGANISMS, INTERTIDAL ZONE, CHEDABUCTO BAY, CANADA, TOXICITY, *MORTALITIES,
1984 OIL SPILLS, MOLLUSKS, MAINE, BIOLOGICAL EFFECTS, *GONADAL NEOPLASMS, *MYA ARENARIA,
1988 OIL SPILLS, OIL INDUSTRY, LIABILITY, LEGISLATION, COMPENSATION, TANKERS, *SPILL SUPERFUNDS,
1989 OIL SPILLS, LIABILITY, ALASKA, REGULATIONS, TANKERS, OIL TRANSFER, PORTS, *OIL SPILL FUND,
1991 OIL SPILLS, INLAND, ECONOMICS, CALIFORNIA, SPILL CLEANUP, RESTORATION,
1992 OIL SPILLS, LEGISLATION, ENVIRONMENTAL EFFECTS, ECONOMIC EFFECTS, CANADA, TANKERS,
1994 OIL SPILLS, ENVIRONMENTAL EFFECTS, TANKERS,
1995 OIL SPILLS, MALAYSIA, ENVIRONMENTAL EFFECTS, TANKERS,
1996 OIL SPILLS, MARINE ORGANISMS, INTERTIDAL ZONE, ENVIRONMENTAL EFFECTS, DISPERSANTS, SHORELINES, TOXICITY,
1997 OIL SPILLS, ENVIRONMENTAL EFFECTS, ATLANTIC OCEAN, US, *WORLD WAR II,
1999 OIL SPILLS, MARSHES, ENVIRONMENTAL EFFECTS, ALASKA, OIL TRANSPORT, VEGETATION, SOIL,
2002 OIL SPILLS, OFFSHORE PRODUCTION, NORTH SEA, FISHERIES, BIRDS, REFINERIES, OIL TRANSPORT, POLLUTION CONTROL, TOXICITY,
2005 OIL SPILLS, MARINE ORGANISMS, HYDROCARBONS, ENVIRONMENTAL EFFECTS, CONTAMINATION, CHRONIC EFFECTS,
2016 OIL SPILLS, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, BIRDS, BASELINE STUDIES, ALASKA, SHORELINES,
2079 OIL SPILLS, BIODEGRADATION, PATENT, *NUTRIENT ADDITION,
2085 OIL SPILLS, HYDROCARBONS, FATE, EVAPORATION, SOLUTION, WEATHERING,
2086 OIL SPILLS, ICE, BEAUFORT SEA, SPREADING, *UNDER-ICE SPILL,
2087 OIL SPILLS, MODELS, EVAPORATION, DELAWARE BAY, WEATHERING, OIL TRANSFER,
2088 OIL SPILLS, MODELS, FATE, OXIDATION, *N-HEXADECANE, *PHOTOOXIDATION ,
2093 OIL SPILLS, NORWAY, FISH, CHEMICAL ANALYSIS, BIOLOGICAL EFFECTS, BIODEGRADATION, AROMATIC HYDROCARBONS , WEATHERING, *T/T "DRUPA" SPILL,
2094 OIL SPILLS, MODELS, INTERTIDAL ZONE, FATE, DISTRIBUTION, BIODEGRADATION, BALTIC SEA,
2095 OIL SPILLS, MOVEMENT, ALASKA, *COASTAL WINDS,

NWMAR116921

2096 OIL SPILLS, ICE, FATE, ALASKA, *OIL-UNDER-ICE , *IMPULSE RADAR SYSTEM,
2098 OIL SPILLS, MOVEMENT, BEAUFORT SEA, ALASKA COAST, SHORELINES, *SPILL IMPACT PROBABILITY,
2099 OIL SPILLS, FATE, DISPERSANTS, BIOLOGICAL EFFECTS,
2108 OIL SPILLS, LIABILITY, LEGISLATION, COMPENSATION, US, SPILL CLEANUP, *COSTS,
2110 OIL SPILLS, LEGISLATION, US, STATE GOVERNMENTS, TANKERS, POLLUTION CONTROL,
2119 OIL SPILLS, LEGISLATION, LAW ENFORCEMENT, ENGLAND, CANADA, SHIPS,
2128 OIL SPILLS, MICROORGANISMS, BIOLOGICAL EFFECTS, BIBLIOGRAPHIES, ANIMALS, PLANTS,
1745 OIL TANKS, CLEANUP, SWEDEN, *TANK CLEANING STATION,
1765 OIL TANKS, CONTAMINATION, ABSORPTION, PATENT, *CLEANUP ,
1798 OIL TANKS, ENVIRONMENTAL EFFECTS, EIS, CRUDE OIL, STORAGE, *SALT DOMES, *STRATEGIC PETROLEUM RESERVE,
1869 OIL TANKS, OIL SPILLS, POLLUTION PREVENTION, TANKERS, *TIN CAN CONTAINERS,
1639 OIL TRANSFER, OIL SPILLS, BIRDS, BIOLOGICAL EFFECTS, REGULATIONS, SCOTLAND,
1655 OIL TRANSFER, OIL SPILLS, NORTH SEA, ENVIRONMENTAL PROTECTION, TANKERS, SURVEILLANCE,
1989 OIL TRANSFER, OIL SPILLS, LIABILITY, ALASKA, REGULATIONS, TANKERS, PORTS, *OIL SPILL FUND,
2087 OIL TRANSFER, OIL SPILLS, MODELS, EVAPORATION, DELAWARE BAY, WEATHERING,
2124 OIL TRANSFER, OFFSHORE DRILLING, NORTH SEA, LIABILITY, INTERNATIONAL AGREEMENTS, STORAGE,
1663 OIL TRANSPORT, OIL SPILLS, EUROPE, PIPELINES, SPILL CLEANUP, *CROSS COUNTRY PIPELINES ,
1679 OIL TRANSPORT, MONITORING, HYDROCARBONS, ENVIRONMENTAL EFFECTS, PIPELINES, REFINERIES, PUGET SOUND,
1742 OIL TRANSPORT, DESIGN-ENGINEERING, SPILL RECOVERY, *DRACONE BARGE,
1797 OIL TRANSPORT, OIL SPILLS, EIS, CRUDE OIL, ALASKA, PIPELINES, TEXAS,
1801 OIL TRANSPORT, TANKERS, SAFETY, *STANDARDS, *ACCIDENT PREVENTION,
1802 OIL TRANSPORT, GROUNDWATER, ADSORPTION, *LIME, *CLAY, *SOIL COMPONENTS,
1696 OIL TRANSPORT, TANKERS, PIPELINES, POLLUTION PREVENTION, SPILL RECOVERY,
1999 OIL TRANSPORT, OIL SPILLS, MARSHES, ENVIRONMENTAL EFFECTS, ALASKA, VEGETATION, SOIL,
2002 OIL TRANSPORT, OIL SPILLS, OFFSHORE PRODUCTION, NORTH SEA, FISHERIES, BIRDS, REFINERIES, POLLUTION CONTROL, TOXICITY,
2017 OIL TRANSPORT, FRESHWATER, EPA, ENVIRONMENTAL EFFECTS, ARCTIC, PIPELINES,
2111 OIL TRANSPORT, OIL DISCHARGES, EIS, TANKERS, US, REGULATIONS, POLLUTION CONTROL,
2112 OIL TRANSPORT, OIL DISCHARGES, EIS, TANKERS, SEGREGATED BALLAST , REGULATIONS, US, POLLUTION CONTROL,
1636 OIL-WATER SEPARATION, OIL DISCHARGES, DISTILLATION, POLLUTION CONTROL, USSR,
1675 OIL-WATER SEPARATION, MONITORING, POLLUTION CONTROL, SHIPS, *ULTRASONIC MONITOR,
1701 OIL-WATER SEPARATION, DETECTION, ANALYTICAL TECHNIQUES, PATENT, *OIL-IN-WATER, *FLUORESCENCE,
1772 OIL-WATER SEPARATION, DISPERSIONS, DESIGN-ENGINEERING, SPILL CLEANUP, PATENT,
1784 OIL-WATER SEPARATION, FLOTATION, EMULSIONS, SEAWATER, PETROLEUM PRODUCTS,
1805 OIL-WATER SEPARATION, FLOTATION, EMULSIONS, DESIGN-ENGINEERING, WASTEWATER TREATMENT,
1806 OIL-WATER SEPARATION, EMULSIONS, PATENT, *AMINE ADDITION,
1808 OIL-WATER SEPARATION, INDUSTRIES, FILTRATION, EMULSIONS, WASTEWATER TREATMENT, *ULTRAFILTRATION ,
1810 OIL-WATER SEPARATION, FILTRATION, WASTEWATER TREATMENT, PATENT,
1811 OIL-WATER SEPARATION, FILTRATION, EMULSIONS, PATENT, *ULTRAFILTRATION ,
1813 OIL-WATER SEPARATION, FILTRATION, WASTEWATER TREATMENT, REFINERIES, PENNSYLVANIA, *SAND FILTERS,
1815 OIL-WATER SEPARATION, FLOTATION, DESIGN-ENGINEERING, COALESCENCE, SHIPS, PATENT,
1823 OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT, PETROLEUM PRODUCTS, PATENT,
1824 OIL-WATER SEPARATION, EMULSIONS, CRUDE OIL, PATENT,
1825 OIL-WATER SEPARATION, WASTEWATER TREATMENT, WASTE OIL, POLLUTION PREVENTION, REFINERIES,
1826 OIL-WATER SEPARATION, EMULSIONS, COALESCENCE, PATENT, *CELLULOSE PULP,
1827 OIL-WATER SEPARATION, GASOLINE, DESIGN-ENGINEERING, SLUDGE, WASTEWATERS, PATENT,
1828 OIL-WATER SEPARATION, COAGULATION, PATENT, *PLASTICS POWDER,
1829 OIL-WATER SEPARATION, WASTE OIL TREATMENT, SURFACTANTS, PATENT,
1830 OIL-WATER SEPARATION, INDUSTRIES, CANADA, WASTEWATER TREATMENT, RECLAMATION, REUSE,
1831 OIL-WATER SEPARATION, EMULSIONS, CRUDE OIL, PATENT,
1832 OIL-WATER SEPARATION, EMULSIONS, ADSORPTION, WASTEWATER TREATMENT, OXIDATION, PATENT,
1833 OIL-WATER SEPARATION, WASTEWATER TREATMENT, PATENT, *POPCORN POLYMER,
1834 OIL-WATER SEPARATION, FILTRATION, CANADA, WASTEWATER TREATMENT, REFINERIES, *DUAL-MEDIA FILTERS,
1836 OIL-WATER SEPARATION, COALESCENCE, PATENT, *ULTRASONICS,
1839 OIL-WATER SEPARATION, DESIGN-ENGINEERING, COALESCENCE, WASTEWATER TREATMENT,
1841 OIL-WATER SEPARATION, DESIGN-ENGINEERING, COALESCENCE, WASTEWATER TREATMENT, *GRAVITY SEPARATION ,
1843 OIL-WATER SEPARATION, WASTEWATER TREATMENT, REFINERIES, *PARALLEL PLATE SEPARATORS,
1845 OIL-WATER SEPARATION, FLOTATION, DESIGN-ENGINEERING, SKIMMERS, PATENT,
1848 OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT, PATENT,
1849 OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT, PATENT,
1852 OIL-WATER SEPARATION, EMULSIONS, CRUDE OIL,
1853 OIL-WATER SEPARATION, ABSORPTION, WASTEWATER TREATMENT, SPILL RECOVERY, PATENT, *SORBENT MATERIAL,

NWMAR116922

1854 OIL-WATER SEPARATION, FLOTATION, EMULSIONS, WASTEWATER TREATMENT, PATENT, *CATIONIC POLYMERS,
1858 OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT, SOLVENTS, PATENT, *SOLVENT RECOVERY ,
1859 OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT, SOLVENTS, PATENT, *SOLVENT RECOVERY ,
1862 OIL-WATER SEPARATION, COALESCENCE, WASTEWATER TREATMENT, WASTEWATERS,
1864 OIL-WATER SEPARATION, FLOTATION, EMULSIONS, WASTEWATER TREATMENT,
1867 OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT, SURFACTANTS, PATENT,
1869 OIL-WATER SEPARATION, FILTRATION, EMULSIONS, WASTEWATER TREATMENT, PATENT, *ULTRAFILTRATION ,
1871 OIL-WATER SEPARATION, EMULSIONS, COALESCENCE, WASTEWATER TREATMENT,
1875 OIL-WATER SEPARATION, FUELS, CRUDE OIL, SPILL RECOVERY, WASTEWATER TREATMENT,
1877 OIL-WATER SEPARATION, LUBRICATING OIL, FUELS, FILTRATION, WASTE OIL, RECLAMATION, *USCG POWER PLANTS,
1644 OIL WELLS, LOUISIANA, BLOWOUTS, *GAS-WELLS,
1729 OIL WELLS, GROUNDWATER, CONTAMINATION, SOURCE IDENTIFICATION, PRODUCTION , WASTEWATERS, *BRINE DISPOSAL,
2035 OIL WELLS, GROUNDWATER, DRILLING , CONTAMINATION, *DRILLING FLUIDS, *WELL COMPLETION,
1660 OLYMPIC GAMES SPILL, DELAWARE, BIRDS, TANKERS, SPILL CLEANUP, *DELAWARE RIVER,
2052 ONSHORE IMPACTS, OFFSHORE DEVELOPMENT, OCS, ENVIRONMENTAL EFFECTS, COASTS, POLLUTION PREVENTION,
1699 OREGON, MOLLUSKS, ESTUARIES, DETECTION, CARCINOGENS, SAMPLING, PAH, *BIVALVES,
1682 OXIDATION, MONITORING, PETROLEUM PRODUCTS, SEAWATER, *CHEMILUMINESCENCE,
1771 OXIDATION, BIODEGRADATION, ABSORPTION, SPILL CLEANUP, PETROLEUM PRODUCTS, SOIL, SOURCES,
1832 OXIDATION, OIL-WATER SEPARATION, EMULSIONS, ADSORPTION, WASTEWATER TREATMENT, PATENT,
1865 OXIDATION, OIL INDUSTRY, WASTEWATER TREATMENT,
2067 OXIDATION, CRUDE OIL, BIODEGRADATION, UPTAKE, *TEMPERATURE EFFECTS,
2080 OXIDATION, FUEL OIL, CASPIAN SEA, BIODEGRADATION, BACTERIA, PETROLEUM PRODUCTS,
2088 OXIDATION, OIL SPILLS, MODELS, FATE, *N-HEXADECANE, *PHOTOOXIDATION ,
2089 OXIDATION, FUEL OIL, TOXICITY, YEASTS, *UV IRRADIATION,
2105 OXIDATION, FATE, EVAPORATION, DISPERSIONS, CONTAMINATION, SEAWATER, SPREADING, SOLUTION,
1699 PAH, OREGON, MOLLUSKS, ESTUARIES, DETECTION, CARCINOGENS, SAMPLING, *BIVALVES,
1680 PATENT, OIL DISCHARGES, MONITORING, DESIGN-ENGINEERING, TANKERS, REGULATIONS,
1683 PATENT, MONITORING, DISPERSIONS, DETECTION, *OIL SOLUBLE DYE,
1701 PATENT, OIL-WATER SEPARATION, DETECTION, ANALYTICAL TECHNIQUES, *OIL-IN-WATER, *FLUORESCENCE,
1736 PATENT, DESIGN-ENGINEERING, BOOMS, SPILL CONTAINMENT, *CONNECTOR HINGE,
1737 PATENT, DESIGN-ENGINEERING, BOOMS, SPILL CONTAINMENT, SKIMMERS,
1740 PATENT, DESIGN-ENGINEERING, BOOMS, SPILL CONTAINMENT,
1762 PATENT, DESIGN-ENGINEERING, SPILL RECOVERY,
1763 PATENT, CONTAMINANTS, ABSORPTION, *OIL-ABSORBENT COMPOUND,
1765 PATENT, OIL TANKS, CONTAMINATION, ABSORPTION, *CLEANUP ,
1766 PATENT, LEAKAGE, TANKERS, SPILL CLEANUP, *OIL SOLIDIFICATION,
1772 PATENT, OIL-WATER SEPARATION, DISPERSIONS, DESIGN-ENGINEERING, SPILL CLEANUP,
1773 PATENT, DISPERSANTS, SPILL CLEANUP, *MAGNETIC POWDER,
1774 PATENT, BOOMS, SPILL RECOVERY,
1775 PATENT, INCINERATION, ABSORPTION, SPILL RECOVERY, *ABSORBENT FIBERS,
1777 PATENT, FUEL OIL, ADSORPTION, SPILL RECOVERY, *SAWDUST,
1779 PATENT, OIL SLICKS, DISPERSANTS, DESIGN-ENGINEERING, SPILL CLEANUP,
1780 PATENT, FLOCCULATION, SPILL RECOVERY, SEAWATER, RIVERS, SOLVENTS, COAGULATION,
1782 PATENT, OIL SLICKS, ABSORPTION, SPILL RECOVERY,
1783 PATENT, DISPERSANTS, BEACHES, SPILL RECOVERY, SURFACTANTS,
1785 PATENT, OIL SLICKS, DESIGN-ENGINEERING, SPILL RECOVERY,
1786 PATENT, DESIGN-ENGINEERING, BOOMS, SPILL RECOVERY, SKIMMERS,
1787 PATENT, GASOLINE, FUEL OIL, ADSORPTION, SPILL CLEANUP,
1788 PATENT, OIL SLICKS, DESIGN-ENGINEERING, SPILL RECOVERY, SKIMMERS, SHIPS,
1796 PATENT, DESIGN-ENGINEERING, STORAGE, TANKERS, *OIL STORAGE TANK,
1803 PATENT, INCINERATION, EVAPORATION, WASTEWATER TREATMENT, REFINERIES, *THERMAL OXIDATION ,
1806 PATENT, OIL-WATER SEPARATION, EMULSIONS, *AMINE ADDITION,
1809 PATENT, DESIGN-ENGINEERING, WASTEWATER TREATMENT, WASTE OIL, *COLLECTION RESERVOIR,
1810 PATENT, OIL-WATER SEPARATION, FILTRATION, WASTEWATER TREATMENT,
1811 PATENT, OIL-WATER SEPARATION, FILTRATION, EMULSIONS, *ULTRAFILTRATION ,
1815 PATENT, OIL-WATER SEPARATION, FLOTATION, DESIGN-ENGINEERING, COALESCENCE, SHIPS,
1821 PATENT, BIODEGRADATION, WASTEWATERS, SPILL CLEANUP, *H2O2,
1823 PATENT, OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT, PETROLEUM PRODUCTS,
1824 PATENT, OIL-WATER SEPARATION, EMULSIONS, CRUDE OIL,
1826 PATENT, OIL-WATER SEPARATION, EMULSIONS, COALESCENCE, *CELLULOSE PULP,
1827 PATENT, OIL-WATER SEPARATION, GASOLINE, DESIGN-ENGINEERING, SLUDGE, WASTEWATERS,
1828 PATENT, OIL-WATER SEPARATION, COAGULATION, *PLASTICS POWDER,
1829 PATENT, OIL-WATER SEPARATION, WASTE OIL TREATMENT, SURFACTANTS,
1831 PATENT, OIL-WATER SEPARATION, EMULSIONS, CRUDE OIL,

NWMAR116923

1832 PATENT, OXIDATION, OIL-WATER SEPARATION, EMULSIONS, ADSORPTION, WASTEWATER TREATMENT,
1833 PATENT, OIL-WATER SEPARATION, WASTEWATER TREATMENT, *POPCORN POLYMER,
1835 PATENT, FLOTATION, WASTEWATER TREATMENT, *TETRAETHYLEAD REMOVAL,
1838 PATENT, OIL-WATER SEPARATION, COALESCENCE, *ULTRASONICS,
1845 PATENT, OIL-WATER SEPARATION, FLOTATION, DESIGN-ENGINEERING, SKIMMERS,
1848 PATENT, OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT,
1849 PATENT, OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT,
1850 PATENT, FLOTATION, EMULSIFIERS, ADSORPTION, WASTEWATER TREATMENT, SLUDGE,
1851 PATENT, WASTEWATER TREATMENT, COAGULATION,
1853 PATENT, OIL-WATER SEPARATION, ABSORPTION, WASTEWATER TREATMENT, SPILL RECOVERY, *SORBENT MATERIAL,
1854 PATENT, OIL-WATER SEPARATION, FLOTATION, EMULSIONS, WASTEWATER TREATMENT, *CATIONIC POLYMERS,
1858 PATENT, OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT, SOLVENTS, *SOLVENT RECOVERY ,
1859 PATENT, OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT, SOLVENTS, *SOLVENT RECOVERY ,
1866 PATENT, ABSORPTION, WASTEWATER TREATMENT, PETROLEUM PRODUCTS, *ABSORBENT POLYOLEFIN,
1867 PATENT, OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT, SURFACTANTS,
1869 PATENT, OIL-WATER SEPARATION, FILTRATION, EMULSIONS, WASTEWATER TREATMENT, *ULTRAFILTRATION ,
1893 PATENT, DRILLING , DESIGN-ENGINEERING, BLOWOUT PREVENTION,
1894 PATENT, LEAKAGE, DETECTION, PIPELINES,
1895 PATENT, LEAKAGE, DESIGN-ENGINEERING, PIPELINES, POLLUTION PREVENTION,
1901 PATENT, LEAKAGE, DETECTION, DESIGN-ENGINEERING, PIPELINES,
2059 PATENT, CRUDE OIL, BIODEGRADATION, BACTERIA, PETROLEUM PRODUCTS, *NUTRIENT ADDITION,
2079 PATENT, OIL SPILLS, BIODEGRADATION, *NUTRIENT ADDITION,
1813 PENNSYLVANIA, OIL-WATER SEPARATION, FILTRATION, WASTEWATER TREATMENT, REFINERIES, *SAND FILTERS,
1882 PERSONNEL TRAINING, SPILL CLEANUP, POLLUTION CONTROL, TEXAS, *OIL SPILL CONTROL COURSE,
1883 PERSONNEL TRAINING, OIL SPILLS, CONTINGENCY PLANNING, POLLUTION CONTROL, *OIL SPILL CONTROL COURSE,
1884 PERSONNEL TRAINING, BLOWOUT PREVENTION, *BLOWOUT SCHOOL,
1887 PERSONNEL TRAINING, EUROPE, CONTINGENCY PLANNING, SPILL CLEANUP, UK, US,
1817 PETROCHEMICALS, HYDROCARBONS, WASTEWATER TREATMENT, REFINERIES, *SOLVENT EXTRACTION ,
1837 PETROCHEMICALS, OIL INDUSTRY, GERMANY, EAST, REFINERIES, WASTEWATER TREATMENT,
1842 PETROCHEMICALS, REFINERIES, WASTEWATER TREATMENT, *BIOLOGICAL DETOXICATION,
1903 PETROCHEMICALS, REFINERIES, POLLUTION CONTROL, WASTEWATERS, WATER QUALITY, RIVERS, USSR,
2026 PETROCHEMICALS, NORWAY, CHEMICAL ANALYSIS, WASTEWATER TREATMENT, POLLUTION CONTROL,
2050 PETROCHEMICALS, OIL INDUSTRY, ENVIRONMENTAL EFFECTS, REFINERIES,
1002 PETROLEUM PRODUCTS, OXIDATION, MONITORING, SEAWATER, *CHEMILUMINESCENCE,
1690 PETROLEUM PRODUCTS, DETECTION, CHEMICAL ANALYSIS, REMOTE SENSING, SPECTROSCOPY, *COMPUTERIZED RAMAN SPECTROSCOPY ,
1693 PETROLEUM PRODUCTS, DETECTION, CRUDE OIL, REMOTE SENSING, *SEA SURFACE, *RADAR,
1702 PETROLEUM PRODUCTS, OCEANS, CONTAMINATION, *LASER RADAR, *SEA SURFACE,
1703 PETROLEUM PRODUCTS, OIL SLICKS, CHEMICAL ANALYSIS, SEAWATER, *SORBENTS,
1712 PETROLEUM PRODUCTS, FISH, CONTAMINATION, CHEMICAL ANALYSIS, SOURCES, GREAT LAKES,
1710 PETROLEUM PRODUCTS, ANALYTICAL TECHNIQUES, SEAWATER, *GRAVIMETRIC ANALYSIS, *SPECTROPHOTOMETRY,
1721 PETROLEUM PRODUCTS, CHEMICAL ANALYSIS, SOIL,
1726 PETROLEUM PRODUCTS, HYDROCARBONS, CHEMICAL ANALYSIS, ADSORPTION, SEAWATER, SURFACTANTS, *ELECTROANALYSIS ,
1727 PETROLEUM PRODUCTS, FUEL OIL, CRUDE OIL, ANALYTICAL TECHNIQUES, SOURCE IDENTIFICATION, SPECTROSCOPY,
1771 PETROLEUM PRODUCTS, OXIDATION, BIODEGRADATION, ABSORPTION, SPILL CLEANUP, SOIL, SOURCES,
1784 PETROLEUM PRODUCTS, OIL-WATER SEPARATION, FLOTATION, EMULSIONS, SEAWATER,
1823 PETROLEUM PRODUCTS, PATENT, OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT,
1866 PETROLEUM PRODUCTS, PATENT, ABSORPTION, WASTEWATER TREATMENT, *ABSORBENT POLYOLEFIN,
1868 PETROLEUM PRODUCTS, WASTEWATER TREATMENT, *COAGULATION,
1870 PETROLEUM PRODUCTS, FLOCCULATION, WASTEWATER TREATMENT,
1881 PETROLEUM PRODUCTS, WASTE OIL, RECLAMATION, REUSE,
1942 PETROLEUM PRODUCTS, METABOLISM, FISH, TOXICITY, *SPICARA SMARIS, *SOLEA LASCARIS NASUTA,
1943 PETROLEUM PRODUCTS, FISH, TOXICITY, *HEMATOLOGICAL CHANGES,
1955 PETROLEUM PRODUCTS, GASOLINE, FRESHWATER, CRUDE OIL, BIODEGRADATION, BACTERIA, ALGAE, TOXICITY, *PHOTOSYNTHESIS,
1964 PETROLEUM PRODUCTS, MARINE ORGANISMS, CRUDE OIL, TOXICITY, *COMPARATIVE TOXICITY , *BIOASSAY,
1969 PETROLEUM PRODUCTS, FUELS, CRUDE OIL, BIOLOGICAL EFFECTS, ALGAE, *GROWTH, *REPRODUCTION, *FUCUS EDENTATUS DE LA PYL,
1981 PETROLEUM PRODUCTS, MOLLUSKS, UPTAKE, SEAWATER, *WATER PURIFICATION, *MYTILUS EDULIS,
2006 PETROLEUM PRODUCTS, MOVEMENT, LUBRICATING OIL, BIOLOGICAL EFFECTS, BACTERIA, SOIL,
2059 PETROLEUM PRODUCTS, PATENT, CRUDE OIL, BIODEGRADATION, BACTERIA, *NUTRIENT ADDITION,

NWMAR116924

2080 PETROLEUM PRODUCTS, OXIDATION, FUEL OIL, CASPIAN SEA, BIODEGRADATION, BACTERIA,
2092 PETROLEUM PRODUCTS, FATE, BIODEGRADATION, SURFACTANTS, SEAWATER, SEDIMENTS, *SELF-PURIFICATION, *SEA OF AZOV,
2106 PETROLEUM PRODUCTS, MOVEMENT, JAPAN, SEDIMENTS, *SETO INLAND SEA,
1985 PHYSICAL EFFECTS, OIL SLICKS, *DETERGENTS, SEAWATER, *SEA SPRAY FORMATION,
2084 PHYSICAL EFFECTS, EMULSIONS, CRUDE OIL, *SUSPENDED SOLIDS, *STABILITY,
2104 PHYSICAL EFFECTS, OIL SLICKS, MODELS, BEHAVIOR, *WIND-CURRENT EFFECTS,
1939 PHYTOPLANKTON, CONTAMINATION, CHRONIC EFFECTS, AEGEAN SEA,
1948 PHYTOPLANKTON, ESTUARIES, CRUDE OIL, TOXICITY, *KUWAIT CRUDE,
1958 PHYTOPLANKTON, METABOLISM, HYDROCARBONS, BIOLOGICAL EFFECTS, *PLANT GROWTH, *PHOTOSYNTHESIS,
1967 PHYTOPLANKTON, OIL DISCHARGES, OCS, HYDROCARBONS, CONTAMINATION, ATLANTIC COAST,
1980 PHYTOPLANKTON, FRESHWATER, CRUDE OIL, ARCTIC, TOXICITY, *PRIMARY PRODUCTION,
2010 PHYTOPLANKTON, OIL SLICKS, ENVIRONMENTAL EFFECTS, DISPERSANTS, TOXICITY, *LIGHT REDUCTION, *PHOTOSYNTHESIS,
1651 PIPELINES, OIL SPILLS, CRUDE OIL, ALASKA, *PUMP STATION ACCIDENT,
1653 PIPELINES, OIL SPILLS, CRUDE OIL, ALASKA, *PUMP STATION ACCIDENT,
1663 PIPELINES, OIL TRANSPORT, OIL SPILLS, EUROPE, SPILL CLEANUP, *CROSS COUNTRY PIPELINES ,
1679 PIPELINES, OIL TRANSPORT, MONITORING, HYDROCARBONS, ENVIRONMENTAL EFFECTS, REFINERIES, PUGET SOUND,
1666 PIPELINES, MONITORING, LEAKAGE, DETECTION,
1797 PIPELINES, OIL TRANSPORT, OIL SPILLS, EIS, CRUDE OIL, ALASKA, TEXAS,
1894 PIPELINES, PATENT, LEAKAGE, DETECTION,
1695 PIPELINES, PATENT, LEAKAGE, DESIGN-ENGINEERING, POLLUTION PREVENTION,
1896 PIPELINES, OIL TRANSPORT, TANKERS, POLLUTION PREVENTION, SPILL RECOVERY,
1699 PIPELINES, OIL SPILLS, LEAKAGE, DETECTION, PRODUCTION , POLLUTION PREVENTION,
1901 PIPELINES, PATENT, LEAKAGE, DETECTION, DESIGN-ENGINEERING,
2017 PIPELINES, OIL TRANSPORT, FRESHWATER, EPA, ENVIRONMENTAL EFFECTS, ARCTIC,
1935 PLANKTON , HYDROCARBONS, CRUSTACEANS, UPTAKE, RELEASE, *14C-1-NAPHTHALENE, *COPEPODS,
1940 PLANKTON , OCS, NEW YORK, CRUDE OIL, BENTHOS, TOXICITY, *NEW YORK BIGHT,
2014 PLANKTON , OFFSHORE DEVELOPMENT, OCS, FISH, ENVIRONMENTAL EFFECTS, BENTHOS, BASELINE STUDIES, ALASKA,
1930 PLANTS, CRUDE OIL, CONTAMINATION, TOXICITY, *OLNEY BULRUSH, *MARSHHAY CORDGRASS,
2128 PLANTS, OIL SPILLS, MICROORGANISMS, BIOLOGICAL EFFECTS, BIBLIOGRAPHIES, ANIMALS,
1671 PLATFORMS, MONITORING, MEXICO/GULF OF, HYDROCARBONS, SOURCES, *GAS VENTING, *BRINE DISCHARGE,
2041 PLATFORMS, OFFSHORE DRILLING, MARINE ORGANISMS, CALIFORNIA/SOUTHERN, UPTAKE, SEDIMENTS,
1836 POLAND, WASTEWATER TREATMENT, SOLID WASTES, REFINERIES,
1872 POLAND, FILTRATION, EMULSIONS, ADSORPTION, WASTEWATER TREATMENT, *CELLULOSE, *DIATOMACEOUS EARTH,
1636 POLLUTION CONTROL, OIL-WATER SEPARATION, OIL DISCHARGES, DISTILLATION, USSR,
1642 POLLUTION CONTROL, NORWAY, NORTH SEA, BLOWOUTS, *EMERGENCY VESSEL,
1649 POLLUTION CONTROL, OFFSHORE DEVELOPMENT, INFORMATION SYSTEMS, STATISTICS, *DATA BANK, UK,
1654 POLLUTION CONTROL, OIL SPILLS, NORTH SEA, EKOFISK BLOWOUT, SPILL CLEANUP,
1656 POLLUTION CONTROL, FATE, COASTS, URQUIOLA SPILL, SPILL CLEANUP, SPAIN,
1665 POLLUTION CONTROL, NORTH SEA, EKOFISK BLOWOUT,
1669 POLLUTION CONTROL, MONITORING, DESIGN-ENGINEERING,
1675 POLLUTION CONTROL, OIL-WATER SEPARATION, MONITORING, SHIPS, *ULTRASONIC MONITOR,
1687 POLLUTION CONTROL, OIL SLICKS, NATURAL SEEPAGE, REMOTE SENSING, *LANDSAT,
1688 POLLUTION CONTROL, OIL SLICKS, MONITORING, REMOTE SENSING, *LANDSAT,
1749 POLLUTION CONTROL, SPILL CLEANUP, *OIL SPILL PUMPS,
1769 POLLUTION CONTROL, USCG, *EQUIPMENT, *FAST SURFACE DELIVERY SYSTEM,
1819 POLLUTION CONTROL, WASTEWATERS, REFINERIES, *RADIOTRACER APPLICATIONS,
1882 POLLUTION CONTROL, PERSONNEL TRAINING, SPILL CLEANUP, TEXAS, *OIL SPILL CONTROL COURSE,
1883 POLLUTION CONTROL, PERSONNEL TRAINING, OIL SPILLS, CONTINGENCY PLANNING, *OIL SPILL CONTROL COURSE,
1892 POLLUTION CONTROL, OIL SPILLS, USCG,
1897 POLLUTION CONTROL, BLOWOUT PREVENTION, *SLIP RINGS, *EQUIPMENT,
1900 POLLUTION CONTROL, ESTUARIES, *CONFERENCE,
1902 POLLUTION CONTROL, OIL SPILLS, OIL DISCHARGES, LIABILITY, INTERNATIONAL CONVENTIONS, TANKERS, SAFETY,
1903 POLLUTION CONTROL, PETROCHEMICALS, REFINERIES, WASTEWATERS, WATER QUALITY, RIVERS, USSR,
1905 POLLUTION CONTROL, OIL SPILLS, BEAUFORT SEA, ARCTIC, *SPILL COUNTERMEASURES,
1906 POLLUTION CONTROL, OIL SPILLS, OCEANS, INLAND, ENVIRONMENTAL EFFECTS, SPILL CLEANUP,
1907 POLLUTION CONTROL, ENVIRONMENTAL EFFECTS, DISPERSANTS, SPILL CLEANUP,
1961 POLLUTION CONTROL, COASTS, BIOLOGICAL EFFECTS, BENTHOS, *PELAGIC ORGANISMS,
1987 POLLUTION CONTROL, OIL INDUSTRY, COST ANALYSIS, API, REGULATIONS, WASTEWATER TREATMENT, REFINERIES,
1990 POLLUTION CONTROL, OIL INDUSTRY, EPA, ECONOMIC EFFECTS, COST ANALYSIS, API, REGULATIONS,
2000 POLLUTION CONTROL, OCEANS, MARINE ORGANISMS, DISPERSANTS, CONTAMINATION, BIOLOGICAL EFFECTS, SOURCES,
2002 POLLUTION CONTROL, OIL TRANSPORT, OIL SPILLS, OFFSHORE PRODUCTION, NORTH SEA,

NWMAR116925

FISHERIES, BIRDS, REFINERIES, TOXICITY,
2008 POLLUTION CONTROL, OCEANS, HYDROCARBONS, HEALTH HAZARDS, CONTAMINATION, BIOLOGICAL EFFECTS,
2021 POLLUTION CONTROL, OFFSHORE DRILLING, OCS, FOSSIL FUELS , ENVIRONMENTAL MANAGEMENT, REGULATIONS,
2023 POLLUTION CONTROL, OIL INDUSTRY, ENVIRONMENTAL EFFECTS, REFINING, *TECHNOLOGY ASSESSMENT,
2026 POLLUTION CONTROL, PETROCHEMICALS, NORWAY, CHEMICAL ANALYSIS, WASTEWATER TREATMENT,
2110 POLLUTION CONTROL, OIL SPILLS, LEGISLATION, US, STATE GOVERNMENTS, TANKERS,
2111 POLLUTION CONTROL, OIL TRANSPORT, OIL DISCHARGES, EIS, TANKERS, US, REGULATIONS,
2112 POLLUTION CONTROL, OIL TRANSPORT, OIL DISCHARGES, EIS, TANKERS, SEGREGATED BALLAST , REGULATIONS, US,
2115 POLLUTION CONTROL, OCEANS, LEGISLATION, INTERNATIONAL CONVENTIONS, INTERNATIONAL AGREEMENTS, UK, US,
2116 POLLUTION CONTROL, LEGISLATION, INTERNATIONAL CONVENTIONS,
2121 POLLUTION CONTROL, CONTAMINANTS, CANADA, REGULATIONS, WASTEWATERS, REFINERIES,
2125 POLLUTION CONTROL, MONITORING, MEDITERRANEAN SEA, INTERNATIONAL CONVENTIONS, BIOLOGICAL EFFECTS, UN,
2131 POLLUTION CONTROL, OIL SHALE, EXTRACTION, ENVIRONMENTAL EFFECTS, DEVELOPMENT , BIBLIOGRAPHIES,
2132 POLLUTION CONTROL, OIL SHALE, EXTRACTION, ENVIRONMENTAL EFFECTS, DEVELOPMENT , BIBLIOGRAPHIES,
2134 POLLUTION CONTROL, LEGISLATION, BIBLIOGRAPHIES, US,
1641 POLLUTION PREVENTION, MOVEMENT, MONITORING, ARGO MERCHANT SPILL, TANKERS, USGS,
1825 POLLUTION PREVENTION, OIL-WATER SEPARATION, WASTEWATER TREATMENT, WASTE OIL, REFINERIES,
1888 POLLUTION PREVENTION, OFFSHORE DRILLING, EMULSIONS, DESIGN-ENGINEERING, *DRILLING MUDS,
1889 POLLUTION PREVENTION, OIL TANKS, OIL SPILLS, TANKERS, *TIN CAN CONTAINERS,
1890 POLLUTION PREVENTION, LEAKAGE, SHIPS, *STERNGEAR SEAL SYSTEM,
1891 POLLUTION PREVENTION, OFFSHORE DRILLING, GREENLAND, ARCTIC, SAFETY, *ICEBERGS,
1895 POLLUTION PREVENTION, PIPELINES, PATENT, LEAKAGE, DESIGN-ENGINEERING,
1896 POLLUTION PREVENTION, PIPELINES, OIL TRANSPORT, TANKERS, SPILL RECOVERY,
1899 POLLUTION PREVENTION, PIPELINES, OIL SPILLS, LEAKAGE, DETECTION, PRODUCTION ,
1908 POLLUTION PREVENTION, OIL SPILLS, LEGISLATION, LAW ENFORCEMENT, USCG,
1909 POLLUTION PREVENTION, OIL SPILLS, OIL DISCHARGES, LEAKAGE, SHIPS,
2018 POLLUTION PREVENTION, OIL INDUSTRY, COST ANALYSIS, REGULATIONS, US, WATER QUALITY,
2019 POLLUTION PREVENTION, OIL INDUSTRY, ECONOMIC EFFECTS, COST ANALYSIS, REGULATIONS,
2052 POLLUTION PREVENTION, ONSHORE IMPACTS, OFFSHORE DEVELOPMENT, OCS, ENVIRONMENTAL EFFECTS, COASTS,
2122 POLLUTION PREVENTION, MANUALS, GUIDELINES, CONTINGENCY PLANNING, TANKERS,
2123 POLLUTION PREVENTION, INTERNATIONAL CONVENTIONS, IMCO, EPA, SWEDEN, *BALTIC CONVENTION,
1921 POLYCHAETES, FUEL OIL, CRUDE OIL, TOXICITY, *REPRODUCTION,
1734 PORTS, SPILL CONTAINMENT, TANKERS, SWEDEN, *SPILL BUBBLE BARRIER,
1969 PORTS, OIL TRANSFER, OIL SPILLS, LIABILITY, ALASKA, REGULATIONS, TANKERS, *OIL SPILL FUND,
2047 PORTS, OFFSHORE DEVELOPMENT, ENVIRONMENTAL DETERIORATION, ATLANTIC COAST,
2048 PORTS, OFFSHORE DEVELOPMENT, NEW JERSEY, FISHERIES, ENVIRONMENTAL EFFECTS, DELAWARE, ATLANTIC COAST,
2120 PORTS, LAW ENFORCEMENT, GOVERNMENT AGENCIES, REGULATIONS, TANKERS, USCG, SAFETY,
1643 PRODUCTION , NORTH SEA, ENVIRONMENTAL EFFECTS, EKOFISK BLOWOUT,
1729 PRODUCTION , OIL WELLS, GROUNDWATER, CONTAMINATION, SOURCE IDENTIFICATION, WASTEWATERS, *BRINE DISPOSAL,
1899 PRODUCTION , POLLUTION PREVENTION, PIPELINES, OIL SPILLS, LEAKAGE, DETECTION,
1998 PRODUCTION , MARINE ORGANISMS, FISHERIES, EXPLORATION , DISPERSANTS, CONTAMINATION, BIOLOGICAL EFFECTS, SOURCES, SHIPS, SEABIRDS, SPILL CLEANUP,
2007 PRODUCTION , FUELS, ENVIRONMENTAL EFFECTS, CONTAMINANTS,
2040 PRODUCTION , OIL SHALE, FOSSIL FUELS , ENVIRONMENTAL EFFECTS, TAR SANDS,
1679 PUGET SOUND, PIPELINES, OIL TRANSPORT, MONITORING, HYDROCARBONS, ENVIRONMENTAL EFFECTS, REFINERIES,
1898 PUGET SOUND, OIL INDUSTRY, CONTINGENCY PLANNING, SPILL CLEANUP, *OIL SPILL COOPERATIVE,
1747 RECLAMATION, DESIGN-ENGINEERING, SPILL RECOVERY,
1830 RECLAMATION, OIL-WATER SEPARATION, INDUSTRIES, CANADA, WASTEWATER TREATMENT, REUSE,
1847 RECLAMATION, FUELS, WASTEWATER DISPOSAL, WASTE OIL, *LAND DISPOSAL, *SPRAY IRRIGATION,
1874 RECLAMATION, LUBRICATING OIL, WASTE OILS, *IFP PROCESS,
1876 RECLAMATION, ECONOMICS, WASTE OIL, REUSE,
1877 RECLAMATION, OIL-WATER SEPARATION, LUBRICATING OIL, FUELS, FILTRATION, WASTE OIL, *USCG POWER PLANTS,
1878 RECLAMATION, INDUSTRIES, INDIA, REFINERIES, WASTEWATERS, REUSE,
1879 RECLAMATION, WASTE OIL, *REVIEW,
1880 RECLAMATION, WASTE OIL, *REVIEW,
1881 RECLAMATION, PETROLEUM PRODUCTS, WASTE OIL, REUSE,
1873 RECYCLING, LUBRICATING OIL, FILTRATION, COALESCENCE, WASTE OIL,
1950 RED SEA, ISRAEL, CORAL REEFS, CONTAMINATION, BIOLOGICAL EFFECTS, *SUCCESSION, *RECOLONIZATION,
1679 REFINERIES, PUGET SOUND, PIPELINES, OIL TRANSPORT, MONITORING, HYDROCARBONS,

NWMAR116926

ENVIRONMENTAL EFFECTS,
1681 REFINERIES, MONITORING, STREAMS, SEDIMENTS, WASTEWATERS, SAMPLING, *HEAVY METALS,
1706 REFINERIES, FOSSIL FUELS , ANALYTICAL TECHNIQUES, WASTEWATERS,
1793 REFINERIES, MARSHES, ENGLAND, CONTAMINATION, RESTORATION, VEGETATION, WASTEWATERS, *SALT MARSH,
1803 REFINERIES, PATENT, INCINERATION, EVAPORATION, WASTEWATER TREATMENT, *THERMAL OXIDATION ,
1812 REFINERIES, INCINERATION, WASTEWATER DISPOSAL, SLUDGE, *FLUID BEDS,
1813 REFINERIES, PENNSYLVANIA, OIL-WATER SEPARATION, FILTRATION, WASTEWATER TREATMENT, *SAND FILTERS,
1816 REFINERIES, EXTRACTION, CONTAMINANTS, WASTEWATER TREATMENT, SOLVENTS,
1817 REFINERIES, PETROCHEMICALS, HYDROCARBONS, WASTEWATER TREATMENT, *SOLVENT EXTRACTION ,
1819 REFINERIES, POLLUTION CONTROL, WASTEWATERS, *RADIOTRACER APPLICATIONS,
1820 REFINERIES, BIODEGRADATION, ACTIVATED SLUDGE , WASTEWATER TREATMENT,
1822 REFINERIES, FILTRATION, WASTEWATER TREATMENT,
1825 REFINERIES, POLLUTION PREVENTION, OIL-WATER SEPARATION, WASTEWATER TREATMENT, WASTE OIL,
1834 REFINERIES, OIL-WATER SEPARATION, FILTRATION, CANADA, WASTEWATER TREATMENT, *DUAL-MEDIA FILTERS,
1836 REFINERIES, POLAND, WASTEWATER TREATMENT, SOLID WASTES,
1837 REFINERIES, PETROCHEMICALS, OIL INDUSTRY, GERMANY, EAST, WASTEWATER TREATMENT,
1842 REFINERIES, PETROCHEMICALS, WASTEWATER TREATMENT, *BIOLOGICAL DETOXICATION,
1843 REFINERIES, OIL-WATER SEPARATION, WASTEWATER TREATMENT, *PARALLEL PLATE SEPARATORS,
1844 REFINERIES, OHIO, FILTRATION, DESIGN-ENGINEERING, WASTEWATER TREATMENT, SOLID WASTES, *UPFLOW SAND FILTERS,
1846 REFINERIES, EPA, CHEMICAL ANALYSIS, WASTEWATER TREATMENT, *ANALYTICAL VARIABILITY,
1855 REFINERIES, INLAND, DISPOSAL , CONTAMINANTS, WASTEWATERS, SOLID WASTES, *WASTE DISPOSAL PRACTICES, *LANDFILLS,
1856 REFINERIES, WASTEWATER TREATMENT, *REVERSE OSMOSIS, *WATER RECOVERY ,
1857 REFINERIES, FILTRATION, WASTEWATER TREATMENT, WATER QUALITY, *ONTARIO,
1860 REFINERIES, EMULSIONS, DESIGN-ENGINEERING, WASTE OIL TREATMENT,
1861 REFINERIES, ECONOMICS, CRUDE OIL, COST ANALYSIS, WASTEWATER TREATMENT, USSR,
1863 REFINERIES, DISPOSAL , WASTEWATER TREATMENT, *BIOLOGICAL TREATMENT, *UNDERGROUND WASTE INJECTION,
1878 REFINERIES, RECLAMATION, INDUSTRIES, INDIA, WASTEWATERS, REUSE,
1905 REFINERIES, POLLUTION CONTROL, PETROCHEMICALS, WASTEWATERS, WATER QUALITY, RIVERS, USSR,
1946 REFINERIES, MONITORING, INVERTEBRATES, FRESHWATER, TOXICITY, WASTEWATERS, *DAPHNIA PULEX, *BIOASSAY,
1987 REFINERIES, POLLUTION CONTROL, OIL INDUSTRY, COST ANALYSIS, API, REGULATIONS, WASTEWATER TREATMENT,
2002 REFINERIES, POLLUTION CONTROL, OIL TRANSPORT, OIL SPILLS, OFFSHORE PRODUCTION, NORTH EA, FISHERIES, BIRDS, TOXICITY,
2050 REFINERIES, PETROCHEMICALS, OIL INDUSTRY, ENVIRONMENTAL EFFECTS,
2064 REFINERIES, DISPOSAL , BIODEGRADATION, SLUDGE, SOIL, WASTE OIL,
2109 REFINERIES, OFFSHORE DEVELOPMENT, OCS, LEGISLATION, ENVIRONMENTAL EFFECTS, COASTS, US,
2117 REFINERIES, GUIDELINES, ENVIRONMENTAL PROTECTION, CANADA, WASTEWATER TREATMENT, *ALBERTA,
2118 REFINERIES, ENVIRONMENTAL PROTECTION, ECONOMICS, CANADA, REGULATIONS, WASTEWATERS, *QUEBEC,
2121 REFINERIES, POLLUTION CONTROL, CONTAMINANTS, CANADA, REGULATIONS, WASTEWATERS,
2023 REFINING, POLLUTION CONTROL, OIL INDUSTRY, ENVIRONMENTAL EFFECTS, *TECHNOLOGY ASSESSMENT,
1639 REGULATIONS, OIL TRANSFER, OIL SPILLS, BIRDS, BIOLOGICAL EFFECTS, SCOTLAND,
1680 REGULATIONS, PATENT, OIL DISCHARGES, MONITORING, DESIGN-ENGINEERING, TANKERS,
1987 REGULATIONS, REFINERIES, POLLUTION CONTROL, OIL INDUSTRY, COST ANALYSIS, API, WASTEWATER TREATMENT,
1989 REGULATIONS, PORTS, OIL TRANSFER, OIL SPILLS, LIABILITY, ALASKA, TANKERS, *OIL SPILL FUND,
1990 REGULATIONS, POLLUTION CONTROL, OIL INDUSTRY, EPA, ECONOMIC EFFECTS, COST ANALYSIS, API,
2018 REGULATIONS, POLLUTION PREVENTION, OIL INDUSTRY, COST ANALYSIS, US, WATER QUALITY,
2019 REGULATIONS, POLLUTION PREVENTION, OIL INDUSTRY, ECONOMIC EFFECTS, COST ANALYSIS,
2020 REGULATIONS, OFFSHORE DEVELOPMENT, NORTH SEA, ENVIRONMENTAL PROTECTION, EKOFISK BLOWOUT, SAFETY,
2021 REGULATIONS, POLLUTION CONTROL, OFFSHORE DRILLING, OCS, FOSSIL FUELS , ENVIRONMENTAL MANAGEMENT,
2111 REGULATIONS, POLLUTION CONTROL, OIL TRANSPORT, OIL DISCHARGES, EIS, TANKERS, US,
2112 REGULATIONS, POLLUTION CONTROL, OIL TRANSPORT, OIL DISCHARGES, EIS, TANKERS, SEGREGATED BALLAST , US,
2113 REGULATIONS, ENVIRONMENTAL PROTECTION, TANKERS, SEGREGATED BALLAST , USCG,
2114 REGULATIONS, OIL DISCHARGES, TANKERS, WASTEWATERS, USCG,
2116 REGULATIONS, REFINERIES, ENVIRONMENTAL PROTECTION, ECONOMICS, CANADA, WASTEWATERS, *QUEBEC,
2120 REGULATIONS, PORTS, LAW ENFORCEMENT, GOVERNMENT AGENCIES, TANKERS, USCG, SAFETY,

NWMAR116927

2121 REGULATIONS, REFINERIES, POLLUTION CONTROL, CONTAMINANTS, CANADA, WASTEWATERS,
1912 RELEASE, HYDROCARBONS, ANNELIDS, SEDIMENT, UPTAKE, *PHASCOLOSOMA AGASSIZII, *NAPHTHALENES,
1929 RELEASE, MOLLUSKS, CRUDE OIL, UPTAKE, *NAPHTHALENES, *RANGEA CUNEATA, *PROTOTHACA TAMINEA,
1933 RELEASE, HYDROCARBONS, FISH, UPTAKE, *COHO AND CHINOOK SALMON, *CHLORINATED BIPHENYLS, *ENZYME ACTIVITY,
1935 RELEASE, PLANKTON , HYDROCARBONS, CRUSTACEANS, UPTAKE, *14C-1-NAPHTHALENE, *COPEPODS,
1947 RELEASE, MARINE ORGANISMS, HYDROCARBONS, UPTAKE, STORAGE,
1962 RELEASE, MARINE ORGANISMS, FUEL OIL, CRUDE OIL, TOXICITY, UPTAKE,
9o8 RELEASE, MOLLUSKS, FUEL OIL, EMULSIONS, UPTAKE, *MYA ARENARIA L.,
1976 RELEASE, OCEANS, HYDROCARBONS, FOOD WEB, UPTAKE, *FOOD CHAIN TRANSFER,
1979 RELEASE, MOLLUSKS, TOXICITY, UPTAKE, *OIL DROPLETS, *MORTALITY, *CRASSOSTREA GIGAS, *MYTILUS SPP.,
2102 RELEASE, OIL SLICKS, INTERTIDAL ZONE, HYDROCARBONS, ALASKA, UPTAKE, SEDIMENTS,
1687 REMOTE SENSING, POLLUTION CONTROL, OIL SLICKS, NATURAL SEEPAGE, *LANDSAT,
1688 REMOTE SENSING, POLLUTION CONTROL, OIL SLICKS, MONITORING, *LANDSAT,
1689 REMOTE SENSING, OIL SLICKS, OCEANS, SURVEILLANCE, *DYS/SLICK SEAMARKING DEVICE,
1690 REMOTE SENSING, PETROLEUM PRODUCTS, DETECTION, CHEMICAL ANALYSIS, SPECTROSCOPY, *COMPUTERIZED RAMAN SPECTROSCOPY ,
1691 REMOTE SENSING, OIL SLICKS, NATURAL SEEPAGE, MONITORING, DETECTION, COASTS, *LANDSAT DATA,
1692 REMOTE SENSING, OIL SPILLS, MONITORING, ENVIRONMENTAL EFFECTS, CONTAMINANTS,
1695 REMOTE SENSING, PETROLEUM PRODUCTS, DETECTION, CRUDE OIL, *SEA SURFACE, *RADAR,
1694 REMOTE SENSING, OIL SLICKS, NATURAL SEEPAGE, DETECTION, SURVEILLANCE, SANTA BARBARA HANNEL, *COASTAL ZONE COLOR SCANNER,
1695 REMOTE SENSING, OIL SLICKS, MOVEMENT, COASTS, WASTEWATERS, *CURRENT CIRCULATION, *SATELLITE-AIRCRAFT-DROGUE STUDIES,
1696 REMOTE SENSING, OIL SLICKS, OCEANS, *WAVE DAMPING, *OIL PROPERTIES,
1697 REMOTE SENSING, OIL SLICKS, OCEANS, BIBLIOGRAPHIES, *RADAR, *SEA SURFACE,
2135 REMOTE SENSING, MONITORING, DETECTION, CHEMICAL ANALYSIS, BIBLIOGRAPHIES, SAMPLING,
1792 RESTORATION, OIL SPILLS, WILDLIFE, SURFACTANTS, SOLVENTS, TOXICITY,
1793 RESTORATION, REFINERIES, MARSHES, ENGLAND, CONTAMINATION, VEGETATION, WASTEWATERS, *SALT MARSH,
1794 RESTORATION, OIL SPILLS, MOLLUSKS, ENGLAND, BIOLOGICAL EFFECTS, ALGAE, SHORELINES, ROCKY SHORES,
1917 RESTORATION, OIL SPILLS, BIRDS, BIOLOGICAL EFFECTS, *SEABIRDS,
1991 RESTORATION, OIL SPILLS, INLAND, ECONOMICS, CALIFORNIA, SPILL CLEANUP,
1830 REUSE, RECLAMATION, OIL-WATER SEPARATION, INDUSTRIES, CANADA, WASTEWATER TREATMENT,
1876 REUSE, RECLAMATION, ECONOMICS, WASTE OIL,
187o REUSE, REFINERIES, RECLAMATION, INDUSTRIES, INDIA, WASTEWATERS,
1881 REUSE, RECLAMATION, PETROLEUM PRODUCTS, WASTE OIL,
1780 RIVERS, PATENT, FLOCCULATION, SPILL RECOVERY, SEAWATER, SOLVENTS, COAGULATION,
1903 RIVERS, REFINERIES, POLLUTION CONTROL, PETROCHEMICALS, WASTEWATERS, WATER QUALITY, USSR,
1646 SAFETY, OIL SPILLS, ECONOMICS, TANKERS, *LIBERIAN REGISTRY,
1801 SAFETY, OIL TRANSPORT, TANKERS, *STANDARDS, *ACCIDENT PREVENTION,
1891 SAFETY, POLLUTION PREVENTION, OFFSHORE DRILLING, GREENLAND, ARCTIC, *ICEBERGS,
1902 SAFETY, POLLUTION CONTROL, OIL SPILLS, OIL DISCHARGES, LIABILITY, INTERNATIONAL CONVENTIONS, TANKERS,
2020 SAFETY, REGULATIONS, OFFSHORE DEVELOPMENT, NORTH SEA, ENVIRONMENTAL PROTECTION, EKOFISK BLOWOUT,
2051 SAFETY, OFFSHORE DEVELOPMENT, OCS, LABRADOR SEA, ICE, *MINING TECHNOLOGY,
2120 SAFETY, REGULATIONS, PORTS, LAW ENFORCEMENT, GOVERNMENT AGENCIES, TANKERS, USCG,
1667 SAMPLING, MONITORING, CONTAMINANTS, ANALYTICAL TECHNIQUES,
1661 SAMPLING, REFINERIES, MONITORING, STREAMS, SEDIMENTS, WASTEWATERS, *HEAVY METALS,
1698 SAMPLING, OIL-GAS LEASING, MEXICO/GULF OF, HYDROCARBONS, CHEMICAL ANALYSIS, SEAWATER, *SEASONAL VARIATIONS, *MAFLA LEASE AREA,
1699 SAMPLING, PAH, OREGON, MOLLUSKS, ESTUARIES, DETECTION, CARCINOGENS, *BIVALVES,
1700 SAMPLING, DISTRIBUTION, BERING SEA, ALASKA/GULF OF, TAR, *PLASTICS,
1713 SAMPLING, INTERTIDAL ZONE, HYDROCARBONS, ANALYTICAL TECHNIQUES, SEDIMENTS, WASHINGTON,
2090 SAMPLING, MOVEMENT, MONITORING, ENVIRONMENTAL EFFECTS, BEHAVIOR, ARGO MERCHANT SPILL,
2135 SAMPLING, REMOTE SENSING, MONITORING, DETECTION, CHEMICAL ANALYSIS, BIBLIOGRAPHIES,
1694 SANTA BARBARA CHANNEL, REMOTE SENSING, OIL SLICKS, NATURAL SEEPAGE, DETECTION, SURVEILLANCE, *COASTAL ZONE COLOR SCANNER,
1722 SANTA BARBARA CHANNEL, NATURAL SEEPAGE, CHROMATOGRAPHY, CHEMICAL ANALYSIS, CALIFORNIA/SOUTHERN, BIODEGRADATION, WEATHERING, SPECTROMETRY,
1927 SANTA BARBARA CHANNEL, OIL SPILLS, MARINE ORGANISMS, ENVIRONMENTAL EFFECTS, BIRDS, BIOLOGICAL EFFECTS,
1648 SARGASSO SEA, OCEANS, DISTRIBUTION, CANADA, ATLANTIC OCEAN, TAR,
1639 SCOTLAND, REGULATIONS, OIL TRANSFER, OIL SPILLS, BIRDS, BIOLOGICAL EFFECTS,
2012 SCOTLAND, OIL INDUSTRY, OFFSHORE DEVELOPMENT, NORTH SEA, FISHERIES,
1682 SEAWATER, PETROLEUM PRODUCTS, OXIDATION, MONITORING, *CHEMILUMINESCENCE,
1698 SEAWATER, SAMPLING, OIL-GAS LEASING, MEXICO/GULF OF, HYDROCARBONS, CHEMICAL ANALYSIS, SEASONAL VARIATIONS, *MAFLA LEASE AREA,

NWMAR116928

1703 SEAWATER, PETROLEUM PRODUCTS, OIL SLICKS, CHEMICAL ANALYSIS, *SORBENTS,
1705 SEAWATER, HYDROCARBONS, FUEL OIL, CHROMATOGRAPHY, CHEMICAL ANALYSIS, *WATER-SOLUBLE FRACTION,
1707 SEAWATER, CHEMICAL ANALYSIS, AROMATIC HYDROCARBONS , *ELECTROCHEMICAL ANALYSIS ,
1711 SEAWATER, HYDROCARBONS, CHROMATOGRAPHY, BEACHES, ANALYTICAL TECHNIQUES, ABSORPTION, SPECTROSCOPY,
1716 SEAWATER, PETROLEUM PRODUCTS, ANALYTICAL TECHNIQUES, *GRAVIMETRIC ANALYSIS, *SPECTROPHOTOMETRY,
1726 SEAWATER, PETROLEUM PRODUCTS, HYDROCARBONS, CHEMICAL ANALYSIS, ADSORPTION, SURFACTANTS, *ELECTROANALYSIS ,
1780 SEAWATER, RIVERS, PATENT, FLOCCULATION, SPILL RECOVERY, SOLVENTS, COAGULATION,
1784 SEAWATER, PETROLEUM PRODUCTS, OIL-WATER SEPARATION, FLOTATION, EMULSIONS,
1791 SEAWATER, MARSHES, FRESHWATER, DISPOSAL , DISPERSANTS, COASTS, BEACHES, ABSORPTION, SPILL CLEANUP,
1975 SEAWATER, MOLLUSKS, CRUDE OIL, BIOLOGICAL EFFECTS, SEDIMENTS, *WATER-SOLUBLE FRACTION, *OIL-TREATED SEDIMENT, *MACOMA BALTHICA,
1981 SEAWATER, PETROLEUM PRODUCTS, MOLLUSKS, UPTAKE, *WATER PURIFICATION, *MYTILUS EDULIS,
1985 SEAWATER, PHYSICAL EFFECTS, OIL SLICKS, *DETERGENTS, *SEA SPRAY FORMATION,
2077 SEAWATER, ICE, HYDROCARBONS, CRUDE OIL, BIODEGRADATION, BEAUFORT SEA, SEDIMENTS,
2083 SEAWATER, DISTRIBUTION, *OIL PARTICLES,
2092 SEAWATER, PETROLEUM PRODUCTS, FATE, BIODEGRADATION, SURFACTANTS, SEDIMENTS, *SELF-PURIFICATION, *SEA OF AZOV,
2097 SEAWATER, HYDROCARBONS, FATE, BIODEGRADATION, ECOSYSTEM, SEDIMENTATION, *NAPHTHALENES,
2101 SEAWATER, MARINE ORGANISMS, HYDROCARBONS, FATE, *MOLECULAR INTERACTIONS,
2105 SEAWATER, OXIDATION, FATE, EVAPORATION, DISPERSIONS, CONTAMINATION, SPREADING, SOLUTION,
2097 SEDIMENTATION, SEAWATER, HYDROCARBONS, FATE, BIODEGRADATION, ECOSYSTEM, *NAPHTHALENES,
1678 SEDIMENTS, MONITORING, MEXICO/GULF OF, HYDROCARBONS, SOURCES, *CONTINENTAL SHELF,
1681 SEDIMENTS, SAMPLING, REFINERIES, MONITORING, STREAMS, WASTEWATERS, *HEAVY METALS,
1704 SEDIMENTS, OFFSHORE PRODUCTION, CHEMICAL ANALYSIS, VENEZUELA, STATISTICAL ANALYSIS,
1710 SEDIMENTS, HYDROCARBONS, CRUSTACEANS, CHROMATOGRAPHY, CHEMICAL ANALYSIS, SPECTROMETRY, ZOOPLANKTON,
1713 SEDIMENTS, SAMPLING, INTERTIDAL ZONE, HYDROCARBONS, ANALYTICAL TECHNIQUES, WASHINGTON,
1717 SEDIMENTS, MONITORING, HYDROCARBONS, CHROMATOGRAPHY, CHEMICAL ANALYSIS, AROMATIC HYDROCARBONS , *GLASS CAPILLARY COLUMNS,
1725 SEDIMENTS, HYDROCARBONS, CHROMATOGRAPHY, ANALYTICAL TECHNIQUES, SPECTROSCOPY, *INTERCALIBRATION,
1730 SEDIMENTS, LAKES, HYDROCARBONS, SOURCE IDENTIFICATION,
1957 SEDIMENTS, MICROORGANISMS, INTERTIDAL ZONE, BIOMASS, BIOLOGICAL EFFECTS, BACTERIA,
1975 SEDIMENTS, SEAWATER, MOLLUSKS, CRUDE OIL, BIOLOGICAL EFFECTS, *WATER-SOLUBLE FRACTION, *OIL-TREATED SEDIMENT, *MACOMA BALTHICA,
1993 SEDIMENTS, METULA SPILL, MAGELLAN/STRAIT OF, ENVIRONMENTAL EFFECTS, BEACHES,
2041 SEDIMENTS, PLATFORMS, OFFSHORE DRILLING, MARINE ORGANISMS, CALIFORNIA/SOUTHERN, UPTAKE,
2069 SEDIMENTS, HYDROCARBONS, FUNGI, FRESHWATER, BIODEGRADATION, BACTERIA,
2071 SEDIMENTS, MICROORGANISMS, LAKES, HYDROCARBONS, GASOLINE, BIODEGRADATION, ALASKA,
2077 SEDIMENTS, SEAWATER, ICE, HYDROCARBONS, CRUDE OIL, BIODEGRADATION, BEAUFORT SEA,
2091 SEDIMENTS, MARINE ORGANISMS, HYDROCARBONS, FUEL OIL, ESTUARIES, VIRGINIA,
2092 SEDIMENTS, SEAWATER, PETROLEUM PRODUCTS, FATE, BIODEGRADATION, SURFACTANTS, *SELF-PURIFICATION, *SEA OF AZOV,
2102 SEDIMENTS, RELEASE, OIL SLICKS, INTERTIDAL ZONE, HYDROCARBONS, ALASKA, UPTAKE,
2106 SEDIMENTS, PETROLEUM PRODUCTS, MOVEMENT, JAPAN, *SETO INLAND SEA,
2112 SEGREGATED BALLAST , REGULATIONS, POLLUTION CONTROL, OIL TRANSPORT, OIL DISCHARGES, EIS, TANKERS, US,
2113 SEGREGATED BALLAST , REGULATIONS, ENVIRONMENTAL PROTECTION, TANKERS, USCG,
1675 SHIPS, POLLUTION CONTROL, OIL-WATER SEPARATION, MONITORING, *ULTRASONIC MONITOR,
1684 SHIPS, MONITORING, DETECTION, DESIGN-ENGINEERING, BILGES,
1750 SHIPS, BOOMS, ABSORPTION, SPILL RECOVERY, SKIMMERS,
1788 SHIPS, PATENT, OIL SLICKS, DESIGN-ENGINEERING, SPILL RECOVERY, SKIMMERS,
1815 SHIPS, PATENT, OIL-WATER SEPARATION, FLOTATION, DESIGN-ENGINEERING, COALESCENCE,
1890 SHIPS, POLLUTION PREVENTION, LEAKAGE, *STERNGEAR SEAL SYSTEM,
1909 SHIPS, POLLUTION PREVENTION, OIL SPILLS, OIL DISCHARGES, LEAKAGE,
1998 SHIPS, PRODUCTION , MARINE ORGANISMS, FISHERIES, EXPLORATION , DISPERSANTS, CONTAMINATION, BIOLOGICAL EFFECTS, SOURCES, SEABIRDS, SPILL CLEANUP,
2119 SHIPS, OIL SPILLS, LEGISLATION, LAW ENFORCEMENT, ENGLAND, CANADA,
1794 SHORELINES, RESTORATION, OIL SPILLS, MOLLUSKS, ENGLAND, BIOLOGICAL EFFECTS, ALGAE, *ROCKY SHORES,
1996 SHORELINES, OIL SPILLS, MARINE ORGANISMS, INTERTIDAL ZONE, ENVIRONMENTAL EFFECTS, DISPERSANTS, TOXICITY,
2015 SHORELINES, OFFSHORE DEVELOPMENT, HABITAT, ENVIRONMENTAL EFFECTS, BIRDS, ARCTIC, ALASKA, *SHOREBIRD SPECIES,
2016 SHORELINES, OIL SPILLS, OFFSHORE DEVELOPMENT, ENVIRONMENTAL EFFECTS, BIRDS, BASELINE STUDIES, ALASKA,
2098 SHORELINES, OIL SPILLS, MOVEMENT, BEAUFORT SEA, ALASKA COAST, *SPILL IMPACT PROBABILITY,
1770 SINKING AGENTS, DISPERSANTS, SPILL CLEANUP, TOXICITY,

NWMAR116929

1737 SKIMMERS, PATENT, DESIGN-ENGINEERING, BOOMS, SPILL CONTAINMENT,
1748 SKIMMERS, DESIGN-ENGINEERING, SPILL RECOVERY,
1750 SKIMMERS, SHIPS, BOOMS, ABSORPTION, SPILL RECOVERY,
1755 SKIMMERS, DESIGN-ENGINEERING, SPILL RECOVERY, *SKIMJET,
1756 SKIMMERS, DESIGN-ENGINEERING, SPILL RECOVERY,
1758 SKIMMERS, DESIGN-ENGINEERING, SPILL RECOVERY, *SEAWARD INTERNATIONAL,
1761 SKIMMERS, DESIGN-ENGINEERING, SPILL RECOVERY, *FAST CURRENT OIL RECOVERY ,
1775 SKIMMERS, DESIGN-ENGINEERING, SPILL RECOVERY,
1786 SKIMMERS, PATENT, DESIGN-ENGINEERING, BOOMS, SPILL RECOVERY,
1788 SKIMMERS, SHIPS, PATENT, OIL SLICKS, DESIGN-ENGINEERING, SPILL RECOVERY,
1845 SKIMMERS, PATENT, OIL-WATER SEPARATION, FLOTATION, DESIGN-ENGINEERING,
1812 SLUDGE, REFINERIES, INCINERATION, WASTEWATER DISPOSAL, *FLUID BEDS,
1827 SLUDGE, PATENT, OIL-WATER SEPARATION, GASOLINE, DESIGN-ENGINEERING, WASTEWATERS,
1850 SLUDGE, PATENT, FLOTATION, EMULSIFIERS, ADSORPTION, WASTEWATER TREATMENT,
2064 SLUDGE, REFINERIES, DISPOSAL , BIODEGRADATION, SOIL, WASTE OIL,
2022 SOCIO-ECONOMIC EFFECTS, OFFSHORE DRILLING, OCS, CRUDE OIL, ALASKA, *SEA GRANT PROGRAM, *ENERGY POLICY,
2033 SOCIO-ECONOMIC EFFECTS, OIL-GAS LEASING, OCS, ENVIRONMENTAL EFFECTS, EIS, ALASKA,
2055 SOCIO-ECONOMIC EFFECTS, OFFSHORE DEVELOPMENT, OCS, ENVIRONMENTAL EFFECTS, COASTS, US, STATE GOVERNMENTS,
1721 SOIL, PETROLEUM PRODUCTS, CHEMICAL ANALYSIS,
1771 SOIL, PETROLEUM PRODUCTS, OXIDATION, BIODEGRADATION, ABSORPTION, SPILL CLEANUP, SOURCES,
1999 SOIL, OIL TRANSPORT, OIL SPILLS, MARSHES, ENVIRONMENTAL EFFECTS, ALASKA, VEGETATION,
2006 SOIL, PETROLEUM PRODUCTS, MOVEMENT, LUBRICATING OIL, BIOLOGICAL EFFECTS, BACTERIA,
2064 SOIL, SLUDGE, REFINERIES, DISPOSAL , BIODEGRADATION, WASTE OIL,
2075 SOIL, MONITORING, FUNGI, BIODEGRADATION, BACTERIA, WASTE OIL, *ARID SITE,
2082 SOIL, HYDROCARBONS, CRUDE OIL, CANADA, BIODEGRADATION, BACTERIA, *NUTRIENT ADDITION,
2100 SOIL, HYDROCARBONS, CRUDE OIL, ADSORPTION, *DESORPTION, *ORGANIC MATTER CONTENT,
1836 SOLID WASTES, REFINERIES, POLAND, WASTEWATER TREATMENT,
1644 SOLID WASTES, REFINERIES, OHIO, FILTRATION, DESIGN-ENGINEERING, WASTEWATER TREATMENT, *UPFLOW SAND FILTERS,
1655 SOLID WASTES, REFINERIES, INLAND, DISPOSAL , CONTAMINANTS, WASTEWATERS, *WASTE DISPOSAL PRACTICES, *LANDFILLS,
1746 SOLUTION, EMULSIFIERS, DISPERSANTS, SPILL CLEANUP, TOXICITY,
2085 SOLUTION, OIL SPILLS, HYDROCARBONS, FATE, EVAPORATION, WEATHERING,
2105 SOLUTION, SEAWATER, OXIDATION, FATE, EVAPORATION, DISPERSIONS, CONTAMINATION, SPREADING,
1780 SOLVENTS, SEAWATER, RIVERS, PATENT, FLOCCULATION, SPILL RECOVERY, COAGULATION,
1792 SOLVENTS, RESTORATION, OIL SPILLS, WILDLIFE, SURFACTANTS, TOXICITY,
1616 SOLVENTS, REFINERIES, EXTRACTION, CONTAMINANTS, WASTEWATER TREATMENT,
1858 SOLVENTS, PATENT, OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT, *SOLVENT RECOVERY ,
1859 SOLVENTS, PATENT, OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT, *SOLVENT RECOVERY ,
1677 SOURCE IDENTIFICATION, MONITORING, DESIGN-ENGINEERING, CHROMATOGRAPHY, *INSTRUMENT SURVEY,
1723 SOURCE IDENTIFICATION, OIL SPILLS, CHEMICAL ANALYSIS,
1727 SOURCE IDENTIFICATION, PETROLEUM PRODUCTS, FUEL OIL, CRUDE OIL, ANALYTICAL TECHNIQUES, SPECTROSCOPY,
1728 SOURCE IDENTIFICATION, OIL SPILLS, ANALYTICAL TECHNIQUES,
1729 SOURCE IDENTIFICATION, PRODUCTION , OIL WELLS, GROUNDWATER, CONTAMINATION, WASTEWATERS, *BRINE DISPOSAL,
1730 SOURCE IDENTIFICATION, SEDIMENTS, LAKES, HYDROCARBONS,
1731 SOURCE IDENTIFICATION, OIL SPILLS, OIL DISCHARGES, OFFSHORE DEVELOPMENT, NATURAL SEEPAGE, INTERNATIONAL AGREEMENTS, TANKERS,
1637 SOURCES, OIL SPILLS, NORTH SEA, STATISTICS, UK,
1671 SOURCES, PLATFORMS, MONITORING, MEXICO/GULF OF, HYDROCARBONS, *GAS VENTING, *BRINE DISCHARGE,
1672 SOURCES, MONITORING, HYDROCARBONS, DISTRIBUTION, CHRONIC EFFECTS, AUSTRALIA, *MYTILUS EDULIS, *INDICATOR SPECIES,
1676 SOURCES, SEDIMENTS, MONITORING, MEXICO/GULF OF, HYDROCARBONS, *CONTINENTAL SHELF,
1712 SOURCES, PETROLEUM PRODUCTS, FISH, CONTAMINATION, CHEMICAL ANALYSIS, GREAT LAKES ,
1715 SOURCES, MARINE ORGANISMS, HYDROCARBONS, CHROMATOGRAPHY, CHEMICAL ANALYSIS, SPECTROSCOPY, SPECTROMETRY,
1771 SOURCES, SOIL, PETROLEUM PRODUCTS, OXIDATION, BIODEGRADATION, ABSORPTION, SPILL CLEANUP,
1998 SOURCES, SHIPS, PRODUCTION , MARINE ORGANISMS, FISHERIES, EXPLORATION , DISPERSANTS, CONTAMINATION, BIOLOGICAL EFFECTS, SEABIRDS, SPILL CLEANUP,
2000 SOURCES, POLLUTION CONTROL, OCEANS, MARINE ORGANISMS, DISPERSANTS, CONTAMINATION, BIOLOGICAL EFFECTS,
2068 SOURCES, MICROORGANISMS, BIODEGRADATION, AROMATIC HYDROCARBONS ,
1656 SPAIN, POLLUTION CONTROL, FATE, COASTS, URQUIOLA SPILL, SPILL CLEANUP,
1710 SPECTROMETRY, SEDIMENTS, HYDROCARBONS, CRUSTACEANS, CHROMATOGRAPHY, CHEMICAL ANALYSIS, ZOOPLANKTON,

NWMAR116930

1715 SPECTROMETRY, SOURCES, MARINE ORGANISMS, HYDROCARBONS, CHROMATOGRAPHY, CHEMICAL ANALYSIS, SPECTROSCOPY,
1722 SPECTROMETRY, SANTA BARBARA CHANNEL, NATURAL SEEPAGE, CHROMATOGRAPHY, CHEMICAL ANALYSIS, CALIFORNIA/SOUTHERN, BIODEGRADATION, WEATHERING,
1690 SPECTROSCOPY, REMOTE SENSING, PETROLEUM PRODUCTS, DETECTION, CHEMICAL ANALYSIS, *COMPUTERIZED RAMAN SPECTROSCOPY ,
1708 SPECTROSCOPY, HYDROCARBONS, DETECTION, CHROMATOGRAPHY, CHEMICAL ANALYSIS, CANADA, ATLANTIC COAST,
1711 SPECTROSCOPY, SEAWATER, HYDROCARBONS, CHROMATOGRAPHY, BEACHES, ANALYTICAL TECHNIQUES, ABSORPTION,
1714 SPECTROSCOPY, MARINE ORGANISMS, HYDROCARBONS, DETECTION, CHROMATOGRAPHY, CHEMICAL ANALYSIS, BASELINE STUDIES,
1715 SPECTROSCOPY, SPECTROMETRY, SOURCES, MARINE ORGANISMS, HYDROCARBONS, CHROMATOGRAPHY, CHEMICAL ANALYSIS,
1725 SPECTROSCOPY, SEDIMENTS, HYDROCARBONS, CHROMATOGRAPHY, ANALYTICAL TECHNIQUES, *INTERCALIBRATION,
1727 SPECTROSCOPY, SOURCE IDENTIFICATION, PETROLEUM PRODUCTS, FUEL OIL, CRUDE OIL, ANALYTICAL TECHNIQUES,
1640 SPILL CLEANUP, LIABILITY, ARGO MERCHANT SPILL, TANKERS,
1650 SPILL CLEANUP, DISPERSANTS, UK, *OIL SPILL POLICY,
1654 SPILL CLEANUP, POLLUTION CONTROL, OIL SPILLS, NORTH SEA, EKOFISK BLOWOUT,
1656 SPILL CLEANUP, SPAIN, POLLUTION CONTROL, FATE, COASTS, URQUIOLA SPILL,
1659 SPILL CLEANUP, OIL INDUSTRY, NEW JERSEY, LEGISLATION, COMPENSATION, *SPILL FUND,
1660 SPILL CLEANUP, OLYMPIC GAMES SPILL, DELAWARE, BIRDS, TANKERS, *DELAWARE RIVER,
1663 SPILL CLEANUP, PIPELINES, OIL TRANSPORT, OIL SPILLS, EUROPE, *CROSS COUNTRY PIPELINES ,
1664 SPILL CLEANUP, OIL SPILLS, MONITORING, FATE, ENVIRONMENTAL EFFECTS, BEHAVIOR, *1977 OIL SPILL CONFERENCE,
1746 SPILL CLEANUP, SOLUTION, EMULSIFIERS, DISPERSANTS, TOXICITY,
1749 SPILL CLEANUP, POLLUTION CONTROL, *OIL SPILL PUMPS,
1752 SPILL CLEANUP, OIL SLICKS, DISPERSANTS, BOOMS, *PUMPS,
1753 SPILL CLEANUP, DESIGN-ENGINEERING, *OIL-SPILL PUMP,
1754 SPILL CLEANUP, CANADA, SPILL CONTAINMENT, *EQUIPMENT LOCATER SYSTEM,
1760 SPILL CLEANUP, ABSORPTION, SPILL CONTAINMENT, *POLYURETHANE FOAMS,
1764 SPILL CLEANUP, SPILL CONTAINMENT, *TREATMENT METHODS,
1766 SPILL CLEANUP, PATENT, LEAKAGE, TANKERS, *OIL SOLIDIFICATION,
1770 SPILL CLEANUP, SINKING AGENTS, DISPERSANTS, TOXICITY,
1771 SPILL CLEANUP, SOURCES, SOIL, PETROLEUM PRODUCTS, OXIDATION, BIODEGRADATION, ABSORPTION,
1772 SPILL CLEANUP, PATENT, OIL-WATER SEPARATION, DISPERSIONS, DESIGN-ENGINEERING,
1773 SPILL CLEANUP, PATENT, DISPERSANTS, *MAGNETIC POWDER,
1776 SPILL CLEANUP, OCEANS, ABSORPTION, *POLYURETHANE FOAMS,
1779 SPILL CLEANUP, PATENT, OIL SLICKS, DISPERSANTS, DESIGN-ENGINEERING,
1787 SPILL CLEANUP, PATENT, GASOLINE, FUEL OIL, ADSORPTION,
1790 SPILL CLEANUP, INCINERATION, ABSORPTION, *GELLING AGENTS,
1791 SPILL CLEANUP, SEAWATER, MARSHES, FRESHWATER, DISPOSAL , DISPERSANTS, COASTS, BEACHES, ABSORPTION,
1821 SPILL CLEANUP, PATENT, BIODEGRADATION, WASTEWATERS, *H2O2,
1882 SPILL CLEANUP, POLLUTION CONTROL, PERSONNEL TRAINING, TEXAS, *OIL SPILL CONTROL COURSE,
1886 SPILL CLEANUP, EPA, CONTINGENCY PLANNING, USCG,
1887 SPILL CLEANUP, PERSONNEL TRAINING, EUROPE, CONTINGENCY PLANNING, UK, US,
1896 SPILL CLEANUP, PUGET SOUND, OIL INDUSTRY, CONTINGENCY PLANNING, *OIL SPILL COOPERATIVE,
1906 SPILL CLEANUP, POLLUTION CONTROL, OIL SPILLS, OCEANS, INLAND, ENVIRONMENTAL EFFECTS,
1907 SPILL CLEANUP, POLLUTION CONTROL, ENVIRONMENTAL EFFECTS, DISPERSANTS,
1916 SPILL CLEANUP, OIL DISCHARGES, MARINE ORGANISMS, DISPERSANTS, TOXICITY,
1956 SPILL CLEANUP, INTERTIDAL ZONE, BIOLOGICAL EFFECTS, BALTIC SEA,
1963 SPILL CLEANUP, FISH, DISPERSANTS, BIOLOGICAL EFFECTS, *EMBRYO DEVELOPMENT,
1991 SPILL CLEANUP, RESTORATION, OIL SPILLS, INLAND, ECONOMICS, CALIFORNIA,
1996 SPILL CLEANUP, SOURCES, SHIPS, PRODUCTION , MARINE ORGANISMS, FISHERIES, EXPLORATION , DISPERSANTS, CONTAMINATION, BIOLOGICAL EFFECTS, SEABIRDS,
2004 SPILL CLEANUP, DETECTION, CHEMICAL ANALYSIS,
2108 SPILL CLEANUP, OIL SPILLS, LIABILITY, LEGISLATION, COMPENSATION, US, *COSTS,
1732 SPILL CONTAINMENT, INLAND, HARBORS, BOOMS, *PRODUCT INFORMATION,
1733 SPILL CONTAINMENT, DESIGN-ENGINEERING, BOOMS, *OILFENCE,
1734 SPILL CONTAINMENT, PORTS, TANKERS, SWEDEN, *SPILL BUBBLE BARRIER,
1735 SPILL CONTAINMENT, DESIGN-ENGINEERING, BOOMS, *PRODUCT INFORMATION,
1736 SPILL CONTAINMENT, PATENT, DESIGN-ENGINEERING, BOOMS, *CONNECTOR HINGE,
1737 SPILL CONTAINMENT, SKIMMERS, PATENT, DESIGN-ENGINEERING, BOOMS,
1738 SPILL CONTAINMENT, OIL SLICKS, BOOMS, BEHAVIOR, *SLICK DROPLET FORMATION, *ENTRAINMENT FAILURE,
1739 SPILL CONTAINMENT, OCEANS, FRESHWATER, DESIGN-ENGINEERING, BOOMS,
1740 SPILL CONTAINMENT, PATENT, DESIGN-ENGINEERING, BOOMS,
1741 SPILL CONTAINMENT, DESIGN-ENGINEERING, BOOMS, *SEABOOM,
1754 SPILL CONTAINMENT, SPILL CLEANUP, CANADA, *EQUIPMENT LOCATER SYSTEM,
1760 SPILL CONTAINMENT, SPILL CLEANUP, ABSORPTION, *POLYURETHANE FOAMS,
1764 SPILL CONTAINMENT, SPILL CLEANUP, *TREATMENT METHODS,

NWMAR116931

1742 SPILL RECOVERY, OIL TRANSPORT, DESIGN-ENGINEERING, *DRACONE BARGE,
1743 SPILL RECOVERY, DESIGN-ENGINEERING, ABSORPTION, USN, *FOAM CHIPS,
1744 SPILL RECOVERY, NORWAY, NORTH SEA, BOOMS, BLOWOUTS,
1747 SPILL RECOVERY, RECLAMATION, DESIGN-ENGINEERING,
1748 SPILL RECOVERY, SKIMMERS, DESIGN-ENGINEERING,
1750 SPILL RECOVERY, SKIMMERS, SHIPS, BOOMS, ABSORPTION,
1751 SPILL RECOVERY, NORTH SEA, DESIGN-ENGINEERING, *OIL COLLECTION SYSTEMS,
1755 SPILL RECOVERY, SKIMMERS, DESIGN-ENGINEERING, *SKIMJET,
1756 SPILL RECOVERY, SKIMMERS, DESIGN-ENGINEERING,
1757 SPILL RECOVERY, CONTINGENCY PLANNING, *RESPONSE TEAMS, US,
1758 SPILL RECOVERY, SKIMMERS, DESIGN-ENGINEERING, *SEAWARD INTERNATIONAL,
1761 SPILL RECOVERY, SKIMMERS, DESIGN-ENGINEERING, *FAST CURRENT OIL RECOVERY ,
1762 SPILL RECOVERY, PATENT, DESIGN-ENGINEERING,
1767 SPILL RECOVERY, DESIGN-ENGINEERING, *LOCKHEED DISC-DRUM DEVICE, *PERFORMANCE,
1769 SPILL RECOVERY, COST ANALYSIS, ABSORPTION, *SORBENTS, *PERFORMANCE EVALUATION,
1774 SPILL RECOVERY, PATENT, BOOMS,
1775 SPILL RECOVERY, SKIMMERS, DESIGN-ENGINEERING,
1776 SPILL RECOVERY, PATENT, INCINERATION, ABSORPTION, *ABSORBENT FIBERS,
1777 SPILL RECOVERY, PATENT, FUEL OIL, ADSORPTION, *SAWDUST,
1780 SPILL RECOVERY, SOLVENTS, SEAWATER, RIVERS, PATENT, FLOCCULATION, COAGULATION,
1781 SPILL RECOVERY, ABSORPTION, SURFACTANTS, *SORBENT WOOD CHIPS,
1782 SPILL RECOVERY, PATENT, OIL SLICKS, ABSORPTION,
1783 SPILL RECOVERY, PATENT, DISPERSANTS, BEACHES, SURFACTANTS,
1785 SPILL RECOVERY, PATENT, OIL SLICKS, DESIGN-ENGINEERING,
1786 SPILL RECOVERY, SKIMMERS, PATENT, DESIGN-ENGINEERING, BOOMS,
1788 SPILL RECOVERY, SKIMMERS, SHIPS, PATENT, OIL SLICKS, DESIGN-ENGINEERING,
1853 SPILL RECOVERY, PATENT, OIL-WATER SEPARATION, ABSORPTION, WASTEWATER TREATMENT, *SORBENT MATERIAL,
1875 SPILL RECOVERY, OIL-WATER SEPARATION, FUELS, CRUDE OIL, WASTEWATER TREATMENT,
1896 SPILL RECOVERY, POLLUTION PREVENTION, PIPELINES, OIL TRANSPORT, TANKERS,
2086 SPREADING, OIL SPILLS, ICE, BEAUFORT SEA, *UNDER-ICE SPILL,
2105 SPREADING, SOLUTION, SEAWATER, OXIDATION, FATE, EVAPORATION, DISPERSIONS, CONTAMINATION,
2055 STATE GOVERNMENTS, SOCIO-ECONOMIC EFFECTS, OFFSHORE DEVELOPMENT, OCS, ENVIRONMENTAL EFFECTS, COASTS, US,
2110 STATE GOVERNMENTS, POLLUTION CONTROL, OIL SPILLS, LEGISLATION, US, TANKERS,
1704 STATISTICAL ANALYSIS, SEDIMENTS, OFFSHORE PRODUCTION, CHEMICAL ANALYSIS, VENEZUELA,
1904 STATISTICAL ANALYSIS, NORTH SEA, ENVIRONMENTAL PROTECTION, ECONOMIC EFFECTS, BLOWOUTS,
1637 STATISTICS, SOURCES, OIL SPILLS, NORTH SEA, UK,
1649 STATISTICS, POLLUTION CONTROL, OFFSHORE DEVELOPMENT, INFORMATION SYSTEMS, *DATA BANK, UK,
1657 STATISTICS, OIL SPILLS, OCEANS, COASTS, ALASKA,
1662 STATISTICS, OIL SPILLS, OCEANS, TANKERS, *TANKER ACCIDENTS,
1795 STORAGE, FEA, ENVIRONMENTAL PROTECTION, CRUDE OIL, TANKERS,
1796 STORAGE, PATENT, DESIGN-ENGINEERING, TANKERS, *OIL STORAGE TANK,
1798 STORAGE, OIL TANKS, ENVIRONMENTAL EFFECTS, EIS, CRUDE OIL, *SALT DOMES, *STRATEGIC PETROLEUM RESERVE,
1799 STORAGE, ENVIRONMENTAL EFFECTS, EIS, CRUDE OIL, *SALT DOMES, *MINES, *STRATEGIC PETROLEUM RESERVE,
1800 STORAGE, LOUISIANA, ENVIRONMENTAL EFFECTS, EIS, CRUDE OIL, *BAYOU CHOCTAW SALT DOME,
1804 STORAGE, ECONOMICS, WASTE OIL DISPOSAL, UK,
1947 STORAGE, RELEASE, MARINE ORGANISMS, HYDROCARBONS, UPTAKE,
2124 STORAGE, OIL TRANSFER, OFFSHORE DRILLING, NORTH SEA, LIABILITY, INTERNATIONAL AGREEMENTS,
1681 STREAMS, SEDIMENTS, SAMPLING, REFINERIES, MONITORING, WASTEWATERS, *HEAVY METALS,
1952 STREAMS, OIL SPILLS, INVERTEBRATES, FUEL OIL, FISH, BIOLOGICAL EFFECTS, VIRGINIA,
1951 SUBARCTIC REGIONS, MARINE ORGANISMS, HYDROCARBONS, ECOSYSTEMS, BIOLOGICAL EFFECTS, ARCTIC,
2076 SUBARCTIC REGIONS, METABOLISM, MARINE ORGANISMS, HYDROCARBONS, BIODEGRADATION, ARCTIC, TOXICITY,
1709 SURFACTANTS, HYDROCARBONS, ENVIRONMENTAL PROTECTION, DETECTION, CONTAMINANTS, CHEMICAL ANALYSIS,
1719 SURFACTANTS, DISPERSANTS, CHEMICAL ANALYSIS,
1726 SURFACTANTS, SEAWATER, PETROLEUM PRODUCTS, HYDROCARBONS, CHEMICAL ANALYSIS, ADSORPTION, *ELECTROANALYSIS ,
1781 SURFACTANTS, SPILL RECOVERY, ABSORPTION, *SORBENT WOOD CHIPS,
1783 SURFACTANTS, SPILL RECOVERY, PATENT, DISPERSANTS, BEACHES,
1792 SURFACTANTS, SOLVENTS, RESTORATION, OIL SPILLS, WILDLIFE, TOXICITY,
1829 SURFACTANTS, PATENT, OIL-WATER SEPARATION, WASTE OIL TREATMENT,
1867 SURFACTANTS, PATENT, OIL-WATER SEPARATION, FLOCCULATION, WASTEWATER TREATMENT,
1932 SURFACTANTS, FISH, DISPERSANTS, BIOLOGICAL EFFECTS, TOXICITY,
1965 SURFACTANTS, MOLLUSKS, HYDROCARBONS, EMULSIFIERS, CRUDE OIL, BIBLIOGRAPHIES, TOXICITY, *MUSSELS,
1978 SURFACTANTS, EMULSIFIERS, ALGAE, TOXICITY, *SEAWEED, *GROWTH RATES,
2092 SURFACTANTS, SEDIMENTS, SEAWATER, PETROLEUM PRODUCTS, FATE, BIODEGRADATION,

NWMAR116932

*SELF-PURIFICATION, *SEA OF AZOV,
1655 SURVEILLANCE, OIL TRANSFER, OIL SPILLS, NORTH SEA, ENVIRONMENTAL PROTECTION, TANKERS,
1689 SURVEILLANCE, REMOTE SENSING, OIL SLICKS, OCEANS, *DYS/SLICK SEAMARKING DEVICE,
1694 SURVEILLANCE, SANTA BARBARA CHANNEL, REMOTE SENSING, OIL SLICKS, NATURAL SEEPAGE, DETECTION, *COASTAL ZONE COLOR SCANNER,
1734 SWEDEN, SPILL CONTAINMENT, PORTS, TANKERS, *SPILL BUBBLE BARRIER,
1745 SWEDEN, OIL TANKS, CLEANUP, *TANK CLEANING STATION,
2123 SWEDEN, POLLUTION PREVENTION, INTERNATIONAL CONVENTIONS, IMCO, EPA, *BALTIC CONVENTION,
1640 TANKERS, SPILL CLEANUP, LIABILITY, ARGO MERCHANT SPILL,
1641 TANKERS, POLLUTION PREVENTION, MOVEMENT, MONITORING, ARGO MERCHANT SPILL, USGS,
1646 TANKERS, SAFETY, OIL SPILLS, ECONOMICS, *LIBERIAN REGISTRY,
1655 TANKERS, SURVEILLANCE, OIL TRANSFER, OIL SPILLS, NORTH SEA, ENVIRONMENTAL PROTECTION,
1660 TANKERS, SPILL CLEANUP, OLYMPIC GAMES SPILL, DELAWARE, BIRDS, *DELAWARE RIVER,
1661 TANKERS, OIL SPILLS, *LIBERIAN REGISTRY, *FLAGS OF CONVENIENCE,
1662 TANKERS, STATISTICS, OIL SPILLS, OCEANS, *TANKER ACCIDENTS,
1680 TANKERS, REGULATIONS, PATENT, OIL DISCHARGES, MONITORING, DESIGN-ENGINEERING,
1731 TANKERS, SOURCE IDENTIFICATION, OIL SPILLS, OIL DISCHARGES, OFFSHORE DEVELOPMENT, NATURAL SEEPAGE, INTERNATIONAL AGREEMENTS,
1734 TANKERS, SWEDEN, SPILL CONTAINMENT, PORTS, *SPILL BUBBLE BARRIER,
1766 TANKERS, SPILL CLEANUP, PATENT, LEAKAGE, *OIL SOLIDIFICATION,
1795 TANKERS, STORAGE, FEA, ENVIRONMENTAL PROTECTION, CRUDE OIL,
1796 TANKERS, STORAGE, PATENT, DESIGN-ENGINEERING, *OIL STORAGE TANK,
1801 TANKERS, SAFETY, OIL TRANSPORT, *STANDARDS, *ACCIDENT PREVENTION,
1889 TANKERS, POLLUTION PREVENTION, OIL TANKS, OIL SPILLS, *TIN CAN CONTAINERS,
1896 TANKERS, SPILL RECOVERY, POLLUTION PREVENTION, PIPELINES, OIL TRANSPORT,
1902 TANKERS, SAFETY, POLLUTION CONTROL, OIL SPILLS, OIL DISCHARGES, LIABILITY, INTERNATIONAL CONVENTIONS,
1988 TANKERS, OIL SPILLS, OIL INDUSTRY, LIABILITY, LEGISLATION, COMPENSATION, *SPILL SUPERFUNDS,
1989 TANKERS, REGULATIONS, PORTS, OIL TRANSFER, OIL SPILLS, LIABILITY, ALASKA, *OIL SPILL FUND,
1992 TANKERS, OIL SPILLS, LEGISLATION, ENVIRONMENTAL EFFECTS, ECONOMIC EFFECTS, CANADA,
1994 TANKERS, OIL SPILLS, ENVIRONMENTAL EFFECTS,
1995 TANKERS, OIL SPILLS, MALAYSIA, ENVIRONMENTAL EFFECTS,
2110 TANKERS, STATE GOVERNMENTS, POLLUTION CONTROL, OIL SPILLS, LEGISLATION, US,
2111 TANKERS, REGULATIONS, POLLUTION CONTROL, OIL TRANSPORT, OIL DISCHARGES, EIS, US,
2112 TANKERS, SEGREGATED BALLAST , REGULATIONS, POLLUTION CONTROL, OIL TRANSPORT, OIL DISCHARGES, EIS, US,
2113 TANKERS, SEGREGATED BALLAST , REGULATIONS, ENVIRONMENTAL PROTECTION, USCG,
2114 TANKERS, REGULATIONS, OIL DISCHARGES, WASTEWATERS, USCG,
2120 TANKERS, SAFETY, REGULATIONS, PORTS, LAW ENFORCEMENT, GOVERNMENT AGENCIES, USCG,
2122 TANKERS, POLLUTION PREVENTION, MANUALS, GUIDELINES, CONTINGENCY PLANNING,
2126 TANKERS, OIL DISCHARGES, LAW ENFORCEMENT, INTERNATIONAL CONVENTIONS, IMCO,
1648 TAR, SARGASSO SEA, OCEANS, DISTRIBUTION, CANADA, ATLANTIC OCEAN,
1700 TAR, SAMPLING, DISTRIBUTION, BERING SEA, ALASKA/GULF OF, *PLASTICS,
2036 TAR SANDS, EXTRACTION, ENVIRONMENTAL PROTECTION, DEVELOPMENT , CANADA, *ALBERTA,
2040 TAR SANDS, PRODUCTION , OIL SHALE, FOSSIL FUELS , ENVIRONMENTAL EFFECTS,
1797 TEXAS, PIPELINES, OIL TRANSPORT, OIL SPILLS, EIS, CRUDE OIL, ALASKA,
1882 TEXAS, SPILL CLEANUP, POLLUTION CONTROL, PERSONNEL TRAINING, *OIL SPILL CONTROL COURSE,
1666 TOXICITY, JAPAN, FISH, DISPERSANTS, TROPICAL REGIONS, *WARREN SPRINGS LABORATORY, *HONG KONG,
1746 TOXICITY, SPILL CLEANUP, SOLUTION, EMULSIFIERS, DISPERSANTS,
1770 TOXICITY, SPILL CLEANUP, SINKING AGENTS, DISPERSANTS,
1792 TOXICITY, SURFACTANTS, SOLVENTS, RESTORATION, OIL SPILLS, WILDLIFE,
1910 TOXICITY, OIL SPILLS, MARINE ORGANISMS, ENVIRONMENTAL EFFECTS,
1913 TOXICITY, METABOLISM, MARINE ORGANISMS, HYDROCARBONS, BEHAVIOR, ANALYTICAL TECHNIQUES, *SUBLETHAL LEVELS,
1914 TOXICITY, FUEL OIL, CRUDE OIL, ALGAE,
1916 TOXICITY, SPILL CLEANUP, OIL DISCHARGES, MARINE ORGANISMS, DISPERSANTS,
1920 TOXICITY, CRUSTACEANS, CRUDE OIL, AROMATIC HYDROCARBONS , *LARVAL DEVELOPMENT, *CANCER MAGISTER,
1921 TOXICITY, POLYCHAETES, FUEL OIL, CRUDE OIL, *REPRODUCTION,
1926 TOXICITY, CRUSTACEANS, CRUDE OIL, *MISSISSIPPI SOUND, *COPEPODS,
1930 TOXICITY, PLANTS, CRUDE OIL, CONTAMINATION, *OLNEY BULRUSH, *MARSHHAY CORDGRASS,
1932 TOXICITY, SURFACTANTS, FISH, DISPERSANTS, BIOLOGICAL EFFECTS,
1934 TOXICITY, ECHINODERMS, DISPERSANTS, *ESSO COREXIT 9527, *FERTILIZATION,
1938 TOXICITY, FISH, CRUDE OIL, CHRONIC EFFECTS, *TROUT REPRODUCTION,
1940 TOXICITY, PLANKTON , OCS, NEW YORK, CRUDE OIL, BENTHOS, *NEW YORK BIGHT,
1942 TOXICITY, PETROLEUM PRODUCTS, METABOLISM, FISH, *SPICARA SMARIS, *SOLEA LASCARIS NASUTA,
1943 TOXICITY, PETROLEUM PRODUCTS, FISH, *HEMATOLOGICAL CHANGES,
1946 TOXICITY, REFINERIES, MONITORING, INVERTEBRATES, FRESHWATER, WASTEWATERS, *DAPHNIA PULEX, *BIOASSAY,
1948 TOXICITY, PHYTOPLANKTON, ESTUARIES, CRUDE OIL, *KUWAIT CRUDE,
1949 TOXICITY, LUBRICATING OIL, FRESHWATER, FISH, CHRONIC EFFECTS, *SYNTHETIC OIL,

NWMAR116933

1955 TOXICITY, PETROLEUM PRODUCTS, GASOLINE, FRESHWATER, CRUDE OIL, BIODEGRADATION, BACTERIA, ALGAE, *PHOTOSYNTHESIS,
1962 TOXICITY, RELEASE, MARINE ORGANISMS, FUEL OIL, CRUDE OIL, UPTAKE,
1963 TOXICITY, METABOLISM, HYDROCARBONS, FUEL OIL, FISH, CRUDE OIL,*RESPIRATION, *ONCORHYNCHUS GORBUSCHA,
1964 TOXICITY, PETROLEUM PRODUCTS, MARINE ORGANISMS, CRUDE OIL, *COMPARATIVE TOXICITY , *BIOASSAY,
1965 TOXICITY, SURFACTANTS, MOLLUSKS, HYDROCARBONS, EMULSIFIERS, CRUDE OIL, BIBLIOGRAPHIES, *MUSSELS,
1970 TOXICITY, ALGAE, *REPRODUCTION,
1972 TOXICITY, HYDROCARBONS, FISH, *BENZENE, *REPRODUCTION, *CLUPEA HARENGUS PALLASI,
1977 TOXICITY, OIL SPILLS, MARINE ORGANISMS, INTERTIDAL ZONE, CHEDABUCTO BAY, CANADA, *MORTALITIES,
1978 TOXICITY, SURFACTANTS, EMULSIFIERS, ALGAE, *SEAWEED, *GROWTH RATES,
1979 TOXICITY, RELEASE, MOLLUSKS, UPTAKE, *OIL DROPLETS, *MORTALITY, *CRASSOSTREA GIGAS, *MYTILUS SPP.,
1980 TOXICITY, PHYTOPLANKTON, FRESHWATER, CRUDE OIL, ARCTIC, *PRIMARY PRODUCTION,
1996 TOXICITY, SHORELINES, OIL SPILLS, MARINE ORGANISMS, INTERTIDAL ZONE, ENVIRONMENTAL EFFECTS, DISPERSANTS,
2002 TOXICITY, REFINERIES, POLLUTION CONTROL, OIL TRANSPORT, OIL SPILLS, OFFSHORE PRODUCTION, NORTH SEA, FISHERIES, BIRDS,
2010 TOXICITY, PHYTOPLANKTON, OIL SLICKS, ENVIRONMENTAL EFFECTS, DISPERSANTS, *LIGHT REDUCTION, *PHOTOSYNTHESIS,
2070 TOXICITY, SUBARCTIC REGIONS, METABOLISM, MARINE ORGANISMS, HYDROCARBONS, BIODEGRADATION, ARCTIC,
2076 TOXICITY, ECHINODERMS, CRUDE OIL, BIODEGRADATION, *EKOFISK OIL,
2089 TOXICITY, OXIDATION, FUEL OIL, YEASTS, *UV IRRADIATION,
1666 TROPICAL REGIONS, TOXICITY, JAPAN, FISH, DISPERSANTS, *WARREN SPRINGS LABORATORY, *HONG KONG,
1637 UK, STATISTICS, SOURCES, OIL SPILLS, NORTH SEA,
1649 UK, STATISTICS, POLLUTION CONTROL, OFFSHORE DEVELOPMENT, INFORMATION SYSTEMS, *DATA BANK,
1650 UK, SPILL CLEANUP, DISPERSANTS, *OIL SPILL POLICY,
1804 UK, STORAGE, ECONOMICS, WASTE OIL DISPOSAL,
1807 UK, SPILL CLEANUP, PERSONNEL TRAINING, EUROPE, CONTINGENCY PLANNING, US,
2115 UK, POLLUTION CONTROL, OCEANS, LEGISLATION, INTERNATIONAL CONVENTIONS, INTERNATIONAL AGREEMENTS, US,
1912 UPTAKE, RELEASE, HYDROCARBONS, ANNELIDS, SEDIMENT, *PHASCOLOSOMA AGASSIZII, *NAPHTHALENES,
1924 UPTAKE, MARINE MAMMALS, HYDROCARBONS, CRUDE OIL, BIOLOGICAL EFFECTS, BEAUFORT SEA, *RINGED SEAL,
1929 UPTAKE, RELEASE, MOLLUSKS, CRUDE OIL, *NAPHTHALENES, *RANGEA CUNEATA, *PROTOTHACA STAMINEA,
1933 UPTAKE, RELEASE, HYDROCARBONS, FISH, *COHO AND CHINOOK SALMON, *CHLORINATED BIPHENYLS, *ENZYME ACTIVITY,
1935 UPTAKE, RELEASE, PLANKTON , HYDROCARBONS, CRUSTACEANS, *14C-1-NAPHTHALENE, *COPEPODS,
1947 UPTAKE, STORAGE, RELEASE, MARINE ORGANISMS, HYDROCARBONS,
1962 UPTAKE, TOXICITY, RELEASE, MARINE ORGANISMS, FUEL OIL, CRUDE OIL,
1966 UPTAKE, RELEASE, MOLLUSKS, FUEL OIL, EMULSIONS, *MYA ARENARIA L.,
1974 UPTAKE, METABOLISM, HYDROCARBONS, FUEL OIL, CRUSTACEANS, *NAPHTHALENES, *HATCHING, *LARVAL GROWTH, *GRASS SHRIMP,
1976 UPTAKE, RELEASE, OCEANS, HYDROCARBONS, FOOD WEB, *FOOD CHAIN TRANSFER,
1979 UPTAKE, TOXICITY, RELEASE, MOLLUSKS, *OIL DROPLETS, *MORTALITY, *CRASSOSTREA GIGAS, *MYTILUS SPP.,
1981 UPTAKE, SEAWATER, PETROLEUM PRODUCTS, MOLLUSKS, *WATER PURIFICATION, *MYTILUS EDULIS,
2041 UPTAKE, SEDIMENTS, PLATFORMS, OFFSHORE DRILLING, MARINE ORGANISMS, CALIFORNIA/SOUTHERN,
2067 UPTAKE, OXIDATION, CRUDE OIL, BIODEGRADATION, *TEMPERATURE EFFECTS,
2102 UPTAKE, SEDIMENTS, RELEASE, OIL SLICKS, INTERTIDAL ZONE, HYDROCARBONS, ALASKA,
1656 URQUIOLA SPILL, SPILL CLEANUP, SPAIN, POLLUTION CONTROL, FATE, COASTS,
1757 US, SPILL RECOVERY, CONTINGENCY PLANNING, *RESPONSE TEAMS,
1887 US, UK, SPILL CLEANUP, PERSONNEL TRAINING, EUROPE, CONTINGENCY PLANNING,
1997 US, OIL SPILLS, ENVIRONMENTAL EFFECTS, ATLANTIC OCEAN, *WORLD WAR II,
2018 US, REGULATIONS, POLLUTION PREVENTION, OIL INDUSTRY, COST ANALYSIS, WATER QUALITY,
2053 US, OIL INDUSTRY, LOUISIANA, LEGISLATION, ENVIRONMENTAL MANAGEMENT, COASTS,
2055 US, STATE GOVERNMENTS, SOCIO-ECONOMIC EFFECTS, OFFSHORE DEVELOPMENT, OCS, ENVIRONMENTAL EFFECTS, COASTS,
2108 US, SPILL CLEANUP, OIL SPILLS, LIABILITY, LEGISLATION, COMPENSATION, *COSTS,
2109 US, REFINERIES, OFFSHORE DEVELOPMENT, OCS, LEGISLATION, ENVIRONMENTAL EFFECTS, COASTS,
2110 US, TANKERS, STATE GOVERNMENTS, POLLUTION CONTROL, OIL SPILLS, LEGISLATION,
2111 US, TANKERS, REGULATIONS, POLLUTION CONTROL, OIL TRANSPORT, OIL DISCHARGES, EIS,
2112 US, TANKERS, SEGREGATED BALLAST , REGULATIONS, POLLUTION CONTROL, OIL TRANSPORT, OIL DISCHARGES, EIS,
2115 US, UK, POLLUTION CONTROL, OCEANS, LEGISLATION, INTERNATIONAL CONVENTIONS, INTERNATIONAL AGREEMENTS,
2134 US, POLLUTION CONTROL, LEGISLATION, BIBLIOGRAPHIES,

NWMAR116934

1789 USCG, POLLUTION CONTROL, *EQUIPMENT, *FAST SURFACE DELIVERY SYSTEM,
1886 USCG, SPILL CLEANUP, EPA, CONTINGENCY PLANNING,
1892 USCG, POLLUTION CONTROL, OIL SPILLS,
1908 USCG, POLLUTION PREVENTION, OIL SPILLS, LEGISLATION, LAW ENFORCEMENT,
2113 USCG, TANKERS, SEGREGATED BALLAST , REGULATIONS, ENVIRONMENTAL PROTECTION,
2114 USCG, TANKERS, REGULATIONS, OIL DISCHARGES, WASTEWATERS,
2120 USCG, TANKERS, SAFETY, REGULATIONS, PORTS, LAW ENFORCEMENT, GOVERNMENT AGENCIES,
1641 USGS, TANKERS, POLLUTION PREVENTION, MOVEMENT, MONITORING, ARGO MERCHANT SPILL,
1743 USN, SPILL RECOVERY, DESIGN-ENGINEERING, ABSORPTION, *FOAM CHIPS,
1636 USSR, POLLUTION CONTROL, OIL-WATER SEPARATION, OIL DISCHARGES, DISTILLATION,
1861 USSR, REFINERIES, ECONOMICS, CRUDE OIL, COST ANALYSIS, WASTEWATER TREATMENT,
1903 USSR, RIVERS, REFINERIES, POLLUTION CONTROL, PETROCHEMICALS, WASTEWATERS, WATER QUALITY,
1793 VEGETATION, RESTORATION, REFINERIES, MARSHES, ENGLAND, CONTAMINATION, WASTEWATERS, *SALT MARSH,
1999 VEGETATION, SOIL, OIL TRANSPORT, OIL SPILLS, MARSHES, ENVIRONMENTAL EFFECTS, ALASKA,
1704 VENEZUELA, STATISTICAL ANALYSIS, SEDIMENTS, OFFSHORE PRODUCTION, CHEMICAL ANALYSIS,
1952 VIRGINIA, STREAMS, OIL SPILLS, INVERTEBRATES, FUEL OIL, FISH, BIOLOGICAL EFFECTS,
2091 VIRGINIA, SEDIMENTS, MARINE ORGANISMS, HYDROCARBONS, FUEL OIL, ESTUARIES,
1713 WASHINGTON, SEDIMENTS, SAMPLING, INTERTIDAL ZONE, HYDROCARBONS, ANALYTICAL TECHNIQUES,
1670 WASTE OIL, OIL SPILLS, MONITORING, CHEMICAL ANALYSIS, *IR ABSORPTION ,
1809 WASTE OIL, PATENT, DESIGN-ENGINEERING, WASTEWATER TREATMENT, *COLLECTION RESERVOIR,
1814 WASTE OIL, EMULSIONS, COALESCENCE, WASTEWATER TREATMENT,
1825 WASTE OIL, REFINERIES, POLLUTION PREVENTION, OIL-WATER SEPARATION, WASTEWATER TREATMENT,
1847 WASTE OIL, RECLAMATION, FUELS, WASTEWATER DISPOSAL, *LAND DISPOSAL, *SPRAY IRRIGATION,
1873 WASTE OIL, RECYCLING, LUBRICATING OIL, FILTRATION, COALESCENCE,
1876 WASTE OIL, REUSE, RECLAMATION, ECONOMICS,
1877 WASTE OIL, RECLAMATION, OIL-WATER SEPARATION, LUBRICATING OIL, FUELS, FILTRATION, *USCG POWER PLANTS,
1879 WASTE OIL, RECLAMATION, *REVIEW,
1880 WASTE OIL, RECLAMATION, *REVIEW,
1881 WASTE OIL, REUSE, RECLAMATION, PETROLEUM PRODUCTS,
2064 WASTE OIL, SOIL, SLUDGE, REFINERIES, DISPOSAL , BIODEGRADATION,
2075 WASTE OIL, SOIL, MONITORING, FUNGI, BIODEGRADATION, BACTERIA, *ARID SITE,
1804 WASTE OIL DISPOSAL, UK, STORAGE, ECONOMICS,
1807 WASTE OIL TREATMENT, FILTRATION, EMULSIONS, *ULTRAFILTRATION ,
1629 WASTE OIL TREATMENT, SURFACTANTS, PATENT, OIL-WATER SEPARATION,
1860 WASTE OIL TREATMENT, REFINERIES, EMULSIONS, DESIGN-ENGINEERING,
1681 WASTEWATERS, STREAMS, SEDIMENTS, SAMPLING, REFINERIES, MONITORING, *HEAVY METALS,
1695 WASTEWATERS, REMOTE SENSING, OIL SLICKS, MOVEMENT, COASTS, *CURRENT CIRCULATION, *SATELLITE-AIRCRAFT-DROGUE STUDIES,
1706 WASTEWATERS, REFINERIES, FOSSIL FUELS , ANALYTICAL TECHNIQUES,
1729 WASTEWATERS, SOURCE IDENTIFICATION, PRODUCTION , OIL WELLS, GROUNDWATER, CONTAMINATION, *BRINE DISPOSAL,
1793 WASTEWATERS, VEGETATION, RESTORATION, REFINERIES, MARSHES, ENGLAND, CONTAMINATION, *SALT MARSH,
1819 WASTEWATERS, REFINERIES, POLLUTION CONTROL, *RADIOTRACER APPLICATIONS,
1821 WASTEWATERS, SPILL CLEANUP, PATENT, BIODEGRADATION, *H2O2,
1827 WASTEWATERS, SLUDGE, PATENT, OIL-WATER SEPARATION, GASOLINE, DESIGN-ENGINEERING,
1840 WASTEWATERS, OIL DISCHARGES, MONITORING, LUBRICATING OIL, GASOLINE, FUEL OIL, ENVIRONMENTAL EFFECTS, *DISSOLVED ORGANICS,
1855 WASTEWATERS, SOLID WASTES, REFINERIES, INLAND, DISPOSAL , CONTAMINANTS, *WASTE DISPOSAL PRACTICES, *LANDFILLS,
1862 WASTEWATERS, OIL-WATER SEPARATION, COALESCENCE, WASTEWATER TREATMENT,
1878 WASTEWATERS, REUSE, REFINERIES, RECLAMATION, INDUSTRIES, INDIA,
1903 WASTEWATERS, USSR, RIVERS, REFINERIES, POLLUTION CONTROL, PETROCHEMICALS, WATER QUALITY,
1946 WASTEWATERS, TOXICITY, REFINERIES, MONITORING, INVERTEBRATES, FRESHWATER, *DAPHNIA PULEX, *BIOASSAY,
2114 WASTEWATERS, USCG, TANKERS, REGULATIONS, OIL DISCHARGES,
2118 WASTEWATERS, REGULATIONS, REFINERIES, ENVIRONMENTAL PROTECTION, ECONOMICS, CANADA, *QUEBEC,
2121 WASTEWATERS, REGULATIONS, REFINERIES, POLLUTION CONTROL, CONTAMINANTS, CANADA,
1812 WASTEWATER DISPOSAL, SLUDGE, REFINERIES, INCINERATION, *FLUID BEDS,
1847 WASTEWATER DISPOSAL, WASTE OIL, RECLAMATION, FUELS, *LAND DISPOSAL, *SPRAY IRRIGATION,
1803 WASTEWATER TREATMENT, REFINERIES, PATENT, INCINERATION, EVAPORATION, *THERMAL OXIDATION ,
1805 WASTEWATER TREATMENT, OIL-WATER SEPARATION, FLOTATION, EMULSIONS, DESIGN-ENGINEERING,
1808 WASTEWATER TREATMENT, OIL-WATER SEPARATION, INDUSTRIES, FILTRATION, EMULSIONS, *ULTRAFILTRATION ,
1809 WASTEWATER TREATMENT, WASTE OIL, PATENT, DESIGN-ENGINEERING, *COLLECTION RESERVOIR,
1810 WASTEWATER TREATMENT, PATENT, OIL-WATER SEPARATION, FILTRATION,
1813 WASTEWATER TREATMENT, REFINERIES, PENNSYLVANIA, OIL-WATER SEPARATION, FILTRATION, *SAND FILTERS,

NWMAR116935

1814 WASTEWATER TREATMENT, WASTE OIL, EMULSIONS, COALESCENCE,
1816 WASTEWATER TREATMENT, SOLVENTS, REFINERIES, EXTRACTION, CONTAMINANTS,
1817 WASTEWATER TREATMENT, REFINERIES, PETROCHEMICALS, HYDROCARBONS, *SOLVENT EXTRACTION ,
1820 WASTEWATER TREATMENT, REFINERIES, BIODEGRADATION, ACTIVATED SLUDGE
1822 WASTEWATER TREATMENT, REFINERIES, FILTRATION,
1823 WASTEWATER TREATMENT, PETROLEUM PRODUCTS, PATENT, OIL-WATER SEPARATION, FLOCCULATION,
1825 WASTEWATER TREATMENT, WASTE OIL, REFINERIES, POLLUTION PREVENTION, OIL-WATER SEPARATION,
1830 WASTEWATER TREATMENT, REUSE, RECLAMATION, OIL-WATER SEPARATION, INDUSTRIES, CANADA,
1832 WASTEWATER TREATMENT, PATENT, OXIDATION, OIL-WATER SEPARATION, EMULSIONS, ADSORPTION,
1833 WASTEWATER TREATMENT, PATENT, OIL-WATER SEPARATION, *POPCORN POLYMER,
1834 WASTEWATER TREATMENT, REFINERIES, OIL-WATER SEPARATION, FILTRATION, CANADA, *DUAL-MEDIA FILTERS,
1835 WASTEWATER TREATMENT, PATENT, FLOTATION, *TETRAETHYLEAD REMOVAL,
1836 WASTEWATER TREATMENT, SOLID WASTES, REFINERIES, POLAND,
1837 WASTEWATER TREATMENT, REFINERIES, PETROCHEMICALS, OIL INDUSTRY, GERMANY, EAST,
1839 WASTEWATER TREATMENT, OIL-WATER SEPARATION, DESIGN-ENGINEERING, COALESCENCE,
1841 WASTEWATER TREATMENT, OIL-WATER SEPARATION, DESIGN-ENGINEERING, COALESCENCE, *GRAVITY SEPARATION ,
1842 WASTEWATER TREATMENT, REFINERIES, PETROCHEMICALS, *BIOLOGICAL DETOXICATION,
1843 WASTEWATER TREATMENT, REFINERIES, OIL-WATER SEPARATION, *PARALLEL PLATE SEPARATORS,
1844 WASTEWATER TREATMENT, SOLID WASTES, REFINERIES, OHIO, FILTRATION, DESIGN-ENGINEERING, *UPFLOW SAND FILTERS,
1846 WASTEWATER TREATMENT, REFINERIES, EPA, CHEMICAL ANALYSIS, *ANALYTICAL VARIABILITY,
1848 WASTEWATER TREATMENT, PATENT, OIL-WATER SEPARATION, FLOCCULATION,
1849 WASTEWATER TREATMENT, PATENT, OIL-WATER SEPARATION, FLOCCULATION,
1850 WASTEWATER TREATMENT, SLUDGE, PATENT, FLOTATION, EMULSIFIERS, ADSORPTION,
1851 WASTEWATER TREATMENT, PATENT, COAGULATION,
1853 WASTEWATER TREATMENT, SPILL RECOVERY, PATENT, OIL-WATER SEPARATION, ABSORPTION, *SORBENT MATERIAL,
1854 WASTEWATER TREATMENT, PATENT, OIL-WATER SEPARATION, FLOTATION, EMULSIONS, *CATIONIC POLYMERS,
1856 WASTEWATER TREATMENT, REFINERIES, *REVERSE OSMOSIS, *WATER RECOVERY ,
1857 WASTEWATER TREATMENT, REFINERIES, FILTRATION, WATER QUALITY, *ONTARIO,
1858 WASTEWATER TREATMENT, SOLVENTS, PATENT, OIL-WATER SEPARATION, FLOCCULATION, *SOLVENT RECOVERY ,
1859 WASTEWATER TREATMENT, SOLVENTS, PATENT, OIL-WATER SEPARATION, FLOCCULATION, *SOLVENT RECOVERY ,
1861 WASTEWATER TREATMENT, USSR, REFINERIES, ECONOMICS, CRUDE OIL, COST ANALYSIS,
1862 WASTEWATER TREATMENT, WASTEWATERS, OIL-WATER SEPARATION, COALESCENCE,
1863 WASTEWATER TREATMENT, REFINERIES, DISPOSAL , *BIOLOGICAL TREATMENT, *UNDERGROUND WASTE INJECTION,
1864 WASTEWATER TREATMENT, OIL-WATER SEPARATION, FLOTATION, EMULSIONS,
1865 WASTEWATER TREATMENT, OXIDATION, OIL INDUSTRY,
1866 WASTEWATER TREATMENT, PETROLEUM PRODUCTS, PATENT, ABSORPTION, *ABSORBENT POLYOLEFIN,
1867 WASTEWATER TREATMENT, SURFACTANTS, PATENT, OIL-WATER SEPARATION, FLOCCULATION,
1868 WASTEWATER TREATMENT, PETROLEUM PRODUCTS, *COAGULATION,
1869 WASTEWATER TREATMENT, PATENT, OIL-WATER SEPARATION, FILTRATION, EMULSIONS, *ULTRAFILTRATION ,
1870 WASTEWATER TREATMENT, PETROLEUM PRODUCTS, FLOCCULATION,
1871 WASTEWATER TREATMENT, OIL-WATER SEPARATION, EMULSIONS, COALESCENCE,
1872 WASTEWATER TREATMENT, POLAND, FILTRATION, EMULSIONS, ADSORPTION, *CELLULOSE, *DIATOMACEOUS EARTH,
1875 WASTEWATER TREATMENT, SPILL RECOVERY, OIL-WATER SEPARATION, FUELS, CRUDE OIL,
1987 WASTEWATER TREATMENT, REGULATIONS, REFINERIES, POLLUTION CONTROL, OIL INDUSTRY, COST ANALYSIS, API,
2026 WASTEWATER TREATMENT, POLLUTION CONTROL, PETROCHEMICALS, NORWAY, CHEMICAL ANALYSIS,
2117 WASTEWATER TREATMENT, REFINERIES, GUIDELINES, ENVIRONMENTAL PROTECTION, CANADA, *ALBERTA,
1857 WATER QUALITY, WASTEWATER TREATMENT, REFINERIES, FILTRATION, *ONTARIO,
1903 WATER QUALITY, WASTEWATERS, USSR, RIVERS, REFINERIES, POLLUTION CONTROL, PETROCHEMICALS,
2016 WATER QUALITY, US, REGULATIONS, POLLUTION PREVENTION, OIL INDUSTRY, COST ANALYSIS,
2081 WATER QUALITY, LAKES, HYDROCARBONS, BIODEGRADATION, BACTERIA, WISCONSIN, *NUTRIENT LIMITATION,
1722 WEATHERING, SPECTROMETRY, SANTA BARBARA CHANNEL, NATURAL SEEPAGE, CHROMATOGRAPHY, CHEMICAL ANALYSIS, CALIFORNIA/SOUTHERN, BIODEGRADATION,
2085 WEATHERING, SOLUTION, OIL SPILLS, HYDROCARBONS, FATE, EVAPORATION,
2087 WEATHERING, OIL TRANSFER, OIL SPILLS, MODELS, EVAPORATION, DELAWARE BAY,
2093 WEATHERING, OIL SPILLS, NORWAY, FISH, CHEMICAL ANALYSIS, BIOLOGICAL EFFECTS, BIODEGRADATION, AROMATIC HYDROCARBONS , *T/T "DRUPA" SPILL,
1658 WILDLIFE, NORTH SEA, ENVIRONMENTAL PROTECTION, EKOFISK BLOWOUT,
1792 WILDLIFE, TOXICITY, SURFACTANTS, SOLVENTS, RESTORATION, OIL SPILLS,
2063 YEASTS, OIL SLICKS, HYDROCARBONS, BIODEGRADATION, BACTERIA, AROMATIC HYDROCARBONS *CHLORINATED HYDROCARBONS ,
2069 YEASTS, TOXICITY, OXIDATION, FUEL OIL, *UV IRRADIATION,
1710 ZOOPLANKTON, SPECTROMETRY, SEDIMENTS, HYDROCARBONS, CRUSTACEANS, CHROMATOGRAPHY, CHEMICAL ANALYSIS,

NWMAR116936

ABELSON, P.H. 1994
ABRAMOV, O.I. 1702
ADAMS, E.E. 2104
ADAMS, M.V. 2021
A. ESSERS COMPANY 1701
AHEARN, D.G. 2063
AHMADJIAN, M. 1727
AIKEN, S.R. 1995
AKHMETOV, A.SH. 2083
ALASKA UNIVERSITY 2022
ALBERS, P.H. 1911
ALBERS, P.H. 1973
ALBRIGHT, L.J. 1923
ALDAKIMOVA, A.YA. 2092
ALEXANDER, G.A. 2041
ALFEROVA, L.A. 1823
ALIVERDIZADE, K.S.O. 1893
ALLEN, D.H. 1759
AMES, R.K. 1806
ANDERSON, J.W. 1912
ANDERSON, J.W. 1913
ANDERSON, J.W. 2097
ANDREWS, A.R. 2067
ANUFRIEVA, N.M. 1703
ANUFRIEVA, N.M. 1760
ANUFRIEVA, N.M. 1778
APPLEMAN, M.D. 2065
ARHELGER, S.D. 2057
ARTHUR D. LITTLE, INC. 2023
ARZUMANOV, S.A. 1893
ATLAS, R.M. 2058
ATLAS, R.M. 2070
ATLAS, R.M. 2071
ATLAS, R.M. 2072
ATLAS, R.M. 2077
AUSTIN, B. 2061
AYERS, R.R. 1761
AZAROWICZ, E.N. 2059
BAILEY, P.A. 1807
BAILEY, P.A. 1808
BAKER, J.M. 1996
BALLAST NEDAM GROEP NV 1762
BALLAST NEDAM GROEP NV 1809
BANKOWSKA, J. 1872
BARGER, W.R. 1689
BARINOVA, S.P. 2080
BARINOVA, S.P. 2107
BARKER, C.D. 1885
BARNES, R.I. 1763
BARON, V.C. 1795
BARRA, F.J. 1810
BARSZCZ, C.A. 1984
BARTHA, R. 2064
BATES, C.C. 1657
BATTERTON, J.C. 1914
BAUER, D. 1825
BEAN, R.M. 1704
BEAN, R.M. 1705
BEATON, N.C. 1811
BECKER, K.P. 1812
BELL, A.O. 1796
BELYAEV, V.I. 2083
BERDUGO, V. 1915
BERDUGO, V. 1935
BERGER, H. 1870
BERKLUND, C. 2024
BERKLUND, C. 2025
BERKNER, A.B. 1792
BERNARD, B.B. 1671
BERNSTEIN, P.J. 2120
BEZUGLYI, N.F. 1835
BIERI, R.H. 2091
BLANKENSHIP, D.W. 2089
BLAYLOCK, J.W. 1704
BLAYLOCK, J.W. 1705
BLAYLOCK, J.W. 1912
BLM 1797
BLM 2028
BLM 2029
BLM 2030
BLM 2031
BLM 2032
BLM 2033
BOCARD, C. 1916
BOELER, J.B. 1728
BOELER, J.B. 2026
BOURNE, W.R.P. 1654
BOURNE, W.R.P. 1655
BOURNE, W.R.P. 1917
BOURNE, W.R.P. 1918
BOURNE, W.R.P. 1997
BOWMAN, P.I. 2063
BOYD, B.D. 1657
BOYENS, V.C. 1894
BRACKEN, J. 1717
BREUIL, C. 1919
BRIDIE, A.L.A.M. 1802
BRITISH PETROLEUM CO., LTD. 1895
BROCK, T.D. 2081
BRODERSEN, C.C. 1962
BRODERICK, L.S. 2060
BRODY, M.A. 1813
BRONFMAN, A.M. 2092
BROOKS, J.M. 1671
BROWN, C.W. 1690
BROWN, C.W. 1727
BROWN, D.W. 1679
BROWN, D.W. 1713
BROWN, L.R. 1931
BROWN, M.A. 2119
BRUCE, H.E. 2027
BRUNGS, W.A. 2127
BURNS, K.A. 1672
BURNS, K.A. 1944
BUTTON, D.K. 2057
CALDARONE, E.M. 1920
CALDER, J.A. 1698
CALDWELL, R.S. 1920
CALOMIRIS, J.J. 2061
CAMPBELL, F.J. 1736
CANEVARI, G.P. 1764
CARLUCCI, G.D., JR. 2044
CARR, R.C. 1921
CASEY, S. 2034
CASTELLINI, M.A. 1986
CHABRECK, R.H. 1930
CHADWICK, E. 1765
CHAMBERS, D.B. 1765
CHAPMAN, P.J. 2074
CHEATHAM, D.L. 1724
CHEATHAM, D.L. 1962
CHEEK, L.M. 2102
CHERNYSHOV, V.I. 1682
CHESLER, S.N. 1714
CHESLER, S.N. 1725
CHIEU, J.N. 1814
CHIKAMI, K. 1766
CHIRAC, M. 1896
CHUNG, J.S. 1767
CLARK, B.R. 1706
CLARK, W.S. 2039
CLAYTON, J.W. 1949

NWMAR116937

CLERE, L.T. 1844
COLLINS, A.G. 2035
COLLINS, C. 1673
COLWELL, R.R. 2061
COLWELL, R.R. 2062
CONNORS, P.G. 2015
CONRAD, B.F. 2062
COOK, D.G. 1815
COOK, F.D. 2082
COOK, L. 1897
COOMES, R.M. 2011
COONEY, J.J. 2060
COONEY, J.J. 2069
COOPER, C.K. 2104
CORDIER, M. 1854
CORNELL, C. 1922
CORNER, E.D.S. 1935
COSOVIC, B. 1707
COSOVIC, B. 1726
COWELL, E.B. 1998
CROW, J.H. 1999
CROW, S.A. 2063
CRUSE, H. 1855
DALE, J. 1708
DANIELIANTS, A.A. 1893
DAVIDSON, F.M. 1704
DAVIS, G. 1695
DAVIS, R.W. 1986
DAWE, L.L. 1719
DENEKE, F. 1673
DE PRATER, B.L. 1846
DEUTSCH, M. 1691
DIBBLE, J.T. 2064
DICK, S. 1674
DICKS, B. 1793
DIETZ, A.S. 1923
DONALDSON, E.C. 1863
DOOLITTLE, J.C. 1898
DORRLER, J.S. 1899
EARHART, J.P. 1816
EARHART, J.P. 1817
ELLIOTT, H.A. 2084
ENG, J. 1834
ENGELHARDT, F.R. 1924
ENKE, C.G. 1768
ENVIRON. PROTECTION SERV. 2121
EPA 1692
EPA 1769
EPA 1818
EPA 1900
EREDITARIO, J.M. 1925
ESTES, J.E. 1691
EVEMIN, V.I. 1702
FAGO, E.T., JR. 1674
FAIN, G.D. 1926
FALK, M.R. 2036
FARN, R.J. 1770
FAY, F.H. 2037
FEA 1798
FEA 1799
FEA 1800
FEBEN, J.C. 1796
FEDERLE, T.W. 1980
FINDLEY, J.E. 2065
FONTANA, M. 1985
FOSTER, M.S. 1927
FRIES, B.A. 1819
FRIES, C.R. 1928
FRIEYRO, O. 2066
FUCIK, K.W. 1929
FUKUHARA, O. 1979
GABSCH, K. 1837
GALAYEV, Y.M. 1693
GARRETT, W.D. 1689
GASANOV, M.V. 1820
GASSMANN, G. 1821
GATELLIER, G.C. 1916
GEBHART, J.L. 1930
GERACI, J.R. 1924
GERAGHTY, J.J. 1729
GERARD, F. 2000
GESSER, H.D. 2088
GIBBS, C.F. 2067
GIBSON, D.T. 2068
GILES, R.C. 1931
GLENN, M.C. 1682
GLOVER, R.L. 1847
GLOYNA, E.F. 1814
GLOYNA, E.F. 1871
GONGAWARE, W. 1684
GOODSON, L.H. 1674
GORDON, D.C., JR. 1708
GORNITSKII, A.B. 1778
GORNITSKY, A.B. 1703
GRAHAM, B. 1949
GRAHAM, D.J. 1736
GRAHL-NIELSEN, O. 2093
GRANMO, A. 1932
GREENSHIELDS, J.N. 1765
GRIFFIN, W.M. 2069
GROENEWOUD, W.M. 1802
GRONLUND, W.D. 1938
GROSE, P.L. 2001
GRUGER, E.H., JR. 1933
GRUTSCH, J.F. 1822
GUDASHEVA, V.M. 1823
GUMP, B.H. 1714
GUMP, B.H. 1725
GUNDLACH, E.R. 1656
GUNKEL, W. 1821
HAGIWARA, M. 1824
HAGSTROM, A. 2094
HAGSTROM, B.E. 1934
HALE, L.C. 1825
HARRALD, J.R. 1657
HARRIS, J.O. 1771
HARRIS, R.P. 1915
HARRIS, R.P. 1935
HARRISON, E.A. 2128
HARTMANN, R. 1772
HASLEDON, J.D. 1811
HATER, G.R. 1980
HAWKES, J.W. 1936
HAWKES, J.W. 1938
HAYES, M.O. 1656
HEATH, J.E. 1826
HEIN, M. 1827
HELLMANN, H. 1955
HERSHNER, C.H. 1937
HERTZ, H.S. 1714
HERTZ, H.S. 1725
HILDRETH, R.G. 2109
HIRANO, T. 1858
HIRANO, T. 1859
HIRATA, T. 1787
HOBBS, J.R. 1877
HOCUTT, C.H. 1952
HODGINS, H.O. 1938
HOKETSU, H. 1773
HOKETSU, H. 1828
HOLLAND, W.F. 2039
HOLMES, R.W. 1927
HOROWITZ, A. 2070
HOROWITZ, A. 2071
HOROWITZ, A. 2072
HOULIHAN, T.M. 1675
HOULIHAN, T.M. 1684
HOULIHAN, T.M. 1685
HOVIS, W.A. 1694
HUANG, C.P. 2084

NWMAR116938

HUANG, C.P. 2087
HUDSON, M. 1658
HUFFORD, G.L. 2095
HUFFORD, G.L. 2098
HUGHES, D.E. 2073
HUGHES, P. 1676
HUNDEMANN, A.S. 2129
HUNDEMANN, A.S. 2130
HUNDEMANN, A.S. 2131
HUNDEMANN, A.S. 2132
HUNT, L.L. 2089
HYDE, B. 2055
IGNATIADES, L. 1939
IKEGUCHI, M. 1829
IL'INSKII, V.V. 2080
IMCO 2122
IN'T VELD, C. 1737
IRONS, D.E. 1774
ISHIMARU, E. 1866
IVANENKO, A.P. 1868
IYENGAR, M.S. 1878
JACKSON, J.L. 2134
JACOBS, W.B. 1674
JACOBSON, J.P. 2038
JANSON, D. 1659
JANSON, D. 1660
JEFFREY, P.G. 1775
JEFFRIES, H.P. 1940
JEHL, J.R., JR. 1941
JENKINS, D.M. 1990
JENKINS, R.G. 1679
JENKINS, R.G. 1713
JENKINS, T. 1673
JOHN, C.B. 2021
JOHNSON, L. 1673
JOHNSON, R.E., JR. 1830
JOHNSON, W.C., II 1940
JOHNSTON, M.H. 1957
JOHNSTON, R. 2002
JOHNSTON, R. 2003
JONES, D.C. 2039
JONES, D.R. 1694
JONES, J.A. 1831
JOUVE, P. 1901
KALMYKOV, A.I. 1693
KAWAMORI, M. 1832
KAPLAN, I.R. 1722
KARINEN, J.F. 1953
KARINEN, J.F. 1962
KARINEN, J.F. 1964
KARINEN, J.F. 1975
KATAI, J. 1865
KAUWLING, T.J. 2133
KAWAGUCHI, N. 1833
KAWAKAMI, N. 1829
KAWASE, Y. 1879
KAWASE, Y. 1880
KAYAMA, M. 2106
KEIZER, P.D. 1708
KELLEY, R.F. 2021
KEMPLING, J.C. 1834
KENDRICK, P.J. 1886
KHAIMOVICH, B.N. 1835
KIELI, J. 1836
KIESSER, S.L. 1912
KIFNER, J. 1661
KIFNER, J. 1662
KILVINGTON, C.C. 1935
KINDER, R. 1837
KING, C.J. 1816
KING, C.J. 1817
KING, E.M. 1663
KING, K.I. 1699
KIRILLOVA, L.M. 1820
KISHIMA, T. 1824
KLEINMAN, B. 1664
KLEMAS, V. 1695
KOBLANSKI, J.N. 1838
KOBYZEV, N.P. 1835
KOKOVKINA, T.F. 1864
KOLLBERG, S. 1932
KOOYMAN, G.L. 1986
KOTOV, A.M. 1942
KOTOV, A.M. 1943
KOVACS, A. 2096
KOZARAC, Z. 1707
KOZARAC, Z. 1726
KREBS, C.T. 1944
KUBELKA, V. 1709
KUMITOMO, Y. 1776
KUNZ, D.A. 2074
KUREKIN, A.S. 1693
KUZ, O. 1772
LACAZE, J.-C. 1948
LACKIE, J. 1695
LACY, J.C. 2039
LAKATOS, G. 1865
LANDRY, M.J. 2044
LA POINTE, A.E. 2021
LARRABEE, R.M. 1769
LARSON, D.W. 2056
LARSON, R.A. 2089
LASETER, J.L. 1710
LASETER, J.L. 1717
LAUGHLIN, R.B., JR. 1945
LAWRENCE BERKELEY LAB. 1677
LEBEDEVA, E.S. 1682
LE BLANC, L. 1665
LEE, D.R. 1946
LEE, R.F. 1947
LEE, R.F. 2097
LEE, W.T. 1711
LEGENDRE, M.C. 1710
LEIBOVICH, S. 1738
LEITZELL, T.L. 1902
LEMENTA, Y.A. 1693
LE PEMP, X. 1948
LICHTENTHALER, R. 1728
LINDSAY, R.C. 1712
LI, W.K.W. 1958
LISSAUER, I.M. 2095
LISSAUER, I.M. 2098
LOBOV, L.I. 1702
LOCK, J. 1839
LOCKHART, W.L. 1949
LOGAN, W.J. 1905
LONNING, S. 1934
LOYA, Y. 1950
LUKAS, L.A. 1721
LUKMANOV, YU.KH. 1781
LUMPKINS, R.J. 1813
LUZAK, J. 2006
LYNCH, M.P. 2038
LYNCH, W.M. 1845
LYSYJ, I. 1840
LYTLE, J.S. 1678
LYTLE, T.F. 1678
MAC ARTHUR, G.P.S. 2012
MAC LEOD, W.D. 1679
MAC LEOD, W.D., JR. 1713
MADSEN, O.S. 2104
MAKAROVA, G.D. 2092
MAKI, H. 1866
MALESZEWSKA, J. 2006
MALINA, J.F., JR. 1871
MALINS, D.C. 1951
MALINS, D.C. 2076
MALLATT, R.C. 1822
MALLON, M.H. 1920
MANNING, F.S. 1863

NWMAR116939

MANOWITZ, B. 2042
MAPCO, INC. 1841
MAR. POLLUTION INFO. CENTRE 2004
MASNIK, M.T. 1952
MASUDA, M. 1859
MATTSON, J.S. 2001
MAY, W.E. 1714
MAY, W.E. 1725
MAYER, A.J. 1801
MC AULIFFE, C.D. 2085
MC AULIFFE, C.D. 2099
MC CARTNEY, J.K. 1881
MC CORMACK, M.M. 2040
MC CORMICK, J.H. 2127
MC DERMOTT-EHRLICH, D. 2041
MC DONALD, S. 2075
MC FADDEN, T. 1673
MC GRATH, F.K. 1675
MEARNS, A.J. 2133
MECKLENBURG, T.A. 1953
MECKLENBURG, T.A. 1962
MEURER, R.W. 2021
MICHAEL, A.D. 2005
MIGHELL, J.L. 1938
MIKHALEVA, I.M. 2107
MIKSCH, K. 1842
MILKOWSKA-JANKOWSKA, D. 2006
MILLER, D.W. 1729
MILLER, J.C., JR. 2044
MILLER, M.C. 1980
MIMICOS, N. 1939
MINCHEW, C.D. 1954
MIRANDA, J.G. 1843
MIRONOV, O.G. 1715
MIRONOV, O.G. 2083
MISCH, C.J. 1962
MITERA, J. 1709
MIX, M.C. 1699
MOE, P.G. 1847
MOHLER, E.F., JR. 1844
MOLES, D.A. 1962
MONASTERO, F.C. 2043
MONGAIT, I.L. 1823
MOORE, G. 2115
MOORE, K.A. 1937
MOORE, L.J. 1912
MOREAU, J.O. 1680
MORGAN, J.E. 1845
MORI, M. 1824
MORRIS, S.C. 2007
MOSS, M.R. 1995
MOSTECKY, J. 1709
MOTOMURA, H. 1856
MOULDER, D.S. 2136
MUELLER,D. 1955
MUMPHREY, A.J., JR. 2044
MURATA, K. 1777
MURRAY, D. 1949
MURRELL, K.R. 1810
MURZAKAEV, F.G. 1903
MYERS, L.H. 1846
NAGATA, Y. 1829
NAGY, A. 1865
NAKAGAKI, H. 1829
NAKAI, S. 1824
NAKARAI, K. 1776
NAMMINGA, H.E. 1681
NATHWANI, J.S. 2100
NAT. RESOUR. DEF. COUNCIL 2046
NEAL, D.M. 1847
NEFF, J.W. 1929
NEFF, J.M. 1945
NEIHEISEL, T.W. 2127
NELEPO, B.A. 1693
NELSON-SMITH, A. 1794
NEMIROVSKAYA, I.A. 1703
NEMIROVSKAYA, I.A. 1716
NEMIROVSKAYA, I.A. 1778
NEPPELBERG, T. 2093
NESTEROVA, M.P. 1703
NEWMAN, D.E. 1739
NIELSEN, E.C. 1740
NOAA 2013
NOAA 2014
NOAA 2045
NOEL, R.A. 1779
NORRELL, S.A. 1957
NOTINI, M. 1956
NOVAK, J. 1709
OBARA, G. 1848
OBARA, G. 1849
OFFICE TECHNOL. ASSESSMENT 2048
OFFICE TECHNOL. ASSESSMENT 2047
O'HARA, S.C. 1915
O'HARA, S.C.M. 1935
OKHORI, K. 1780
OKUMURA, M. 1850
OKUMURA, M. 1851
ONO, H. 1776
ONO, H. 1829
OSHIDA, P.S. 2133
OSOSKOV, V.K. 1784
OVERTON, E.B. 1717
PALMORK, K.H. 2093
PARSONS, T.R. 1958
PAUL, A.J. 2102
PAUS, P.E. 1728
PAYNE, J.F. 1959
PAYNE, J.L. 1883
PEAKE, E. 1718
PEARCE, J.B. 2049
PELEVIN, L.A. 1781
PELTON, P.M. 1845
PENROSE, W.R. 1719
PERCY, J.A. 1960
PERES, J.M. 1961
PETERS, H.H. 1806
PETROV, Y.M. 1981
PFAENDER, F.K. 1925
PFEFFER, F.M. 1846
PHILLIPS, C.R. 2100
POLLACK, A.M. 2104
POLOVINKO, V.V. 1702
POLOVINKO, V.V. 1720
PONOMAREV, V.G. 1823
PORTE, P. 1782
PORTMANN, J.E. 2116
POTAPOV, M.P. 1721
POZDNYSHEV, G.N. 1781
POZDNYSHEV, G.N. 1852
PRAUSNITZ, J.M. 1816
PRAUSNITZ, J.M. 1817
PREUS, P. 1853
PRONK, A.C. 1696
PUGH, K.B. 2067
QUENTIN, K.E. 1870
RADIAN CORP. 2050
RAMOS, L.S. 1713
READ, C.M. 1904
REED, W.E. 1722
REISH, D.J. 1921
REISH, D.J. 2133
RENAULT, P. 1916
RICCI, G.C. 2008
RICE, S.D. 1724
RICE, S.D. 1953
RICE, S.D. 1962
RICE, S.D. 1963
RICE, S.D. 1964
RILEY, R.T. 1699

NWMAR116940

RISEBROUGH, R.W. 2015
ROBE, K. 1860
ROBERTS, D. 1965
ROBERTSON, B.R. 2057
ROBISCH, P.A. 1933
ROBISCH, P.A. 1936
ROGERS, J. 1783
ROGIER, P. 1663
ROLAND, W. 1905
ROSEN, A.A. 1723
ROSENBERG, D.M. 1966
ROSS, S.L. 1905
ROSSI, S.S. 2133
ROUBAL, G. 2077
ROVEL, J.M. 1854
RUDIGER, C.E., JR. 1767
RUSSELL, E.C. 1840
SACKETT, W.M. 1671
SAETHER, O.A. 1966
SAIDA, T. 1776
SAKAGUCHI, S. 1979
SAKAKI, K. 1858
SAKAKI, K. 1859
SANDBROOK, R. 2125
SANJOUR, W. 1855
SATO, T. 1856
SAWYER, W.M. 1826
SCHAFFER, R.L. 1699
SCHAMEL, D. 2016
SCHECHTER, R.S. 1814
SCHEIBLA, S. 2110
SCHINDEL, G.W. 1857
SEESMAN, P.A. 2062
SETHNESS, E.D. 2039
SHAW, D.G. 1700
SHAW, D.G. 2101
SHAW, D.G. 2102
SHCHEKATURINA, T.L. 1715
SHCHEPANYUK, V.YU. 1668
SHECHTER, R.S. 1871
SHELTON, R.G.T. 2009
SHEPPARD, W.J. 1990
SHEPPARD, W. 2019
SHIBATA, H. 1833
SHINDLER, D.B. 1919
SHISHIDO, N. 1858
SHISHIDO, N. 1859
SHMELEV, M.V. 1852
SHORT, J.W. 1724
SHORT, J.W. 1962
SHORT, J.W. 1963
SHORT, J.W. 1964
SHORT, T.E., JR. 1846
SIMONOV, A.I. 1682
SKAKUN, T.O. 2080
SKOCYPEC, R.J. 2126
SKRYLEV, L.D. 1784
SKRYLEV, L.D. 1864
SKUJINS, J. 2075
SMAYDA, T.J. 1967
SMITH, A.W. 1860
SMITH, C.L. 2103
SMITH, D.C. 1792
SMITH, J.L. 1672
SMITH, J.O. 2134
SMITH, M.F. 2135
SMITH, T.G. 1924
SNYDER, H.L. 2051
SOC. GEN. CONS. ELEC. MEC. A. 1765
SONE, T. 1787
SORKIN, YA.G. 1861
SPEER, L. 1684
SPEHAR, R.L. 2127
SPIELMAN, L.A. 1862
STAFFORD, S. 2073
STAINKEN, D. 1968
STAMOCIDIS, V.C. 2091
STANG, P.R. 2055
STAUFFER, J.R. 1952
STEELE, R.L. 1969
STEELE, R.L. 1970
STEPHAN, C.E. 2127
STIZELCZYK, W. 1872
STOERMER, F.C. 2078
STOKES, G.N. 2127
STOLZENBACH, K.D. 2104
STOVALL, L.F. 1786
STRAUGHAN, D. 1971
STRONG, A.E. 1691
STRUHSAKER, J.W. 1972
SUBAEVA, R.M. 1820
SUKAI, K. 1850
SUKAI, K. 1851
SUKHOVERKHOVA, N.A. 1868
SU, Y.P. 1862
SUTTERFIELD, F.D. 1863
SUTTON, E.A. 1704
SVIRIDOV, V.V. 1864
SZABO, J. 1865
SZARO, R.C. 1973
TAKAHASHI, R. 1787
TAKEDA, N. 1866
TAKUEV, YU.S. 1682
TANIGUCHI, Y. 1856
TARATUNIN, A.F. 1835
TATEM, H.E. 1974
TAYLOR, T.L. 1975
TEAL, J.M. 1976
TEDESCHI, E.T. 1741
THOMAS, M.L.H. 1977
THOMAS, R.E. 1963
THOMAS, S.J. 2136
THOMPSON, B.D. 2095
THOMPSON, G.B. 1666
THYRUM, P.T. 1683
TITLOW, E.T. 1881
TOKAR, M. 1865
TOKUDA, H. 1978
TOLOKONNIKOVA, L.I. 2092
TOMITA, Y. 1867
TORNATORE, G. 1695
TOWNSLEY, P.M. 2079
TRENHOLM, S.R. 1699
TRIPP, M.R. 1928
TSNBAN, A.V. 2080
TSUCHIYA, H. 1858
TSUCHIYA, H. 1859
TSUNOI, I. 1788
TSYBAN, A.V. 2107
TUOMINEN, T. 1923
TYLER, B. 1684
TYLER, B.D. 1685
UMEZAWA, S. 1979
USCG 2111
USCG 2112
USCG 2113
USCG 2114
US LIBRARY OF CONGRESS 2052
VAN BAALEN, C. 1914
VAN DER WAARDEN, A. 1802
VANHOOZIER, J.M. 1897
VAN KUILENBURG, J. 1697
VAN LOPIK, J.R. 2053
VASILENKO, I.I. 1868
VESTAL, J.R. 1980
VILLEDON DE NAIDE, O. 1948
VOKYO, Y.V. 1981
VON OERTZEN, J.A. 1982
VON PREEN, W. 1869
VSHIVTSEV, V.G. 1864

NWMAR116941

WADHAMS, P. 2086
WAGATSUMA, T. 1776
WAGEMANN, R. 1949
WAGNER, F.W. 2044
WAKEHAM, S.G. 1730
WALKER, B. 1765
WALKER, J.D. 2061
WALKER, J.D. 2062
WALL, C.J. 1812
WALTER, R.A. 1877
WANG, H. 2087
WARD, D.M. 2081
WARD, J.M. 1761
WARD, R.S. 1789
WARDLEY-SMITH, J. 1731
WARDLEY-SMITH, J. 1790
WARDLEY-SMITH, J. 1791
WARDLEY-SMITH, J. 1887
WARDLEY-SMITH, J. 1906
WARDLEY-SMITH, J. 1907
WARDLEY-SMITH, J. 2010
WARDLEY-SMITH, J. 2105
WATERS, R. 1958
WEIL, L. 1870
WEISBERG, E. 1855
WEKELL, M.M. 1933
WELLER, G. 2054
WELSH, J.P. 2095
WELSH, J.P. 2096
WESTLAKE, D.W.S. 2082
WESTRHEIM, K. 2093
WHELAN, W. 1695
WHITE, J. 1991
WIENS, A.P. 1966
WILDUNG, R.E. 1704
WILHELMSEN, S. 2093
WILHM, J. 1681
WILLIAMS, A.S. 1792
WILLIAMS, D.C. 2055
WILLIAMS, H.D. 1908
WILSON, J.H. 1952
WILSON, K.W. 1983
WINTERS, K. 1914
WISE, S.A. 1714
WISE, S.A. 1725
WON, K.W. 1816
WON, K.W. 1817
WONG, H.Y. 1817
WOODRUFF, D.L. 1912
WU, C.J. 1871
YAMADA, H. 2106
YANG, W.C. 2087
YARBROUGH, J.D. 1954
YEN, T.F. 2065
YEVICH, P.P. 1984
YOUNG, H.A. 1686
YOUNT, J.D. 2017
YUDITSKII, F.L. 1909
ZAGORSKI, K. 1872
ZINGULA, R.P. 2056
ZUBAKINA, A.N. 2107
ZUBEKINA, A.N. 2080
ZUTIC, V. 1707
ZUTIC, V. 1726
ZVONARIC, T. 1707

NWMAR116942

APPENDIX

Periodicals Reviewed

Alternatives: Perspectives on Society and Environment
Ambio
American Fisheries Society Transactions
Applied Ecology Abstracts
Applied Energy
Applied Microbiology
Applied Science & Technology Index
Aquatic Sciences & Fisheries Abstracts
Audubon
Australian Science Index
Berichte der Deutschen Wissenschaftlichen Komission fuer Meeresforschung
Biological Abstracts
Bioscience
British Birds
Bulletin of Environmental Contamination and Toxicology
Chemical Abstracts
Chemical and Engineering News
Chemical Engineering
Chemical Engineering Progress
Chemical Week
Chemistry in Canada
Chemosphere
Current Contents: Life Sciences
Current Contents: Physical and Chemical Sciences
Deep-Sea Research
Ecolibrium
Ecological Abstracts
Ecological Modelling
Ecology Law Quarterly
Energy Information Abstracts
Energy Review
Environment
Environment Abstracts
Environmental Action
Environmental Conservation
Environmental Geology
Environmental Health and Pollution Control
Environmental Periodicals Bibliography
Environmental Pollution
Environmental Science & Technology
Environmental Technology and Economics
EPA Reports Bibliography Quarterly
ERDA Energy Research Abstracts
Erdoel und Kohle Erdgas Petrochemie vereinigt mit Brennstoffchemie
Estuarine and Coastal Marine Science
Fuel Abstracts and Current Titles
Government Reports Announcements

NWMAR116943

Hydrocarbon Processing
IMS Newsletter
India Journal of Environmental Health
Industrial Wastes Information Bulletin
International Aerospace Abstracts
International Journal of Ecology and Environmental Science
International Journal of Environmental Analytical Chemistry
International Petroleum Abstracts
Iranian Journal of Science and Technology
Journal of Canadian Petroleum Technology
Journal of Chromatography
Journal of Environmental Science and Health
Journal of Environmental Sciences
Journal of Petroleum Technology
Journal of the Fisheries Research Board of Canada
Journal of Toxicology and Environmental Health
Limnology and Oceanography
Marine Biological Association of the United Kingdom, Journal
Marine Biology
Marine Chemistry
Marine Fisheries Review
Marine Geology
Marine Geotechnology
Marine Policy
Marine Pollution Bulletin
Marine Science Contents Tables
Marine Technology Society, Journal
Maritime Research Information Service Abstracts
Massachusetts Audubon
Microbial Ecology
National Fisherman
National Research Council, News Report
National Wildlife
Nature
New Technical Books
Nippon Susan Gakkai Shi. Bulletin of the Japanese Society of Scientific Fisheries
Ocean Engineering
Ocean Industry
Ocean Management
Oceanic Abstracts
Oceanus
Offshore
Oil and Gas Journal
Outdoor California
Pacific Oil World
Petroleum Abstracts
Petroleum Engineer International
Petroleum Today
Pollution Abstracts
Pollution Engineering
Proceedings in Print

NWMAR116944

Resources
Resource Recovery and Conservation
Royal Society of London, Proceedings, Series B, Biological Sciences
Science
Science News
Science of the Total Environment
Scientific and Technical Aerospace Reports
Sea Frontiers
Sea Secrets
Sea Technology
Selected References on Environmental Quality
Selected Water Resources Abstracts
Technical Book Review
The Ecologist
The Engineering Index
The Sciences
UDS Water Quality Control Digest
Underwater Information Bulletin
Underwater Naturalist
Water, Air, and Soil Pollution
Water Pollution Control
Water Pollution Control Federation, Journal
Water Research
WRC Information
Western Fisheries

NWMAR116945

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-78-005		

4. TITLE AND SUBTITLE	5. REPORT DATE
OIL SPILL AND OIL POLLUTION REPORTS August 1977 - October 1977	January 1978 issuing date
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Penelope Melvin, Helmut Ehrenspeck, Elizabeth Sorenson	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Marine Science Institute University of California Santa Barbara, California 93106	1NE623
	11. CONTRACT/GRANT NO.
	R-805052-01
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Industrial Environmental Research Laboratory--Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	Quarterly, Aug-Oct., 1977
	14. SPONSORING AGENCY CODE
	EPA/600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The August 1977 - October 1977 issue of Oil Spill and Oil Pollution Reports is a quarterly compilation of oil pollution publications and ongoing project summaries. Presented in the report are: (a) summaries and citations of published literature and patents; (b) summaries and status of current research projects; and (c) current oil-related conferences. This report is submitted in partial fultillment of EPA Grant No. R-805052-01 by the Marine Science Institute, University of California, Santa Barbara, under the sponsorship of the Environmental Protection Agency.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Bibliographies *Abstracts *Patents *Documents *Research	Oil pollution Oil spill events Oil spill research Oil pollution control Oil pollution patents	13B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
	UNCLASSIFIED	291
RELEASE TO PUBLIC	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

☆ U S. GOVERNMENT PRINTING OFFICE: 1978-757-140/6695 Region No. 5-11

NWMAR116946

U.S. Environmental Protection Agency
Industrial Environmental Research Laboratory
Edison, New Jersey 08817

We are requesting your assistance upon receiving this report ("Oil Spill and Oil Pollution Reports, August 1977 - October 1977").

Is the information usable?
Is the format helpful?

We invite your comments and suggestions. Thank you.

cut here

Name_____

Organization_____

Address_____

NWMAR116947

affix
stamp

Mr. J. S. Dorrler
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Edison, New Jersey 08817

NWMAR116948

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Environmental Research Information Center
Cincinnati, Ohio 45268

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300
AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
U S ENVIRONMENTAL PROTECTION AGENCY
EPA-335

Special Fourth-Class Rate
Book

NWMAR116950

012500016

MS L TILLEY
REGION V LIBRARY
USEPA
230 SOUTH DEARBORN
CHICAGO, IL 60604

If your address is incorrect, please change on the above label tear off, and return to the above address.
If you do not desire to continue receiving these technical reports, CHECK HERE ☐, tear off label, and return it to the above address,

EPA-600/2-78-005