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43538

PRELIMINARY ASSESSMENT

DATE : May 20, 1990

Prepared by: Patrick Molloy, Health Physicist, Navajo Superfund Office

Site : Navajo - Brown Vandever Uranium Mine

EPA ID # : Not assigned

SITE INFORMATION

Site Location. The Brown Vandever Uranium Mine (Brown Uranium Mine, sic)is located approximately 4 miles east of Prewitt, New Mexico. The site is also located approximately 20 miles north-northwest of Grants, New Mexico (figure# 1). The site may be found by proceeding east from the Prewitt, New Mexico post office on the Interstate 40 frontage road approximately 1 mile and subsequently traveling east on an improved dirtroad for approximately 5 miles (figure #2). The road turns north at the eastern edge of Haystack mountain, a prominent geological feature in the area. The site is located on the southeastern margin of Haystack mountain approximately 1 mile north of El Tintero cinder cone (figure #2). The Geographic coordinates for the site are 35° 21' 02" N latitude and 107°56'25" W longitude (7).

The mine is located on an expired mining claim of approximately ¼ section in area. Approximately 65 persons, including small childern live on-site in a semi-agricultural rural setting (3,4; worksheet #2, 7). Two inclined adits, an almost vertical timbered shaft, two vertical ventilation shafts and a strip mine covering approximately 100 acres are notable features of the abandoned claim (3; Frames).

OWNER AND OPERATOR. The Brown Vandever Mine is currently owned, and was owned throughout its history by the Navajo Nation (17). The land is held in trust for the Navajo Nation by the Federal Government through the authority of the Bureau of Indian Affairs (BIA).

The primary lease holders for the claim were variously; Williams and Thompson (full names not found) and Mr. Brown Vandever (2;pg 1-276, 3-5). The site was presumably subleased to the various operators (2; page 3-5). Several other mines are to be found in the area the most notable being the Haystack 2 mine (11). The lease is currently owned by the Navajo Nation (17).

PURPOSE OF INVESTIGATION The Brown Vandever Uranium Mine was reported to be a potentially contaminated waste site by the Navajo Superfund office field reconnaissance team in 1990 (1).

SITE HISTORY The Brown Vandever Uranium Mine is located in the Ambrosia Lake sub-district of the Grants Mining District (7,10). No Historical record for naturally occuring radiation levels for the area has survived until the present. Two inclined adits were driven north-northwestward into the dip of the Todilto formation (3;frame #12, figure #4). These inclines were reported to be approximately 300 ft. deep (14; page #6, direct quote): additionally, two 400 yd. drifts were driven into the ore bodies associated with the incline in Frame #12 (14; page #2).

A timbered shaft inclined at approximately 10° from the vertical, was driven into the dip of the Todilto formation approximately 1000 ft. west of the inclined adits (3; frame #33). This shaft was reported to be approximately 300 ft. deep (14; page #6): drifts were also excavated northwest and northeast from the shaft.

Two, two-foot diameter vertical shafts were excavated between the inclined adits and the timbered shaft in order to provide ventilation for the mining operation (3; frame #33); the ventilation shafts were reported to be approximately 300 ft. deep (Mr. Brown Vandever, personal communication, April 11, 1990).

The area south of the inclined adits has been extensively strip-mined: The area of surface disturbances has been estimated to be approximately 100 acres in extent (4; page # 8, Figure #2). Tailings associated with the N. and B. Vandever Mines were used to "pave" a road leading to the N. Vandever works.

It is presumed that the mining operation was carried out using conventional mining techniques; Due to the extensive and elaborate nature of the surface works and adits (shafts), it is unlikely that manual labor was utilized to any great degree. A powerline extension which was used to provide electricity for an air compressor still exists on site.

The Brown Vandever Uranium Mine was operated intermitently over the period of years from 1952 until 1966 (2). Santa Fe Uranium, Federal Uranium Mesa Mining Co. and Cibola Mining Co. were some of the mining interests involved: Other individuals operated the mine (2).

Mining operations at the site produced 25,796 tons of ore rich in Uranium (U_3O_8,0.) 0.19% grade) and Vanadium (V_2O_5, 0.30% grade). A total of 98,175 lbs of U_3O_8 and 75,342 lbs of V_2O_5 were milled from the raw production tonnage (2, pg# 1-276, 3-5).

It is presumed that the ore was transported to Shiprock, New Mexico or Durango, Colorado for milling. However, no record of where the milling took place was found: It is not known whether the Phillips Petroleum Ambrosia mill was in operation during the time the ore was being produced.

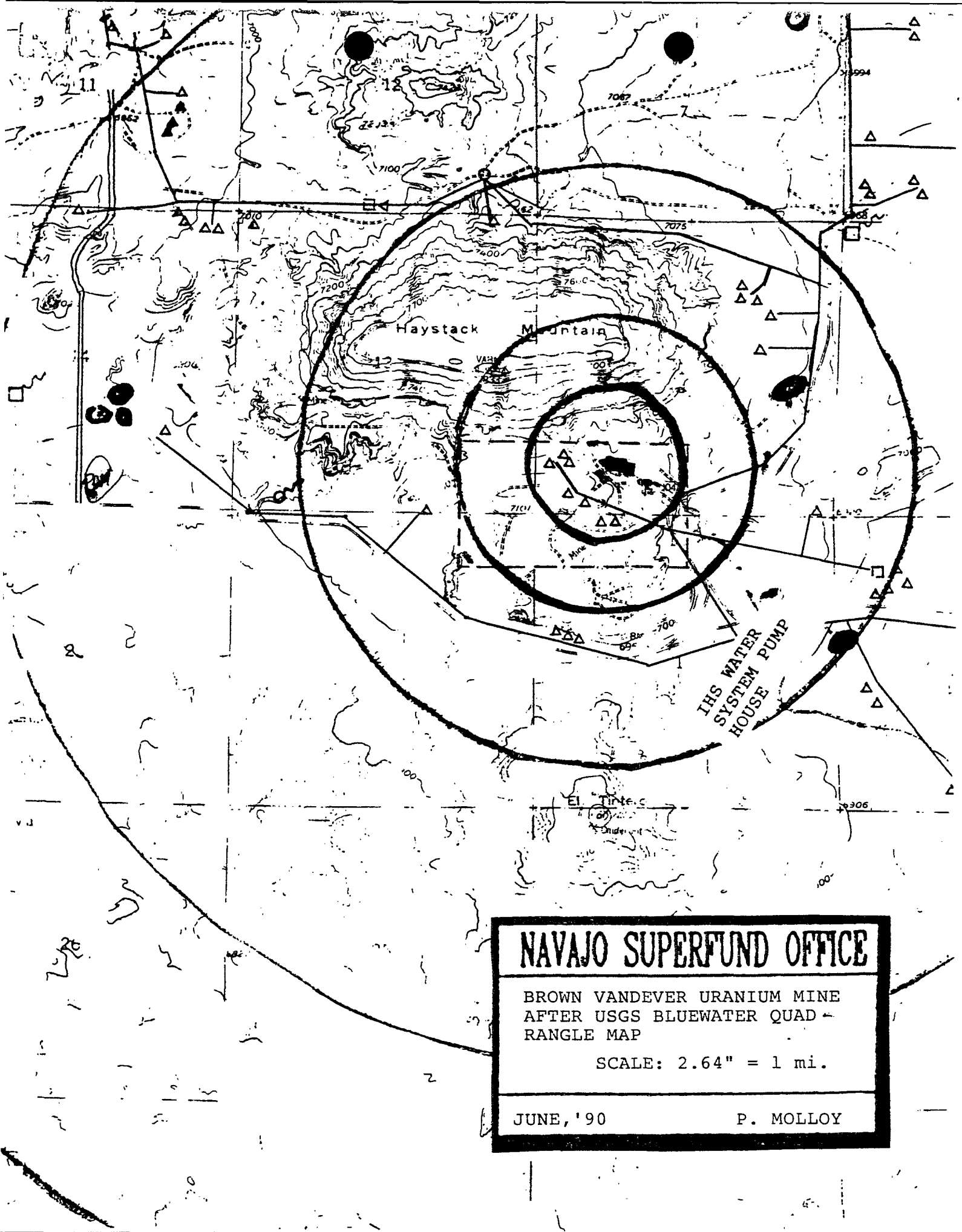
DISSCUSSION OF KNOWN/POTENTIAL PROBLEMS During a windshield survey of the site and environs, in order to ascertain population, population distribution, water usage patterns and area radiometric background

FIGURE # 1 ; REPRINTED BY PERMISSION

NAVAJO SUPERFUND OFFICE

NAVAJO-BROWN VANDEVER URANIUM MINE

JUNE,'90 P. MOLLOY



NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE
AFTER USGS BLUEWATER QUAD-
RANGLE MAP

SCALE: 2.64" = 1 mi.

JUNE,'90 P. MOLLOY

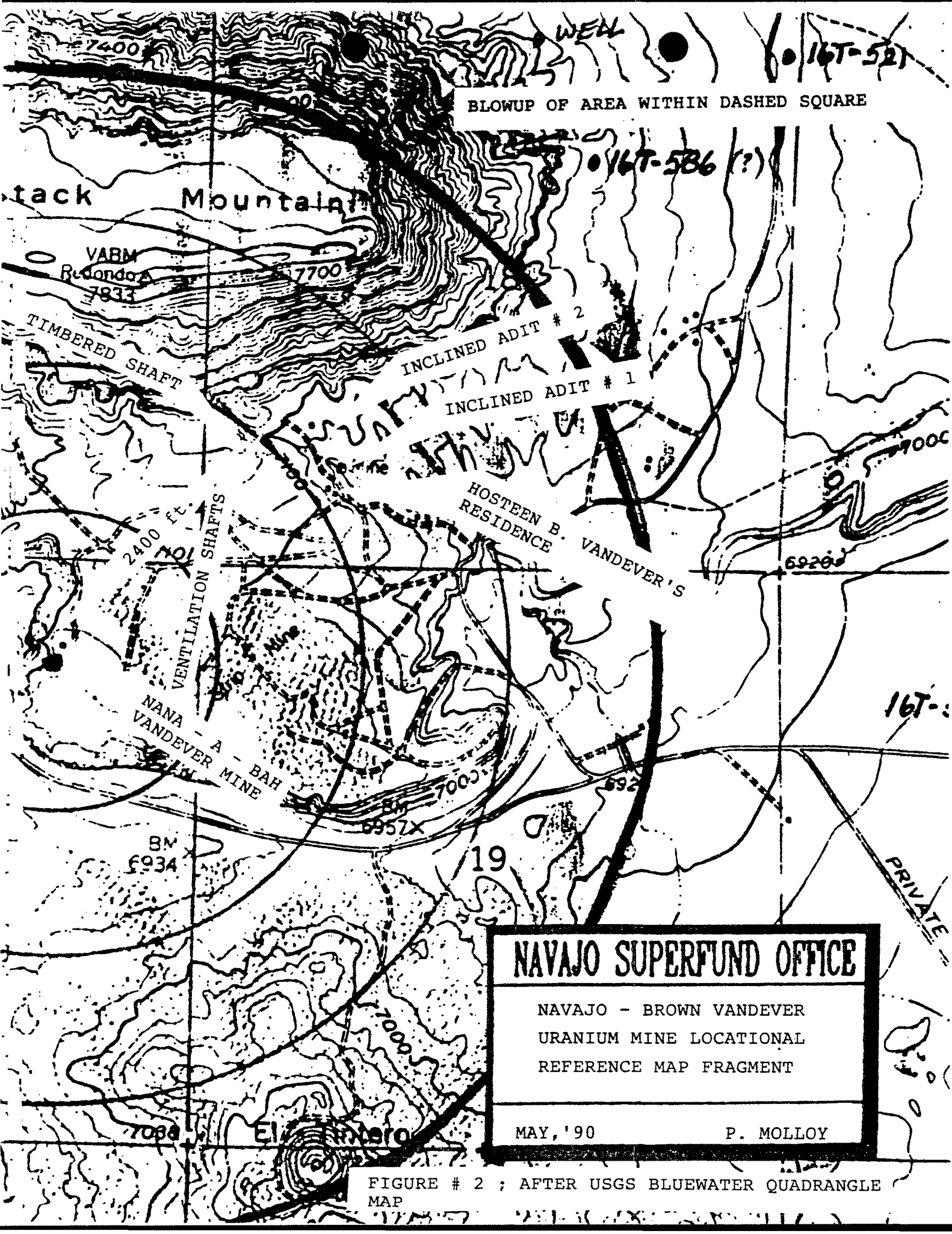
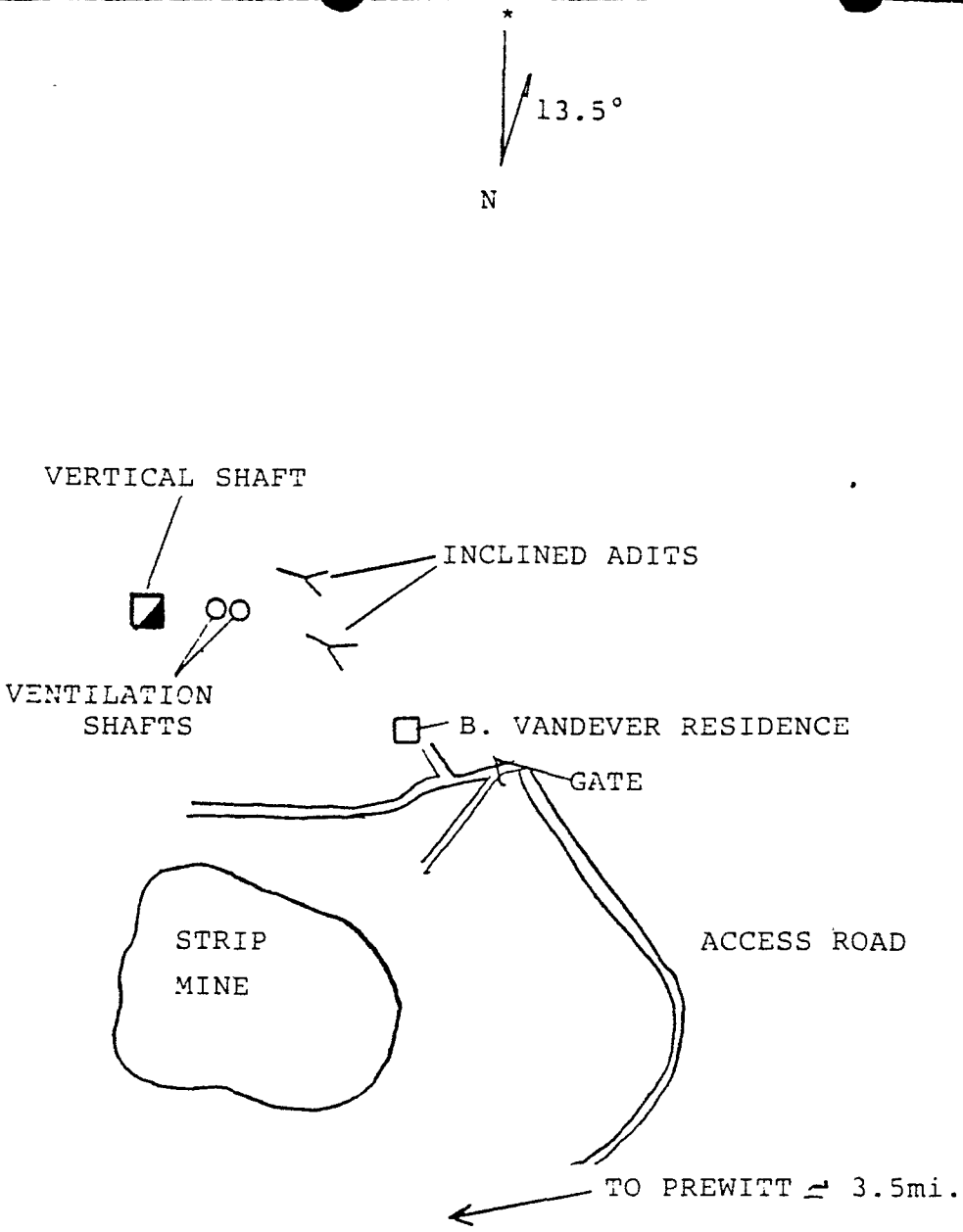


FIGURE # 2 ; AFTER USGS BLUEWATER QUADRANGLE MAP



SCALE - 1" ≃ 1418 ft.

FIGURE # 4 ; SITE SKETCH

NAVAJO SUPERFUND OFFICE

NAVAJO-BROWN VANDEVER URANIUM MINE SITE SKETCH

JUNE,'90 P. MOLLOY

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 10:20am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 20°/ENE

FILM TYPE POLAROID **FRAME NO.** 5

DATA TAKEN WITH PHOTOGRAPH: NONE

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey ( )
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

5TH FC

7. DESCRIPTION HAYSTACK BUTTE, REFERENT, LOOKING E OF ENE

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

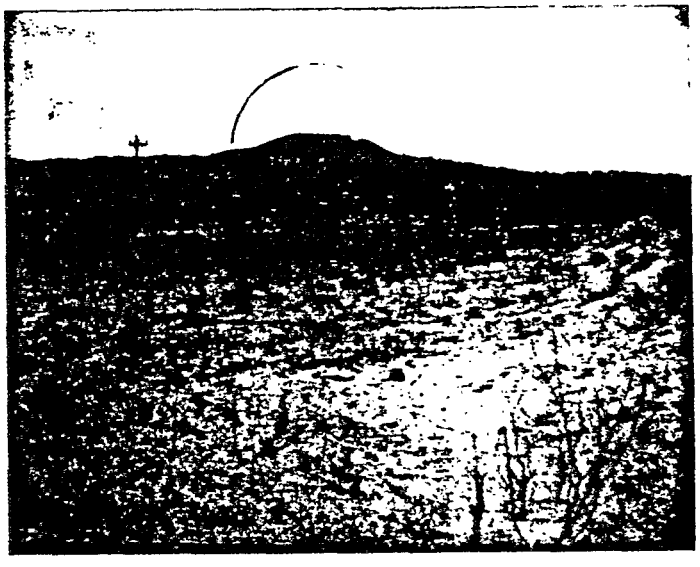
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 270°/S

FILM TYPE POLAROID **FRAME NO.** 20'

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey ( )
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



270° FR. (EL TINTERO CINDER CONE, REF. 1

7. DESCRIPTION EL TINTERO CINDER CONE REFERENT, LOOKING S

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 20°/ENE

FILM TYPE POLAROID **FRAME NO.** 7

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: LUDLUM#19-24uR.hr^{-1} :: ESP-II - $2.2(10^4)$ BACKGROUND @ B VANDEVER
5. Deep Well Water Sample ( )
6. Photograph Below: YES

TH FIR.

7. **DESCRIPTION** TRENCH CUT NNE OF B. VANDEVER RESIDENCE, LOOKING NE. NOTE FRAMES 8, 9, 10 TAKEN AT SAME LOCATION

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 10°/N OF NNE

FILM TYPE POLAROID **FRAME NO.** 15

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading: 350uR.hr^{-1}(LUDLUM#19) : @ EDGE OF "LOADING BAY"
5. Deep Well Water Sample ( )
6. Photograph Below: YES

15TH FR.

7. DESCRIPTION TRENCH AT CENTER MIDDLEGROUND IS ORE "LOADING BAY", LOOKING N OF NNE

levels, the following observations were made;

* The population distribution is closely correlated with the Indian Health Service (IHS) water system (tautological).

* Several windmills in the area are no longer in service. At least one windmill shows infrequent use (18; pg #1).

* There are 7 residences on site: not all these residences are connected to the IHS water system.

* The old haulage road (for ore transport) is plainly visible and shows definite erosion: The road that obtains access to the site was at one time the haulage road. There is radiometric evidence that contaminants are migrating off site (18, pg #2).

* A drainage which trends east from the site exhibits radiometric readings consistent with contaminant transport/migration.

* The onsite haulage road was "paved" with mine tailings and provides a receptacle for mechanical transport of contaminants. An Eberline Gamma Ratemeter registered 10^5 cpm at the edge of the road (3; frame #22, 14; page #4) There is radiometric evidence of mechanical (eg, vehicle) transport of contaminants approximately 2 mi. from the site environs via the haulage road (18; page #2)

* The timbered shaft retains a shack at its mouth, however, access to the shaft can easily be gained by removing a wire grate covering the portal (3: Frame #33). Additionally, the shaft "aspirates" under certain meteorological conditions, contributing to the area Radon burden.

* The vertical ventilation shafts are poorly capped and young children in the area could easily gain access to the excavations (3; Frame #33).

* One inclined adit is used for waste disposal (3; Frame #12).

* Small quantities of ore grade material are to be found almost anywhere on site.

* Approximately 1880 tons of tailings materials are presently onsite. The material is uncovered and accessible (3.; Frames #8, #13, #15, #19, Frames #25 through #32).

* The Navajo Superfund Office FIT digilert alerted (enabled) inside the vehicle being used for reconnaissance at one point along the "Hot Road" (3; Frame #22): enable/alert on the device is set at .098 mR.hr-1.

Tailings material, the inclined adits and the timbered shaft are suspected of producing a leachate rich in toxic heavy metals and radioactive contaminants (4,11,23). Radiometric readings taken during

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 180°/W

FILM TYPE POLAROID **FRAME NO.** 16'

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: SEE BELOW IN DESCRIPTION
5. Deep Well Water Sample ( )
6. Photograph Below: YES , EXTRA FRAME

16TH FR.
MOUTH OF DRAINAGE

7. **DESCRIPTION** MOUTH OF DRAINAGE. TAILINGS PILE ON RIGHT, ESP-II READINGS: @MOUTH - $5(10^4)$; @MIDWAY PAST TAILING. - $6.5(10^4)$; @END OF TAILINGS - $3.25(10^4)$; ALL READINGS IN cpm., LOOKING W

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 0°/E

FILM TYPE POLAROID **FRAME NO.** 22

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading: 10^5cpm(ESP-II) @ EDGE OF ROAD
5. Deep Well Water Sample ( )
6. Photograph Below: YES

22

7. **DESCRIPTION** "HOT ROAD" WEST OF B. V. RESIDENCES, SURFACE WORKS WASTE PILES @ RIGHT MIDDLEGROUND, MT. TAYLOR @ UPPER LEFT BACKGROUND AS REFERENT

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** ~~NOT ASSIGNED~~

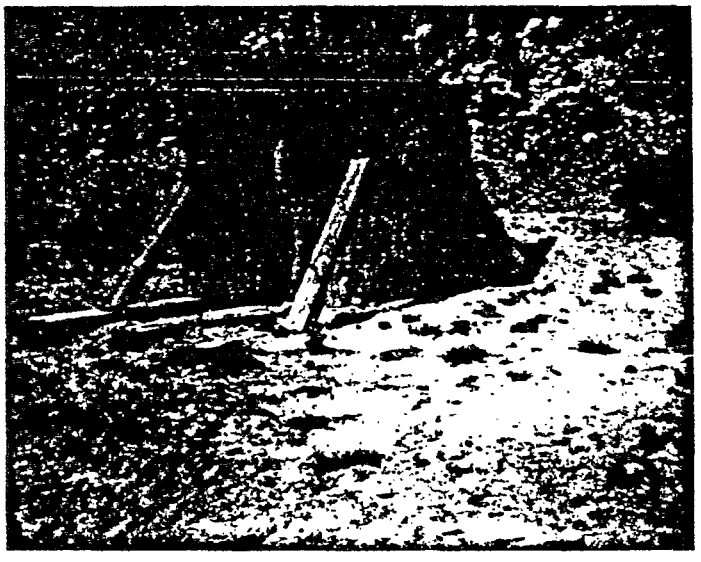
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 135° NW

FILM TYPE POLAROID **FRAME NO.** 33

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading: 10uR.hr^{-1}(LUDLUM#19), 10^4cpm(ESP-II) @ WEST FACE OF SHACK
5. Deep Well Water Sample ( )
6. Photograph Below: YES



33 ER.

7. DESCRIPTION B. VANDEVER TIMBERED SHAFT, SHAFT AT AN INCLINATION OF 10° FROM VERTICAL. CIRCULAR APERTURE ON S FACING WALL IS WIRED OVER BUT WIRE IS EASILY REMOVED, SHAFT ASPIRATES, "300 FT. DEEP" B. V. TO P. MOLLOY, APRIL 11,1990

PLM

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 250° WNW

FILM TYPE POLAROID **FRAME NO.** 33

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

33rd FR.
(VENT. SH. VERTICAL !)

7. **DESCRIPTION** VERTICAL VENTILATION SHAFTS(2), HOSTEEN BROWN VANDEVER AT RIGHT MIDDLEGROUND. SHAFTS "300 FT. DEEP" - B. V. TO P. MOLLOY, APRIL 11,1990, LOOK-WNW

PCH

NAVAJO [illegible]

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** [illegible]°/NNW

FILM TYPE POLAROID **FRAME NO.** 12

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: LUDLUM-19 - 21uR.hr^{-1} : @ FACE OF ADIT
5. Deep Well Water Sample ( )
6. Photograph Below: YES

ADIT

7. DESCRIPTION INCLINED ADIT N OF B. VANDEVER RESIDENCE, LOOKING NNW

NAVAJO SUPERFUND DEPARTMENT

PIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

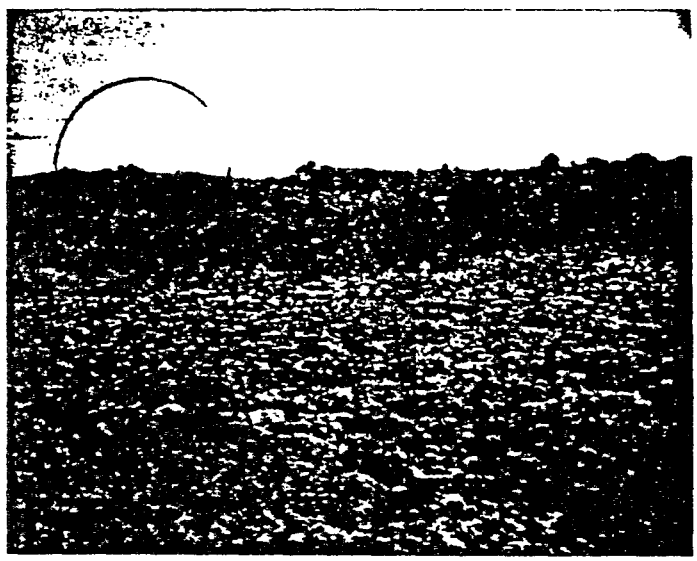
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 350° E OF ESE

FILM TYPE POLAROID **FRAME NO.** 26

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



26 TH FR

7. **DESCRIPTION** SURFACE WORKS WSW OF B. V. RES., LOOKING E OF ESE; NOTE MT. TAYLOR IN FAR LEFT BACKGROUND AS REFERENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** _____ **WEATHER** CLEAR

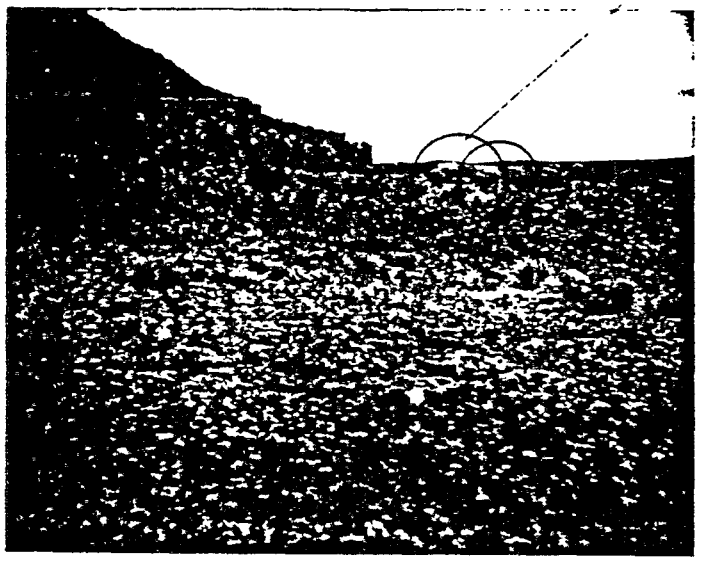
PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** _____

FILM TYPE POLAROID **FRAME NO.** 28

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: _____
5. Deep Well Water Sample ( )
6. Photograph Below: YES, SEE SKETCH

YES, UNCUT
PCM



3 NEG.

28 = FR.

7. DESCRIPTION SEE SKETCH

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

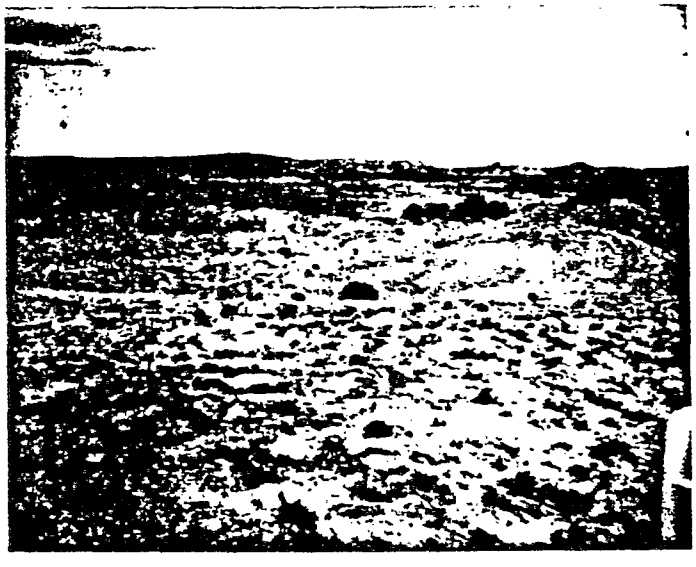
DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** SEE SKETCH

FILM TYPE POLAROID **FRAME NO.** 31

DATA TAKEN WITH PHOTOGRAPH:

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



SHIFER.

7. DESCRIPTION _____

NAVAJO SUPERFUND DEPARTMENT

PIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

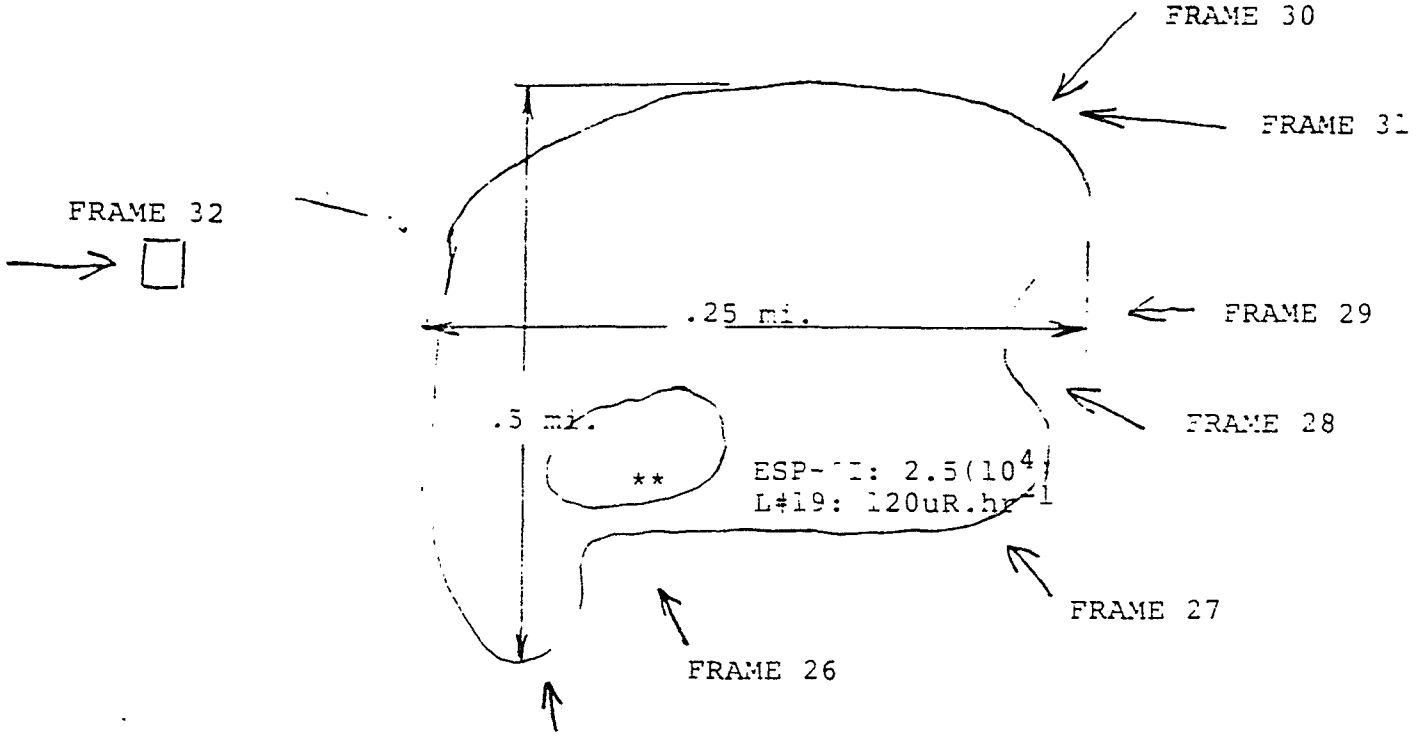
DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** _____

FILM TYPE POLAROID **FRAME NO.** NO FRAME

DATA TAKEN WITH PHOTOGRAPH: SKETCH

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: SEE BELOW
5. Deep Well Water Sample ( )
6. Photograph Below: *** NONE ***



* RADIOMETRIC READINGS ASSOCIATED WITH FRAME 27

7. **DESCRIPTION** SKETCH OF AREA WHERE RADIOMETRIC READINGS WERE TAKEN, NO SCALE

a windshield survey indicate that a substantial fraction of ¼ of a section (160 acres) is contaminated with mine tailings. Tailings piles, the incined adits and the timbered shaft are unfenced and readily accesible to site residents (3). There is no documentation of emergencies, accidents or remedial action regarding the Brown Vandever Uranium mine site.

3. WASTE CONTAINMENT/HAZARDOUS SUBSTANCE

An estimated total of 532,000 tons of mining waste is present in the two major tailings piles on site (4). Computations indicate that there are approximately 1880 tons of toxic compounds and elements dessiminated within the 532,000 tons of rubble at the site (3; Frames #8, #13, #15, #19, #25 through #32, 4). These contaminants are exposed and uncontained and are therefore capable of producing leachate subject to migration into atmospheric, ground water and surface water systems (11, 22, 23, 24, 25). The exposed inclined adits, timbered shaft and stopes may also be producing a leachate similar in composition to that produced by the tailings piles.

Specific radioactive species contributing to contamination of the leachate are uranium (U^{235}, U^{238}), and its daughter products Ra^{226}, Th, isotopes of Pb, Bi^{214}, etc). The enclosed portions of the adits and shaft may contain significant concentrations of Radon gas. Toxic heavy metal species suspected of being present in the mining waste in significant concentrations are Vanadium, Arsenic, Barium, Chromium, Magnesium, Manganese, Strontium, Titanium and Zirconium. Table 1 provides a summary of hazardous substances potentially present in the waste piles and in the open excavations.

4. PATHWAY CHARACTERISTICS

A. AIR CHARACTERISTICS

The potential for mobility of hazardous and toxic compounds associated with U_3O_8 and V_2O_5 mining waste is high due to the particulate nature of the waste and the occasional high winds native to the area which may cause migration of windblown contaminants offsite.

B. GROUNDWATER CHARACTERISTICS

Regionally, the site is bounded on the north by the central San Juan Basin and on the south by the Zuni uplift. Structural elements of the Acoma Sag lie southeast of the site (5;pgs 16,18:6). The geological element where the site is located is termed the Chaco slope (5;pg 16).

"Kelley (1951, p. 126) describes the Chaco slope as the southern part of the San Juan Basin that lies between the central Basin (fig. 2.5 -1) and the Zuni uplift and Acoma Sag. The Chaco slope resembles the platforms but differs from them because of "Its more pronounced and continous regional inclination toward the center of the basin and by the absence of a 'Monocline' separating it from the central basin " (Kelley, 1951, p.126).

Jurassic rocks from the Morrison formation and Chinle formation (which

TABLE 1. Quantity of Undisseminated Toxic Compounds and Elements Within Tailings Piles at Brown Vandever Uranium Mine

	Waste	Quantity of Undisseminated Hazardous Waste*	Disposal Location	Origination
1.	U_3O_8	6.35 (10)kg	On-Site	Low Grade Uranium/ Vanadium
2.	V_2O_5	1.04 (10 kg	On-Site	" "
3.	Radium	Unknown	"	" "
4.	Thorium	"	"	" "
5.	Arsenic	"	"	" "
6.	Selenium	"	"	" "
7.	Radon	"	"	" "
	TOTAL	**1880 tons**		

* CUSTOMARY UNITS FOR REPORITNG ABUNDANCES OF RADIOISOTOPES ARE MASS UNITS.

locally includes the Moenkopi formation) dip westwardly into the adjacent Chaco slope (3; frame# 20 and enlargement: 6:8). A Cretaceous sequence is present adjacent to the site on Haystack mountain and is represented by the Dakota sandstone exposure (3: frame #20 and enlargement). Triassic units represented by the Moenkopi and Chinle formations dip eastwardly into the adjacent Chaco slope (3;frame #20 and enlargement Figure #3).

Quaternary Alluvium (Pleistocene) has accumulated in variable thicknesses in streambeds in the area (32).

The Aquifer of concern in the Vicinity of the site is the Sonsela Sandstone member of the Chinle formation which sources the Navajo Nation Water Resources Division (NNWRD) well #16T-551 (19). Depth to water in ths well is documented and is reported to be 417 feet (circa 1976). Depth to the Sonsela sandstone member of the Chinle formation is 1083 feet. The only other Aquifer known to source wells in the area is the Entrada Sandstone (19). the net precipitation for the locale is estimated to be minus 44 inches (5, 12).

Contaminants of concern present in the tailings piles are the radiospecies U^{238}, U^{235} and their progeny Th^{232}, Bi^{214}, Po^{214}, isotopes of Pb and Radon gas. Toxic heavy metal species suspected of being present in the mining waste in significant concentrations are Ar, Ba, Mg, Mn, Sr, Ti and Zr. (11, table 1). Many of these species have been demonstrated by various authors to be mobile in waters associated with Uranium mines (23,24,25,26,27,28 and 29). The Hydraulic conductivity of the formations between the Alluvium and the Sonsela sandstone member is estimated to be of the order of 10^{-3} because of fractures and faults. This is consistent with the close proximity of the El Tintero Cinder Cone and the epochal geological development of the area. In addition, at least three excavations are driven to within 100 feet of the static water level in NNWRD well #16T-551. It follows that the possibility exists for these Radioactive and toxic heavy metal species to have migrated into the alluvial and Sonsela sandstone Aquifers which source an Artesian spring and NNWRD well #16T-551, respectively (3; frame #35: 19). Water depth in the alluvial Aquifer is not known but is expected to be shallow (5; pg. #40, fig.#4.3-1)

C. SURFACE WATER CHARACTERISTICS

A portion of the Brown Vandever mine site is located on a southeastwardly dipping Alluvial plate (3;frame #8) whose upgradient drainage area is estimated to be approximately 59.1 acres (4; worksheet #1). The stripmine portion of the site is located on a northwardly dipping Alluvial plate whose upgradient drainage area is estimated to be 14.23 acres (4; worksheet #1). Surface runoff from the 59.1 acre portion proceeds overland and along minor drainages eastwardly (3;frame,#16') until encountering a well-defined drainage which trends southeastwardly,(3;frame #17,#18). Surface runoff from the 14.23 acre portion proceeds overland and along minor drainages eastnortheastwardly (3;frame#31) until encountering the well-defined drainage which trends southeastwardly (7). The drainage proceeds southeastwardly for approximately 4 mi. before becoming evanescent (7, 31). Data from a gauging station on the Rio San Jose at Grants, New Mexico indicates an

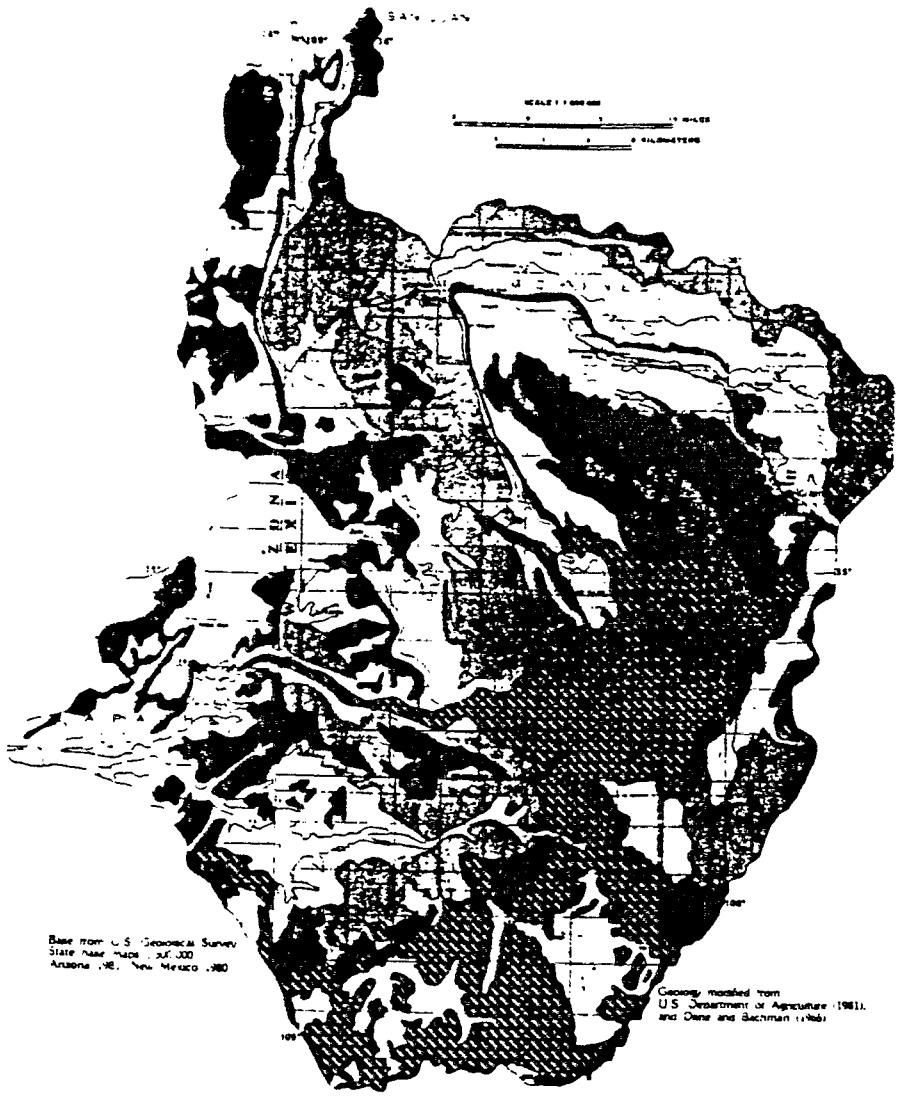


Figure 2.6-1 Generalized geologic map.

EXPLANATION

QUATERNARY AND TERTIARY	ALLUVIUM AND BOLSON DEPOSITS
	IGNEOUS ROCKS, INCLUDES BASALT FLOWS, VOLCANIC BRECCIA, TUFF AND CINDERS, AND EXPOSED INTRUSIVE IGNEOUS ROCKS
TERTIARY	SEDIMENTARY ROCKS INCLUDING BIDAHOCHI FORMATION, CHUSKA SANDSTONE, AND BACA FORMATION
CRETACEOUS	MESAVERDE GROUP
	MANCOS SHALE AND DAKOTA SANDSTONE, UNDIVIDED
JURASSIC	MORRISON FORMATION, ZUNI SANDSTONE, AND SAN RAFAEL GROUP, UNDIVIDED
JURASSIC AND TRIASSIC	GLEN CANYON GROUP
TRIASSIC	CHINLE FORMATION; LOCALLY INCLUDES MOENKOPI FORMATION
PERMIAN	SAN ANDRES LIMESTONE AND GLORIETA SANDSTONE IN NEW MEXICO, DE CHELLY SANDSTONE IN ARIZONA, AND THE YESO AND ABO FORMATIONS IN NEW MEXICO
PERMIAN AND PENNSYLVANIAN	SUPAI FORMATION
PRECAMBRIAN	PRECAMBRIAN ROCKS, UNDIVIDED

FIGURE = 3 ; REGIONAL GEOLOGY,
AFTER USGS, HYDROLOGY OF REGION 62

NAVAJO SUPERFUND OFFICE

NAVAJO-BROWN VANDEVER URANIUM MINE

JUNE,'90 P. MOLLOY

annual discharge rate of 2.97 cfs (20). The regional 1-yr, 24-hr rainfall event for the locale is 1.26 inches (13). Radioactive and toxic heavy metal species have been shown to be mobile in surface waters (23 throught 29). In particular, Arsenic and Selenium are known to sorb strongly to surface water sediments (26,28). The possibility exists for contaminated sediments to have been carried by flash floods, over the decades, onto the Alluvial plain east of El Tintero cinder cone (figure #2,7). A slight possiblilty exists for contaminated sediments to have been carried into Bluewater creek and the Rio San Jose (5,7). The area has not been mapped in a flood plain, However, due to the arid nature of the upgradient terrain and the general topography, the locale is prone to flash flooding events. Moreover, Haystack Mountain is very likely to be a recharge zone for aquifers in the area (5;pg#38).

D. ON SITE PATHWAY

As with other mines in the area the proto-ore was abandoned on-site. In the case of the Brown Vandever Mine, some of it was used to pave a haulage road which is used by site residents frequently (3;frame#22). The Brown Vandever mine environs are readily accessible by site residents and visitors to the area (3). There are no access barriers or danger signs on or near the mine site (3). Direct contact with contaminated particulates is possible during periods of high winds or physical disturbance of the tailings material. Humans living on-site and visitors to the area would are at risk to exposure from the same suite of radiospecies and heavy metals detailed above. Moreover, the ventilation shafts, the almost vertical timbered shaft and the inclined adits pose physical danger immediately dangerous to life and health status.

5. TARGETS

GROUND WATER TARGETS. There are three active wells within the 4 mile radius of influence of the site (19,21). The Indian Health Service (IHS) completed installation of a community Water System in October 1986 (21). Subsequent to the completion of the water system, operation and maintenance of the system was turned over to the Navajo Nation and is currently under the purvue of NNWRD (19). The community water system utilizes well #16T-551 which was formerly a livestock water well. The water system serves approximately 430 persons in the Haystack area (4;worksheet #2). Total population within the four mile radius of influence of the site was estimated to be approximately 500 (4;worksheet#2): The percentage of area residents not connected to the NNWRD water system was estimated to be 23% (=100 persons) on the basis of a residence count and the fact that 43.8% of Indian homes had their source of water more than 100 yds from their residennce (3,18,31). Area residents too indigent to afford plumbing and sewerage systems for their residences might utilize water from the active NNWRD stockwells #16T-522 and # 16T-521 (19,3;frame#41,18;pg.#1). In addition, there is at least 1 artesian spring in the immediate vicinity of the site (7;Bluewater Quad, 3;frame #35). There is a slight possibility that this spring could be utilized for drinking water.

The Aquifer of concern in the area is the Entrada sandstone unit which

sources windmills possibly utilized for potable water by as many as 100 persons (4;worksheet#2,18;pg.#1,3;frame#41). Depth to the water table in this confined unit is reported to be approximately 400 feet (19). As pointed out before, the shaft and inclines have been driven to within 100 feet of this aquifer. Targets in the area consuming groundwater from the Entrada sandstone unit are at risk to exposure from Radionucleides and heavy metals (II).

SURFACE WATER TARGETS Surface water targets would be potentially exposed to the same suite of Radionucleides and heavy metals that is the case with ground water targets. Risk of exposure may be low due to the low value for net precipitation for the area. However, extreme conditions brought in the area would inundate the highly eroded haulage road (18).

The well-defined drainage coursing first east and then southeast from the site crosses at least one federally designated wetland (9).

AIR TARGETS Humans living on site are being exposed to elevated Radon concentrations.

ON-SITE TARGETS In addition to being exposed to elevated Radon concentrations, residents of the Brown Vandever mine environs are confronted daily with the dangerous inclines, shafts and the insult to their land.

SENSITIVE ENVIRONMENTS At least one federally designated sensitive environment lies within 1 mile of the site.

6. OTHER REGULATORY INVOLVEMENT

PERMITS: No permit was found for the Brown Vandever Uranium mine

STATE AGENCIES: None

OTHER FEDERAL PROGRAMS: None

7. CONCLUSIONS AND RECOMMENDATIONS

The Brown Vandever Uranium mine site is exceptionally dangerous. However, no steps toward remediation or mitigation have been undertaken over the two and one half decades since cessation of activities. To assert that residents of the site have not been adversely affected by the insult to their land and very possibly their health is inadmissable.

Immediate action should be taken.

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REFERENCE # 1

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

EPA POTENTIAL HAZARDOUS WASTE SITE IDENTIFICATION

REGION	SITE NUMBER
VI	

NOTE: The initial identification of a potential site or incident should not be interpreted as a finding of illegal activity or confirmation that an actual health or environmental threat exists. All identified sites will be assessed under the EPA's Hazardous Waste Site Enforcement and Response System to determine if a hazardous waste problem actually exists.

A. SITE NAME	B. STREET (or other identifier)		
BROWN URANIUM MINES	35° 21' 02" : 107° 56'25"		
C. CITY	**D. STATE**	**E. ZIP CODE**	**F. COUNTY NAME**
PREWITT	NM	87045	MCKINLEY

G. OWNER/OPERATOR (If known)

1. NAME	2. TELEPHONE NUMBER
WILLIAMS AND THOMPSON, BROWN VANDEVER	(UNKNOWN)

H. TYPE OF OWNERSHIP (If known)

☐ 1. FEDERAL ☐ 2. STATE ☐ 3. COUNTY ☐ 4. MUNICIPAL ☒ 5. PRIVATE ☐ 6. UNKNOWN X 7. TRIBAL

I. SITE DESCRIPTION

An abandoned uranium/vanadium mine located approximately 1/4 mile from residence. Site located on ledge of Haystack Mountain. Tailings used to backfill one adit. Open and second adit.

J. HOW IDENTIFIED (i.e., citizen's complaints, OSHA citations, etc.)	K. DATE IDENTIFIED (mo., day, & yr.)
WINDSHIELD SURVEY	01/23/90

L. SUMMARY OF POTENTIAL OR KNOWN PROBLEM

Maximum reading of 400 $uR \cdot^{-1}$ on North tailings pile by adit. Tailings spilled into drainage southeast of north adit. Adits presently used as trash dumping areas.

M. PREPARER INFORMATION

1. NAME	2. TELEPHONE NUMBER	3. DATE (mo., day, & yr.)
PATRICK MOLLOY, NAVAJO SUPERFUND OFFICE	602/871-3153	Feb. 26, 1990

EPA Form 2070-8 (5-80)

REFERENCE # 2

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

"Uranium & Thorium Occurrences in N.M.: Distribution, Geology, Production & Resources"

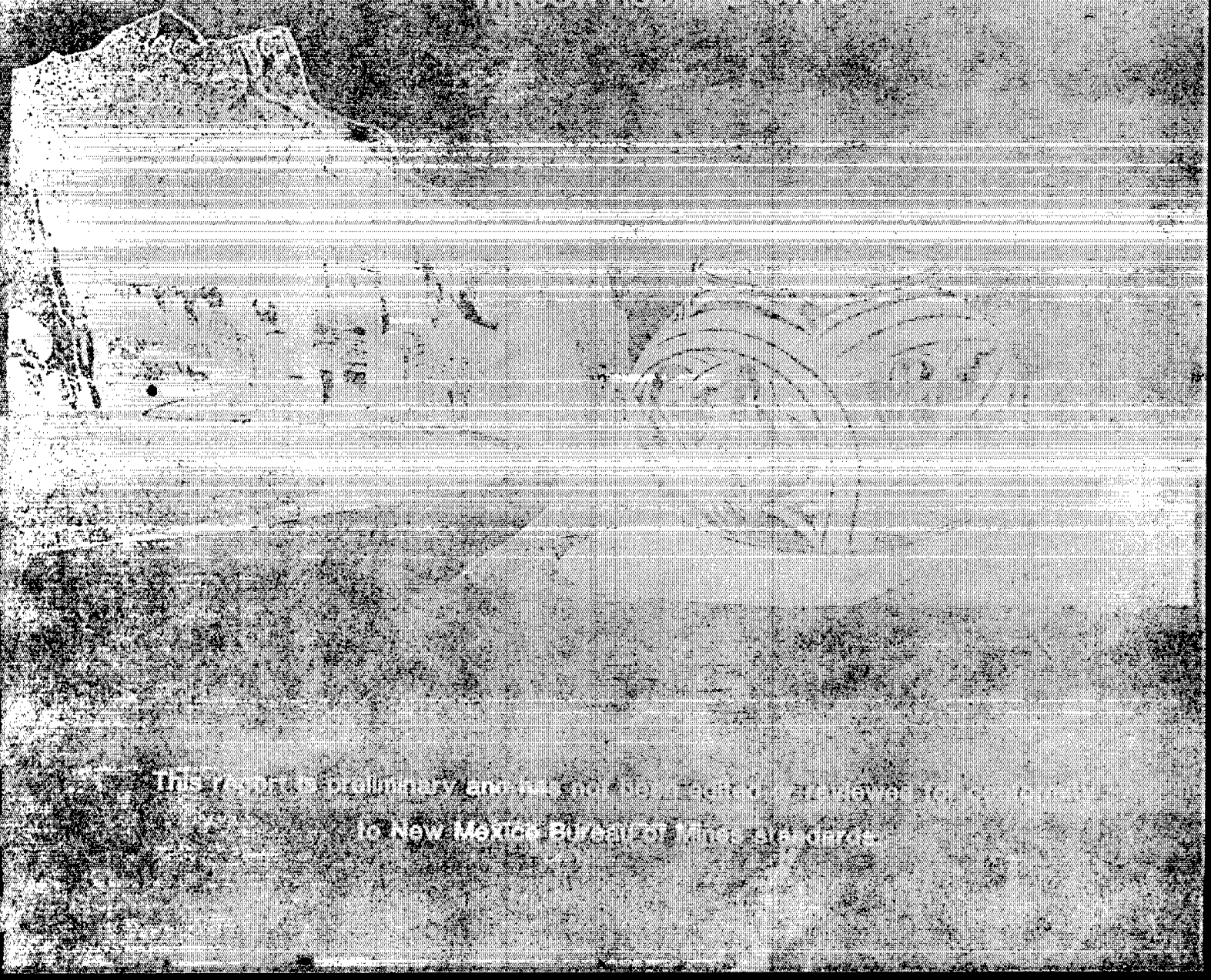
New Mexico Bureau of Mines & Mineral Resources

Socorro, New Mexico 87801

O.F.R.
183

OPEN FILE REPORT

NAVAJO SUPERFUND OFFICE
P.O. BOX 2946
WINDOW ROCK, AZ 86515



This report is preliminary and has not been edited or reviewed for conformity to New Mexico Bureau of Mines standards.

Number	Mine Name	Tons Ore	Pounds U_3O_8	%U_3O_8	Pounds V_2O_5	%V_2O_5	Type of Deposit	Host Rock	Periods of Production/ Shipper
13N.9W.20.321	Mesa Top Mine	108,261	512,965	0.24	144,610	—	sandstone	Jmp	1954-1957 - Lea Explorat(1957-Holly Minerals and
13N.10W.4.244	Pat - Section 4 (Dakota Mine)	5,069	12,645	0.12	2,478	—	sandstone	Jmw,Kd	1952-1959 - Dakota Mining Co.; 1962-1963-Farris Mines, Inc.
13N.9W.19.420	[1]Poison Canyon	217,066	1,004,574	0.23	338,094	—	sandstone	Jmp	1952-1959 - Haystack Mour Development Corp.; 1960-1962-Farris Mines Inc.
14N.11W.28.113	Red Cap Group (T Group)	195	497	0.13	951	0.24	limestone	Jt	1952-1953 - Navajo Develo ment Co.; 1953-Fitzhugh Doerrie
13N.10W.16.134	Red Point Lode	482	1,223	0.13	746	0.07	limestone	Jt	1952-1955 - R.M. Shaw
14N.11W.20.144	Red Top Mines	165	390	0.12	1,287	0.39	limestone	Jt	1955 - Red Top Uranium Mining Co.
14N.9W.34.424	[1]Sandstone	1,034,255	3,540,829	0.17	—	—	sandstone	Jmw	1959-1963 - Phillips Petroleum Co.; 1963-1970 United Nuclear Corp.
13N.9W.1.200	[1]Section 1 (13N-9W) mined through Cliffside	148,066	1,699,137	0.57	—	—	sandstone	Jmw	1967 - Kerr-McGee; 1969-1 Kerr-McGee and Nation Le
15N.16W.3.332	Section 3 (15N-16W) Santa Fe-Christensen Rats Nest Mine	324	1,836	0.28	404	—	sandstone (coal)	Kd	1957 - Christensen and Ra Uranium Co.; 1957-1958-R Uranium Co.
13N.10W.5.144	Section 5 (13N-10W)	23	54	0.12	—	—	sandstone	Kd	1958 - Westvaco
13N.9W.8.114	Section 8 (13N-9W) Spencer Shaft	47,808	165,319	0.17	—	—	sandstone	Jmp	1958-1960 - United Western 1961-Hyde and Casper; 196 1966-W.D. Tripp; 1966-196 James J. Goode
14N.10W.10.244	[1]Section 10 (14N-10W)	130,767	510,935	0.20	—	—	sandstone	Jmw	1957-1962 - Kermac Nuclear 1964-Homestake-Sapin
14N.10W.12.411	[1]Section 12 (14N-10W)	74,975	211,873	0.14	—	—	sandstone	Jmw	1961 - Anderson Developmen Corp.; 1962-1963-Stella Dysart
14N.10W.15.441	[1]Section 15 (14N-10W)	1,213,814	3,625,924	0.15	—	—	sandstone	Jmw	1958-1961 - Homestake-Sapi 1961-1965-Rio and Home-stake-Sapin; 1966-1969-Homestake-Sapin; 1969-197 United Nuclear-Homestake
14N.9W.17.323	[1]Section 17 (14N-9W)	544,164	2,315,182	0.21	—	—	sandstone	Jmw	1960-1964 - Kermac Nuclear Corp.; 1965-1970-Kerr-McG
13N.10W.18.341	Section 18 (13N-10W) (Indian Allotment)	25,796	98,175	0.19	75,342	0.30	limestone	Jt	1952 - Sutton, Thompson, Williams; 1953-Williams; 1955-Santa Fe Uranium; 19 1956-Santa Fe Uranium and Federal Uranium; 1957-195 Federal Uranium; 1963-1964 Mesa Mining Co.; 1966-Cibo Mining Co.
14N.9W.18.400	[1]Section 18 (14N-9W) mined through Sec. 17	501,946	1,506,447	0.16	—	—	sandstone	Jmw	1962-1964 - Kermac Nuclear; 1965-1970-Kerr-McGee
14N.9W.20.114	[1]Section 20 (14N.9W) mined through Sec. 17	486,375	2,223,977	0.23	—	—	sandstone	Jmw	1962 - Kerr-McGee
14N.10W.22.223	[1]Section 22	2,189,051	11,605,672	0.18	—	—	sandstone	Jmw	1958-1964 - Kermac Nuclear; 1965-1970-Kerr-McGee
	(14N-10W) heap leach	—	38,105	—	—	—			
14N.10W.23.134	[1]Section 23 (14N-10W)	2,528,797	9,679,773	0.19	—	—	sandstone	Jmw	1959-1968 - Homestake-Sapir 1969-1970-Homestake-United Nuclear
13N.10W.23.444	Section 23 (13N-10W)	21,826	138,541	0.32	10,256	0.06	limestone	Jt	1957-1965 - Haystack Mounta Development Corp.; 1965-1966-Santa Fe Pacific
13N.9W.24.121	Section 24 (13N-9W) Chili Wills, Rialto (Section 13)	10,950	37,693	0.17	—	—	sandstone	Jmp	1960-1963 - Febco Mines, In
13N.11W.24.222	Section 24 (13N-11W) Indian Allotment to Nana-A-Bah Vandever	24,638	115,075	0.22	85,545	0.18	limestone	Jt	1952-1954 - Glen Williams; 1955-1956-Santa Fe Uranium 1955-Federal Uranium Corp. Santa Fe Uranium; 1956-195 Federal Uranium Corp.
14N.10W.24.332	[1]Section 24 (14N-10W)	1,904,582	7,071,564	0.19	—	—	sandstone	Jmw	1959-1964 - Kerr-McGee Nuclear; 1965-1970-Kerr-McGee
	Heap leach	—	579	—	—	—			
13N.10W.25.411	[1]Section 25 (13N-10W)	235,156	958,058	0.20	153,657	0.12	limestone	Jt	1952 - A T and SF RR; 1955-1961-Haystack Mountain Development Corp.; 1962-1963-Santa Fe Pacific; 1963-Farris Mines, Inc.; 1963-1965-Santa Fe Pacific; 196 1966-Farris Mines, Inc.; 1968-Homestake; 1969-1970-United Nuclear Corp.
14N.10W.25.144	[1]Section 25 (14N-10W)	1,791,048	6,444,889	0.18	—	—	sandstone	Jmw	1959-1969 - Homestake-Sapin 1969-1970-Homestake-United Nuclear
13N.10W.26.221	[1]Section 26 (13N-10W) Desidero Group	11,110	83,752	0.38	17,518	0.08	limestone	Jt	1952-1957 - Hanosh Mines
14N.10W.26.220	[1]Section 26 (14N-10W) mined through Section 24	362,110	1,190,696	0.17	—	—	sandstone	Jmw	1965-1970 - Kerr-McGee

McKinley County

Occurrence Number	Property Name (Occurrence Name)	PRR Number (year)	Classification	Host	Ref.
———	Airbourne Anomaly 11N/15W/23	ED-R-426 (1954)	none	-	1
14N.13W.12.333	Alpha	ED-R-680 (1956)	Shale/Sandstone	Km,Jm	2(p.
14N.11W.18.340	Bottoms Claims (Red Top #1 and #2)	CEB-18 (1950)	Limestone	Jt	1
16N.18W.26.220	Car Ball #13	ED-R-240 (1953)	Shale	Kc	3
15N.16W.4.414	Claim (U Mine)	ED-R-234 (1953)	Sandstone	Kd	3
13N.18W.4.244	Dakota Mining Co. (pat-Sec.4)	GJEB-R-188 (1952);	Sandstone	Kd	3
15N.17W.33.244	Diamond #2	unnumbered (1953)	Sandstone	Jmw	3
14N.18W.11.312	Dysart #1	NM-101 (1955)	Sandstone	Kd	3
14N.12W.24.24	Elkins Claims	CEB-17 (1950); GJEB (1950)	Limestone	Jmw	1
14N.11W.20.133	Grover Claims	CEB-21 (1950); GJEB (1950)	Limestone	Jt	3
14N.9W.4	Green Pick #20, 21	DEB-252 (1952)	Sandstone	Jt	1
13N.18W.16.100	Hard-word, Red Point, and others	CEB-15 (1950); GJEB (1950)	Limestone	Kp	3
15N.18W.12.244	Hogback No. 4	GJEB:R-173 (1952)	Sandstone/Shale	Jt	1
14N.14W.2.123	Last Chance #2	DEB-248 (1951)	Sandstone	Kd	1
19N.6W.13,14;19N.6W., 23.344; 19N.6W.25,26	L.L. Farr Ranch (Farr Ranch)	ED-R-458 (1955)	Sandstone Beach placer	Jmr	1
13N.18W.25.411	Operation Haystack-Sec.25 (Sec.25-SEQ-Desiderio)	unnumbered (1956)	Limestone	Kpc	1
15N.16W.4.111	Prospect #1 (Foutz #1)	ED-R-214 (1953)	Sandstone	Jt	3
15N.16W.5.222	Prospect #2 (Foutz #2)	ED-R-215 (1953)	Sandstone	Jmw	3
14N.13W.14.222	Reynolds (June)	unnumbered (1958)	Sandstone	Jmw	3
13N.18W.36.224	Rimrock #1 (Section 36)	CEB-14 (1950); GJEB (1950)	Limestone	Jmr	3
14N.18W.31.233	Silver Spur #5 (Silver Spur Pits)	DEB-251 (1952)	Sandstone	Jt	3
18N.14W.35.300	Standury Rock	ED-R-620 (1956)	Sandstone Beach placer	Kd	1
14N.11W.28.113	T Claims #1-4 (Red Cap Group)	CEB-20 (1950); GJEB 1950)	Limestone	Kp	3
14N.13W.8	Tietjon-Lewis #8	DEB-249 (1951)	Sandstone	Jt	1
13N.9W.29.141	Unknown (Faith)	RR-209 (1951)	Limestone	Jmr	1
13N.18W.18.341	Unknown (Section 18)	CEB-18 (1950); GJEB (1950)	Limestone	Jt	2(p.8
———	Unknown	ED-R-426 (1954)	none	Jt	1
13N.18W.19.110	Unknown (Haystack-Sec.19)	CEB-9 (1950); GJEB (1950)	Limestone	-	1
13N.18W.24.222	Unknown (Shirley and Gunther, G.)	RR-202-AEC (1951)	Sandstone	Jt	1
13N.18W.25.114	Unknown (Section 25 Open-pit)	CEB-8 (1950)	Limestone	Jmw	1; 2(
13N.18W.26.221	Unknown (Section 26)	CEB-7 (1950)	Limestone	Jt	1
13N.11W.13.314	Unknown (Haystack Sec.13 p.t)	CEB-16 (1950); GJEB (1950)	Limestone	Jt	1
13N.11W.21	Unknown - Prewitt	211-AEC (1951)	Limestone	Jt	1
14N.18W.31.344	Unknown (Febco)	GJEB-R-172 (1952)	Sandstone	Jt	2(p.8
14N.11W.19.414	Unknown - Andrews	CEB-19 (1950); GJEB (1950)	Limestone	Kd	1
9N.17W.4	Unknown - Zuni Indian Reservation	RR-207 (1951)	Orthomagmatic	Jt	1
14N.11W.35.120	Unknown (Last Mine)	DEB-237 (1951); RR-210 AEC (1952)	Sandstone	Ti	1 (un Valencia Co Kd
14N.13W.14.114	Unknown (Largo)	RR-208 AED (1951)	Limestone	Jt	2 (p.(2 (p.(
15N.17W.28.114	Unknown (Anomaly)	GJEB-145 (1952)	Sandstone	Jmw	1
15N.17W.33.422	Unknown (Anomaly)	GJEB-144 (1952)	Sandstone	Kd	1
15N.19W.32.432	Weingarten State Lease (Gallup titanium deposit)	ED-R-618 (1956)	Sandstone Beach Placer	Kg	3

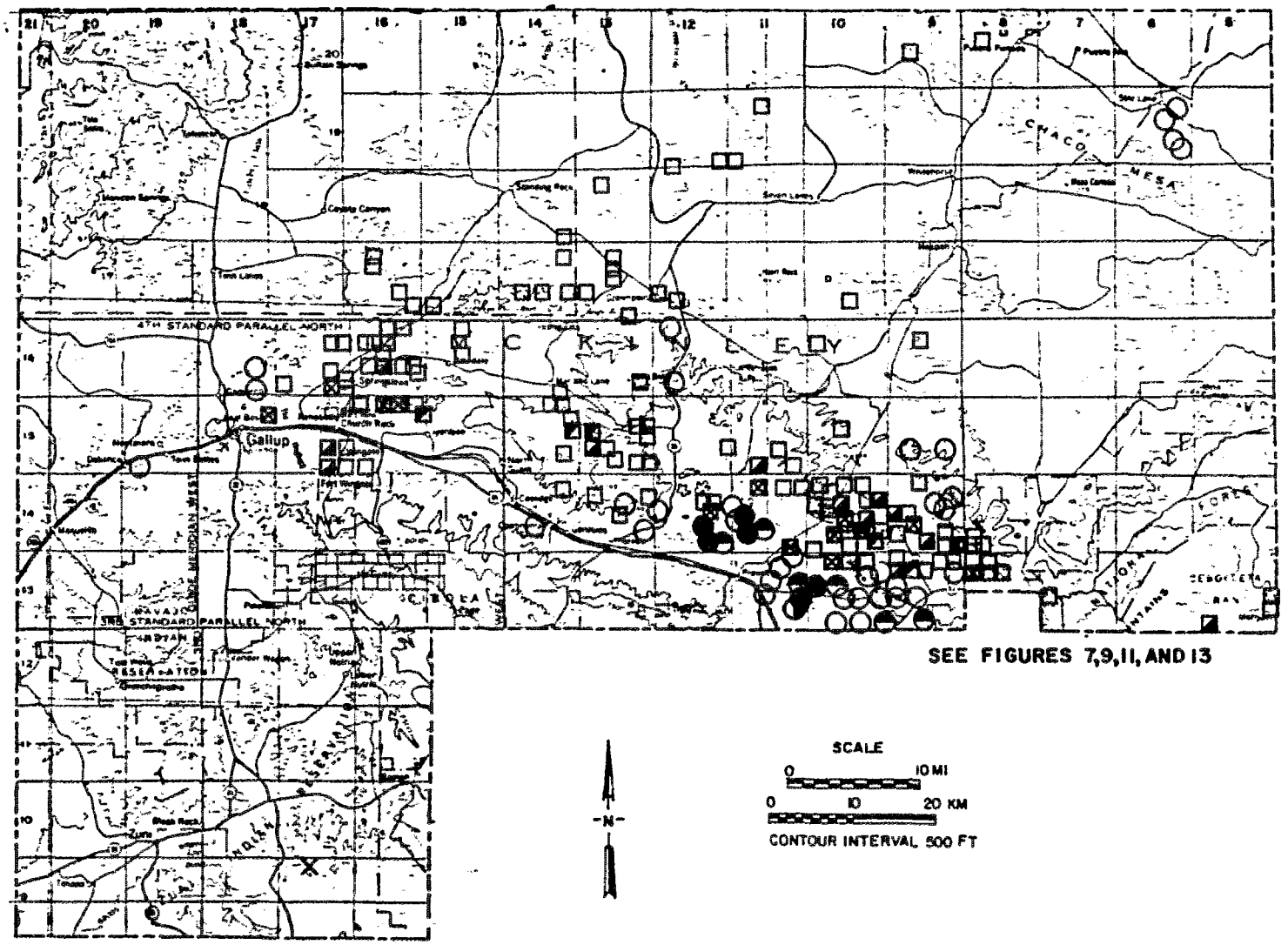
Mora County

Occurrence Number	Property Name (Occurrence Name)	PRR Number (year)	Classification	Host	Ref.
21N.16E.22	A and M Mining	ASO-93 (1955)	Pegmatit-	Pg	2(p.9
22N.16E.1	William Atkins	ASO-64 (1955)	Shale/Sandstone	Ps	2(p.92
22N.16E.13	Le Deoux Ranch	DAO-P-4-1491 (1953)	Sandstone	Ps	2(p.91
20N.24E.5,19N.23E.1	Sanford Ranch	ASO-65 (1955)	Sandstone	Jm	2(p.86
———	Turkey Mountain Area	DEB-RRA-545 (1953)	none	-	3
22N.17E.,21N.16E	United Development Co.(Coyote Creek Misc.prospects)	ASO-66 (1955)	Sandstone/Shale	Ps	2(p.87
22N.17E.,21N.16E	United Development Co.(Coyote Creek Misc.prospects)	ASO-67 (1955)	Sandstone/Shale	Ps	2(p.88
———	Unknown	unnumbered (1951)	none	-	3
22N.17E.,21N.16E	Unknown (Coyote Creek Misc. prospects)	D-243 (1951)	Sandstone/Shale	Ps	1
———	Unknown	ED-R-1121 (1958)	none	-	3
22N.16E.9	Unknown (Unknown-Mora Grant)	ED-R-1135 (1953)	Orthomagnetic	Pg	1
———	Unknown	ED-R-1136 (1953)	none	-	1
22N.17E.,21N.16E; 22N.16E.13	Unknown (Coyote Creek Misc. prospects) (Le Deoux Ranch Lease)	ED-R-1138 (1953)	Sandstone/Shale; Sandstone	Ps	1
———	Unknown	DEB-RRA-1111 (1953)	none	-	1
———	Unknown	ED-R-1140 (1953)	none	-	3
———	Unknown	DEB-RR-501 (1953)	none	-	3
22N.17E.,21N.16E.	Unknown (Coyote Creek Misc. prospects)	ASO-92 (1955)	Sandstone/Shale	Ps	2(p.89
22N.17E.,21N.16E.	Unknown (Coyote Creek Misc. prospects)	D-244 (1951)	Sandstone/Shale	Ps	1
———	Unknown	M-1475 (1954)	none	-	1
———	Unknown (No Location given)	unnumbered (1951)	none	-	1

Otero County

Occurrence Number	Property Name (Occurrence Name)	PRR Number (year)	Classification	Host	Ref.
———	Alice, Nannie Beard and Garnet Mines	DEB-RRA-1104 (1953)	none	-	1
16S.11E.17.234	Courtney Mine	DEB-RRA-1134 (1953)	Sandstone-tabular	Pa	3
16S.11E.17.234	Courtney and Grandview	RG-9-51 (1951)	Sandstone-tabular	Pa	1
16S.11E.30.441	Holmes (East Warnock)	RG-14-51 (1951)	Sandstone-tabular	Pa	1
———	Iron Ousen Mine	DEB-RRA-105 (1953)	none	-	1
15S.11E.24.142	Luz #2	ASO-73 (1955)	Sandstone-tabular	Pa	2(p.94)
———	Muscalero Apache Indian Res.	ASO-28 (1954)	none	-	2(p.93)
———	Providence Mine	DEB-RR-1103 (1953)	none	-	1

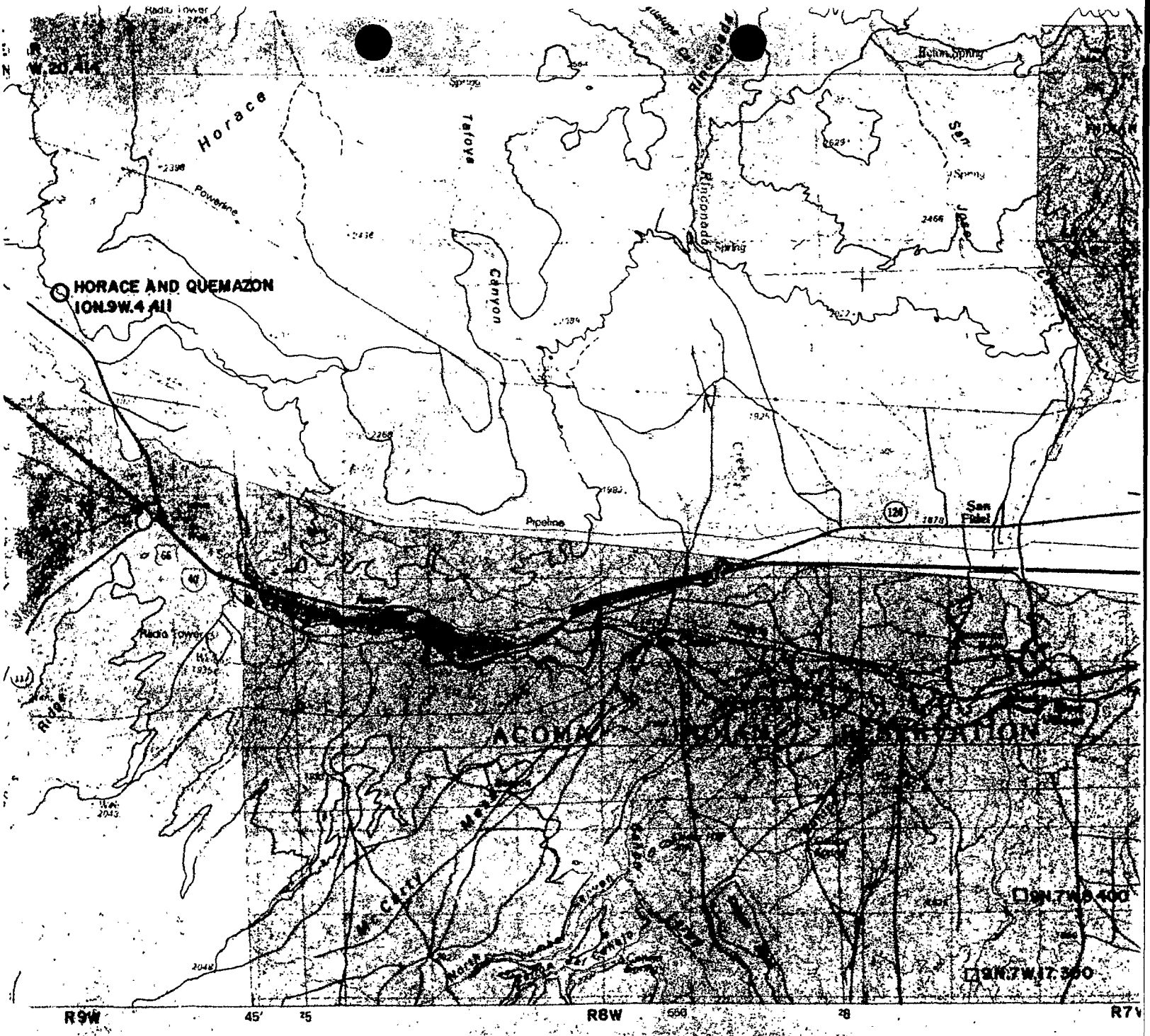
FIGURE 1-19–RADIOACTIVE OCCURRENCES IN McKINLEY COUNTY, NEW MEXICO



SEE FIGURES 7,9,11, AND 13

PRODUCTION CATEGORY / CLASS	DEPOSITS IN IGNEOUS AND METAMORPHIC ROCKS	DEPOSITS IN VOLCANIC ROCKS	SANDSTONE DEPOSITS	DEPOSITS IN OTHER SEDIMENTARY ROCKS	DEPOSITS OF UNCERTAIN ORIGIN
OCCURRENCE, NO PRODUCTION	×	△	□	○	◇
UP TO 20,000 POUNDS U_3O_8	⚒	▲	⊠	◓	◈
20,000-200,000 POUNDS U_3O_8	⊗		◪	◑	♦
200,000-2 MILLION POUNDS U_3O_8			◪	●	
2 MILLION-20 MILLION POUNDS U_3O_8			⊠		
GREATER THAN 20 MILLION POUNDS U_3O_8			■		

TABLE 1-1 - KEY TO SYMBOLS USED ON RADIOMETRIC OCCURRENCE LOCATION MAPS



INDEX

1 Goat Mountain–1957
2 Ambrosia Lake–1957
3 San Lucas Dam–1963
4 Cerro Mesina–1963
5 El Dado Mesa–1961
6 Laguna Seca–1961
7 Cerro Tinajon–1961
8 Casa Salazar–1961
9 Bluewater–1957
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19 Lobo Springs–1957
20 Mount Taylor–1957
21 Seboyeta–1957
22 Moquino–1957
23 Arch Mesa–1957
24 Herrera–1954
25 San Rafael–1957
26 Grants SE–1957 (Photorevised–1971)
27 McCarty–1957 (Photorevised–1971)
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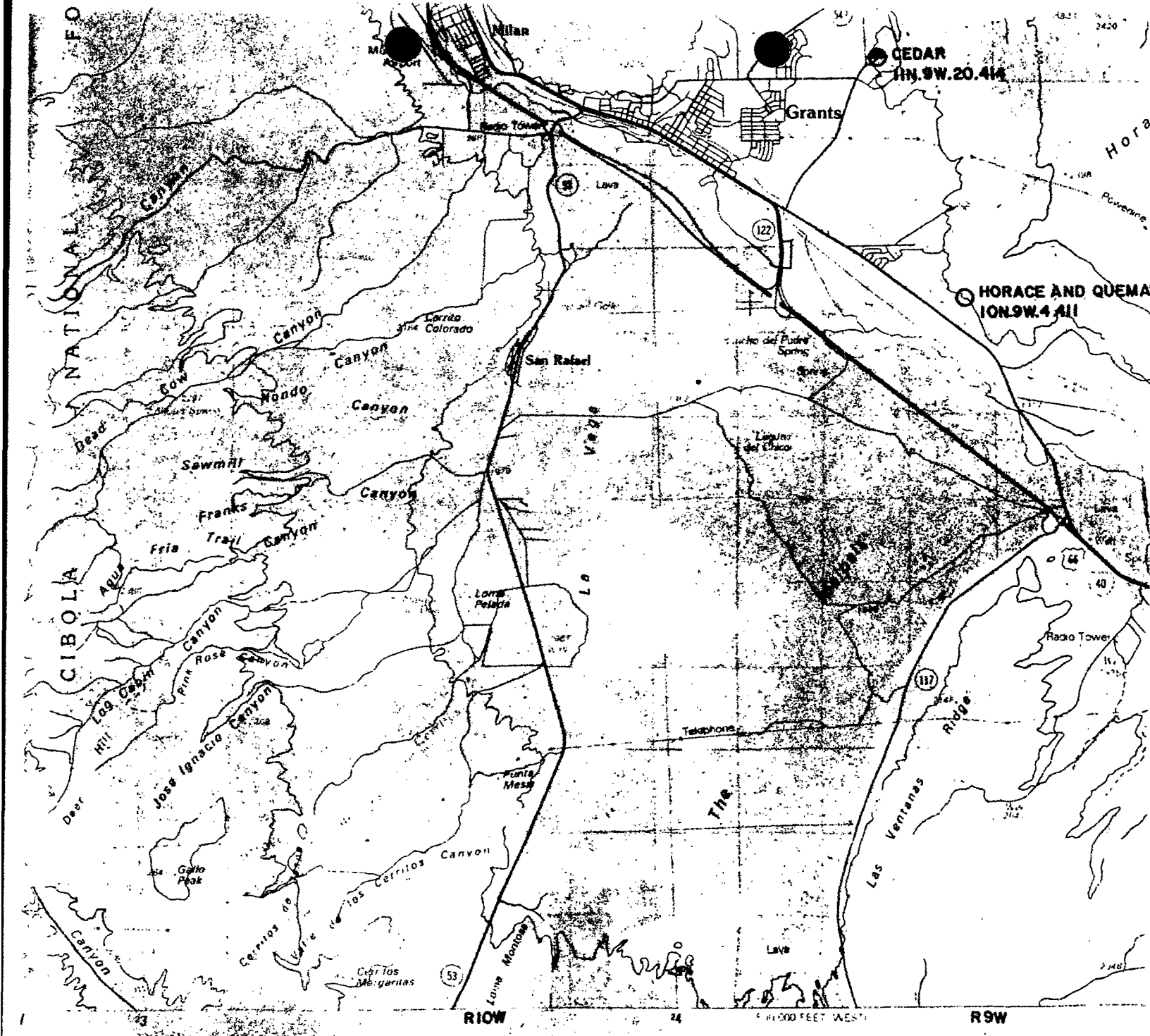
GN MN
1°27' 12½°
26 MILS 222 MILS

UTM GRID AND 1978 MAGNETIC NORTH DECLINATION AT CENTER OF MAP

FIGURE 7 – URANIUM MINES, DEPOSITS, AND

AND BERNALILLO COUNTIES, NEW

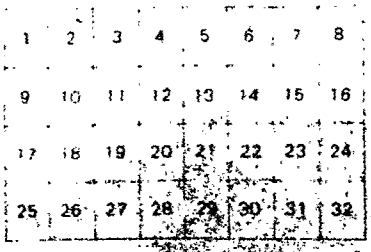


e ted, and published by the Geological Survey

om USGS 1:24 000 - scale topographic maps
963. See index for dates of individual maps
i from aerial photographs taken 1973–75 and
l sources. Revised information not field checked
1978

r 10 000 - meter grid, zone 13,
r- sverse Mercator
t grid ticks based on New Mexico coordinate system
rral zones. 1927 North American datum

MAP INDEX



1 Goat Mountain–1957
2 Arabela Lake–1957
3 San Lucas Dam–1963
4 Cerro Alesna–1963
5 El Diablo Mesa–1961
6 Laguna Seca–1961
7 Cerro Tinaja–1961
8 Casa Salazar–1961
9 Bluewater–1957
(Photorevised–1971)
10 Dos Lomas–1957
11 San Mateo–1963
12 Cerro Prieto–1963
13 Laguna Carpinteros–1961
14 Marquez–1961
15 La Gotera–1961
16 Pueco Dam–1961
17 Milan–1957
(Photorevised–1971)
18 Grants–1957
(Photorevised 1971)
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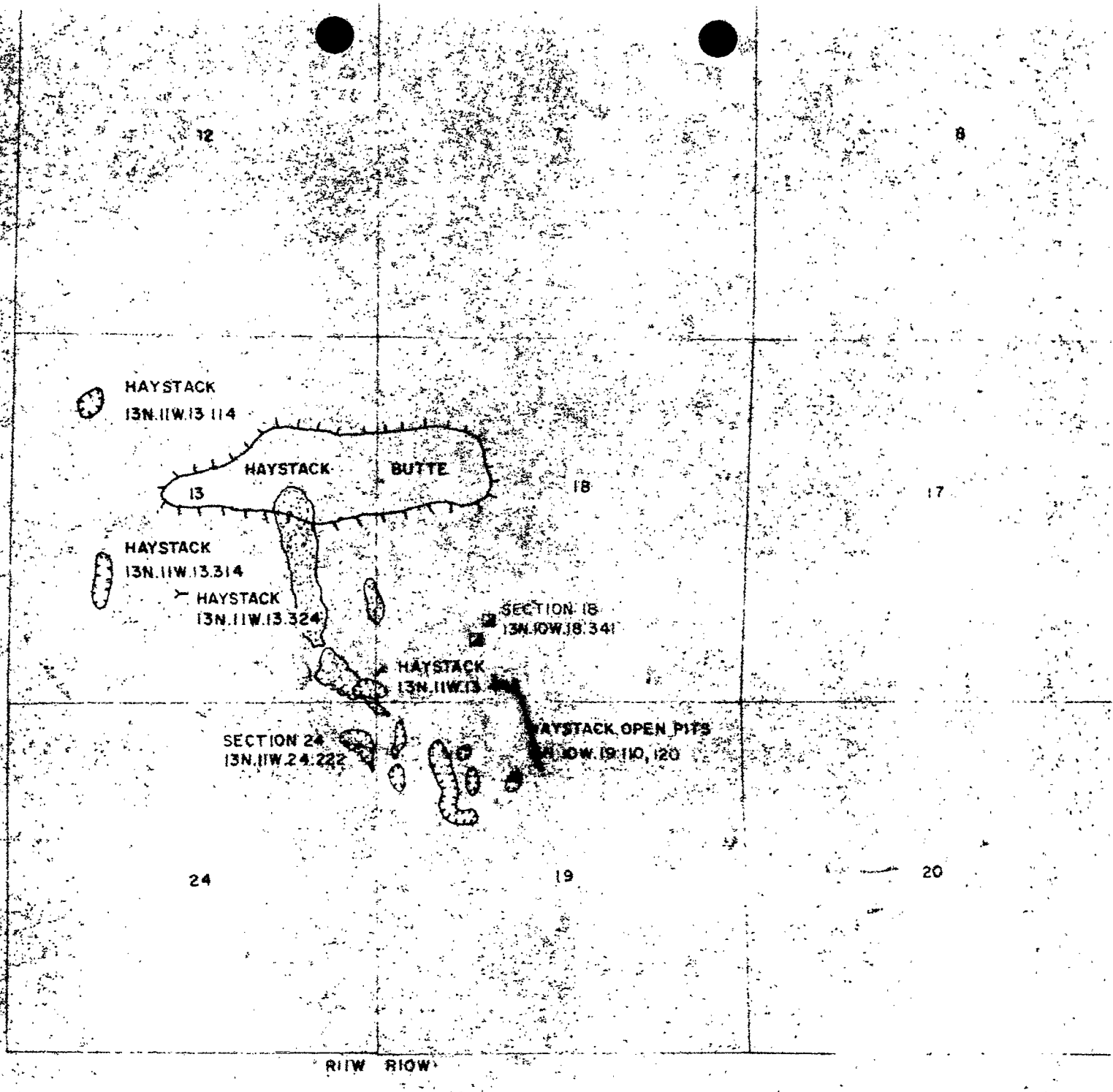
11 -URANIUM ORE DEPOSITS AND MINES IN THE AMBROSIA LAKE SUBDISTRICT, GRANTS URANIUM DISTRICT, MCKINLEY AND CIBOLA COUNTIES, NEW MEXICO.

COMPILED BY V.T. MCLEMORE FROM FIELD RECONNAISSANCE (1980 -1982), U.S. ATOMIC ENERGY COMMISSION UNPUBLISHED DATA, NMBMMR UNPUBLISHED DATA, CHAPMAN , WOOD, AND GRISWOLD, INC. (1979), SMITH AND PETERSON (1980), HAZLETT AND KREEK (1983), SQUYRES (1982), TRAUGER AND SANTOS (1968), AND CLARY AND OTHERS (1968). THIS MAP IS COMPILED FROM THE BEST DATA AVAILABLE.


12
8
HAYSTACK
13N.11W.13 114
HAYSTACK
BUTTE
13
18
17
HAYSTACK
13N.11W.13.314
HAYSTACK
13N.11W.13.324
SECTION 18
13N.10W.18.341
HAYSTACK
13N.11W.13
SECTION 24
13N.11W.24.222
HAYSTACK OPEN PITS
N.10W.19.110, 120
24
19
20
R11W
R10W

SCALE 1:100 000

KILOMETERS

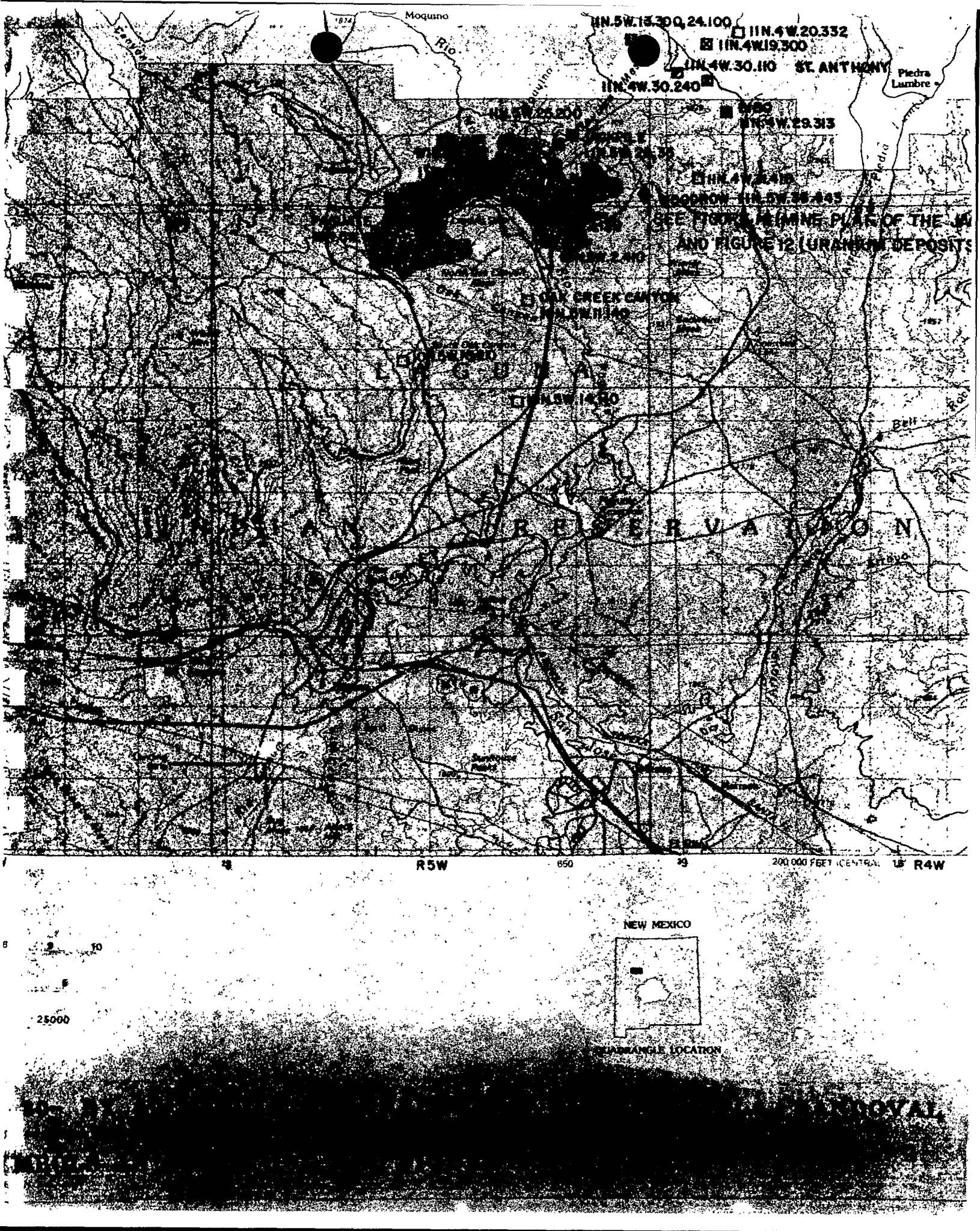
MILES

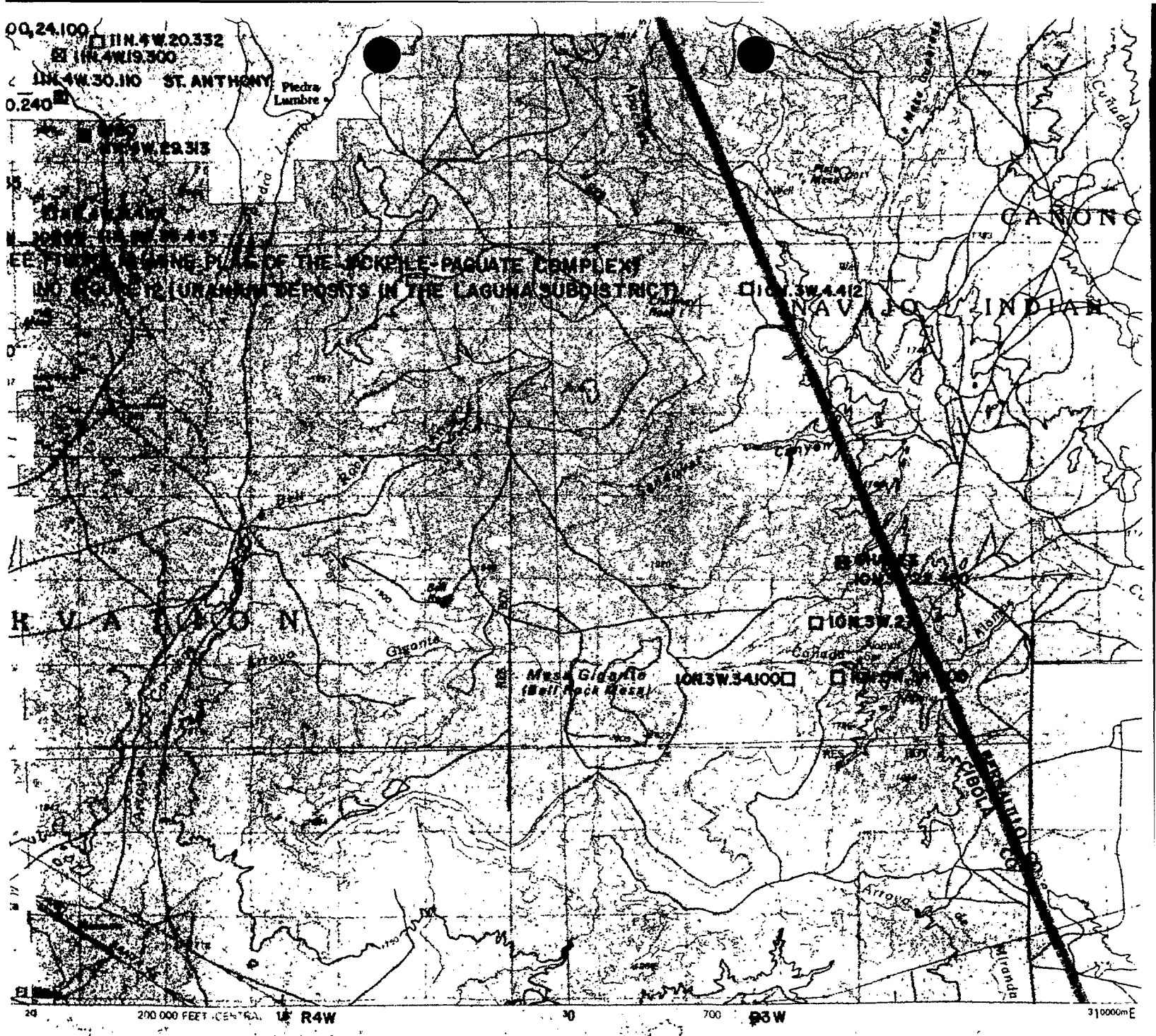
FEET

CONTOUR INTERVAL 50 METERS

...AND OCCURRENCES IN THE GRANTS 30- BY 60-MINUTE QU...

...EXPLANATION OF SYMBOLS IN TABLE 1-1...


Moquino
Rio
11N.5W.13.300, 24.100
11N.4W.20.332
11N.4W.19.300
11N.4W.30.110
ST. ANTHONY
Piedra Lumbre
11N.4W.30.240
11N.4W.29.313
SEE FIGURE 11 (MINE PLAN OF THE JA
AND FIGURE 12 (URANIUM DEPOSITS
OAK CREEK CANYON
L A G U N A
R E S E R V A T I O N
Bell
R5W
650
200 000 FEET (CENTRAL)
R4W
NEW MEXICO
QUADRANGLE LOCATION
25000



XICO

LOCATION

CIBOLA, SANDOVAL

LEGEND

Perennial stream, lake

Intermittent stream, lake

Village or locality

Landmark structure

Public park or recreation area

Forest or game land area

Other public area or
Military or Indian reservation

Primary h

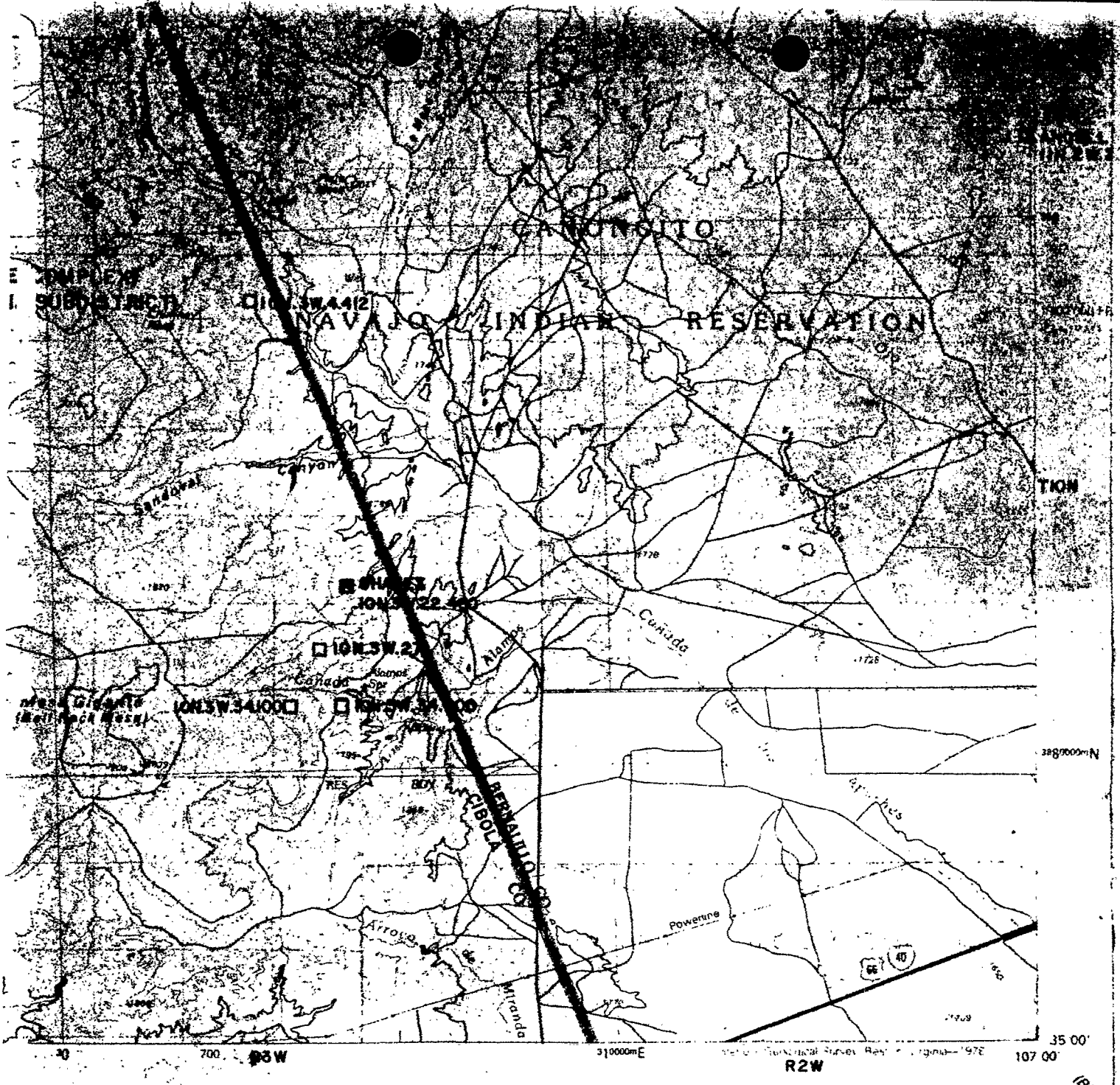
Secondary

Light-duty

Street or

Trail

Inter



LEGEND

- Perennial stream, lake
- Intermittent stream, lake
- Village or locality
- Landmark structure
- Public park or recreation area
- Forest or wood land area

ROAD CLASSIFICATION

- Primary highway, hard surface
- Secondary highway, hard surface
- Light-duty road, hard or improved surface
- Street or unimproved road
- Trail
- Interstate route
- U.S. route
- State route

GRANTS, NEW MEXICO

SW.4 ALBUQUERQUE

1978

3682

PA
Reference

REFERENCE # 3

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME PREWITT **USEPA SITE NO.** NMD980622773

DATE APRIL 11,1990 **TIME** 10:00 am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 235°/ SW

FILM TYPE POLAROID **FRAME NO.** 1

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey ( )
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

1ST FR

7. DESCRIPTION NW CORNER OF SITE, LOOKING SW: BARRELS AND CATCHMENTS, NO PERSONNEL ON SITE

NAVAJO SUPERFUND DEPARTMENT

SA Ref 3

FIT PHOTOGRAPH LOG SHEET

SITE NAME PREWITT **USEPA SITE NO.** NMD980622773

DATE APRIL 11,1990 **TIME** 10:00am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 235°/ SW

FILM TYPE POLAROID **FRAME NO.** 2

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey ( )
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

2nd FR.

7. **DESCRIPTION** NW CORNER OF SITE, LOOKING SW, WINCH, DRILLING RIG AND LAGOONS

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

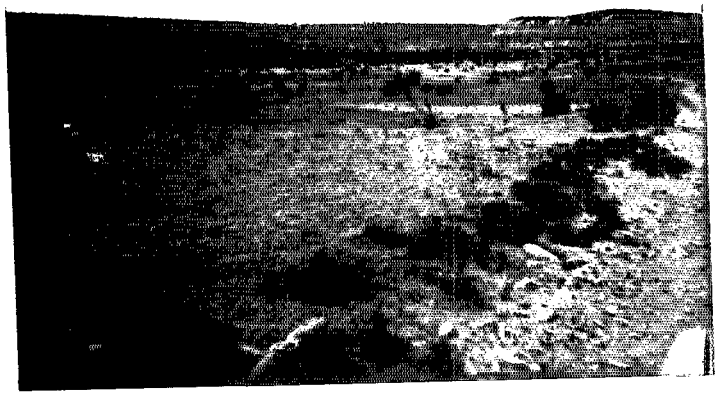
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 200°/NNW

FILM TYPE POLAROID **FRAME NO.** 38

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: NONE
5. Deep Well Water Sample ( )
6. Photograph Below: YES



4 RES.

38TH PR.

7. **DESCRIPTION** HAYSTACK COMMUNITY RESIDENCE SURVEY, NW OF HAYSTACK BUTTE.

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR TO SLIGHTLY OVERCAST
PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 135°/NW
FILM TYPE POLAROID **FRAME NO.** 38

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: NONE
5. Deep Well Water Sample ( )
6. Photograph Below: YES

SEE FRAME #39

39TH FR.

7. **DESCRIPTION** HAYSTACK COMMUNITY RESIDENCE SURVEY, NW OF HAYSTACK BUTTE.

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

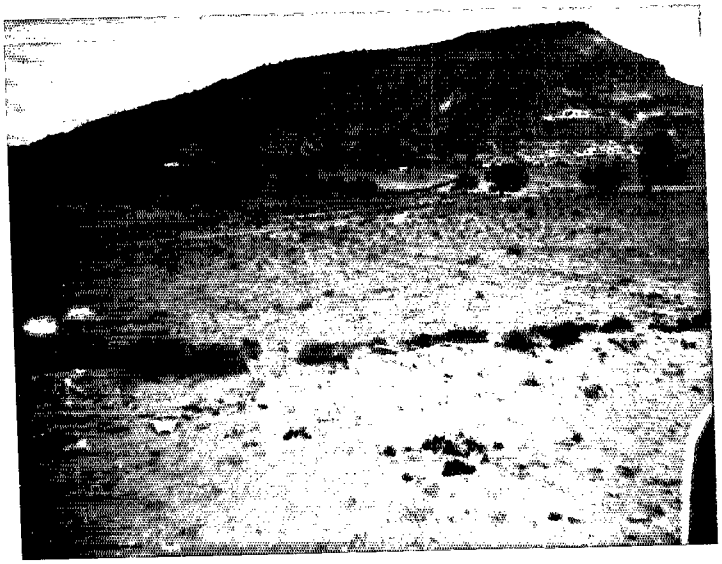
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 340°/ESE

FILM TYPE POLAROID **FRAME NO.** 40

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: NONE
5. Deep Well Water Sample ( )
6. Photograph Below: YES



3 PES.

40TH FR

7. **DESCRIPTION** HAYSTACK COMMUNITY RESIDENCE SURVEY, NNW OF HAYSTACK BUTTE.

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR TO SLIGHTLY OVERCAST
PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 200°/WSW
FILM TYPE POLAROID **FRAME NO.** 41

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: NONE
5. Deep Well Water Sample ( )
6. Photograph Below: YES

41ST FR.

7. **DESCRIPTION** WELL 16T-552 DUE W OF HAYSTACK BUTTE 1.4 mi.; WELL NOT FUNCTIONAL

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

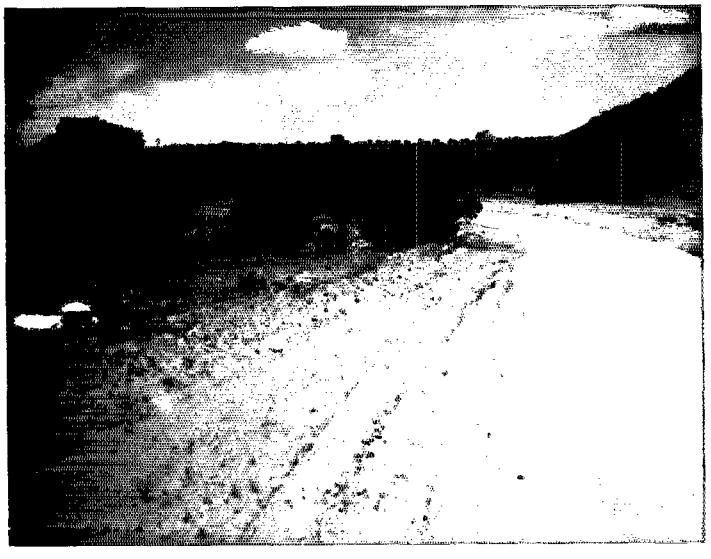
DATE MAY 11,1990 **TIME** 12:30pm **WEATHER** BROKEN CLOUDS, WINDY

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 180°/W

FILM TYPE POLAROID **FRAME NO.** 1

DATA TAKEN WITH PHOTOGRAPH: *** NO ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: ROAD DUE E OF B. VANDEVER OUTFIT



FR. #1, LKG W

7. DESCRIPTION NOTE RESIDENCES ON HORIZON, LOOKING W

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE MAY 11,1990 **TIME** 1:30pm **WEATHER** BROKEN CLOUDS, WINDY

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 60°/NE

FILM TYPE POLAROID **FRAME NO.** 2

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: LUDLUM#19 - RANGE: 11 - 22uR.hr^{-1}
   ESP - II-RANGE: 1.1 - 2.5(10^4)cpm
5. Deep Well Water Sample ( )
6. Photograph Below: DRAINAGE SW OF N. VANDEVER URANIUM MINE

FR. #2, LKG NE

7. **DESCRIPTION** MIGRATION OF RADIOACTIVE MATERIAL ACROSS ROAD UNCERTAIN DUE TO RADIOACTIVE MATERIAL DEPOSITED ON ROAD DURING HAULING OPERATIONS. NOTE SHEEP GRAZING IN FIELD, RIGHT CENTER MIDDLEGROUND.

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 2:30pm **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** SEE SKETCH

FILM TYPE POLAROID **FRAME NO.** 32

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

32 ND FR. HKG S

7. DESCRIPTION _____

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

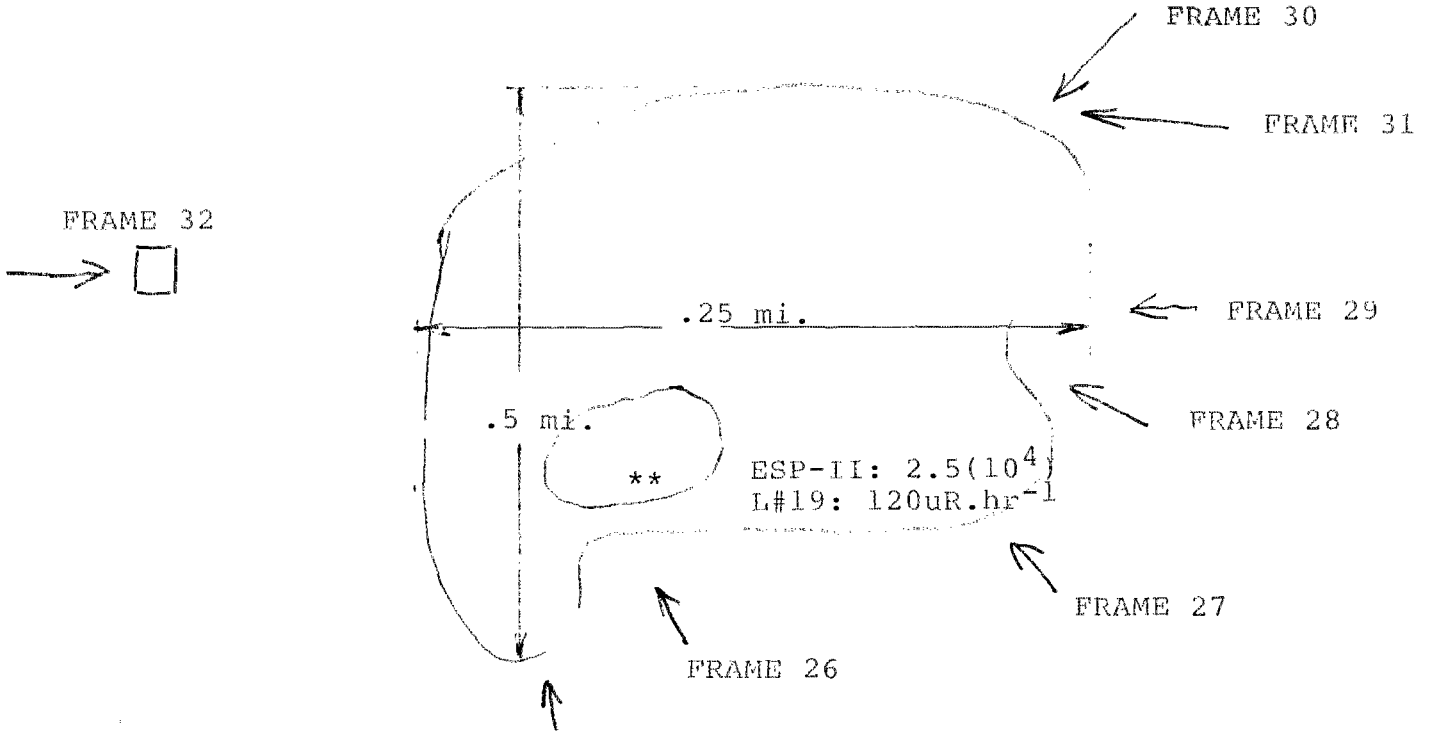
DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** _

FILM TYPE POLAROID **FRAME NO.** NO FRAME

DATA TAKEN WITH PHOTOGRAPH: SKETCH

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: SEE BELOW
5. Deep Well Water Sample ( )
6. Photograph Below: *** NONE ***



* RADIOMETRIC READINGS ASSOCIATED WITH FRAME 27

7. **DESCRIPTION** SKETCH OF AREA WHERE RADIOMETRIC READINGS WERE TAKEN, NO SCALE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** ~~NOT ASSIGNED~~

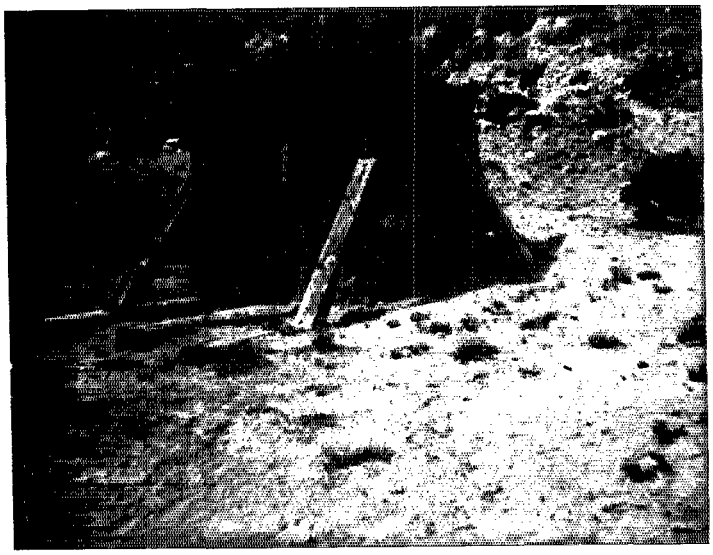
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 135°/NW

FILM TYPE POLAROID **FRAME NO.** 33

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading: 10uR.hr^{-1}(LUDLUM#19), 10^4cpm(ESP-II) @ WEST FACE OF SHACK
5. Deep Well Water Sample ( )
6. Photograph Below: YES



330° FR.

7. **DESCRIPTION** B. VANDEVER TIMBERED SHAFT, SHAFT AT AN INCLINATION OF 10° FROM VERTICAL, CIRCULAR APERTURE ON S FACING WALL IS WIRED OVER BUT WIRE IS EASILY REMOVED, SHAFT ASPIRATES, "300 FT. DEEP" B. V. TO P. MOLLOY, APRIL 11,1990

PCM

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 250°/WNW

FILM TYPE POLAROID **FRAME NO.** 33

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

33rd FR.
(VENT. SH. VERTICAL !)

7. **DESCRIPTION** VERTICAL VENTILATION SHAFTS(2), HOSTEEN BROWN VANDEVER AT RIGHT MIDDLEGROUND, SHAFTS "300 FT. DEEP" - B. V. TO P. MOLLOY, APRIL 11,1990, LOOK-WNW

PCM

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

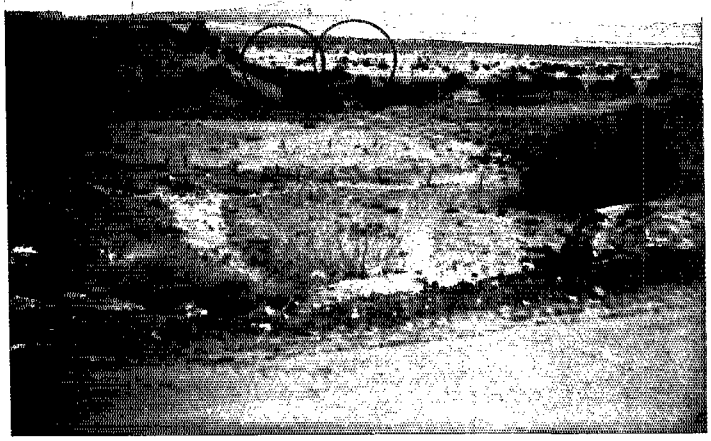
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 0°/ E

FILM TYPE POLAROID **FRAME NO.** 34

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: NONE
5. Deep Well Water Sample ( )
6. Photograph Below: YES



SOUTH FR

7. **DESCRIPTION** DRAINAGE E OF B. VANDEVER RESIDENCE, FLOWS APPROXIMATELY SE. NOTE MT. TAYLOR IN MIDDLE BACKGROUND AS REFERENT.

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 75°/NNE

FILM TYPE POLAROID **FRAME NO.** 35

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: NONE
5. Deep Well Water Sample ( )
6. Photograph Below: YES

35TH FR.
NOTE TAILINGS PILE CTR MIDDLEGROUND

7. **DESCRIPTION** ARTESIAN WELL SSW OF HAYSTACK BUTTE. WELL USED FOR STOCKWATER AND ?. NOTE N. VANDEVER URANIUM MINE TAILINGS PILE @ CENTER MIDDLEGROUND.

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

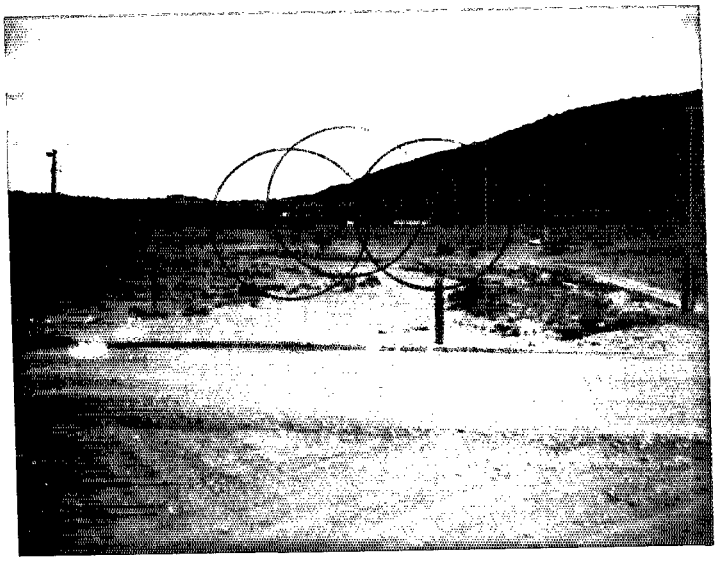
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 30°/ENE

FILM TYPE POLAROID **FRAME NO.** 36

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: NONE
5. Deep Well Water Sample ( )
6. Photograph Below: YES



6 PICTURES.

36 EXP.

7. **DESCRIPTION** HAYSTACK COMMUNITY RESIDENCE SURVEY, WNW OF HAYSTACK BUTTE.

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

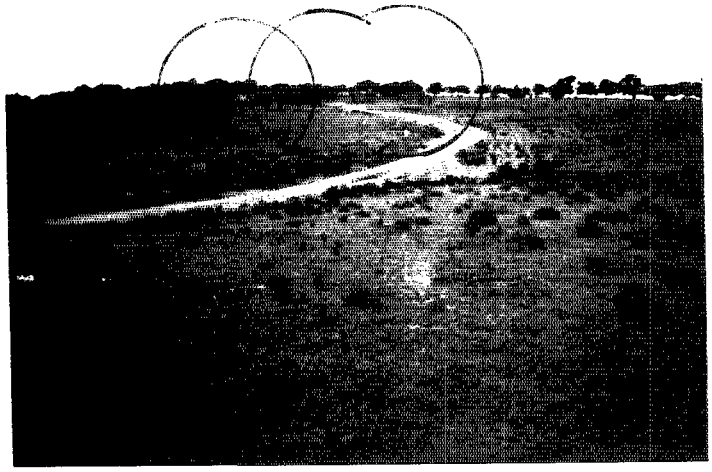
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 180°/W

FILM TYPE POLAROID **FRAME NO.** 37

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading: NONE
5. Deep Well Water Sample ( )
6. Photograph Below: YES



4 RES.

37TH FR.

7. **DESCRIPTION** HAYSTACK COMMUNITY RESIDENCE SURVEY, NW OF HAYSTACK BUTTE.

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME HAYSTACK BACKGROUND **USEPA SITE NO.** NONE

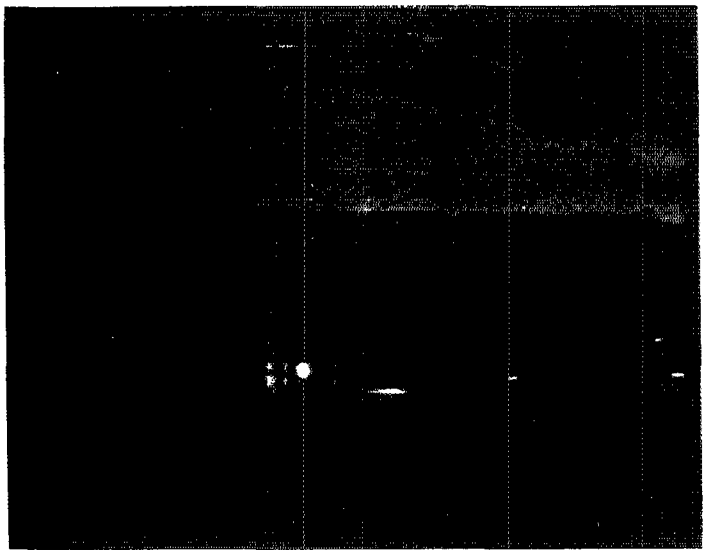
DATE APRIL 11,1990 **TIME** 10:15am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 90°/N

FILM TYPE POLAROID **FRAME NO.** 3

DATA TAKEN WITH PHOTOGRAPH: YES

1. **Soil Sample** ( )
2. **Surface Water Sample** ( )
3. **Air Monitoring Device** ( )
   Reading:_____
4. **Radiation Survey** (X)
   Reading: LUDLUM#19-7uR.hr^{-1} :: ESP-II-7(10^3)cpm
5. **Deep Well Water Sample** ( )
6. **Photograph Below:** YES



FR,

7. **DESCRIPTION** HAYSTACK AREA REFERENCE/BACKGROUND CHECK LOCATION, LOOKING N

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 20°/ENE

FILM TYPE POLAROID **FRAME NO.** 7

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: LUDLUM#19-24uR.hr^{-1} :: ESP-II - $2.2(10^4)$ BACKGROUND @ B VANDEVER
5. Deep Well Water Sample ( )
6. Photograph Below: YES

7TH FR.

7. DESCRIPTION TRENCH CUT NNE OF B. VANDEVER RESIDENCE, LOOKING NE. NOTE FRAMES 8, 9, 10 TAKEN AT SAME LOCATION

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

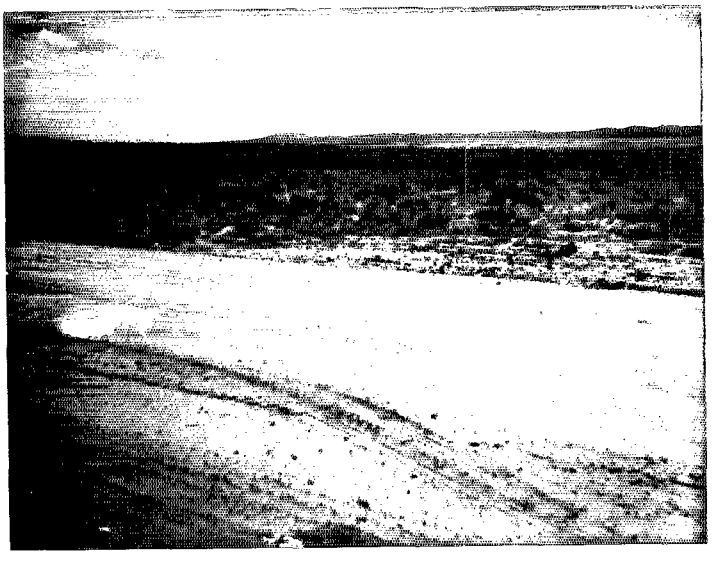
DATE MAY 11,1990 **TIME** 2:00pm **WEATHER** BROKEN CLOUDS, WINDY

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 320°/SE

FILM TYPE POLAROID **FRAME NO.** 3

DATA TAKEN WITH PHOTOGRAPH: YES, SEE PREVIOUS FRAME

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: CONTINUATION OF DRAINAGE SW OF N. VANDEVER URANIUM MINE



FR. # 3; LKG SE

7. DESCRIPTION ROAD IS OLD HAULAGE ROAD

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME PREWITT **USEPA SITE NO.** NMD980622773

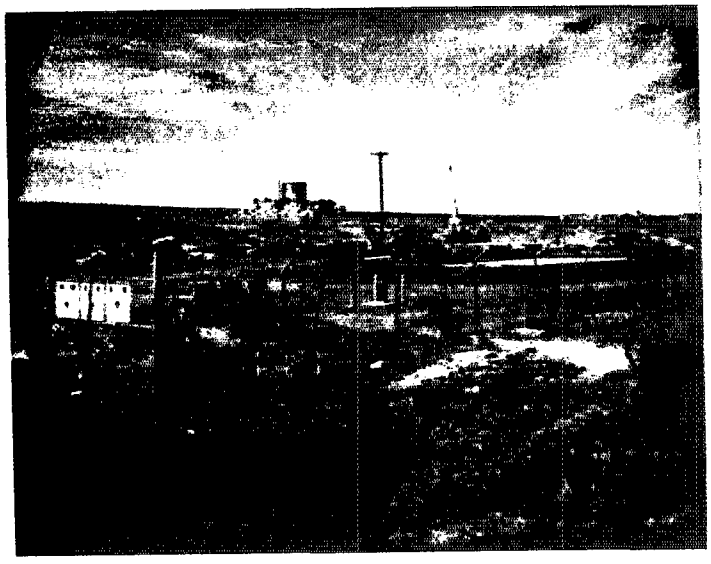
DATE APRIL 11,1990 **TIME** 10:00am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 235°/ SW

FILM TYPE POLAROID **FRAME NO.** 2

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey ( )
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



2nd FR.

7. DESCRIPTION NW CORNER OF SITE, LOOKING SW, WINCH, DRILLING RIG AND LAGOONS

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME HAYSTACK BACKGROUND **USEPA SITE NO.** NONE

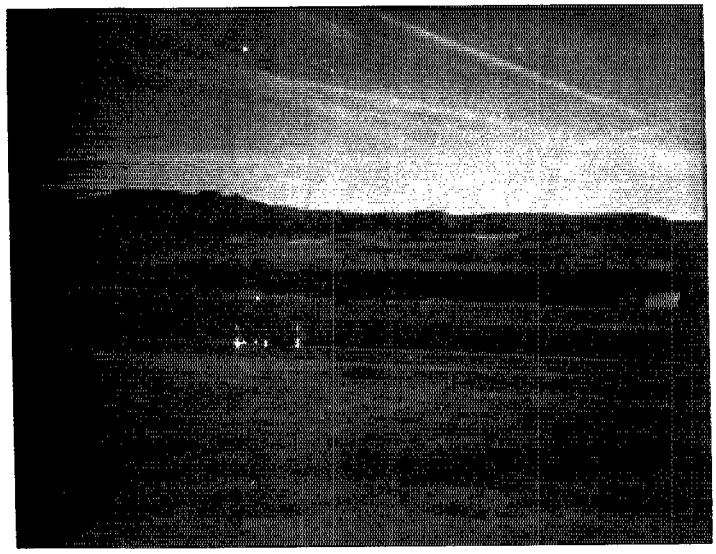
DATE APRIL 11,1990 **TIME** 10:15am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 90°/N

FILM TYPE POLAROID **FRAME NO.** 3

DATA TAKEN WITH PHOTOGRAPH: YES

1. **Soil Sample** ( )
2. **Surface Water Sample** ( )
3. **Air Monitoring Device** ( )
   Reading: _____
4. **Radiation Survey** (X)
   Reading: LUDLUM#19-7uR.hr^{-1} :: ESP-II-7(10^3)cpm
5. **Deep Well Water Sample** ( )
6. **Photograph Below:** YES



~~3rd~~ FR,

7. **DESCRIPTION** HAYSTACK AREA REFERENCE/BACKGROUND CHECK LOCATION, LOOKING N

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE _____ **TIME** 10:00am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 60°/NNE

FILM TYPE POLAROID **FRAME NO.** 4

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey ( )
   Reading: _____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

WINDMILL
16T-552

1 RES.

4TH FR

7. **DESCRIPTION** RESIDENCE LOCATIONS W OF HAYSTACK BUTTE, LOOKING NNW

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

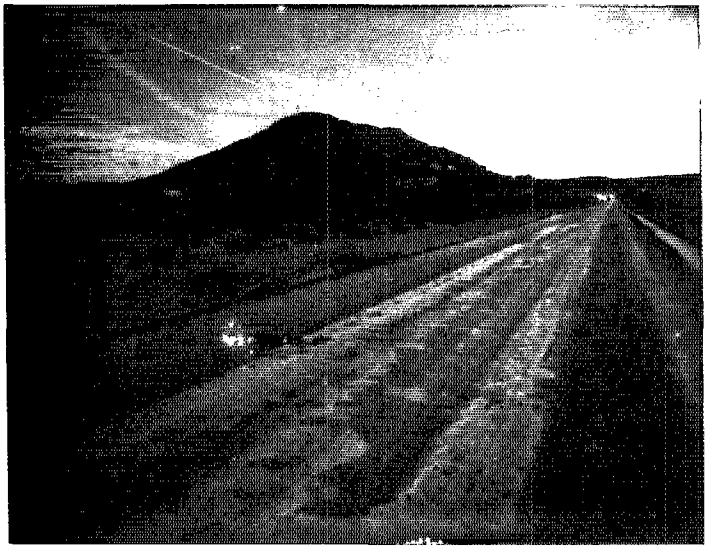
DATE APRIL 11,1990 **TIME** 10:20am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 20°/ENE

FILM TYPE POLAROID **FRAME NO.** 5

DATA TAKEN WITH PHOTOGRAPH: NONE

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey ( )
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



5TH FR

7. **DESCRIPTION** HAYSTACK BUTTE, REFERENT, LOOKING E OF ENE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** _____

FILM TYPE POLAROID **FRAME NO.** 6

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey ( )
   Reading: _____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

2 RES.

6TH FR.

7. **DESCRIPTION** RESIDENCES W OF HAYSTACK BUTTE, LOOKING NE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 20°/ENE

FILM TYPE POLAROID **FRAME NO.** 7

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: LUDLUM#19-24uR.hr^{-1} :: ESP-II - $2.2(10^4)$ BACKGROUND @ B VANDEVER
5. Deep Well Water Sample ( )
6. Photograph Below: YES

7TH F12.

7. **DESCRIPTION** TRENCH CUT NNE OF B. VANDEVER RESIDENCE LOOKING NE. NOTE FRAMES 8, 9, 10 TAKEN AT SAME LOCATION

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

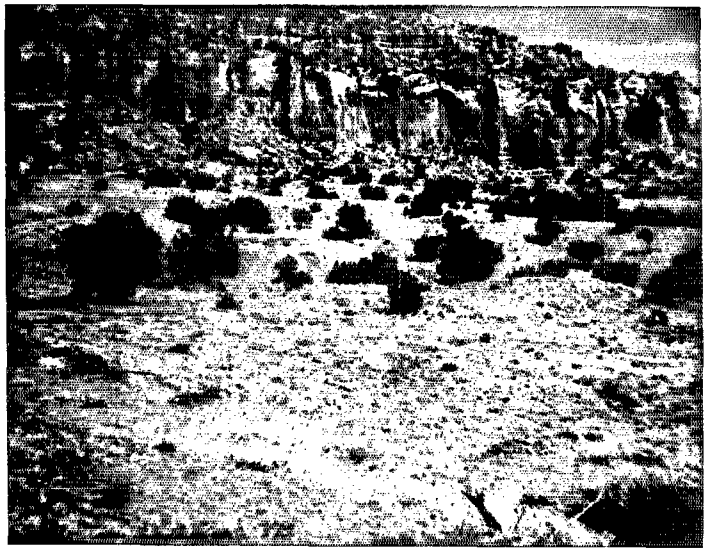
DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 70°/NNE

FILM TYPE POLAROID **FRAME NO.** 8

DATA TAKEN WITH PHOTOGRAPH: YES, SEE FRAME 7

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



8TH FR.

7. **DESCRIPTION** TAILINGS FROM INCLINED ADIT IN FRAME 12, LOOKING NNE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 0°/E

FILM TYPE POLAROID **FRAME NO.** 9

DATA TAKEN WITH PHOTOGRAPH: YES, SEE FRAME 7

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

9TH FR,

7. **DESCRIPTION** MT. TAYLOR AS REFERENT IN FAR RIGHT CENTER BACKGROUND, LOOKING E

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 70°/NNE

FILM TYPE POLAROID **FRAME NO.** 10

DATA TAKEN WITH PHOTOGRAPH: YES, SEE FRAME 7

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

3 RES.

10-27 FR
(MARTINEZ RES.)

7. DESCRIPTION MARTINEZ RESIDENCES AT CENTER MIDDLE-GROUND, LOOKING NNE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** -

FILM TYPE POLAROID **FRAME NO.** 11

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey ( )
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: NO

7. DESCRIPTION FRAME LOST

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 110°/NNW

FILM TYPE POLAROID **FRAME NO.** 12

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading: LUDLUM#19 - 21uR.hr^{-1} : @ FACE OF ADIT
5. Deep Well Water Sample ( )
6. Photograph Below: YES

12TH FR.

7. DESCRIPTION INCLINED ADIT N OF B. VANDEVER RESIDENCE, LOOKING NNW

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 45°/NE

FILM TYPE POLAROID **FRAME NO.** 13

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey ( )
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

13TH FR.
(TRENCH & TP.)

7. DESCRIPTION R&R TRENCH AND TAILINGS PILE SSE OF INCLINED ADIT, LOOKING NE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** -

FILM TYPE POLAROID **FRAME NO.** 14

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: .1mR.hr^{-1}(LUDLUM#19) @ FACE OF MATERIAL
5. Deep Well Water Sample ( )
6. Photograph Below: YES

WITH FR.
("HOT ROCK")

7. DESCRIPTION ORE SAMPLE "HOT ROCK"

FILM TYPE _____ FRAME NO. _____

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: 350uR.hr^{-1}(LUDLUM#19) : @ EDGE OF
5. Deep Well Water Sample ( )
6. Photograph Below: YES

15TH FR.

7. DESCRIPTION TRENCH AT CENTER MIDDLEGROUND "LOADING BAY", LOOKING N OF NNE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

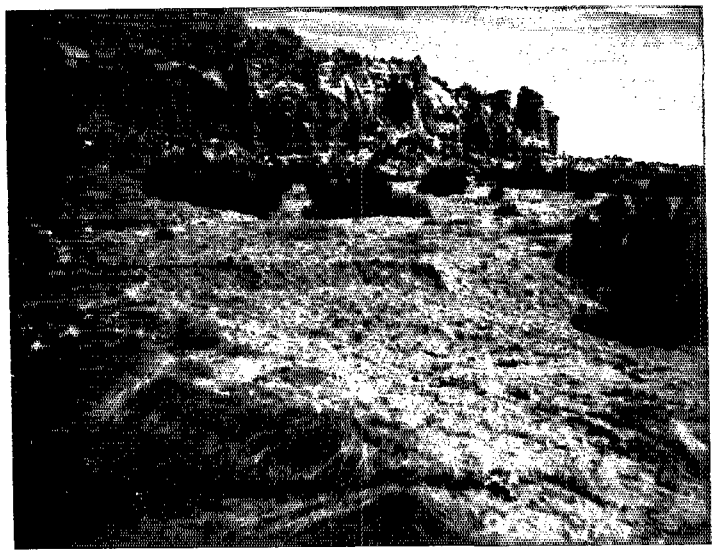
DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 10°/N OF NNE

FILM TYPE POLAROID **FRAME NO.** 15

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: 350uR.hr^{-1}(LUDLUM#19) : @ EDGE OF "LOADING BAY"
5. Deep Well Water Sample ( )
6. Photograph Below: YES



15TH FR.

7. **DESCRIPTION** TRENCH AT CENTER MIDDLEGROUND IS ORE "LOADING BAY", LOOKING N OF NNE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

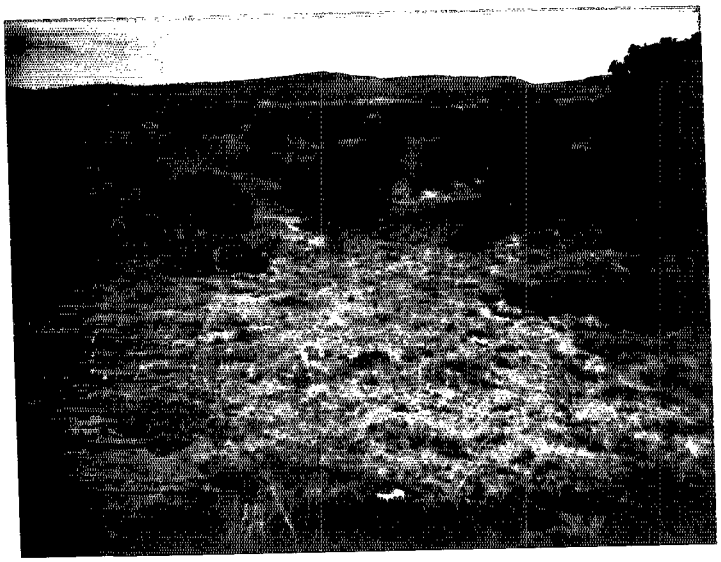
DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 45°/NE

FILM TYPE POLAROID **FRAME NO.** 16

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey ( )
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



16TH FR - DRAINAGE

7. DESCRIPTION DRAINAGE E OF TAILINGS PILES, LOOKING ENE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 180°/W

FILM TYPE POLAROID **FRAME NO.** 16'

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading: SEE BELOW IN DESCRIPTION
5. Deep Well Water Sample ( )
6. Photograph Below: YES , EXTRA FRAME

16TH FR.
MOUTH OF DRAINAGE

7. **DESCRIPTION** MOUTH OF DRAINAGE, TAILINGS PILE ON RIGHT, ESP-II READINGS: @MOUTH - $5(10^4)$; @MIDWAY PAST TAILINGS - $6.5(10^4)$; @END OF TAILINGS - $3.25(10^4)$; ALL READINGS IN cpm., LOOKING W

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 90°/N

FILM TYPE POLAROID **FRAME NO.** 17

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading: 6.5(10^4)cpm(ESP- II) IN DRAINAGE BELOW CEDAR TREE
5. Deep Well Water Sample ( )
6. Photograph Below: YES

17TH E/2

7. **DESCRIPTION** GAMMA RATEMETER READING IN DRAINAGE E OF TAILINGS PILES(SEE DIAGRAM ON FOLLOWING PAGE), LOOKING N

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 20°/ENE

FILM TYPE POLAROID **FRAME NO.** 18

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: 3.5(10^4)cpm(ESP-II) : @ BEND IN WASH
5. Deep Well Water Sample ( )
6. Photograph Below: YES

18TH FR.

7. **DESCRIPTION** GAMMA RATEMETER READING DOWN DRAINAGE (E) IN WASH E OF TAILINGS, LOOKING SSE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

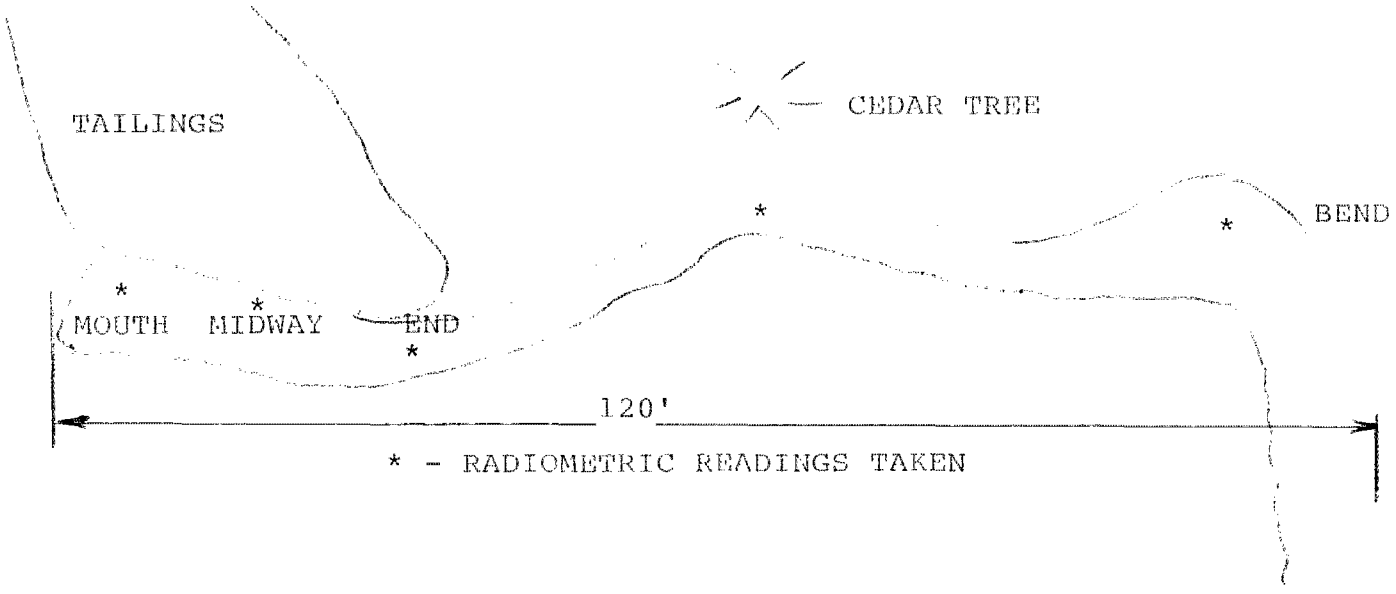
DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** _____

FILM TYPE POLAROID **FRAME NO.** NO FRAME

DATA TAKEN WITH PHOTOGRAPH: SKETCH, OF E FLOWING DRAINAGE

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey ( )
   Reading: _____
5. Deep Well Water Sample ( )
6. Photograph Below: *** NONE ***



7. **DESCRIPTION** SKETCH OF DRAINAGE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 180°/W

FILM TYPE POLAROID **FRAME NO.** 19

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: 2.5(10^4)cpm(ESP-II) @ENTRANCE TO TRENCH
5. Deep Well Water Sample ( )
6. Photograph Below: YES

10721 E
(TRENCH & "SPOT")

7. **DESCRIPTION** TRENCH CUT NE OF B. VANDEVER RES., SEE ACCOMPANYING SKETCH ON FOLLOWING PAGE, LOOKING W.

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

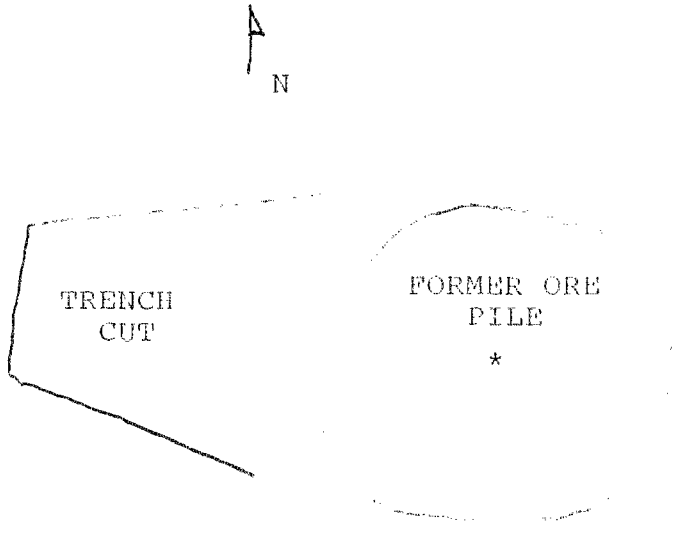
DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** -

FILM TYPE POLAROID **FRAME NO.** NO FRAME

DATA TAKEN WITH PHOTOGRAPH: SEE PREVIOUS FRAME

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: *** SKETCH ***



* - 2.5(104)cpm

7. DESCRIPTION SKETCH OF TRENCH CUT NE OF B.V. RESIDENCE

NAVAJO NATION EPA

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

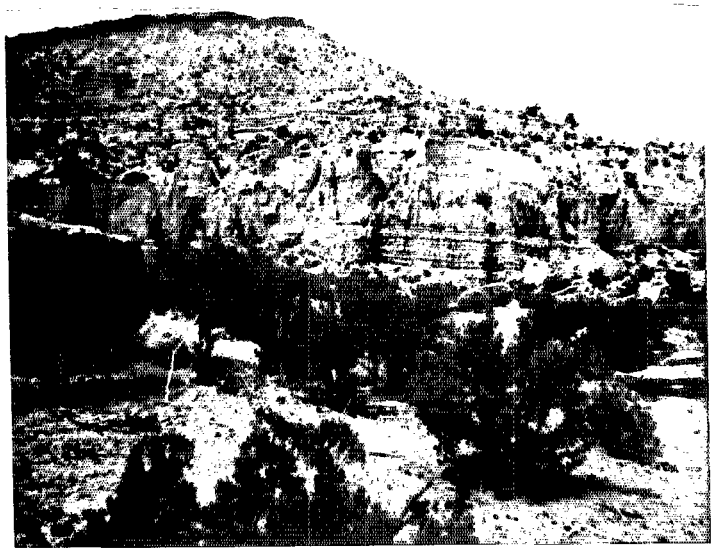
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 90°/N

FILM TYPE POLAROID **FRAME NO.** 20

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey ( )
   Reading: _____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



20TH FE.
(GEOL.)

7. **DESCRIPTION** REFERENCE FRAME - GEOLOGY/FORMATIONS PRESENT @ HAYSTACK BUTTE, LOOKING N., SEE FOLLOWING ANNOTATED PHOTO FACSIMILE

FIT PHOTOGRAPH LOG SH[illegible]

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

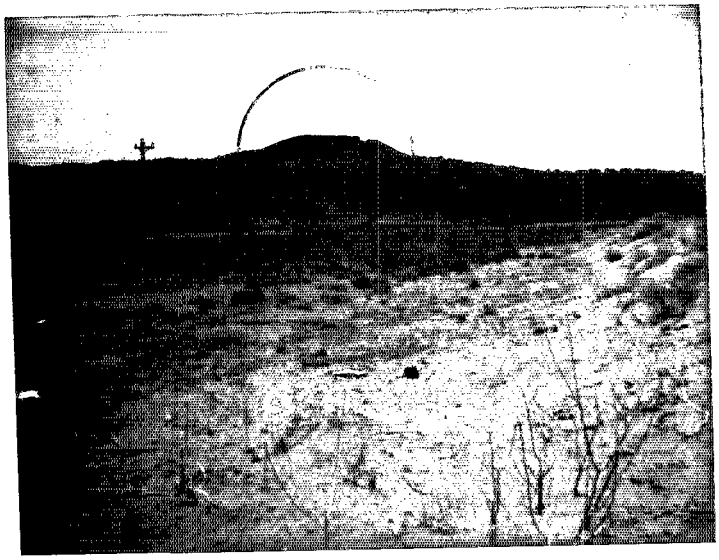
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 270°/S

FILM TYPE POLAROID **FRAME NO.** 20'

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey ( )
   Reading: _____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



20TH FR. (EL TINTERO CINDER CONE, REF. 1

7. DESCRIPTION EL TINTERO CINDER CONE REFERENT, LOOKING S

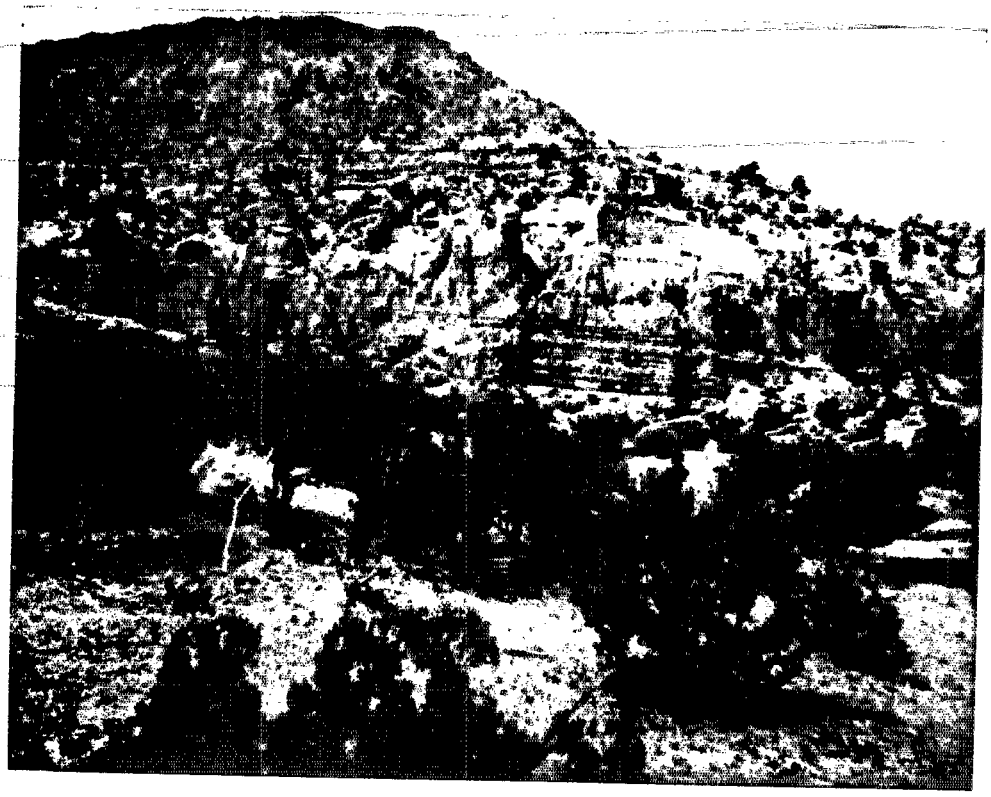
DAKOTA Kd

MORRISON FORMATION Jm

COW SPRINGS SS Jcs

SUMMERVILLE Js

TODILTO Jt



20TH FR.
(GEOL.)

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE
LOCAL GEOLOGY: PATRICK ANTONIO, NSO STAFF HYDROLOGIST TO P. MOLLOY

JCM

APRIL,'90 P. MOLLOY

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 200°/WSW

FILM TYPE POLAROID **FRAME NO.** 21

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey ( )
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

2 RES.

21ST FR.

7. **DESCRIPTION** B. VANDEVER OUTFIT RESIDENCES, LOOKING WSW

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 0°/E

FILM TYPE POLAROID **FRAME NO.** 22

DATA TAKEN WITH PHOTOGRAPH: YES

1. **Soil Sample** ( )
2. **Surface Water Sample** ( )
3. **Air Monitoring Device** ( )
   Reading: _____
4. **Radiation Survey** (x)
   Reading: 10^5cpm(ESP-II) @ EDGE OF ROAD
5. **Deep Well Water Sample** ( )
6. **Photograph Below:** YES

22nd Fr.

7. **DESCRIPTION** "HOT ROAD" WEST OF B. V. RESIDENCES, SURFACE WORKS WASTE PILES @ RIGHT MIDDLEGROUND, MT. TAYLOR @ UPPER LEFT BACKGROUND AS REFERENT

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** _____ **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 270°/W

FILM TYPE POLAROID **FRAME NO.** 23

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: _____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

23rd FR - T.P.
(No. VANDEVER?)

DRAIN

7. **DESCRIPTION** NANA - A - BAH VANDEVER MINE ? WESTERN EXTENT OF B. VANDEVER WORKS, NOTE DRAINAGE, LOOKING W

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

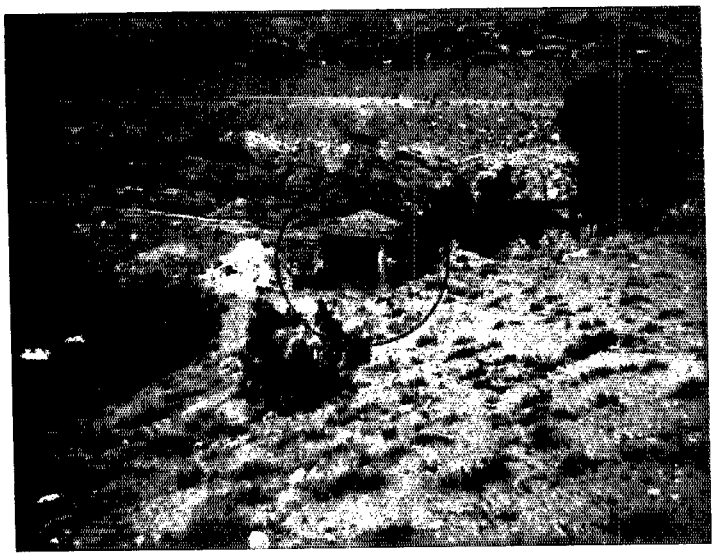
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 135°/NW

FILM TYPE POLAROID **FRAME NO.** 24

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



24TH FEB. - ADIT
(N. VANEVER 2.)

7. **DESCRIPTION** NANA - A - BAH VANDEVER MINE ADIT TRENDING N, ADIT IS BARRED

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 315°/ESE

FILM TYPE POLAROID **FRAME NO.** 25

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

25TH FP

7. **DESCRIPTION** WESTERN EXTENT OF SURFACE WORKS WSW OF B. V. RESIDENCE, LOOKING ESE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

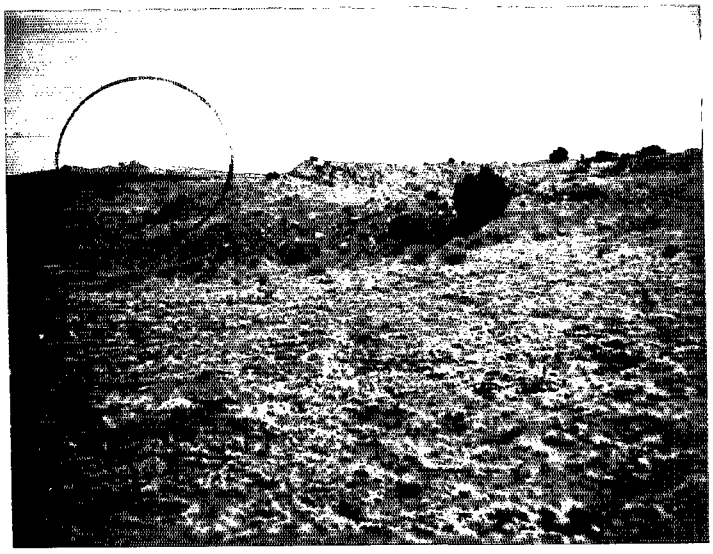
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 350°/E OF ESE

FILM TYPE POLAROID **FRAME NO.** 26

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



26 1st E of

7. **DESCRIPTION** SURFACE WORKS WSW OF B. V. RES., LOOKING E OF ESE; NOTE MT. TAYLOR IN FAR LEFT BACKGROUND AS REFERENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

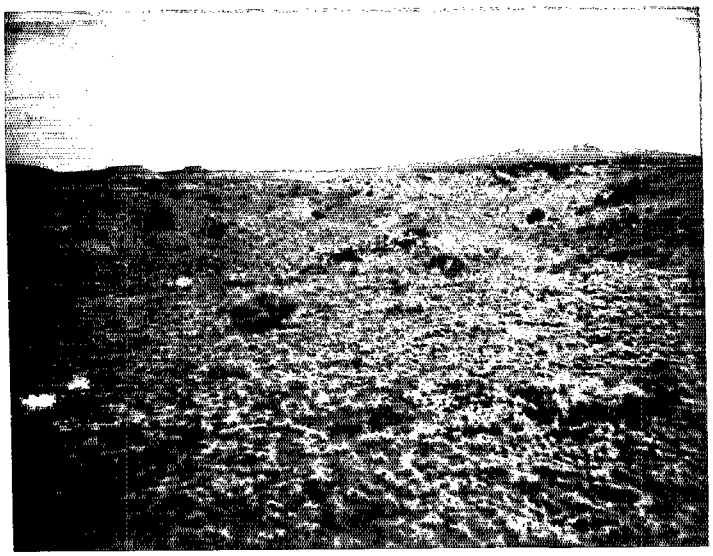
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR -HIGH HAZY CLOUDS

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 20°/E OF ENE

FILM TYPE POLAROID **FRAME NO.** 27

DATA TAKEN WITH PHOTOGRAPH: YES, NOT WRITTEN DOWN

1. **Soil Sample** ( )
2. **Surface Water Sample** ( )
3. **Air Monitoring Device** ( )
   Reading: _____
4. **Radiation Survey** (X)
   Reading: ~~150uR.hr-1(I~~UDLUM#19), 10^4cpm(ESP-II)
   *** APPROXIMATE ***
5. **Deep Well Water Sample** ( )
6. **Photograph Below:** YES



27 94 FR

7. **DESCRIPTION** SURFACE WORKS WSW OF B. V. RES., SEE FOLLOWING SKETCH, LOOKING E OF ENE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

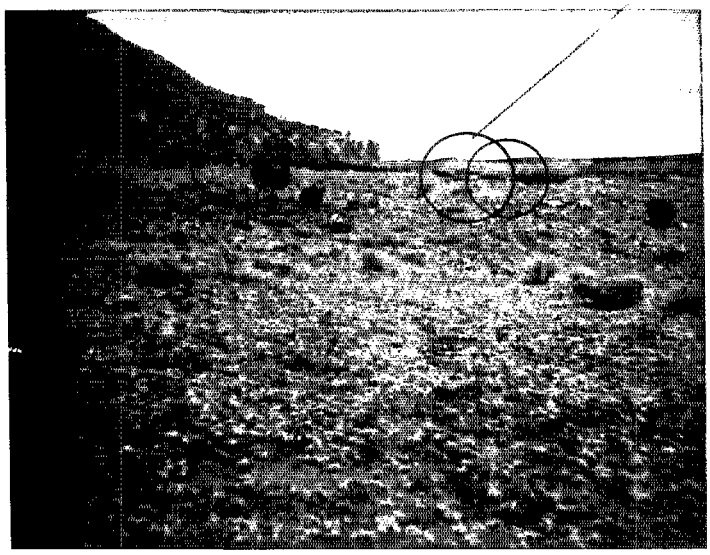
DATE APRIL 11,1990 **TIME** _____ **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** _____

FILM TYPE POLAROID **FRAME NO.** 28

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: _____
5. Deep Well Water Sample ( )
6. Photograph Below: YES, SEE SKETCH



28 TH E/

7. DESCRIPTION SEE SKETCH

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

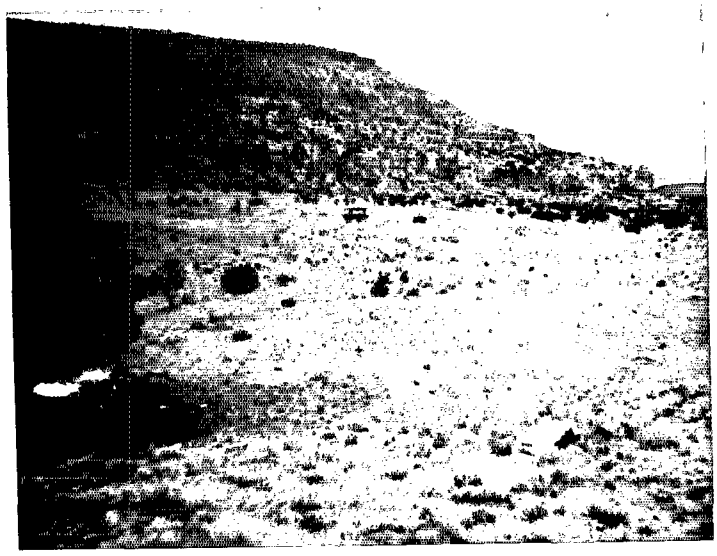
DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** SEE SKETCH

FILM TYPE POLAROID **FRAME NO.** 29

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey ( )
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



29TH FC

7. DESCRIPTION _____

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

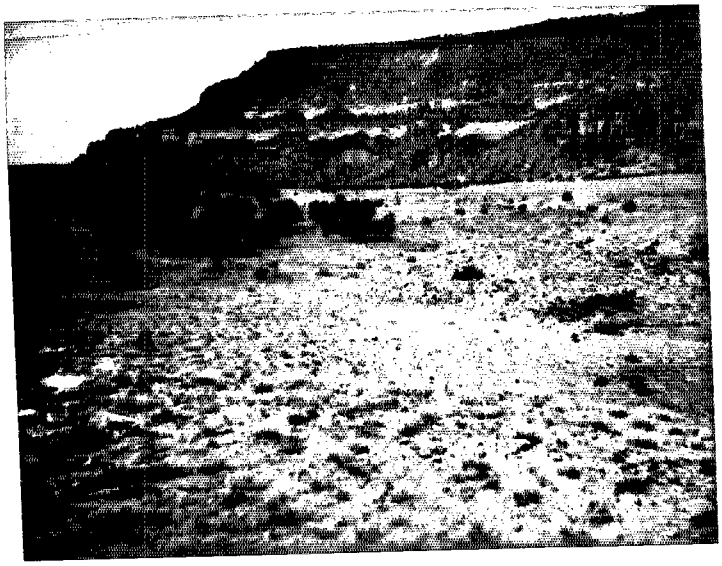
DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** SEE SKETCH

FILM TYPE POLAROID **FRAME NO.** 30

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



30TH FR.

7. DESCRIPTION _____

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

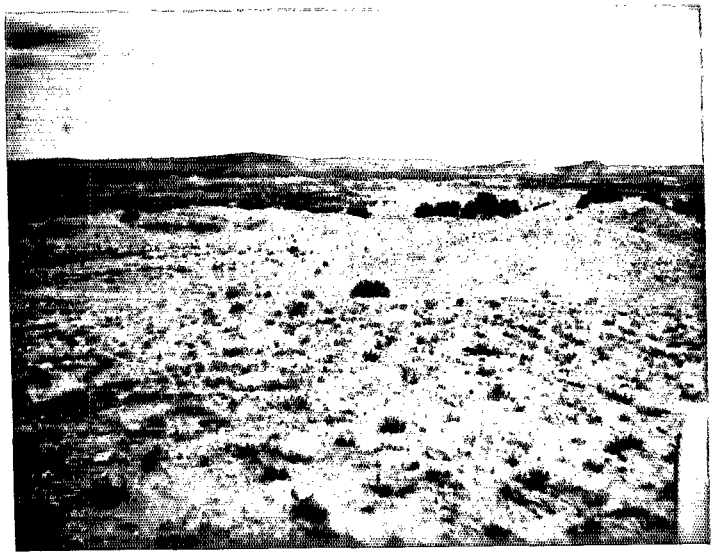
DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** SEE SKETCH

FILM TYPE POLAROID **FRAME NO.** 31

DATA TAKEN WITH PHOTOGRAPH:

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (x)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



31ST FR.

7. DESCRIPTION _____

NAVAJO SUPERFUND DEPARTM

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE N**

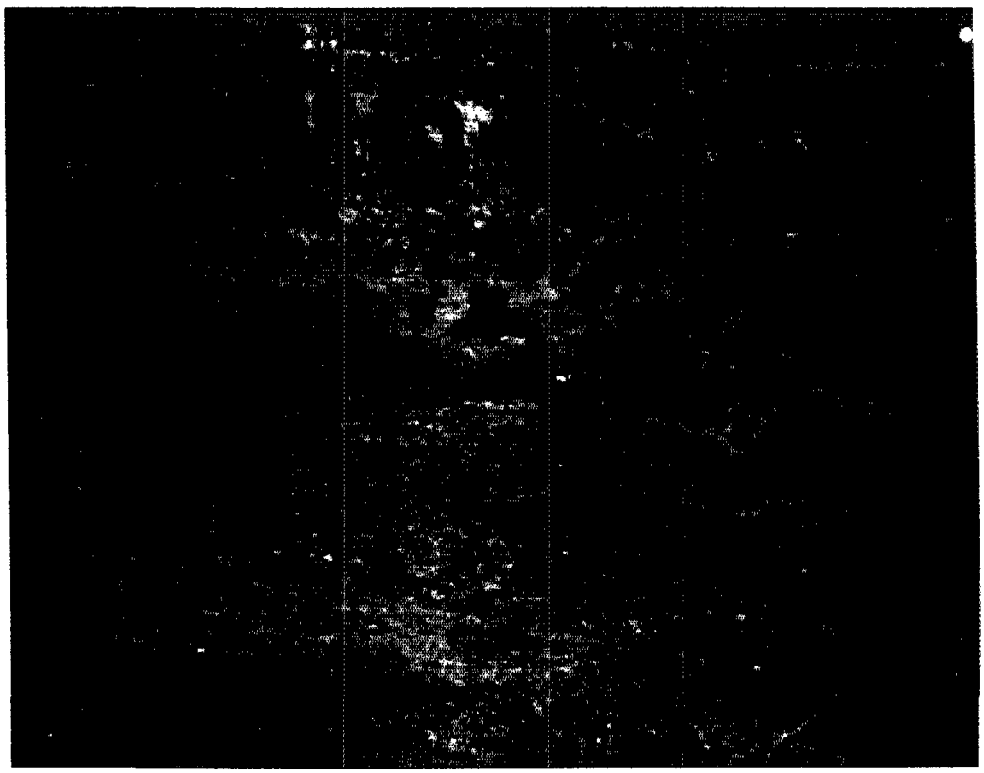
DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECT**

FILM TYPE POLAROID **FRAME NO.** 8

DATA TAKEN WITH PHOTOGRAPH: YES, SEE FRAME 7

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 110°/NNW

FILM TYPE POLAROID **FRAME NO.** 12

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading: LUDLUM#19 - 21uR.hr^{-1} : @ FACE OF ADIT
5. Deep Well Water Sample ( )
6. Photograph Below: YES

12TH FR.

7. **DESCRIPTION** INCLINED ADIT N OF B. VANDEVER RESIDENCE, LOOKING NNW

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

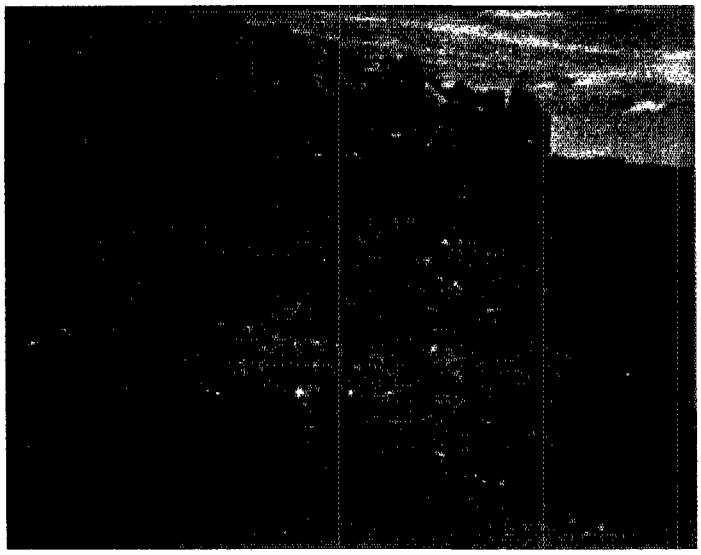
DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 10°/N OF NNE

FILM TYPE POLAROID **FRAME NO.** 15

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading: 350uR.hr^{-1}(LUDLUM#19) : @ EDGE OF "LOADING BAY"
5. Deep Well Water Sample ( )
6. Photograph Below: YES



15TH FR.

7. DESCRIPTION TRENCH AT CENTER MIDDLEGROUND IS ORE "LOADING BAY", LOOKING N OF NNE

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE**

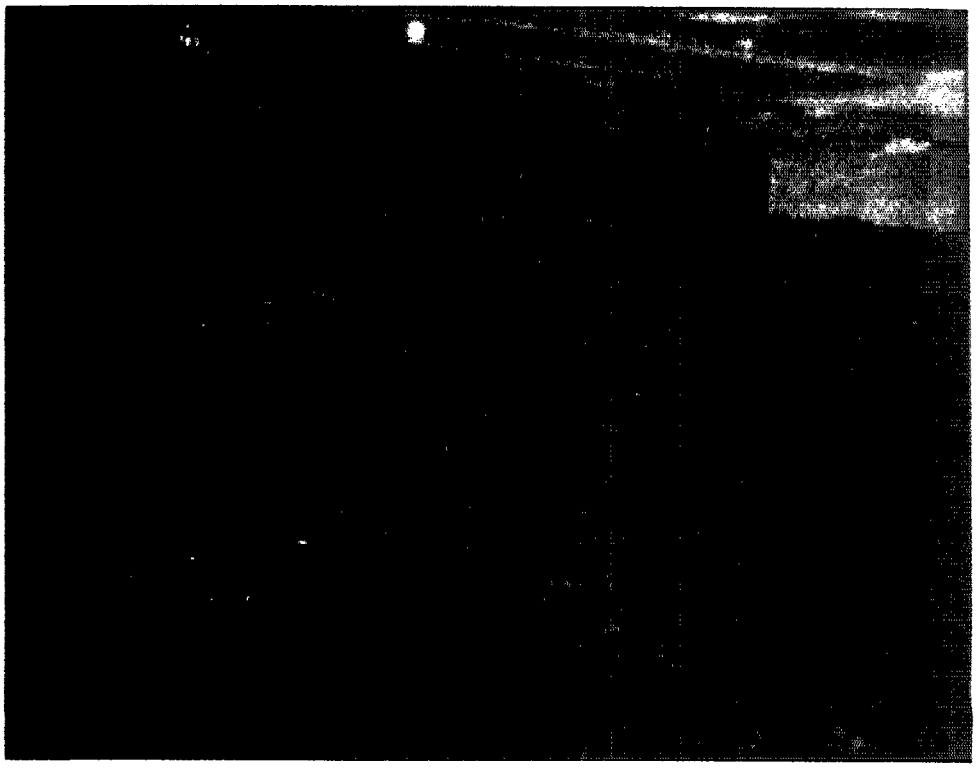
DATE APRIL 11,1990 **TIME** 10:25am **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECT**

FILM TYPE POLAROID **FRAME NO.** 15

DATA TAKEN WITH PHOTOGRAPH: YES

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: 350uR.hr^{-1}(LUDLUM#19) : @ EDGE
5. Deep Well Water Sample ( )
6. Photograph Below: YES



REFERENCE # 4

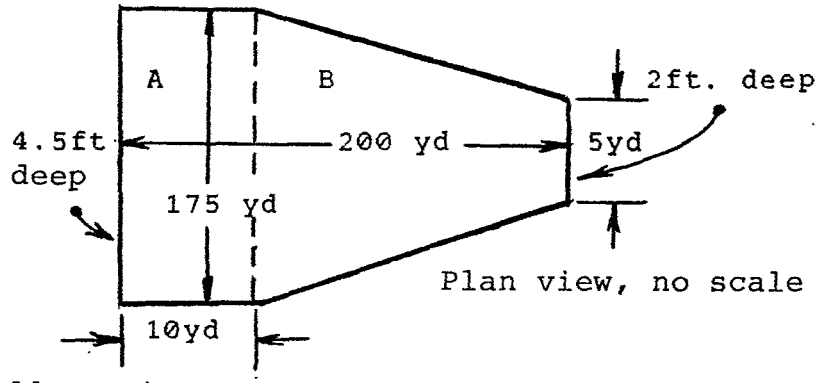
NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

Mine spoils calculations for the Brown Vandever uranium mine

1. From frame #15 of Ref #3 and field notes page #3 (Ref #14) consider that the tailings pile has the geometric shape;



It follows that

$$V_A = (525\text{ft.})(30\text{ft.})(4.5\text{ft.})$$
$$= 7.09(10^4)\text{ft}^3$$

and

$$V_B = (570\text{ft.})\left(\frac{15\text{ft.} + 525\text{ft}}{(2)}\right)*\left(\frac{4.5\text{ft.} + 2\text{ft}}{(2)}\right)$$
$$= 5(10^5)\text{ft}^3$$

2. The combined geometric volume is;

$$V_{geo} = 5.7(10^5)\text{ft.}^3 \text{ or } V_{geo} = 1.62(10^{10})\text{cm}^3$$

3. Compensate this volume for void volume overestimate to obtain;

$$V_{TP} \sim (.7)(1.62(10^{10})\text{cm}^3 = 1.13(10^{10})\text{cm}^3.$$

4. Assume that the percentage of U_3O_8 within this volume is 10^{-2}% whereby;

$$Vu_3o_8 = 1.13(10^6)\text{cm}^3.$$

5. From general assumptions, the density of U_3O_8 was found to be 23.26 gm. cm^{-3} Applying this quantity to volume of U_3O_8 find

$$Mu_3O_8 = 2.63(10^4)\text{kg}$$
$$\approx 30 \text{ tons}$$

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE

MAY,'90 P. MOLLOY

FIELD NOTES

PAGE#1

- 9TH FRAME - DRUM #27 (ELDRIN)
□ KLEENGARD - KIMBERLY CLARK
* - MORE TEAR RESIST. THAN TYVEK

*** ◇ WHOLE BODY COUNTS! ***

APRIL 11, 1990: B. VANDEVER MINE (HAYSTACK BUTTE AREA)
◇ @ NSO
- LUDLUM #19 - 7 μR·hr⁻¹
- ESP-II γ RATEMETER ≃ 7 (10³) cpm
◇ - PREWITT SITE
- 2 FRAMES OF RECLAMATION WORK
◇ TURN OFF TO HAYSTACK BUTTE
○ BACKGROUND (LUDLUM #19)
- @ SHINE ~ 5 μR·hr⁻¹
- @ FACE ~ SAME
○ B'GRND (ESP-II
- @ SHINE ~ 6.5 (10³) cpm: FACE SAME
◇ od. RESET @ 17218.4 mi.
◇ 3rd FR. - REFERENT FRAME FOR B'GRND CHECK (NOTE EXTENSIVE SURFACE WORKS, RIGHT CNTR MIDDLE GROUND)
◇ 17220 (1.6)
○ 2 FRAMES OF RES. W OF HAYSTACK BUTTE
- 6TH FR. NOTE HAYSTACK B. IN MIDDLE GROUND AS REFERENT ALSO WINDMILL

◇ 17220.9 (
- 6TH FR.
HAYSTAC
◇ 17222.4 (
- 1 RES. &
◇ 17223.7
- BROWN V.
- 1 RES. (
◇ 3 FRAME
- 7TH FR. -
- 8TH FR. -
RES
- 9TH FR. -
DZM
- 10TH FR. -
◇ 1 FRAME
@ B. VAN
- B'GRND
○ LUDLUM
○ ESP II
○ SHINE
○ SHINE
◇ 12TH FR. -
◇ 13TH FR. -
○ LUDLUM
SHINE
◇ B. VANDEV
- "STOPES
400 yds
** - "BORREGO

M #27 (ELDRIN)
BERLY CLARK
1ST. THAN

NTS! ***

VER MINE
AREA)

.hr⁻¹
ER ≈ 7(10³) cpm

ECLAMATION!

TACK BUTTE
LUM #19)
R.hr⁻¹
E

(10³) cpm:

218.4 mi.
ERENT FRAME
CK (NOTE EXTEN-
RKS, RIGHT CNTR

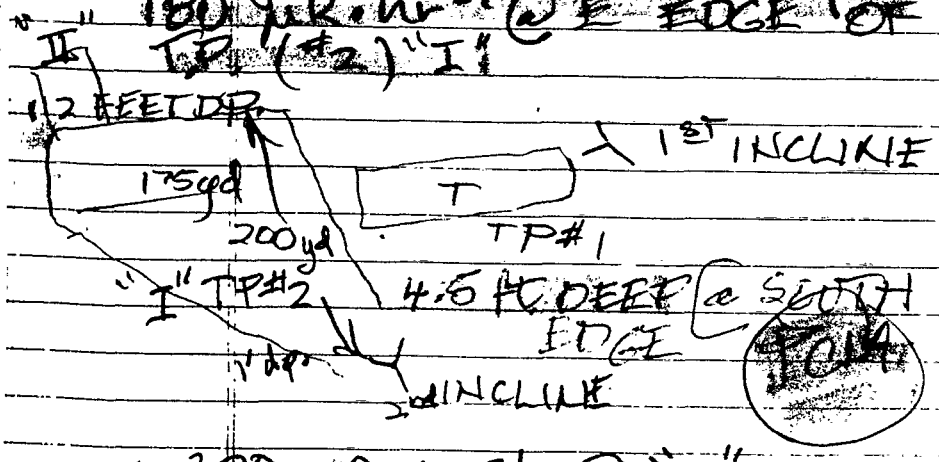
ES. W OF HAYSTACK

HAYSTACK B. IN
S REFERENT

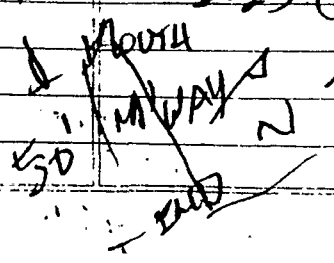
◇ 17220.9 (2.2 od.)
- 6TH FR. - RES. (2) W OF HAYSTACK B.
◇ 17222.4 (3.7 od.)
- 1 RES. & CHURCH - NO PICTURE
◇ 17223.7 (5.0 od.)
- BROWN VANDEVER RES.
- 1 RES. @ THIS LOCATION
◇ 3 FRAMES
- 7TH FR. - TRENCH CUT
- 8TH FR - GOPHERINGS N OF RES
- 9TH FR - REFERENT [redacted] + DEM
- 10TH FR - MARTINEZ RES'S.
◇ 1 FRAME, REFERENT B'GRND @ B. VANDEVER'S SONS RES.
- [redacted]
- [redacted] LUDLUM #19 - 21 μR hr⁻¹ (FACE
- ESP II - 2.15(10⁴) cpm ([redacted])
- SHINE - SAME
- SHINE - 2.25(10⁴) cpm
NOTE DRAINAGE INTO
◇ 12TH FR. - INCLINED ADIT
◇ 13TH FR. - TRENCH & RXR BED
- LUDLUM #19 - 21 μR hr⁻¹ @ SHINE.
◇ B. VANDEVER
- "STOPES ARE 400 yds ([redacted]), 400 yds (N)"
** - "[redacted] MINE; 300' OP." *

PAGE#3

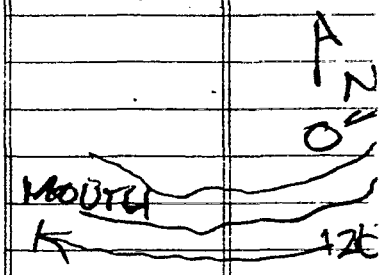
◇ TOP OF T.P. NE OF INCLINE
80 μR·hr⁻¹
◇ HOT ROCK – .1 mR·hr⁻¹
– 14TH FR.
◇ 350 μR·hr⁻¹ @ LOADING "BAY" EDGE; 400 μR·hr⁻¹ @ CTR (SHINE) 650 μR·hr⁻¹ (@ FACE), VANADATE OBSERVED
◇ 2nd INCLINE – FACE 160 μR·hr⁻¹
◇ TAILINGS STREWN 200 yds x 175 yds APPROX. 1 foot dp. 180 μR·hr⁻¹ @ E EDGE OF T.P. (#2) "I"



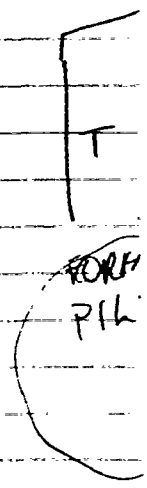
◇ 380 μR·hr⁻¹ @ "II"
☆ 15TH FR. – TP#2
☆ 16TH FR. – DRAINAGE (E)
□ IN DRAINAGE (E) AND S OF TP'S
– MOUTH – 5 (10⁴) cpm
– MIDWAY – 6.5 (10⁴)
– END – 3.25 (10⁴)



□ @ 100' : CE
6.5 (10⁴) C
– 17TH FRA
– 18TH "
(E)
□ DRAINAG



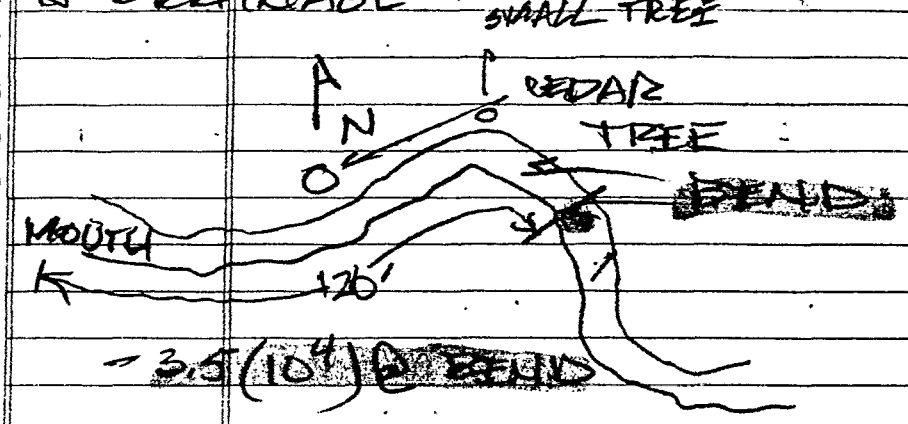
– 3.5 (10⁴)



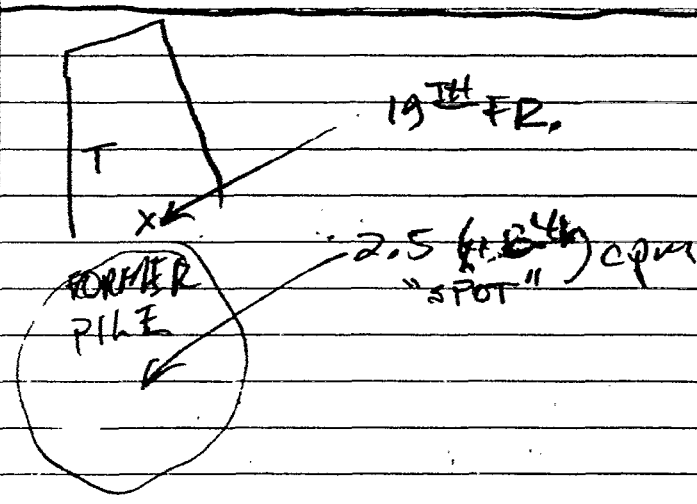
□ DUE S OF
– 20TH FR. –
– 21ST FR. –
LOOKING
□ DUE W OF E
ED W TAILI
– 22nd FR.

E OF INCLINE
1 mR·hr⁻¹
LOADING "BAY"
hr⁻¹ @ CTR (SHINE
FACE), VANADATE
FACE 160 μR·hr⁻¹
A 200 yds x
1 foot dp. :
E EDGE OF
1ST INCLINE
E
@ "II"
NAGE (E)
S OF TP's
pm

☐ @ 100' : CEDAR TREE, IN DR.
[redacted]
– 17TH FRAME [redacted] 6.5(10⁴)
– 18TH " – DOWN DRAINAGE
(E)
☐ DRAINAGE



– 3.5(10⁴) @ BEND



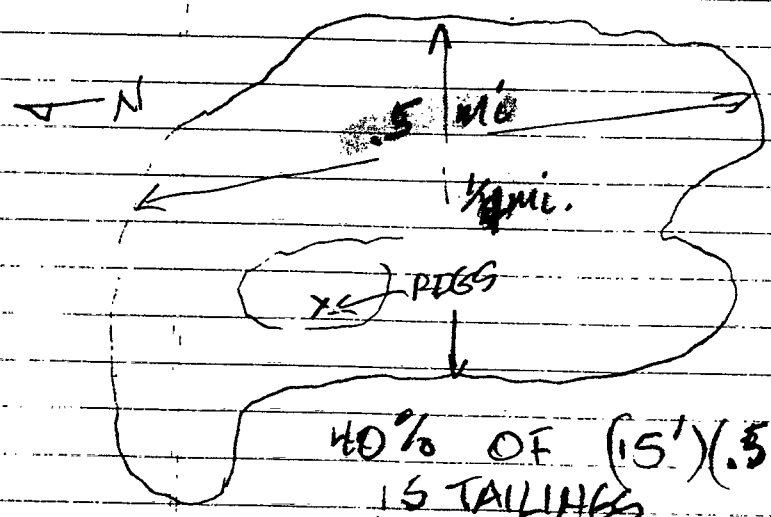
☐ DUE S OF MARTINEZ RES.
– 20TH FR. – STRAT. SECTION / HYSTK B
– 21ST FR. – B. VANDERVER OUTFIT,
LOOKING WSW
☐ DUE W OF B. VANDEVER, ROAD GRAVEL
ED W TAILINGS (ESP. II – 10⁵ CPM)
– 22ND FR – LOOKING E, NOTE: [redacted]
IN BACKGROUND [redacted]

- ESP II - 5.2 (10^4) cfm
- LUDLUM #19 - 100 μR.hr^{-1}

★ - NOTE: BOTH RDGS @ SHINE

□ @ .8 mi. W OF B. VANDEVER RES.
- NANA-A-BAH VANDEVER MINE?
* FRAMES 23 AND 24

□ @ EXTENSIVE SURFACE WORKS W. OF B.V. RESIDENCE
- FRAMES 25 THRU 28 - SEMI-PANORAMA



40% OF (15')(.5 mi.)(.25 mi.)
15 TAILINGS

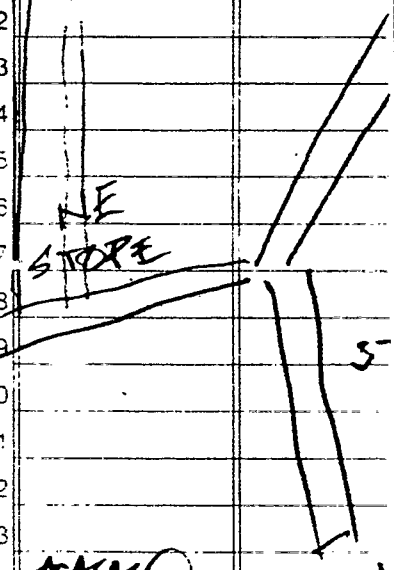
□ @ OVERLOOK
- 29TH FR - LOOKING N, RES. IN CTR MIDDLEGROUND
- 30TH FR - LKG NW, WESTERN EXTENT OF SURFACE WORKS
- 31ST FR - LKG NE, EASTERN EXTENT OF SURFACE WORKS; NOTE TAILINGS FAR CENTER M'GRND

□ @ TIMBERED INCLINE
- 32ND FR.

□ 32nd FR. - LKG SURFACE WORKS

CONT'D @ T
- ESP-II
- LUD #19
★ B. VANDEVE
- "T
- "DRILLING
- "EXR L
- "B.V. -
¼ SEC.

VENT SHAFTS?

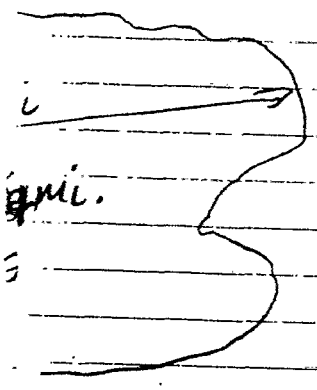


@ DUE N
- 33RD FR.
- AND MR.

□ @ TURN OFF
- 34TH FR -
MINE (N
B'GRND

-) cpm
10 μR. hr⁻¹
DGS @ SHINE
B. VANDEVER

VANDEVER MINE?
AND 24
FACE WORKS W. OF
LE
THRU 28 - SEMI-

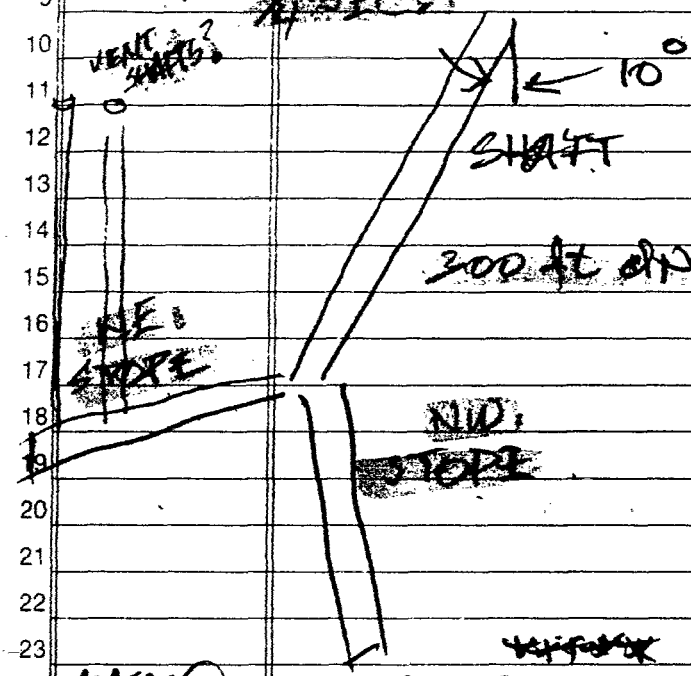


OF (15')(.5mi.)(.25mi.)
LINGS

NG N, RES. IN
HD
NW, WESTERN EX-
E WORKS
NE, EASTERN EX-
CE WORKS: NOTE
CENTER M'GRND
LINE

SURFACE WORKS

CONT'D @ TIMB. SHAFT
- ESP-II - 10^4 cpm
- LUD #19 - 10 μR hr⁻¹
★ B. VANDEVER:
- "TIMB. SHAFT ~ 300 ft DEEP"
- "DRILLING (EXPL.) NNW OF SHAFT"
- "RXR LAND W & SE OF B.V."
- "B.V. - ¼ SEC. 18, B.V. G'MOTH ¼ SEC."



~~XXXX~~ @ DUE N OF SURFACE WORKS
- 33rd FR. - VENT. SHAFTS: VECTRA
~~XXXX~~ ~~XXXX~~
- AND MR. BROWN VANDEVER
□ @ TURN OFF TO B.V.
- 34th FR - DRAINAGE E OF B.V. MINE (NOTE: MT. TAYLOR IN B'GRND AS REFERENT)

- ☐ @ DUE S OF H'STK B.
  - 35TH ER. - ARTESIAN WELL USED FOR STOCK WATER AND ?
- ☐ @ DUE E OF H'STK B.
  - FRAMES 36 THRU 39 - HAYSTACK COMMUNITY/RES'S.
  - FRAME 40 SAA
- ☐ @ WELL 16T-552
  - DIP, VAT, & TANK - 1ST FR
  - WELL NOT FUNCTIONING
- ☐ BACK TO THE E.S. GRINDER

• • •

APRIL 12, 1990: STF. MTG.

- ☐ WABOS, WABOS, WABOS, WABOS
- ☐ LEE BIGWATER
  - "WIFE IS LAB S'VISOR @ SAGE MEM."
- ☐ LTL SPOKE (TECH. STF GOT STUCK AGAIN)
- ☆ CHRIS PETRE :: WILL BRING,
  - HNO_3, NALGENE 2 L, 500 mL, 8-OZ. SOIL SAMPLE JARS, PH, COND. METERS
  - STAY IN FARMINGTON? WEE FOR CHRIS P.
- ○ CIBOLA NED, $362
- ☐ CHECK OUT VEH. FROM BEVERLY NEZ
- ☐ GET TA B4
- ☐ "BOYS" AGAIN
- ☆ MONTHLY REPORT - APRIL 27, 1990

NSO :: NEPA SAME

◇ BMB: "REG. IX - LEAD AGENCY"

*30 ◇ CEQ: IS MANDATED TO DO THIS

LOUISE? HOLA

6. From frames 25 through 32 (Ref#3) and page #5 of Ref #14 field notes (sketch of area) the following dimensions are obtained;

   L=2640ft.

   and

   w=1320ft. utilize the geometric mean of these two values to compute the area:

   $r = ((2.64(10^3))(1.32(10^3)))^{\frac{1}{2}}$ ft.

   $\simeq 1867$ft. so that

   $A \simeq \pi r^2 = 1.1(10^7)ft^2$

   $= 251$ acres

7. Assume that 50% of this area is covered with tailings with a mean height of 2.5 ft: The corresponding volume computes to be;

   $V_{geo} = (.5)(1.1(10^7))(2.5)ft^3.$

   $= 1.38(10^7)ft^3.$

8. Compensate this volume for void volume overestimate to find

   $.7V_{geo} = 9.63(10^6)ft^3$

9. Assume that the fraction of U_3O_8 within the tailings is the order of 10^{-4}whereby,

   $V_{u3o8} \simeq 9.36(10^2)ft^3 = 2.73(10^7)cm^3.$

10. Apply the density of 23.26 gm.cm to the above volume to find

    $M_{u3o8} = 6.35(10^5)kg.$

    $= 700.1$ tons

11. Combining quantities from 10. above and the previously obtained value of $2.63(10^4)$ kg. and utilizing the empirical u:v ratio from reference #__2__find

    $$\frac{M_{u3o8}}{M_{v2o5}} \simeq \frac{.19}{.30}$$

    solving for M_{v2o5} find

    $M_{v2o5} = 1.579\ M_{u3o8}$

    $= 1.579(6.613(10^5))kg$

    $= 1.04(10^6)kg$

12. Combining totals for M_{v2o5} and M_{u3o8} find

    $M_{v2o5} + M_{u3o8} = 1.7(10^6)kg$

    $= 1880.3$ tons

Resulting in hazmat QF of 7.

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE

MAY, '90 P. MOLLOY

Number	Mine Name	Tons Ore	Pounds U_3O_8	U_3O_8	Pounds V_2O_5	V_2O_5	Type of Deposit	Host Rock	Periods of Production/ Shipper
13N.9W.28.321	Mesa Top Mine	188,261	512,965	0.24	144,618	—	sandstone	Jmp	1954-1957 - Lee Explorat 1957-Holly Minerals and
13N.10W.4.244	Pat - Section 4 (Dakota Mine)	5,869	12,645	0.12	2,478	—	sandstone	Jmw,Kd	1952-1959 - Dakota Minin Co.; 1962-1963-Farris Mines, Inc.
13N.9W.19.428	[1]Poison Canyon	217,866	1,804,574	0.23	338,894	—	sandstone	Jmp	1952-1959 - Haystack Mour Development Corp.; 1960- 1962-Farris Mines Inc.
14N.11W.28.113	Red Cap Group (T Group)	195	497	0.13	951	0.24	limestone	Jt	1952-1953 - Navajo Develc ment Co.; 1953-Fitzhugh Doerrie
13N.10W.16.134	Red Point Lode	482	1,223	0.13	746	0.07	limestone	Jt	1952-1955 - R.M. Shaw
14N.11W.28.144	Red Top Mines	165	398	0.12	1,287	0.39	limestone	Jt	1955 - Red Top Uranium Mining Co.
14N.9W.34.424	[1]Sandstone	1,834,255	3,548,829	0.17	—	—	sandstone	Jmw	1959-1963 - Phillips Petroleum Co.; 1963-1978 United Nuclear Corp.
13N.9W.1.200	[1]Section 1 (13N-9W) mined through Cliffside	148,866	1,699,137	0.57	—	—	sandstone	Jmw	1967 - Kerr-McGee; 1969-1 Kerr-McGee and Nation Le
15N.16W.3.332	Section 3 (15N-16W) Santa Fe-Christensen Rats Nest Mine	324	1,836	0.28	464	—	sandstone (coal)	Kd	1957 - Christensen and Re Uranium Co.; 1957-1958-R Uranium Co.
13N.10W.5.144	Section 5 (13N-10W)	23	54	0.12	—	—	sandstone	Kd	1958 - Westvaco
13N.9W.8.114	Section 8 (13N-9W) Spencer Shaft	47,888	165,319	0.17	—	—	sandstone	Jmp	1958-1960 - United Wester 1961-Hyde and Casper; 19 1966-W.D. Tripp; 1966-19 James J. Goode
14N.10W.18.244	[1]Section 18 (14N-10W)	138,767	518,935	0.28	—	—	sandstone	Jmw	1957-1962 - Kermac Nuclea 1964-Homestake-Sapin
14N.10W.12.411	[1]Section 12 (14N-10W)	74,975	211,873	0.14	—	—	sandstone	Jmw	1961 - Anderson Developme Corp.; 1962-1963-Stella Dysart
14N.10W.15.441	[1]Section 15 (14N-10W)	1,213,814	3,625,924	0.15	—	—	sandstone	Jmw	1958-1961 - Homestake-Sap 1961-1965-Rio and Home- stake-Sapin; 1966-1969- Homestake-Sapin; 1969-19 United Nuclear-Homestake
14N.9W.17.323	[1]Section 17 (14N-9W)	544,164	2,315,182	0.21	—	—	sandstone	Jmw	1960-1964 - Kermac Nuclea Corp.; 1965-1978-Kerr-McG
13N.10W.18.341	Section 18 (13N-10W) (Indian Allotment)	25,796	98,175	0.19	75,342	0.30	limestone	Jt	1952 - Sutton, Thompson, Williams; 1953-Williams; 1955-Santa Fe Uranium; 19 1956-Santa Fe Uranium and Federal Uranium; 1957-195 Federal Uranium; 1963-196 Mesa Mining Co.; 1966-Cib Mining Co.
14N.9W.18.400	[1]Section 18 (14N-9W) mined through Sec. 17	581,946	1,586,447	0.16	—	—	sandstone	Jmw	1962-1964 - Kermac Nuclear 1965-1978-Kerr-McGee
14N.9W.20.114	[1]Section 20 (14N.9W mined through Sec. 17	406,375	2,223,977	0.23	—	—	sandstone	Jmw	1962 - Kerr-McGee
14N.10W.22.223	[1]Section 22 (14N-10W) heap leach	2,189,851 —	11,605,672 38,185	0.18 —	— —	— —	sandstone	Jmw	1958-1964 - Kermac Nuclear 1965-1978-Kerr-McGee
14N.10W.23.134	[1]Section 23 (14N-10W)	2,528,797	9,679,773	0.19	—	—	sandstone	Jmw	1958-1968 - Homestake-Sapi 1969-1978-Homestake-Unite Nuclear
13N.10W.23.444	Section 23 (13N-10W)	21,826	138,541	0.32	18,256	0.86	limestone	Jt	1957-1965 - Haystack Mount Development Corp.; 1965- 1966-Santa Fe Pacific
13N.9W.24.121	Section 24 (13N-9W) Chill Mills, Rialto (Section 13)	18,958	37,693	0.17	—	—	sandstone	Jmp	1958-1963 - Febco Mines, I
13N.11W.24.222	Section 24 (13N-11W) Indian Allotment to Nana-A-Bah Vandever	24,638	115,875	0.22	85,545	0.18	limestone	Jt	1952-1954 - Glen Williams; 1955-1956-Santa Fe Uraniu 1955-Federal Uranium Corp Santa Fe Uranium; 1956-19 Federal Uranium Corp.
14N.10W.24.332	[1]Section 24 (14N-10W)	1,904,582	7,871,564	0.19	—	—	sandstone	Jmw	1959-1964 - Kerr-McGee Nuclear; 1965-1978-Kerr- McGee
	Heap leach	—	579	—	—	—			
13N.10W.25.411	[1]Section 25 (13N-10W)	235,156	958,858	0.28	153,657	0.12	limestone	Jt	1952 - A T and SF RR; 1955- 1961-Haystack Mountain De velopment Corp.; 1962-196 Santa Fe Pacific; 1963- Farris Mines, Inc.; 1963- 1965-Santa Fe Pacific; 19 1966-Farris Mines, Inc.; 1968-Homestake; 1969-1978- United Nuclear Corp.
14N.10W.25.144	[1]Section 25 (14N-10W)	1,791,848	6,444,889	0.18	—	—	sandstone	Jmw	1959-1969 - Homestake-Sapir 1969-1978-Homestake-Unitec Nuclear
13N.10W.26.221	[1]Section 26 (13N-10W) Dawidero Group	11,118	83,752	0.38	17,518	0.08	limestone	Jt	1952-1957 - Hanosh Mines
14N.10W.26.228	[1]Section 26 (14N-10W) mined through Section 24	362,118	1,198,696	0.17	—	—	sandstone	Jmw	1965-1978 - Kerr-McGee

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

-9-

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

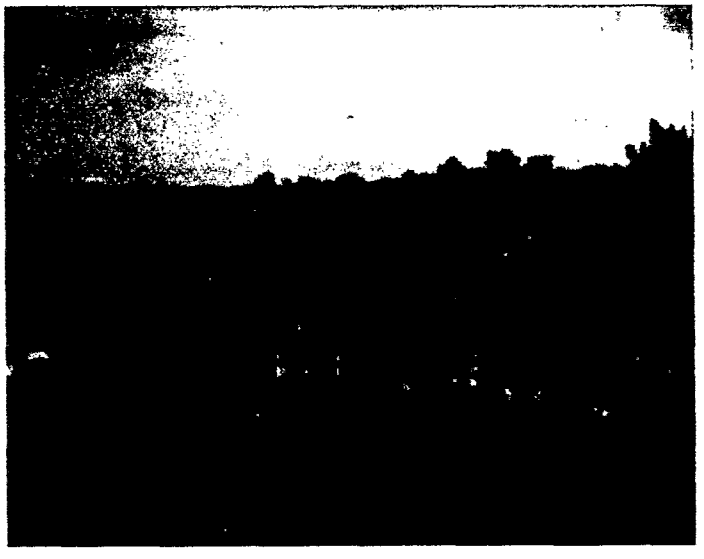
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 315°/ESE

FILM TYPE POLAROID **FRAME NO.** 25

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



25TH Fr

7. **DESCRIPTION** WESTERN EXTENT OF SURFACE WORKS WSW OF B. V. RESIDENCE, LOOKING ESE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

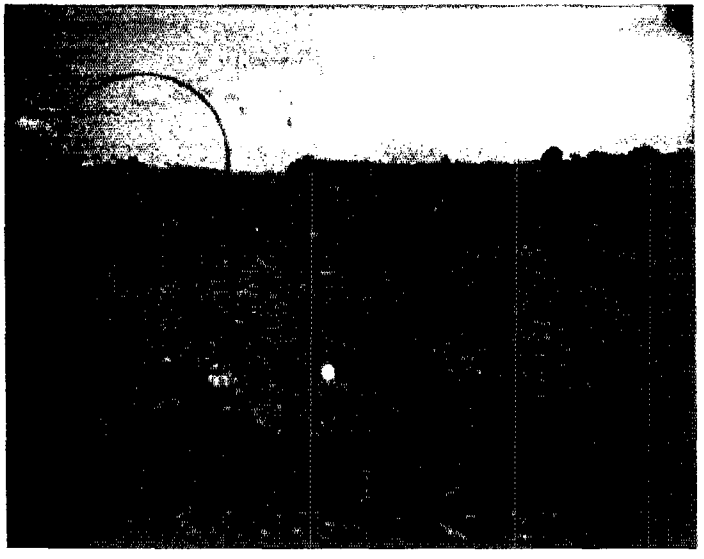
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 350°/E OF ESE

FILM TYPE POLAROID **FRAME NO.** 26

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



26TH FR

7. **DESCRIPTION** SURFACE WORKS WSW OF B. V. RES., LOOKING E OF ESE; NOTE MT. TAYLOR IN FAR LEFT BACKGROUND AS REFERENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

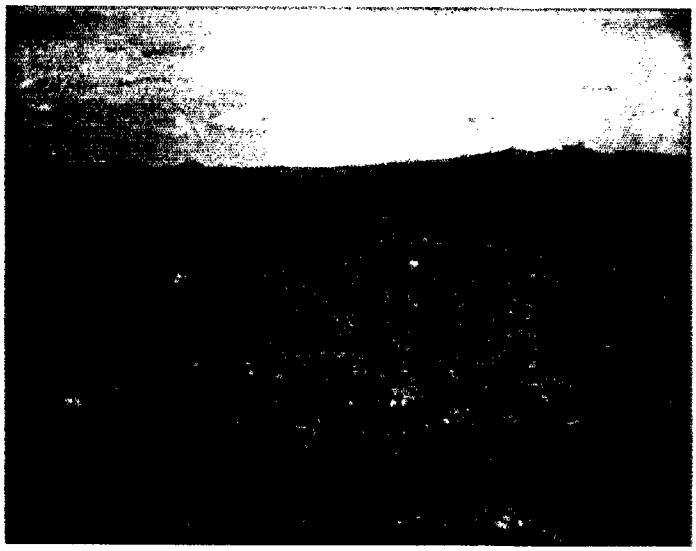
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR -HIGH HAZY CLOUDS

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 20°/E OF ENE

FILM TYPE POLAROID **FRAME NO.** 27

DATA TAKEN WITH PHOTOGRAPH: YES, NOT WRITTEN DOWN

1. **Soil Sample** ( )
2. **Surface Water Sample** ( )
3. **Air Monitoring Device** ( )
   Reading: _____
4. **Radiation Survey** (X)
   Reading: ~~150uR.hr-1(LUDLUM#19)~~, 10^4cpm(ESP-II)
5. **Deep Well Water Sample** *** (APPROXIMATE ***
6. **Photograph Below:** YES



27TH FR

7. **DESCRIPTION** SURFACE WORKS WSW OF B. V. RES., SEE FOLLOWING SKETCH, LOOKING E OF ENE

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

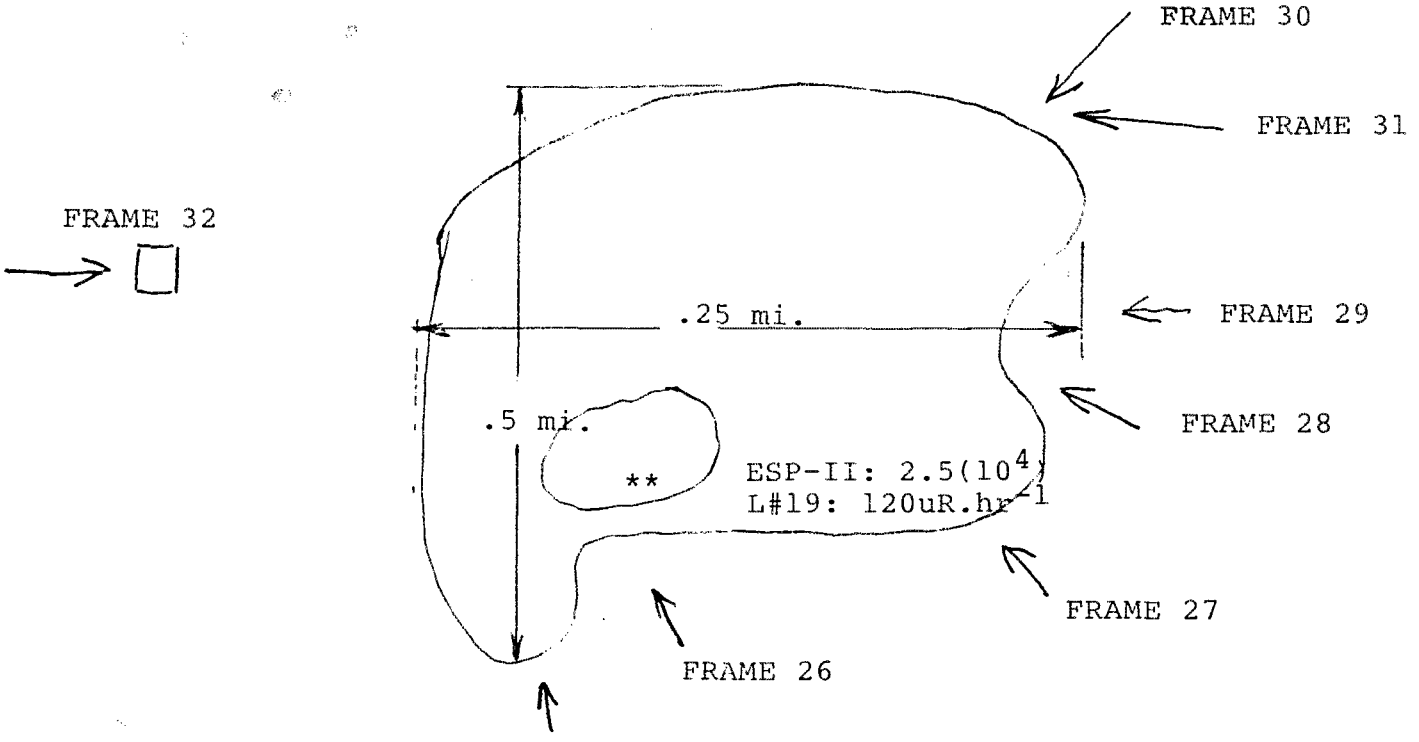
DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** _ _

FILM TYPE POLAROID **FRAME NO.** NO FRAME

DATA TAKEN WITH PHOTOGRAPH: SKETCH

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: SEE BELOW
5. Deep Well Water Sample ( )
6. Photograph Below: *** NONE ***



* RADIOMETRIC READINGS ASSOCIATED WITH FRAME 27

7. **DESCRIPTION** SKETCH OF AREA WHERE RADIOMETRIC READINGS WERE TAKEN, NO SCALE

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** _____ **WEATHER** CLEAR

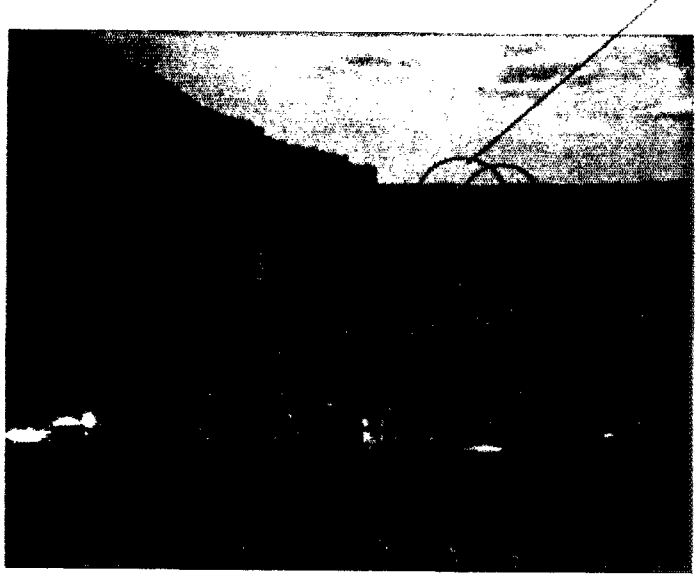
PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** _____

FILM TYPE POLAROID **FRAME NO.** 28

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading: _____
4. Radiation Survey (X)
   Reading: _____
5. Deep Well Water Sample ( )
6. Photograph Below: YES, SEE SKETCH

YES, UNACCEPTABLE PCM



2 YES.

28TH FR.

7. DESCRIPTION SEE SKETCH

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

-14-

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

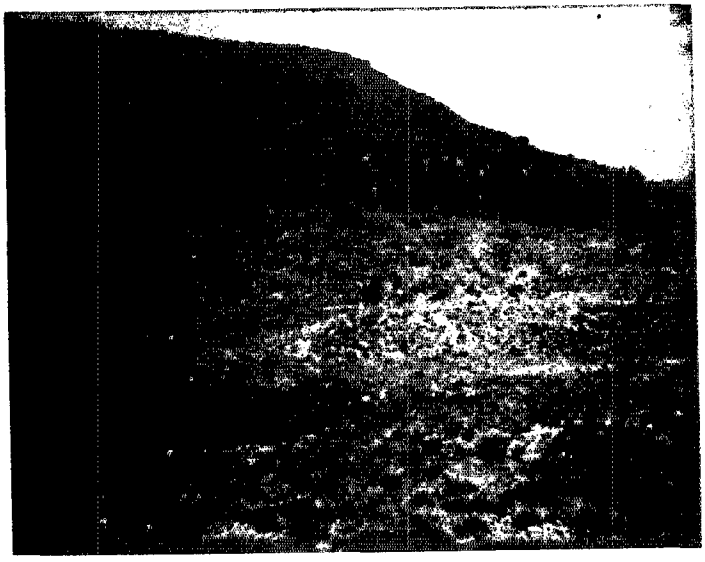
DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** SEE SKETCH

FILM TYPE POLAROID **FRAME NO.** 29

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey ( )
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



29TH FR.

7. DESCRIPTION _____

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** SEE SKETCH

FILM TYPE POLAROID **FRAME NO.** 30

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES

30TH ER.

7. DESCRIPTION _____

NAVAJO SUPERFUND DEPARTMENT

FIT PHOTOGRAPH LOG SHEET

-16-

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

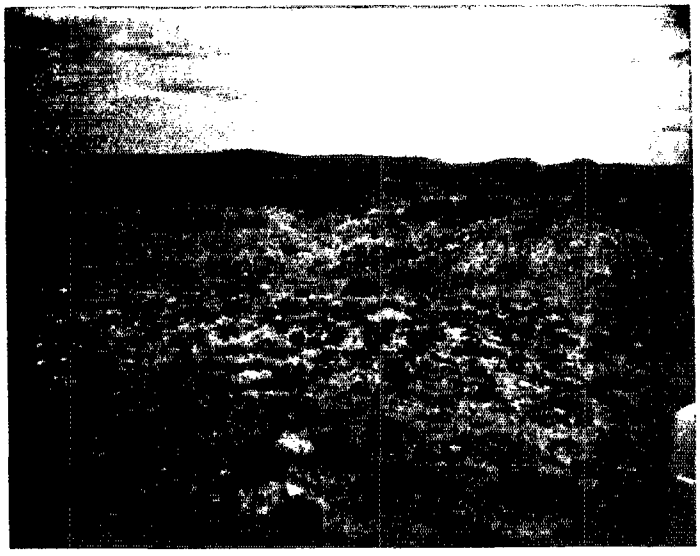
DATE APRIL 11,1990 **TIME** 11:15am **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** SEE SKETCH

FILM TYPE POLAROID **FRAME NO.** 31

DATA TAKEN WITH PHOTOGRAPH:

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (x)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



SHT FR.

7. DESCRIPTION _____

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

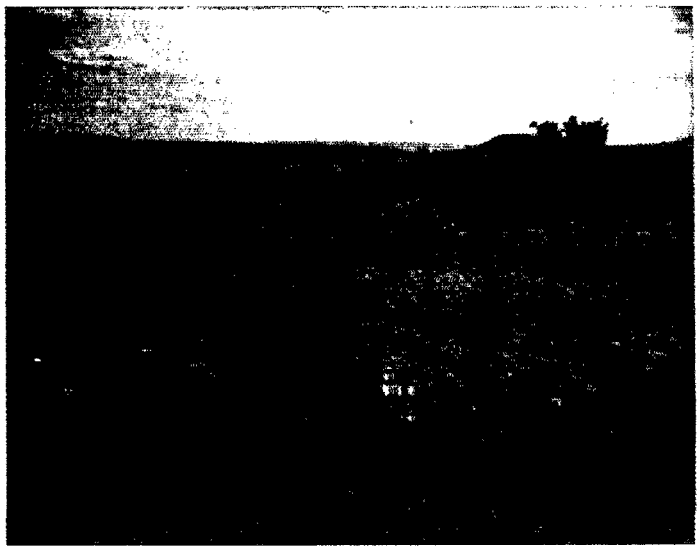
DATE APRIL 11,1990 **TIME** 2:30pm **WEATHER** CLEAR TO SLIGHTLY OVERCAST

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** SEE SKETCH

FILM TYPE POLAROID **FRAME NO.** 32

DATA TAKEN WITH PHOTOGRAPH: *** NONE ***

1. Soil Sample ( )
2. Surface Water Sample ( )
3. Air Monitoring Device ( )
   Reading:_____
4. Radiation Survey (X)
   Reading:_____
5. Deep Well Water Sample ( )
6. Photograph Below: YES



32nd FR., LKG S

7. DESCRIPTION _____

13. From page #6 (Ref #14) of field notes, direct quote of Mr. B. Vandever, "Timbered shaft is approximately 300 feet deep" and the personal observation that the shaft is approximately 5 feet square. The following surface area computation obtains;

$$S = 4((5ft.)(300ft.))$$
$$= 6{,}000ft^2.$$

It is assumed that the timbered shaft was not the primary shaft, but was a shaft driven for both mining and ventilation purposes to connect with the Nana-a-bah Vandever mine which is approximately 2400 ft. Southest of the timbered shaft.

14. From page #6 of field notes (Ref #14), direct quote of Mr. B. Vandever and page #2 of field notes, direct quote of Mr. B. Vandever, "stopes are approximately 400 yds ESE and N", the observational fact that there are two inclined adits and the assumption that the inclines are 300 ft. deep the following surface area computation obtains;

$$S_{IA} = S_{A1} + 2S_S + S_{A2}$$
$$= 2(S_{A1} + S_S)$$

or

$$S = 2((4)(5ft.)(5ft.)(300ft.) + (4)(5ft.)(5ft.)(1200ft.)$$
$$= 3.0(10^5)ft^2.$$

15. Combining the results of calculations 13. and 14. find;

$$S_T = S_{TS} + S_{IA}$$
$$= 3.06(10^5)ft^3 : 8.665(10^3)m^2$$
$$= 7.02 \text{ acres}$$

16. From frame #22 (Ref #3) and field notes (Ref #14) pages #4 and #5, gamma ratemeter/ESP-II reading on the "hot road" was

$$\varphi = 10^5 \text{ cpm.}$$

Assume that this quantity is attributable to Bi^{214} activity exclusively and that the following relationship is true

$$\varphi = CV_D \int_0^e (K(.61\ Mev)\psi.61 + K(1.76Mev)\psi 1.76)dt.$$

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE

MAY,'90 P. MOLLOY

FIT PHOTOGRAPH LOG SHEET

SITE NAME BROWN VANDEVER URANIUM MINE **USEPA SITE NO.** NOT ASSIGNED

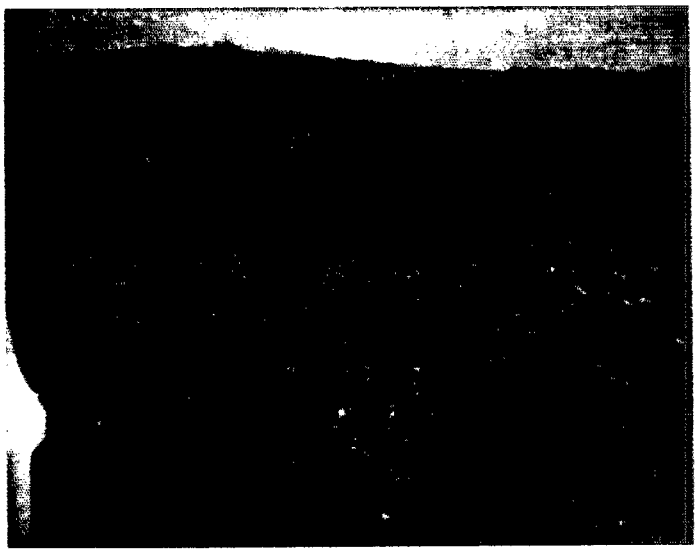
DATE APRIL 11,1990 **TIME** AFTERNOON **WEATHER** CLEAR

PHOTOGRAPHER P. MOLLOY **ANGLE/DIRECTION** 0°/E

FILM TYPE POLAROID **FRAME NO.** 22

DATA TAKEN WITH PHOTOGRAPH: YES

1. **Soil Sample** ( )
2. **Surface Water Sample** ( )
3. **Air Monitoring Device** ( )
   Reading: _____
4. **Radiation Survey** (X)
   Reading: 10^5cpm(ESP-LI) @ EDGE OF ROAD"
5. **Deep Well Water Sample** ( )
6. **Photograph Below:** YES



22nd Fr.

7. **DESCRIPTION** "HOT ROAD" WEST OF B. V. RESIDENCES, SURFACE WORKS WASTE PILES @ RIGHT MIDDLEGROUND, MT. TAYLOR @ UPPER LEFT BACKGROUND AS REFERENT

GEOCHEMISTRY OF URANIUM

I. Atomic Chemistry of Uranium

A. Atomic Number: 92, heaviest naturally occurring element.

B. Atomic Weight: 238.03

C. Naturally Occurring Isotopes

Mass No.	Abundance Wt. %	Activity % (radioactive decay events per unit of time)
238	99.28	48.9
235	0.71	2.2
234	0.0054	48.9

D. Nuclear Properties

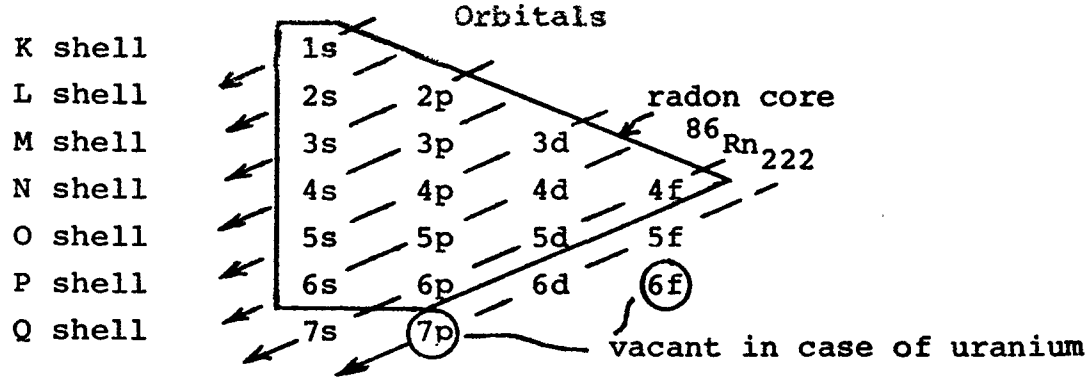
1. All isotopes of uranium are radioactive.

2. U-235 is readily fissionable.

3. All isotopes of all elements above Bismuth (83) are radioactive.

Isotope	Half Life
U^{238}	4.51×10^9 years
U^{235}	7.1×10^8 years
U^{234}	2.48×10^5 years

E. Electronic Structure and Valence States



2. Energy of decay process often results in oxidation, therefore U^{234} may be U^{+6} from U^{238} in UO_2 (uraninite) Note: U^{238} and U^{235} always in fixed ratio in nature.

VI. Measurement of Nuclear Radiation

A. Alpha (α) radiation measured by

1. proportional counters (gross α radioactivity)

2. semiconductor detectors, for α energy spectrometry

3. photographic techniques (track etch) radon α particularly

4. helium analysis with mass spectrometer

B. Beta (β) radiation

1. measured with proportional counter

2. not very useful, except for ore grade control

C. Gamma (γ) radiation

1. Because of high range and discrete energy levels, most frequently measured radiation

2. Geiger counter

a. inexpensive, measures total γs from all sources, non energy selective

b. γs enter gas-filled tube, ionize gas, giving electrical impulse

3. Scintillation counter

a. medium resolution γ energy spectra

b. medium cost $2000 - 20,000

c. γ strikes NaI crystal, converts energy to light. Sorts light intensity for different energies

4. Semiconductor detector (germanium)

   a. high resolution γ spectra

   b. high cost

D. Uranium Analysis by Gamma Spectrometry

1. U^{238} series

   a. U^{238}, U^{235}, U^{234} γ energies are too low for practical measurement

   b. Bi^{214}, daughter in U^{238} series, has γ energies of 0.61 MeV and 1.76 MeV which are readily measured. Figure 28

   c. Bi^{214} is good measure of Rn^{222}

   d. Bi^{214} activity is reliable measure of U^{238}-U^{235} activity only if sample has not weathered for 1 million years, and radon has not escaped for 3 weeks

   e. Bi^{214} is the mechanism of "radiometric assaying" for uranium

2. Th^{232} series

   a. Tl^{208} daughter has high energy 2.615 MeV γ (Figure 29)

   b. Th^{232} analysis by measuring Tl^{208} activity because short-lived daughters

   c. Some Th^{232} series γs interfere with 1.76 MeV γ from Bi^{214}, so need to know Th content when measure Bi^{214} activity

3. K^{40} gamma spectrum

   a. high energy 1.46 MeV γ (Figure 30)

4. Superimpose U^{238}, Th^{232}, and K^{40} γ spectra

   a. 2.615 MeV, Tl^{208} from Th^{232}

   b. 1.76 MeV, Bi^{214} from U^{238}

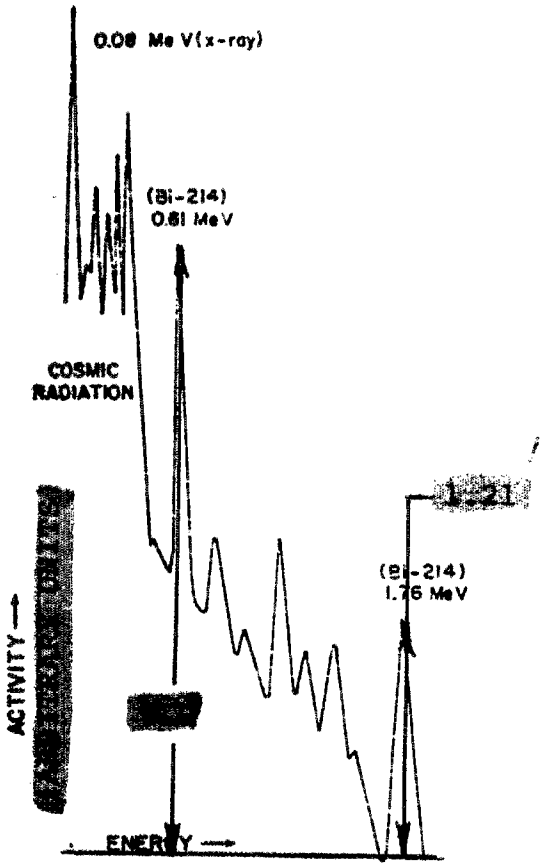


Fig. 28. Gamma spectrum of equilibrium U-238, U-235 series.

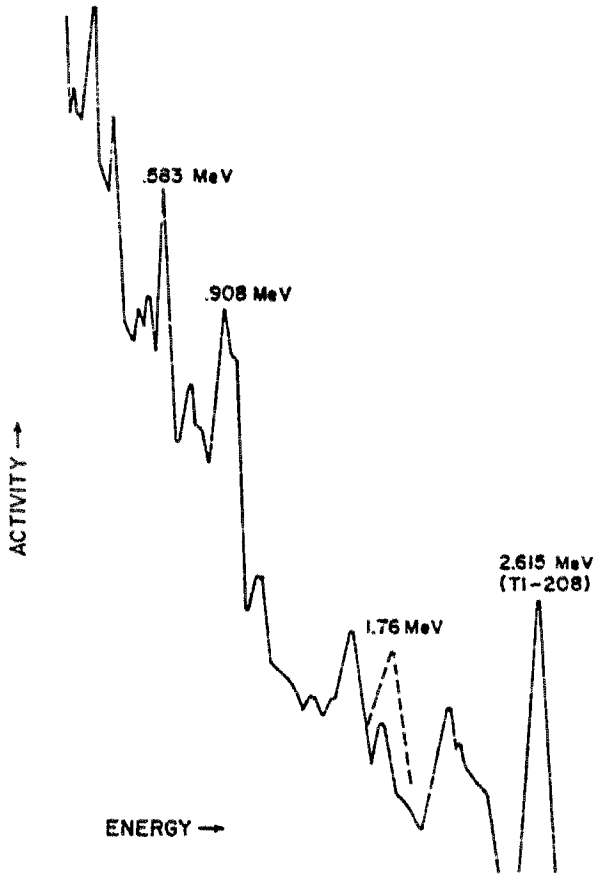


Fig. 29. Gamma spectrum of equilibrium Th-232 series.

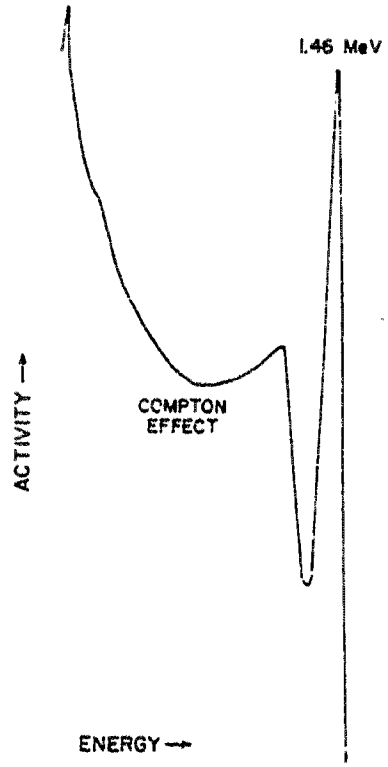


Fig. 30. K-40 gamma spectrum.

Where the integral is taken over the convolution "capture window" interval of the NaI(Tl) detector. Assume that the kernels of the convolution K(.61 Mev) and K(1.76 Mev) are equal and of unit amplitude. Further assume that the instrument response factor C is unity.

From page #40 of reference # 10 ,figure #28, the ratio of the amplitudes of production is;

$$\frac{\Psi_{.61}}{\Psi_{1.76}} \simeq \frac{3.2}{1.21} \qquad \text{(Arbitrary units)}$$

It then follows that

$$\Psi_{.61} = 2.645\,\Psi_{1.76}$$

and inversely. Recognize that the Ψ, are proportional to the number of B^{214} atoms present at the grab site. Calculate the volume of the NaI detector as follows:

$$V_D = \frac{\pi (5.1\text{cm})^2}{2} \quad (5.1\text{cm})$$

$$= 104.183\ \text{cm}^3.$$

Compute the integral as follows;

since $10^5 = 10^2 \int_0^e 1.3784\,\Psi_{.61}\,dt.$

Consider that $\Psi_{.61}$ is constant during the interval and that the instrument capture window time constant is 100 msec., then

$$10^3 = 1.378\,\Psi_{.61}\Delta t$$
$$= 1.378(10^{-1})\,\Psi_{.61}$$

Solve for $\Psi_{.61}$ to obtain $\Psi_{.61} = 7.26(10^3)$.

Set the above quantity equal to the number of Rn^{222} atoms (per cubic centimeter) present at the grab site, eg.,

$$N(Rn\,222) \simeq 10^4$$

Given that the gamma ratemeter reads 10^5 cpm.

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE

MAY,'90 P. MOLLOY

OTHER SPECIFICATIONS

Dimensions: 5.0 inches high × 5.0 inches wide × 10.25 inches long (12.7 cm × 12.7 cm × 26.0 cm)
Temperature Range: -4°F to +122°F (-20°C to +50°C)
Weight: 4.1 pounds (1.86 kg)
Connectors: MHV for detector input, 9-pin "D" shell female connector for RS-232C communication

DETECTOR PROBES RECOMMENDED FOR USE WITH ESP-2

Model No.	Type Measurement	Useful Range with ESP-2	5 Percent*
HP-270	Exposure or Exposure Rate	Bkg to 3000 mR/h	1 to 3000 mR/h
HP-290	Exposure or Exposure Rate	0.0005 to 80 R/h	0.01 to 80 R/h
HP-210L	Beta-Gamma	Bkg to 100,000 counts/s	14 to 100,000 counts/s
HP-260	Contamination		
AC-3	Alpha Contamination	Bkg to 50,000 counts/s	14 to 50,000 counts/s
NRD	Neutron Dose Equivalent or Dose Equivalent Rate	0.001 to 60 rem/h	0.02 to 60 rem/h
LEG-1	Low Energy Gamma or x-ray	Bkg to 50,000 counts/s	14 to 50,000 counts/s
SPA-3	**High Sensitivity Gamma**	**Bkg to 50,000 counts/s**	**14 to 50,000 counts/s**
SPA-6	Medium Sensitivity Gamma	Bkg to 50,000 counts/s	14 to 50,000 counts/s

*Ratemeter mode provides 5 percent, or better, standard deviation readout capability over the indicated range.

ACCESSORIES

Audio Headset: Part No. ADHS4

Any of the following Eberline detectors can be used with the ESP-2:

Detector Probe	Cable	Check Sources	Probe Holder/Bracket
AC-3	CA-12-60	CS-1, CS-10, CS-12, CS-15	
HP-190A	CA-16-60	CS-7A	ZP10434029
HP-210AL	CA-16-60	CS-13	
HP-210L	CA-16-60	CS-13	
HP-210T	CA-16-60	CS-13	
HP-220A	CA-16-60		
HP-260	CA-16-60	CS-13	ZP10434029
HP-270	CA-16-60	CS-7A	ZP10434029
HP-280	CA-15-36		
HP-290	CA-16-60		ZP10434029
LEG-1	CA-12-60		
NRD	CA-15-60		ZP11292020
PG-2	CA-12-60		
SPA-3	CA-12-60	CS-7B	ZP10465017
SPA-6	CA-15-36	CS-7B	ZP10465017
SPA-8	CA-15-36	CS-7B	
SPA-9	CA-15-36	CS-7B	ZP10465017

Model SPA-3, Scintillation Probe

GENERAL DESCRIPTION

The Model SPA-3 scintillation probe is a rugged, waterproof gamma detector designed for high sensitivity of pulse-height applications.

The SPA-3 contains a 2-inch-diameter, 2-inch-long NaI(Tl) crystal, a 2-inch, 10-stage photomultiplier tube, tube socket with a dynode resistor string, and a magnetic shield.

SPECIFICATIONS

Crystal: NaI(Tl), 2-inch-diameter × 2 inches long (5.1 cm × 5.1 cm)

Photomultiplier Tube: ≅2-inch-diameter, 10-dynode, end-window with S-11 photocathode.

Operating Voltage: Variable dependent upon application.

Maximum Voltage: +1600 V

Sensitivity: ≅1200k cpm per mR/h with ^{137}Cs

Current Drain: ≅120 MΩ resistance string yields 10 μA at 1200 V.

Wall Material: Aluminum

Wall Thickness: ⅛-inch (0.32 cm), 1/16-inch (0.16 cm) at crystal

Connector: Mates with Eberline CP-1

Finish: Enameled body with chrome-plated connector

Size: 2⅝-inch-diameter × 11⅛ inches long (6.7 cm × 28.3 cm)

Weight: 3.25 pounds (1.5 kg)

AVAILABLE ACCESSORIES

Instruments	Cables
ASP-1	CA-12-60
ESP-1	CA-12-60
ESP-2	CA-12-60
ESP-2/PHA	CA-12-60
MS-2	CA-12-60
RM-20	CA-12-60
RM-21	CA-12-60
RM-23	CA-12-60
SAM-2	CA-12-60
SRM-100	CA-12-60
SRM-200	CA-12-60
SRM-200PHA	CA-12-60

Eberline
A subsidiary of Thermo Instrument Systems Inc.

P.O. Box 2108
Santa Fe, New Mexico 87504-2108
(505) 471-3232 TLX: 66-0438 EIC SFE
Telecopy: (505) 473-9221

GENERAL ASSUMPTIONS

1. Take $\rho_{ss} \simeq 1.7$ gm.cm^{-3}

Consider the U^{235} and U^{238} abundances (U^{234} negligible) whereby,

"Fraction U^{235}" = 7.2 (10^{-3})

"Fraction U^{235}" = .9927

Then derive the molecular weight of U_3O_8 as;

$$MW_{u_3o_8} = [7.2\ (10^{-3})]\ [(3)\ (235)] + (.9927)\ (3)\ (238)] + 8\ (16) = 821.86$$

Likewise, derive the molecular weight of SiO_2 (sandstone).

$$MWSiO_2 = 28.09 + 2\ (16) = 60.89$$

$$\frac{MW_{u_3o_8}}{MWSiO_2} = \frac{821.86}{60.09} = 13.68$$

Then,

$$\frac{\rho_{u_3o_8}}{\rho_{ss}} = \frac{\rho_{u_3o_8}}{1.7} = 13.68$$

So that,

$$\rho_{u_3o_8} \simeq 23.26 \text{ gm.cm}^{-3}$$

2. (From reference #22)

$$MWu^{235} = 235 \text{ gm. .mole}^{-1}$$

$$MWu^{238} = 238 \text{ gm. .mole}^{-1}$$

Yet, the atomic volume associated with $_{92}U^{235}$; periodic properties of elements

$$A_v = 12 \text{ cm}^3 \text{ .mole}^{-1}$$

whereby,

$$A_v^{-1}\ MWu^{235} = 19.58 \text{ gm.cm}^{-3}$$

and,

$$A_v^{-1}\ MW_g 238 = \rho_{u^{238}} = 19.83 \text{ gm.cm}^{-3}$$

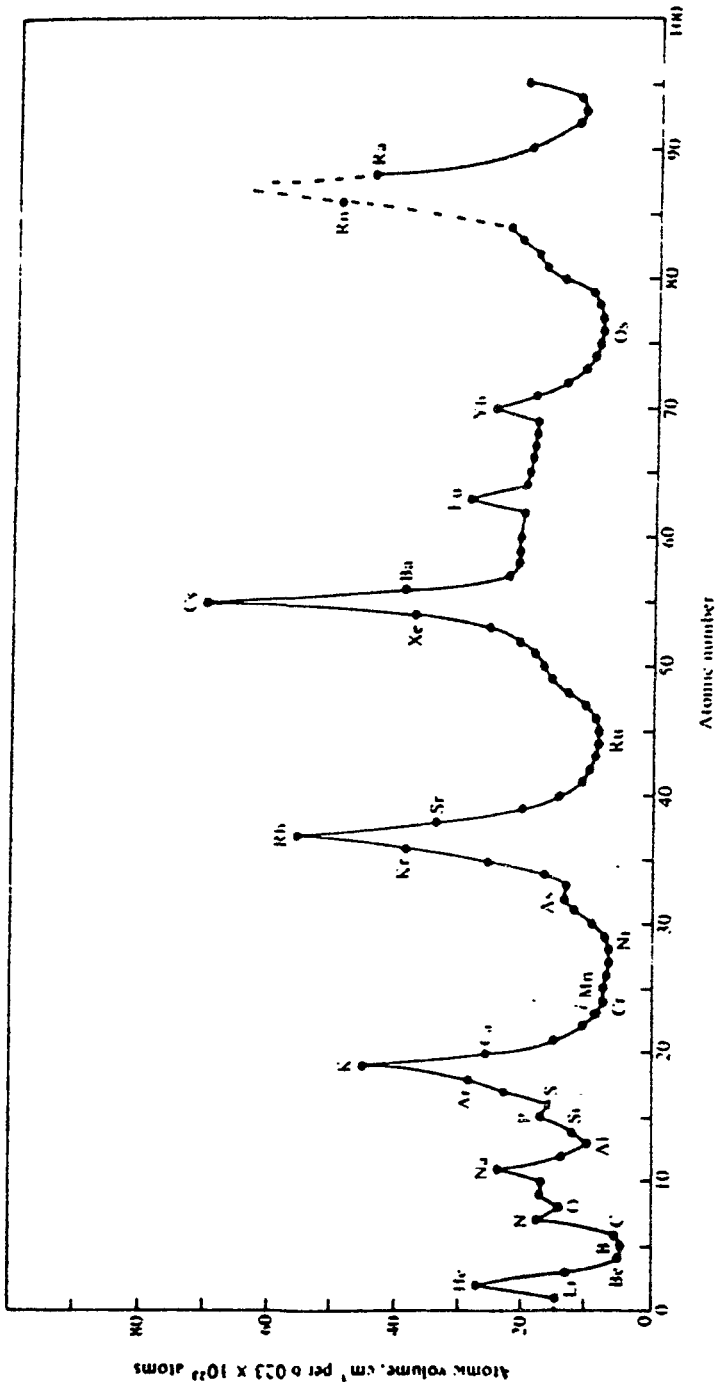


Figure 1-1 *Atomic volumes*

PERIODIC PROPERTIES OF ELEMENTS

NAVAJO SUPERFUND OFFICE	
GENERAL ASSUMPTIONS	
MAY, '90	P. MOLLOY

Upgradien[redacted]rainage area calculation[redacted]

$A_T = A_1 + A_2 = 1.59\ in^2$,

However map fragment is a 141% blowup of part of bluewater quad, then

2.64"=1 mi.
or,
1" =.379 mi.
=2000ft.

It then follows that for a 141% boost

$$1" = 1418\ ft. = \frac{2000}{1.41}$$

and

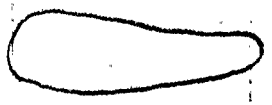
$A_T = 1.59(1.418(10^3)ft.)^2$
$= 3.197(10^6)ft^2$
$= 73.39$ acres

NAVAJO SUPERFUND OFFICE

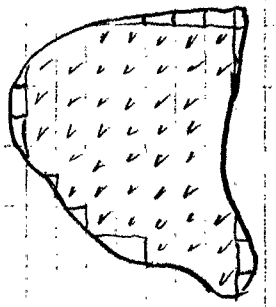
BROWN VANDEVER URANIUM MINE
WORKSHEET#1

MAY,'90 P. MOLLOY

17
6900
7000
7400
7100
Mine
7004
7101
6926
6869
6 Homes
6926
7000
Church
19
PRIVA
7088
Tintero
6900
5
6880
Lava
6834
6835
6858
6827



A_1



A_2

11 □'s
9 △'s = 2 □'s
12 TOTAL

43 □'s
7 11
50 TOTAL

$A_1 \propto$ 12 □'s

$\square = (.64)\left(\frac{1''}{4}\right)^2 = .026\,in^2$

$\Rightarrow A_1 = .31\,in^2$

$A_2 \propto$ 50 □'s

$\Rightarrow A_2 = 1.28\,in^2$

WORKSHEET#2; ALTERNATE COMMUNITY POPULATION DERIVATION

1. FROM THE "AS BUILT" FOR THE HAYSTACK COMMUNITY WATER SYSTEM THE FOLLOWING QUANTITIES ARE DEDUCED;

$$N_{res} = 86,$$

$$N_{prv} = 2$$

SO THAT,

$$N_{SERV} = 86 - 2 = 84$$

2. FROM REFERENCE#31(NAVAJO NATION FAX '88), THERE ARE 5.14 PERSONS PER NAVAJO HOUSEHOLD(AVERAGE) SO THAT;

$$N_p = (5.14)(N_{SERV}) = 432 \text{ PERSONS}$$

3. IT IS ESTIMATED THAT THERE ARE AT LEAST 100 PERSONS IN THE AREA THAT ARE NOT CONNECTED TO THE NNWRD WATER SYSTEM.

NAVAJO SUPERFUND OFFICE

NAVAJO-BROWN VANDEVER URANIUM MINE

JUNE,'90 P. MOLLOY

Worksheet for population total, population distribution and population at risk from noncertified water source.

Bracket	Res.	Pop.	*Res.	#Pop.	
0-¼	7	36	0	0	
¼-½	0	0	0	0	
½-1	12	62	3	15	
1-2	29	149	6	31	
2-3	24	123	2	10	
3-4	6	31	3	15	
	78	401	15	71	TOTALS

Potential
*Non-Certified water consumers

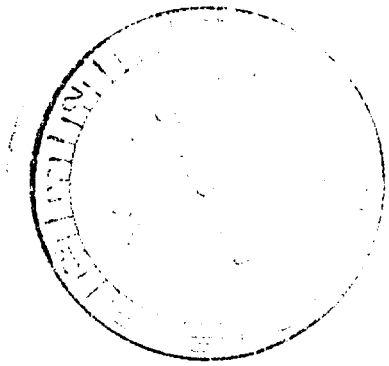
V IETN

46. LEO MARTINEZ
... MARTINEZ
47. ... DELGARITO
... VANDEVER
... VANDEVER
... GEORGE BEC...
... VANDEVER
54. HANK VANDEVER
... VANDEVER
... JAMES
... EUSTACHE
... BEGAY
... VANDEVER
... FRANCIS WILL...
... TOM JIM
... LEO GARCIA
... JAMES
... JAMES
... CASTILLO
... NELSON
... WILSON NELSON
... GILBERT YAZZIE
... LEWIS
... LEWIS JR.
... YAZZIE
... LEWIS JR.
... LEWIS
76. ERVIN D LEWIS
77. PAUL LEWIS JR.
... LEWIS
... MARIE DESIDERIO
80. MARY DESIDERIO
81. JOHNNY KENNETH

8. HAROLD PLATERO
9. LEON JOHNSON
0. PATRICIA JIM

PROJECT INDE...

NAVAJO - BROWN VANDEVER URANIUM
MINE SPOILS CALCULATIONS ADDENDA
(PLEASE ATTACH TO REFERENCE # 4)



NAVAJO SUPERFUND OFFICE

NAVAJO - BROWN VAN-
DEVER URANIUM MINE

JUNE,'90 P. MOLLOY

NOTES ADDED IN PROOFS FOR THE NAVAJO - BROWN VANDEVER URANIUM MINE PRELIMINARY ASSESSMENT

1. FROM REFERENCE # 35, THE SOLUTION FOR THE ONE - DIMENSIONAL, STEADY - STATE RADON DIFFUSION EQUATION (EQ.(1)) IS;

$$J_t = 10^4 R\rho E(\lambda D_t)^{\frac{1}{2}} \tanh[(\lambda D_t^{-1})^{\frac{1}{2}} x_t]$$

WHERE

J_t - THE RADON FLUX FROM TAILINGS SURFACE IN $pCi.m^{-2}s^{-1}$

AND

x_t - THICKNESS OF TAILINGS IN cm.

2. REASONABLE VALUES FOR THE PARAMETERS ARE ASSUMED AND ARE;

ρ = 1.5 $gm.cm^{-3}$ (DRY BULK DENSITY OF TAILINGS)
E = 0.23(RADON EMANATION COEFFICIENT, DIMENSIONLESS, FROM FIGURE 15, PAGE 5 - 2)
D_t = 1.3(10^{-2}) $cm^2.s^{-1}$(DIFFUSION COEFFICIENT FOR RADON IN THE TOTAL PORE SPACE)
$R = K_a G$ = (.19)(2812 pCi) (SEE PAGE 5-1)
= 534.28 pCi

AND

λ = 2.1(10^{-6})s^{-1}(DECAY CONSTANT OF RADON)

3. FURTHER ASSUME THAT THE TAILINGS EQUILIBRIUM MOISTURE CONTENT(DRY WT.%) IS;

M = 11.7%

(FROM FIGURE 15): THIS VALUE YIELDS A RADON EMANATION COEFFICIENT CONSISTENT WITH THE VALUE 0.23.

4. COMPUTE THE RADON FLUX:

$$J_t = 10^4(534.28)(1.5)(0.23)[(2.1(10^{-6})(1.3(10^{-2})]^{\frac{1}{2}} \times \tanh[(2.1(10^{-6})(1.3(10^{-2})^{-1}]^{\frac{1}{2}}(300)$$
$$= 304.26\ pCi.m^{-2}.s^{-1}$$

5. FROM 6. AND 7. OF REFERENCE#4 OF THE PRELIMINARY ASSESSMENT, ASSUME THAT APPROXIMATELY 30% OF THE 251 ACRES IS COVERED WITH TAILINGS TO A DEPTH OF 3m(300 cm) WHEREBY

$$A_t = (0.3)[1.1(10^7)ft^2]$$
$$= 9.34(10^4)\ m^2$$

6. COMPUTE THE TOTAL FLUX

$$J_t A_t = 2.84(107)\ pCi.s^{-1}$$

NAVAJO SUPERFUND OFFICE
BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL
MAY,'90 P. MOLLOY

7. COMPUTE THE TOTAL YEARLY RADON PRODUCTION (IN CURIES);

$$P_{Rn} = (60)^2(24)(365)J_t A_t$$
$$= 8.97(10^{14})(10^{-12})Ci$$
$$= 897 \text{ Curies}$$

8. FROM REFERENCE #2, PAGE #43 THE VALUE FOR THE AVERAGE SPECIFIC FLUX FROM AGED TAILINGS PILES IS;

$$J_t' = (0.19)(10^3) = 190 \text{ pCi.m}^{-2}\text{s}^{-1}$$

WHERE 0.19% IS THE B. VANDEVER ORE GRADE VALUE.

9. THE ALTERNATE TOTAL FLUX FOR THE ASSUMED 75.3 ACRES IS;

$$J_t' A_t = (190)[9.34(10^4)] \text{ pCi.s}^{-1}$$
$$= 1.78(10^7) \text{ pCi.s}^{-1}$$

10. COMPUTE THE TOTAL YEARLY RADON PRODUCTION GIVEN THE ABOVE FLUX;

$$P_{Rn} = (60)^2(24)(365)$$
$$= 560 \text{ Curies}$$

11. THE VALUE FROM REFERENCE #2 FOR TAILINGS PILES IS;

$$J_t'' = (0.19)[3.3(10^3)] \text{ pCi.s}^{-1}$$
$$= 5.87(10^7) \text{ pCi.s}^{-1}$$

12. THE TOTAL YEARLY RADON PRODUCTION FOR A WORST CASE SCENARIO IS THEN;

$$P_{Rn} = (60)^2(24)(365)[5.87(10^7)] \text{ pCi}$$
$$= 1850 \text{ Ci}$$

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY, '90 P. MOLLOY

Grand 119 - 10.05 10½W, 16T-521
6 miles E of Prewitt

PROPERTY EASEMENT
for Water Development

THIS INDENTURE made the 16 day of JUNE, 1963 between Mary Martinez Desidero C# 6921 party of the first part and the Navajo Tribe, party of the second part.

WHEREAS the party of the first part is the holder of Mary Martinez Desidero C# 6921 more particularly described as follows:

Third person is Mary Martinez Desidero C# 6921 made an agreement and solomnly swore To have her five acres allotment To be drilled for water. She leased her allotment Section 18, T13N, R10W, N.M.P.M. Northeast 1/4 for 99 years. AL. 058009

And whereas, the party of the first part has agreed in consideration for the development by the Navajo Tribe of water supply on the property described aforesaid, by means of wells, reservoirs, pipelines and other installations, which he will share in community with neighboring land holders, to permit the Navajo Tribe or its authorized representative or employees to enter upon the property heretofore described for the purpose of the development of the water supply.

am

Property Easement for
Water Development

And further agrees to permit full and free right and access to the water supply developed in accordance with the Navajo Tribal water policy to all neighboring land holders.

To have and to hold the said easement and right of way hereby granted, as appurtenant to the said land held by the party of the first part.

In witness whereof the party of the first part has hereunto set his hand and seal the day and year first above written.

GRACE D. LARGO
Party of the first part

Joe Vandever
Prewitt New Mexico
Witness

Jack Long
Prewitt New Mexico
Witness

Property Easement for
Water Development

And further agrees to permit full and free right and access to the water supply developed in accordance with the Navajo Tribal water policy to all neighboring land holders.

To have and to hold the said easement and right of way hereby granted, as appurtenant to the said land held by the party of the first part.

In witness whereof the party of the first part has hereunto set his hand and seal the day and year first above written.

Right Thumb print

Party of the first part

Witness

Witness

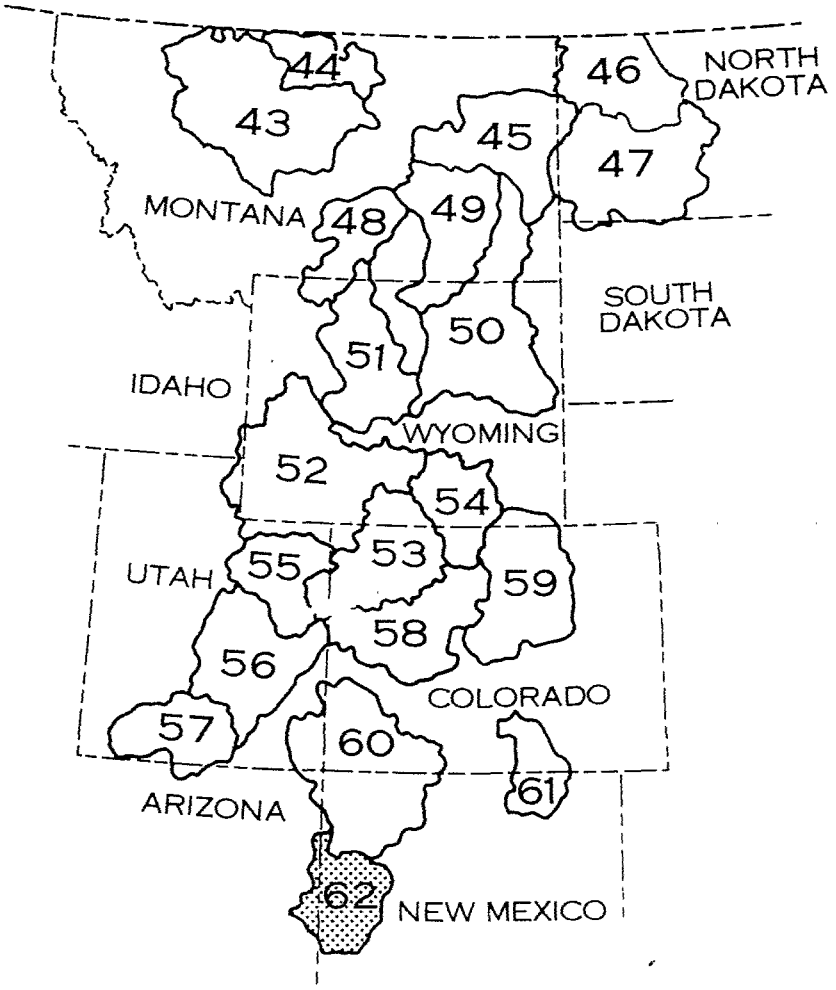
REFERENCE # 5

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

HYDROLOGY OF AREA 62, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, NEW MEXICO AND ARIZONA



- PUERCO RIVER
- ZUNI RIVER
- LARGO CREEK
- CARRIZO WASH
- RIO SAN JOSE
- BLACK CREEK

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 83-698

HYDROLOGY OF AREA 62, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, NEW MEXICO AND ARIZONA

BY
F. E. ROYBAL, J. G. WELLS, R. L. GOLD, AND J. V. FLAGER

U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 83-698

ALBUQUERQUE, NEW MEXICO
APRIL, 1984

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Land-Ownership Pattern is Complicated

Indian, Federal, and private ownership is represented.

As shown in figure 2.1-1, the land-ownership pattern in Area 62 is complicated. The checkerboard pattern created by several types of ownership makes it difficult to effectively manage these lands and consequently complicates the water rights. Indian ownership includes trust and deeded lands, but these categories are not identified on the map. Three Indian reservations are located entirely or partly within Area 62: the Navajo Reservation in New Mexico and Arizona, the Zuni and Acoma Reservations in New Mexico.

Federal land in Area 62 is administered by the U.S. Forest Service, the U.S. Bureau of Land Management, the National Park Service and the U.S. Department of Defense. Parts of Cibola and Apache National Forests are included in the New Mexico part of Area 62. El Morro National Monument is administered by the National Park Service, Fort Wingate Military Reservation, east of Gallup, New Mexico, is administered by the Department of Defense.

State and private lands are generally scattered in a checkerboard pattern. In the early 1850's, the Santa Fe Railroad received government grants for alternate sections of land in strips to build railroads in vacant and sparsely settled sections of the area. These grants created a checkerboard pattern of land ownership (Lower Colorado Region State-Federal Interagency Group for the Pacific Southwest Interagency Committee, Appendix VI, 1971, p. 56). Most of the privately owned lands are within Cibola County, New Mexico. In New Mexico, State lands are administered by the Commissioner of Public Lands with assistance from other agencies such as the State Park Commission, the State Forestry Commission, the State Department of Game and Fish, the State Engineer Office, and the State Department of Transportation.

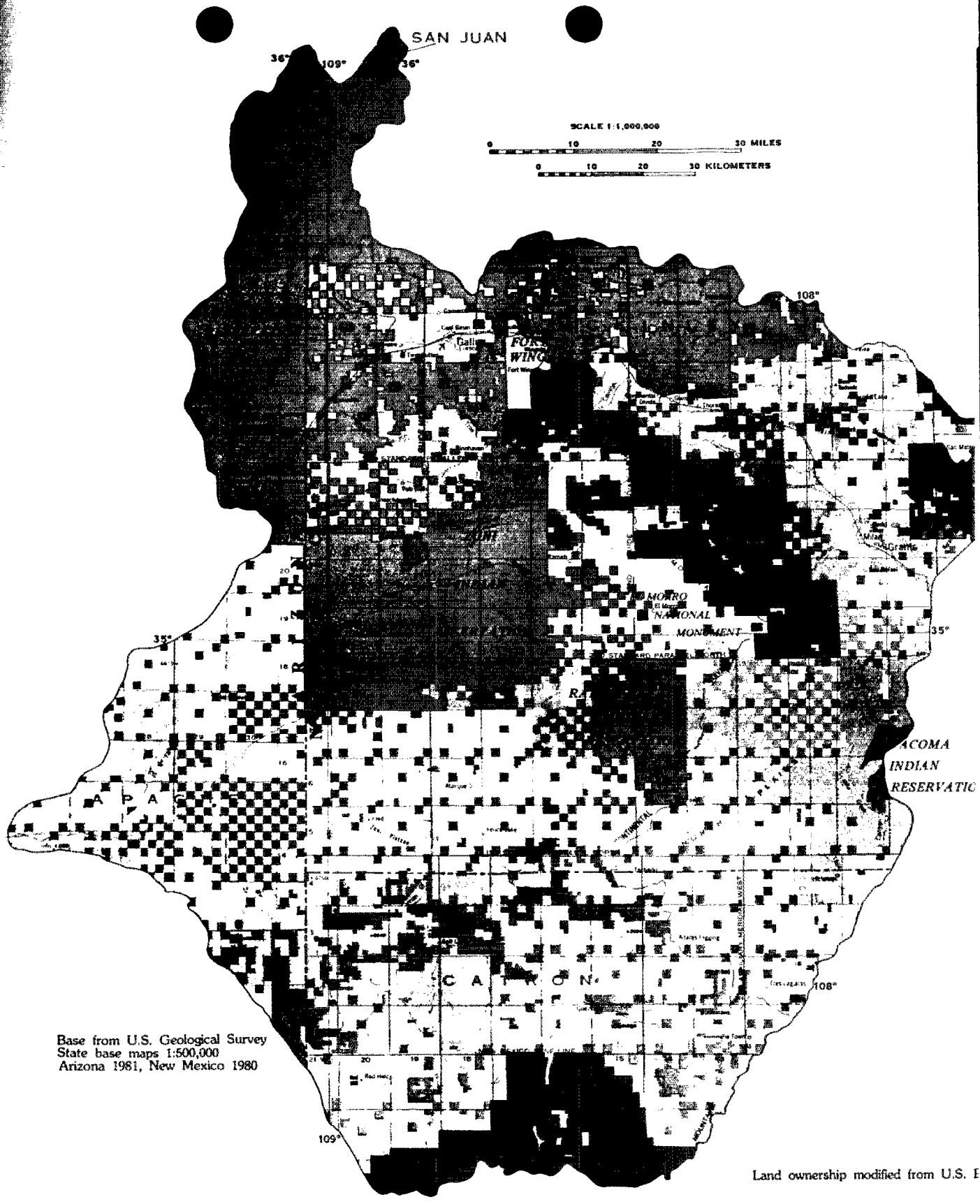
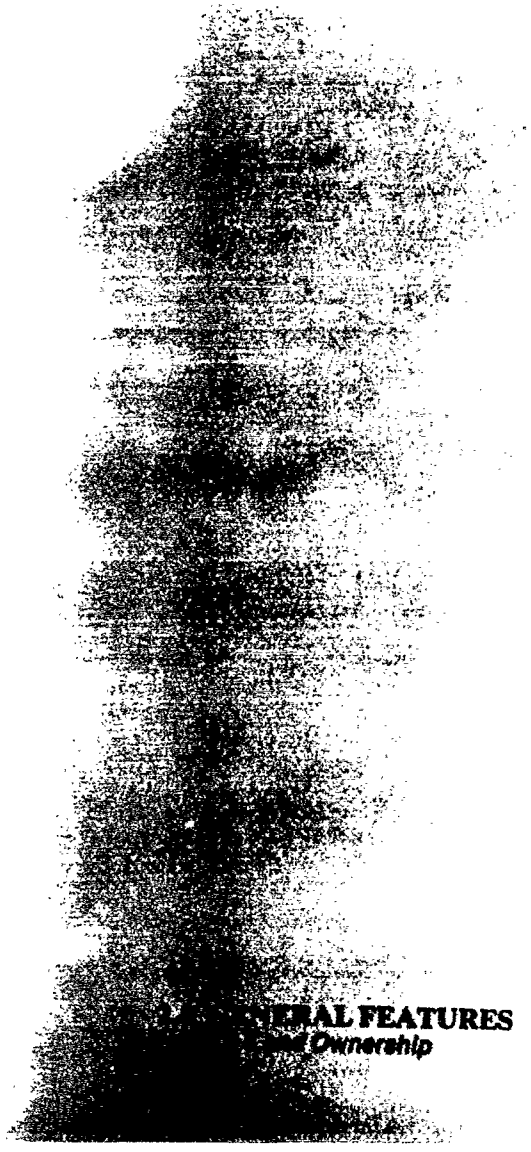


Figure 2.1-1 Generalized land ownership.

EXPLANATION

- INDIAN LANDS
- U.S. FOREST SERVICE
- U.S. BUREAU OF LAND MANAGEMENT
- NATIONAL PARK SERVICE
- U.S. DEPARTMENT OF DEFENSE
- STATE TRUST AND DEEDED
- PRIVATE



RAL FEATURES
Ownership

lamation (1968) and U.S. Department of Agriculture (1981a).

Average Annual Precipitation is 10 to 12 Inches in the Valleys and Plateaus and 16 to 20 Inches in the Mountains

Temperatures generally are warmest in July and coolest in January.

The climate is semiarid (about 10 to 20 inches of annual rainfall), except for a few isolated areas that receive more than 20 inches of precipitation per year. The variation in precipitation and temperature is controlled by altitude. Areas at high altitude have greater precipitation and lower temperatures than areas at lower altitudes. The approximate areal distribution of average annual precipitation is shown in figure 2.2-1. Average annual precipitation from long-term records are available for three stations: 12.34 inches at El Morro, 11.33 inches at Zuni, and 9.24 inches at Quemado. The distribution of average monthly precipitation for these three stations is shown in figure 2.2-2. The wettest months generally are July and August and the dryest months are generally May and June. During the winter, snowfall is common; a total of about 50 inches was recorded at McGaffey, New Mexico, in December 1967.

In Area 62, winters are rather cold, summers are warm, and days are sunny. Daily temperatures vary by 30 to 40 degrees. Temperatures greater than 90 degrees are not common in most of the area, but at Gallup, the maximum recorded was 99 degrees; the minimum was 23 degrees below zero (Tuan and others, 1973, p. 193). The distribution of average monthly temperatures at selected stations is shown in figure 2.2-2. The average temperature for the warmest month (July) is about 70° Fahrenheit, and for the coolest month (January) is about 32° Fahrenheit.

Daily precipitation and temperature data are available in monthly issues of "Climatological Data for New Mexico" and "Climatological Data for Arizona." The data are published by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

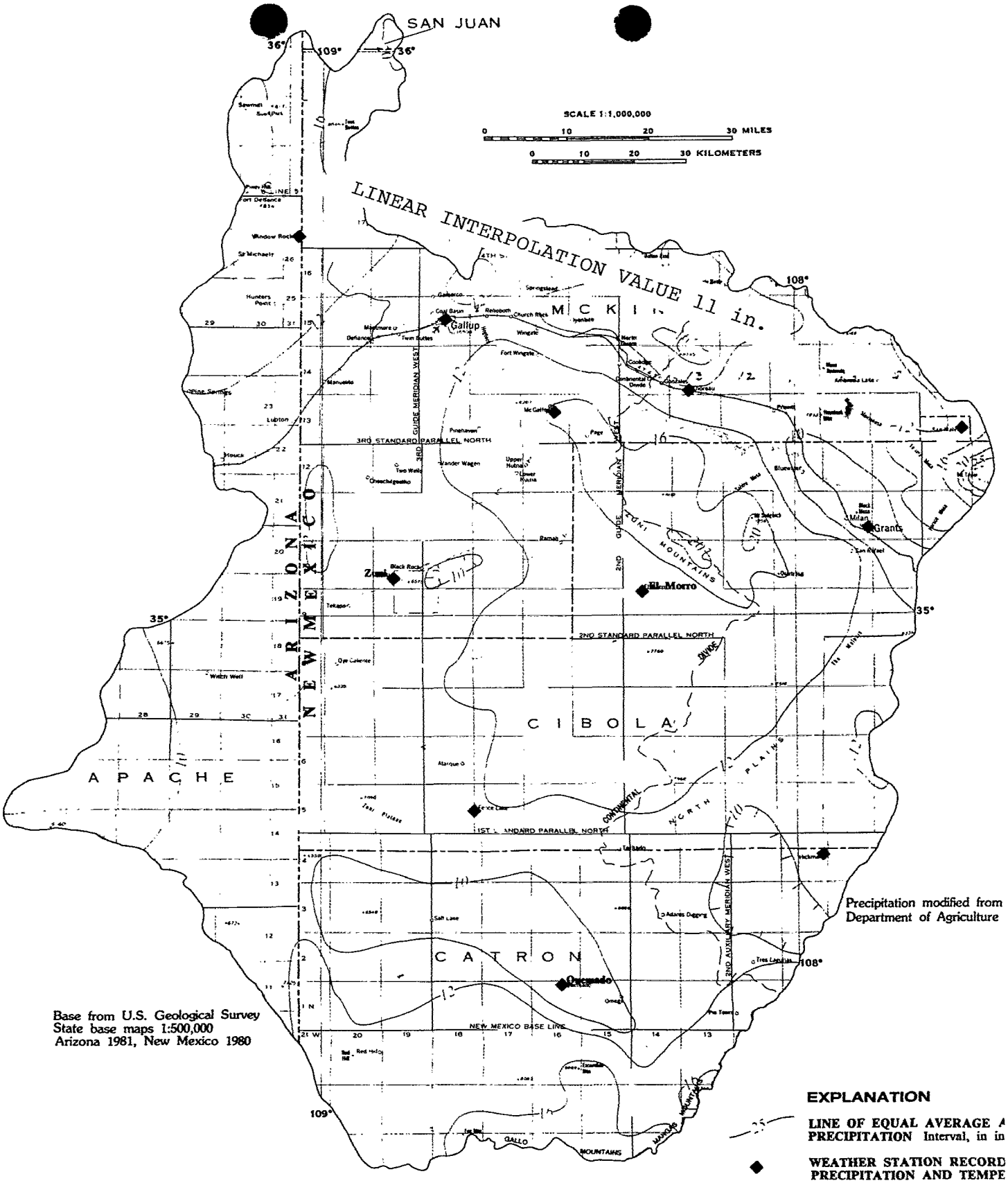
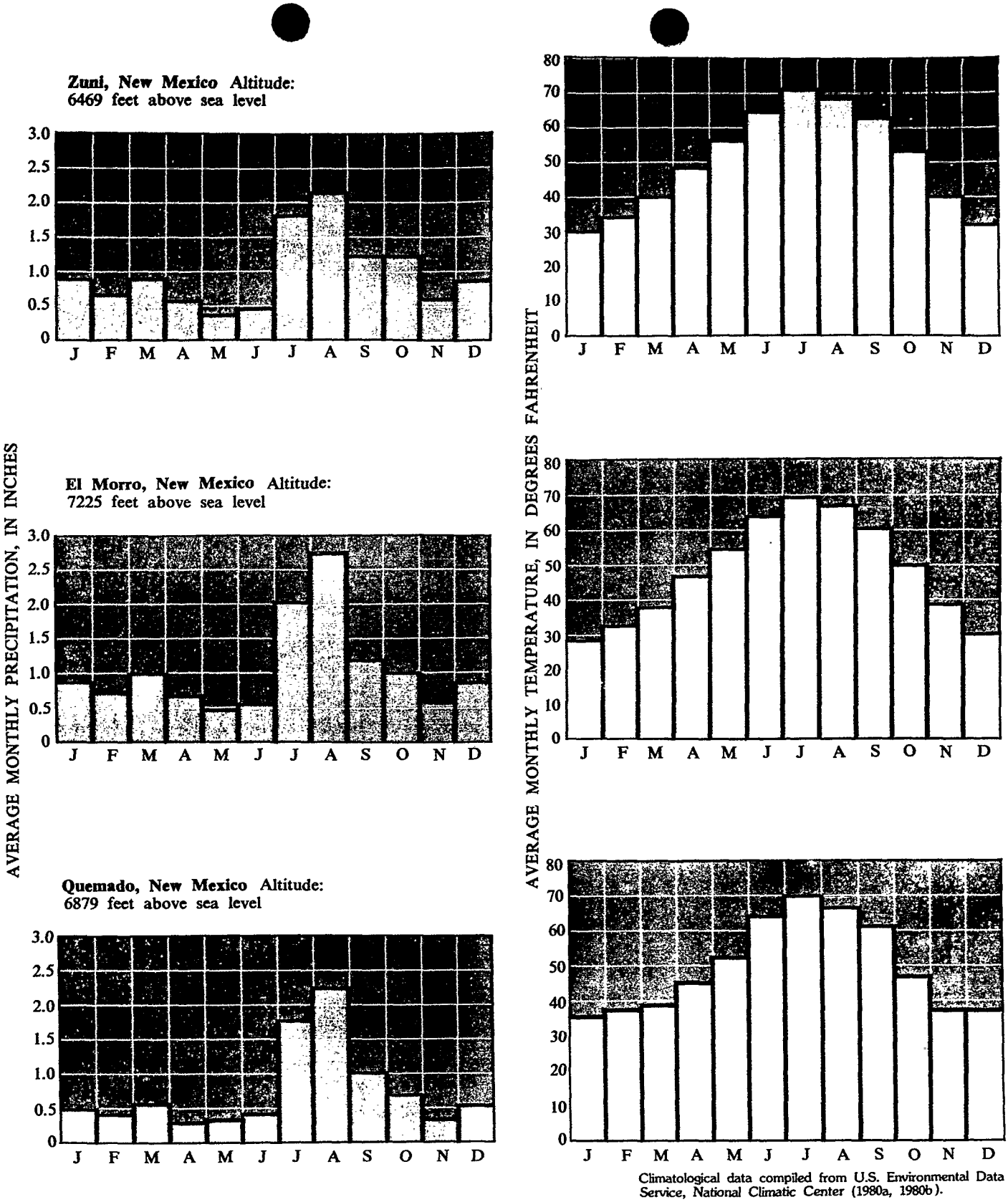


Figure 2.2-1 Average annual precipitation, 1931-60.



Climatological data compiled from U.S. Environmental Data Service, National Climatic Center (1980a, 1980b).

.S.
)72, 1981a).

NUAL
es, is variable.

Figure 2.2-2 Average monthly precipitation and temperature at selected weather stations, 1941-70.

The Major Structural Features of the Coal Area were Largely Developed by Middle Tertiary Time

The major structural features in Area 62 are the southern San Juan Basin, its bounding structures, and the Mogollon slope.

Area 62 lies in the southeastern quarter of the Colorado Plateau, one of the major structural provinces of the United States. The Plateau is characterized by a thick sequence of sedimentary rocks that indicate a long tectonic history (Foster, 1971, p. 363 and Kelley, 1951, p. 124-129). The southern part of the San Juan Basin, its major bounding structures (Kelley, 1951), and the Mogollon slope are the major structural features in Area 62 (fig. 2.5-1).

During the nineteenth century the study of sedimentary rocks and the plant and animal fossils they contained led to the development of the geological time scale (fig. 2.5-2). The scale shows the immensity of time involved for formation of the structural features in Area 62.

The San Juan Basin, a structural embayment of the Colorado Plateau, began to form during a period of uplift as early as Late Paleozoic time (Kelley, 1951, p. 130). The Defiance and Zuni uplifts the major highland elements in the southern San Juan Basin were forming in Paleozoic and Mesozoic Time. Kelley states that the present structural elements of the San Juan Basin were probably developed by Middle Tertiary time.

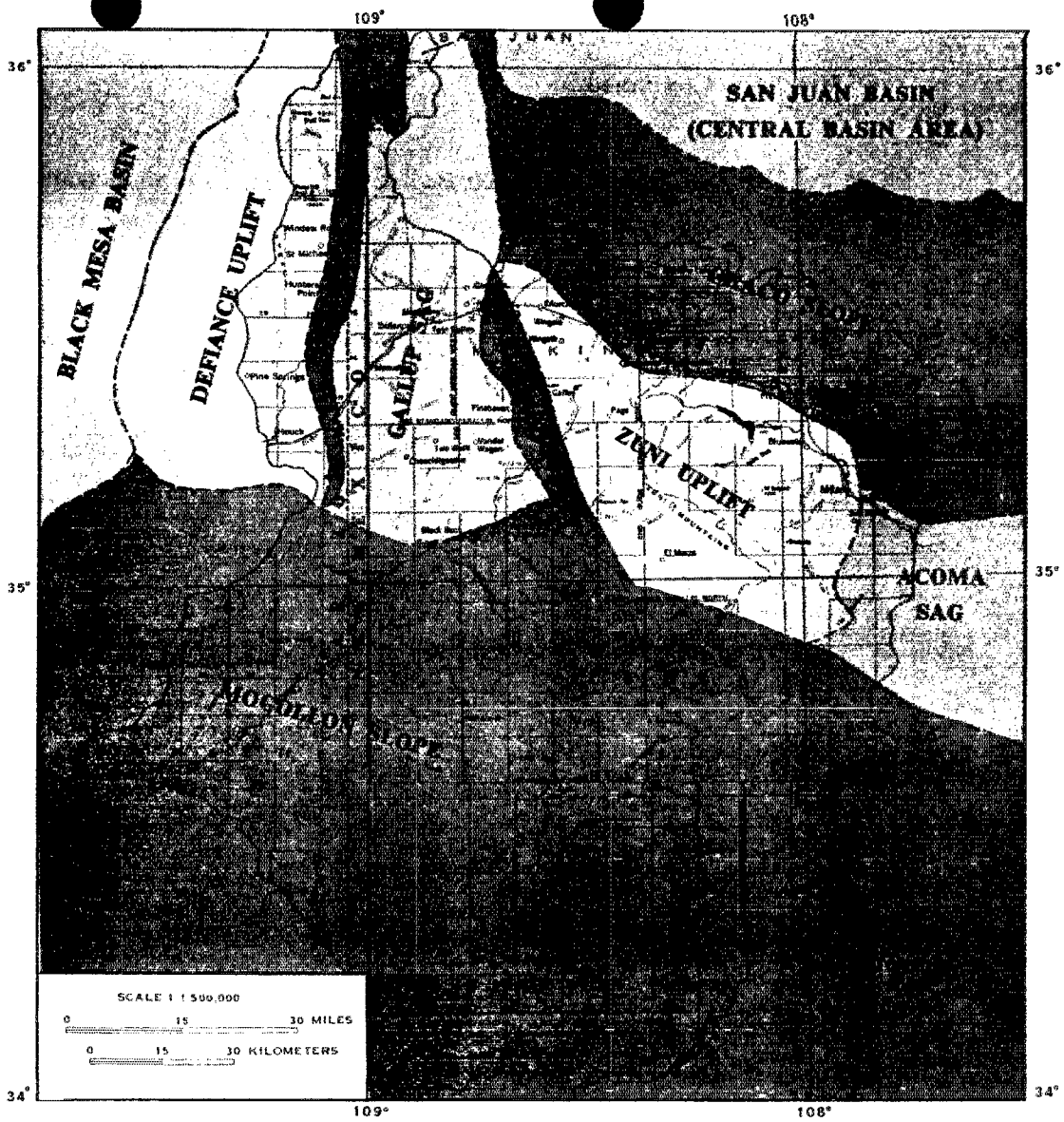
The Mogollon highland dominated the south side of the Colorado Plateau during Late Jurassic time. The south half of the highland (shown in fig. 2.5-1 as the Mogollon slope) was broken and tilted to the northeast during volcanic episodes at the end of the Jurassic Period (Saucier, 1976, p. 152). The Mogollon slope is the structural feature which represent the tectonic remnants of the Mogollon highland.

The Zuni and Defiance uplifts are located on the southern and western edges of the San Juan basin. The Zuni uplift trends northwestward, is 80 miles long by 35 miles wide, and has a structural relief of 5,500 feet (Kelley, 1951, p. 126). The steep limb of the uplift dips southwestward away from the basin. The Defiance uplift trends northward past the study area, is 100 miles long by 30 miles wide, and has a maximum structural relief of 7,500 feet (Kelley, 1967, p. 28). The steep limb dips east toward the San Juan basin (Kelley, 1951).

Two structural platforms (Kelley, 1951, p. 126) are located in the study area: The Acoma sag and the Gallup sag. The Acoma sag is a flat wide area bordering the Zuni uplift on the east. The Gallup sag extends from the San Juan basin southward between the Defiance and Zuni uplifts (Kelley, 1967, p. 29).

Two monoclines border the Gallup sag. The Nutria Monocline bounds the north two-thirds of the Zuni uplift on its west side (Kelley, 1967) and the Defiance monocline borders the Defiance uplift on its east side.

Kelley (1951, p. 126) describes the Chaco slope as the southern part of the San Juan Basin that lies between the Central Basin (fig. 2.5-1) and the Zuni uplift and Acoma sag. The Chaco slope resembles the platforms but differs from them because of "its more pronounced and continuous regional inclination toward the center of the basin and by the absence of a 'monocline' separating it from the Central Basin" (Kelley, 1951, p. 126).

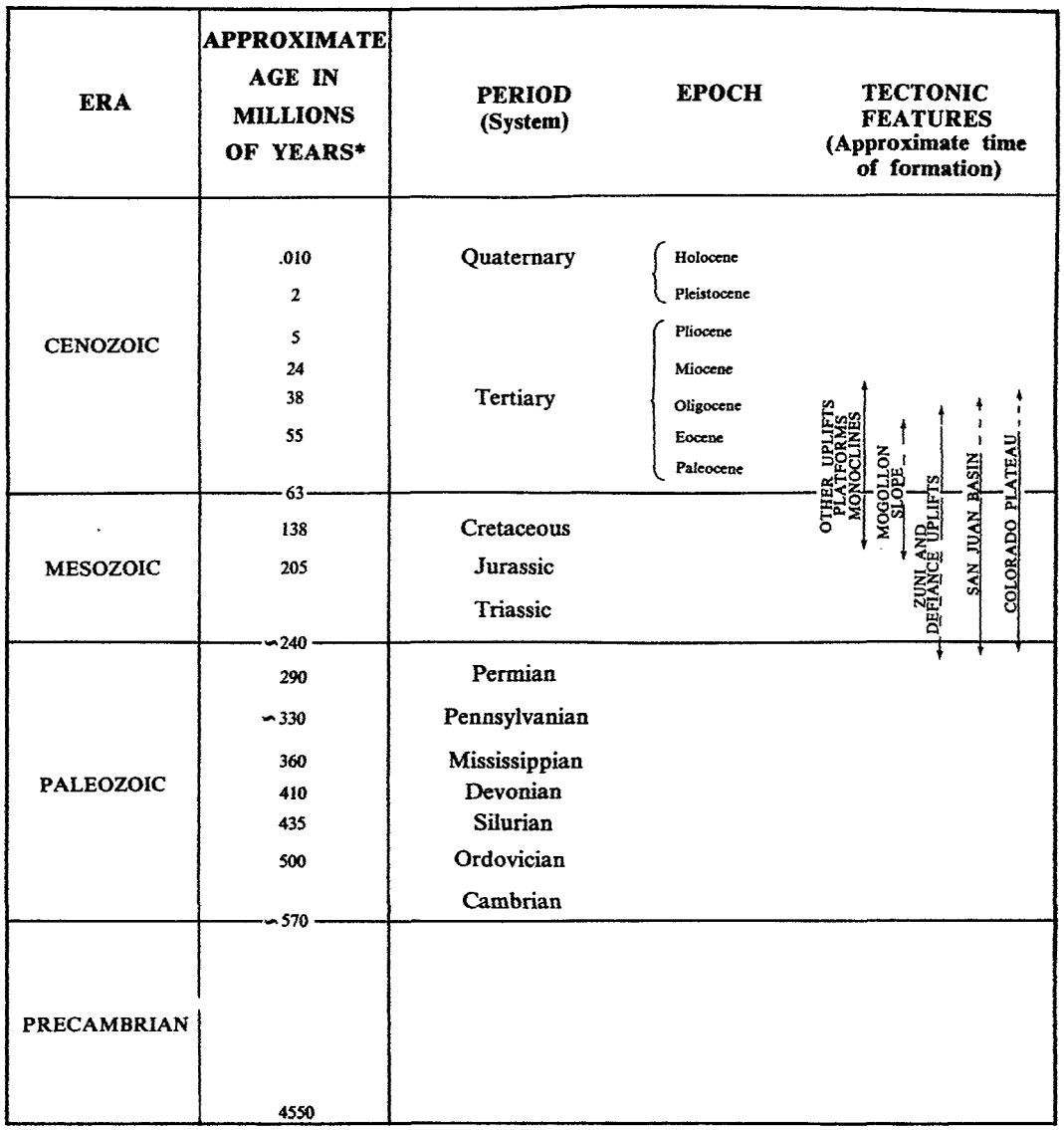


Structural features modified from Kelley (1951, 1955)

EXPLANATION

- UPLIFTS
- BASINS AND PLATFORMS
- SLOPES AND MONOCLINES
- BOUNDARY BETWEEN STRUCTURAL FEATURES

Figure 2.5-1 Major structural features.



*Ages shown are estimates based on isotopic and biostratigraphic age assignments.
Age of rocks represented by ∽ are not supported as closely by existing data.

Figure 2.5-2 Geologic time.

Exposed Rocks Range in Age from Precambrian to Quaternary

Cretaceous rocks in the New Mexico part of the study area make up the most extensive outcrops of any of the rock units.

Exposed rocks in the area range in age from Precambrian (older than 570 million years ago) to Quaternary (about 10,000 years age to the present). The geologic map (fig. 2.6-1) shows the rocks exposed at the surface. Cross sections in section 4.5 provide information on stratigraphic relationships. Exposures of Precambrian gneissic granite are found southeast of Gallup in the Zuni Mountains (Hackman and Olson, 1977). Rocks of Cambrian through Mississippian age do not crop out in the study area. Pennsylvanian to Permian rocks of the Supai Formation are exposed along the Defiance uplift (fig. 2.5-1) in Apache County. The lithology of the Supai Formation consists of alternating beds of reddish-brown sandstone, siltstone, mudstone and white gypsum and gray limestone (Hackman and Olson, 1977).

A thick sequence of Permian rocks was deposited by alternating transgressions and regressions of the sea (McKee, 1967, p. 219). Extensive exposures of Permian rock are present along the Defiance uplift in Apache County, Arizona, and the Zuni uplift in Cibola and McKinley Counties, New Mexico. The Permian De Chelly Sandstone in Apache County is composed of orange, pink, and red fine-to-medium-grained sandstone (Hackman and Olson, 1977). The exposed Permian sequence of rocks in Cibola and McKinley Counties in ascending order consists of the Abo and Yeso Formations, the Glorieta Sandstone, and the San Andres Limestone. The Abo and Yeso Formations of Early Permian age are composed mostly of reddish sandstone and siltstone with several limestone and gypsum beds in the upper part of the Yeso Formation (Hackman and Olson, 1977). The Glorieta Sandstone, a white and buff-colored sandstone, is overlain by the San Andres Limestone, a gray and yellow thick-bedded dolomitic limestone (Hackman and Olson, 1977).

Triassic, Jurassic, and Cretaceous sediments were deposited in continental, near-shore, and marine environments. Frequent facies changes represent the fluctuations of the depositional environments and regional unconformities illustrate periods of erosion in Mesozoic time.

The Moenkopi Formation and Chinle Formation are the Triassic sedimentary rocks in Area 62. The Moenkopi Formation is composed mainly of red to brown gypsiferous sandstone, siltstone, and shale and is shown in figure 2.6-1 as part of the Triassic rocks cropping out in southern Apache County. The Chinle Formation, a variegated sequence of sandstone and siltstone (Repenning and others, 1969, p. B-2) is exposed near Window Rock, Arizona, along the Zuni River in Arizona, in southern and central McKinley and northern Cibola Counties, New Mexico (fig. 2.6-2).

Rocks in the Glen Canyon Group are probably both Jurassic and Triassic in age and are found in the northern part of the study area along the Arizona-New Mexico boundary, in southern and central McKinley County, and northern Cibola County. The Glen Canyon Group contains several formations that are composed mainly of sandstone and siltstone and that have cross-bedding (Cooley and others, 1969, p. A-14).

Middle and Upper Jurassic sedimentary rocks include the San Rafael Group, the Zuni Sandstone (fig. 2.6-2) and the Morrison Formation, which lie unconformably on the Glen Canyon Group. They are exposed in the northern part of the study area in Arizona, in southern and central McKinley County, and northern Cibola County. These formations consist of mostly sandstone with some silty sandstone and siltstone (Cooley and others, 1969, p. A-14 and Dane and Bachman, 1965).

Cretaceous rocks form the most extensive outcrops of rock units in the New Mexico part of the study area. The Dakota Sandstone and Mancos Shale exposures are scattered throughout the area. These formations are composed of mostly gray, yellow, and orange sandstone, shale, clay, and silt (Hackman and Olson, 1977). The Mesaverde Group overlies the Mancos Shale and major lithologies are characterized by transgressive and regressive wedges of sandstone with thick lenses of shale and coal (Silver, 1951, p. 111-113).

Tertiary formations include the Bidahochi and the Baca Formations which are mostly fluvial sediments and contain some sediments of volcanic origin (Orr, 1982, p. 30 and U.S. Department of Agriculture, 1981a, p. 1-14). These formations are present in the southern part of the study area. The Tertiary Chuska Sandstone contains wind-blown and fluvial sediments and is present along the extreme northern edge of the area (Cooley and others, 1969, p. A-17). Other sedimentary rocks are included in the Tertiary designation on figure 2.6-1 and consist of conglomerate, sandstone, siltstone, and limestone. They are found at the surface in the western and central parts of the study area.

A considerable amount of volcanic activity started in Tertiary time and continued through much of Quaternary time (Cooley and others, 1969, p. A-17). Outcrops of Tertiary and Quaternary lava flows and volcanic deposits (including volcanic breccia, tuff, basalt, and cinders) are present along the southeastern edge of the area at Pie Town, New Mexico, westward to the State line and into southern Apache County, Arizona, and in the northeast including the Mount Taylor volcanic field. Necks, volcanic buttes, and diatremes protrude locally and are composed mostly of intrusive igneous rocks (rhyolite, trachyte, and latite), basalt, and consolidated ash (tuff) (Callaghan, 1951, p. 120-122, and U.S. Department of Agriculture, 1981a, p. 1-14).

Quaternary and Tertiary alluvium and bolson deposits are found mostly along streams and valleys, and as landslide deposits throughout the study area. These sedimentary deposits are composed of sand, silt, and gravel.

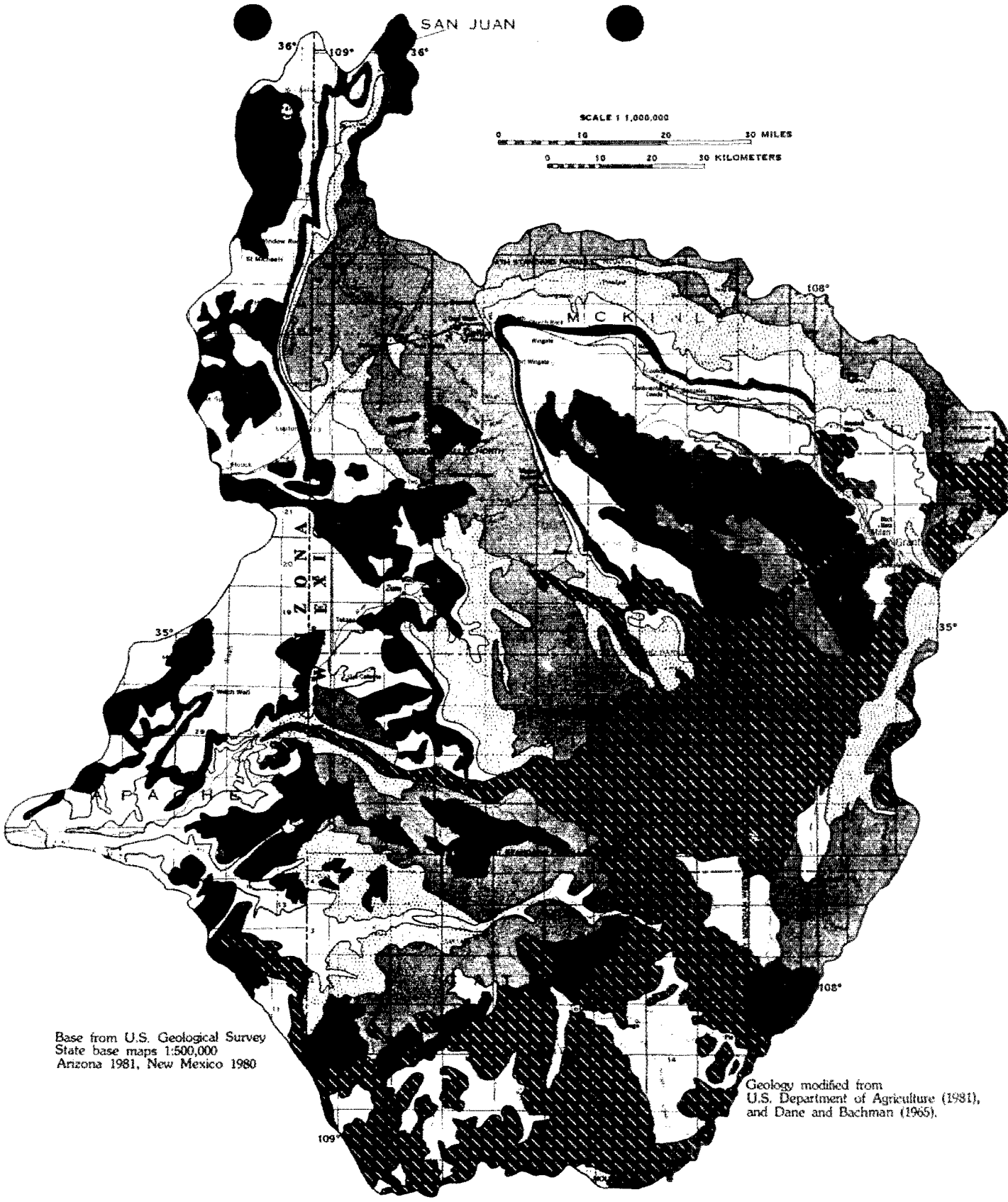
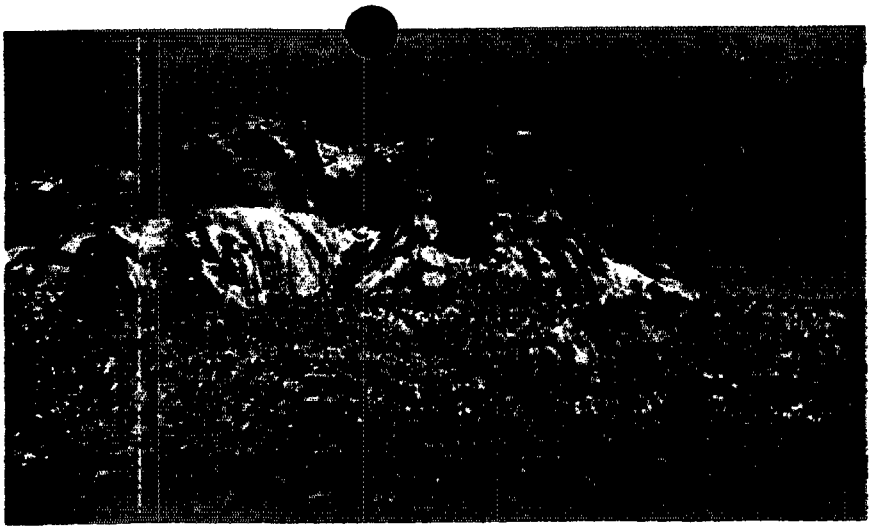


Figure 2.6-1 Generalized geologic map.



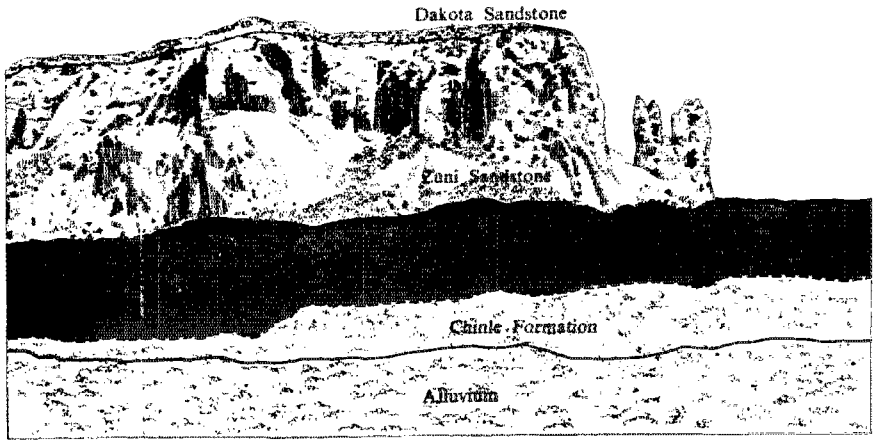


Figure 2.6-2 Dowa Yallane Mesa near Zuni, New Mexico, showing exposed formations (contact dashed where approximated).

EXPLANATION

QUATERNARY AND TERTIARY	ALLUVIUM AND BOLSON DEPOSITS
	IGNEOUS ROCKS, INCLUDES BASALT FLOWS, VOLCANIC BRECCIA, TUFF AND CINDERS, AND EXPOSED INTRUSIVE IGNEOUS ROCKS
TERTIARY	SEDIMENTARY ROCKS INCLUDING BIDAHOCHI FORMATION, CHUSKA SANDSTONE, AND BACA FORMATION
CRETACEOUS	MESAVERDE GROUP
	MANCOS SHALE AND DAKOTA SANDSTONE, UNDIVIDED
JURASSIC	MORRISON FORMATION, ZUNI SANDSTONE, AND SAN RAFAEL GROUP, UNDIVIDED
JURASSIC AND TRIASSIC	GLEN CANYON GROUP
TRIASSIC	CHINLE FORMATION; LOCALLY INCLUDES MOENKOPI FORMATION
PERMIAN	SAN ANDRES LIMESTONE AND GLORIETA SANDSTONE IN NEW MEXICO, DE CHELLY SANDSTONE IN ARIZONA, AND THE YESO AND ABO FORMATIONS IN NEW MEXICO
PERMIAN AND PENNSYLVANIAN	SUPAI FORMATION
PRECAMBRIAN	PRECAMBRIAN ROCKS, UNDIVIDED

Streamflow-Gaging Network Consists of 25 Stations

Streamflow data have been collected for a variety of needs.

Data have been collected at three types of streamflow gaging stations in Area 62. These stations, classified as continuous, partial-record, and miscellaneous, have been established in response to various needs and provide differing types of streamflow information. For example, daily mean discharges, peak flows, base flows, and instantaneous measurements for the complete year are available for continuous-record stations. The daily mean discharges are computed from records of continuous stage readings collected at the stations. Data concerning peak flows, low-flows and some instantaneous measurements are available at partial-record stations. Instantaneous measurements of streamflow are made at miscellaneous stations. The gaging stations were established for various purposes, including long term hydrologic assessment, data collection for short-term projects established to study specific problems, or in response to data needs caused by legal decisions or compacts.

The Continental Divide, shown in figure 3.1-1, crosses the study area. Streams to the east of the Divide are within the Rio Grande basin. The Rio San Jose (fig. 3.1-2) is included in this area. Streams to the west of the Divide, which include the Zuni River, Black Creek, Puerco River, and Carrizo Wash-Largo Creek are part of the Little Colorado River basin. The major river basins in the study area are delineated in figure 3.1-1.

The locations of the stations for which streamflow data were analyzed in this report are shown in figure 3.1-1. Periods of record, drainage areas and other information about the streamflow stations are tabulated in section 6.1. As noted in section 6.1 some of the stations shown have been discontinued or changed from partial record to continuous record. Fifteen of the 25 stations are currently being operated. Miscellaneous discharge measurements have not been included in analysis of surface-water data performed in the following sections.

Data from miscellaneous stations are available from the Geological Survey offices in Tucson, Arizona and Albuquerque, New Mexico.

Additional details about the period of record and type of data collected as well as the actual data, are available from computer storage through the National Water Data Exchange (NAWDEX) (section 5.2) and WATSTORE (section 5.3).

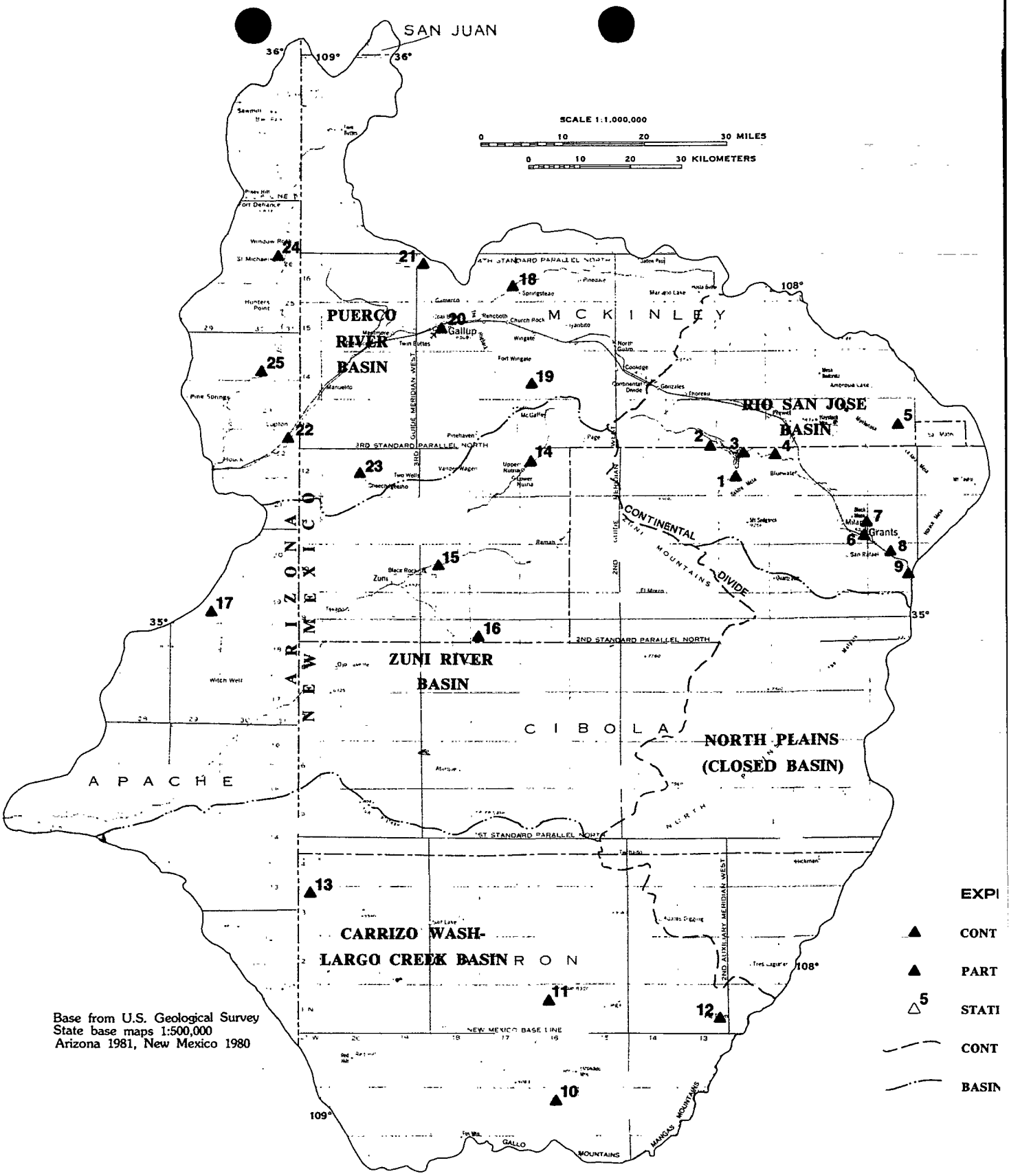


Figure 3.1-1 Location of surface-water gaging stations.

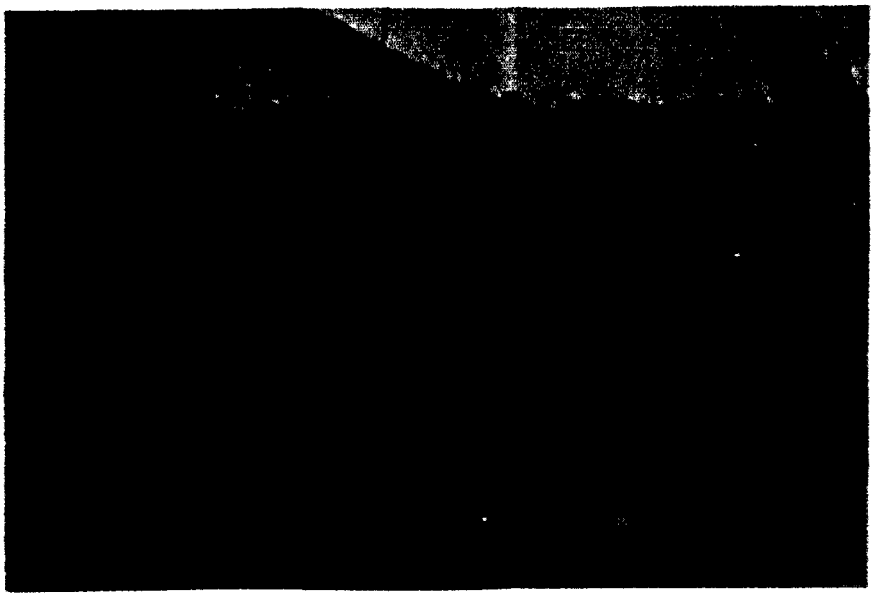


Figure 3.1-2. Streamflow-gaging station (9), Rio San Jose near Grants, New Mexico.

ATION

OUS-RECORD GAGING STATION

CORD GAGING STATION

AND NUMBER

AL DIVIDE

VIDE

Streamflows Exhibit Marked Changes Throughout the Year

Variation in streamflow is directly related to rainfall and snowmelt.

Most streams draining Area 62 are typical of streams in arid or semiarid lands. For such streams, there is no flow during most of the year. Most of the streamflow results from infrequent intense storms and from snowmelt causing a great deal of variability within a year.

To illustrate the variability of streamflow that exists within a particular year, streamflow hydrographs for the 1980 water year for the Zuni River (subject to regulation from upstream reservoirs) and Rio San Jose (regulated by Bluewater Lake) are presented in figure 3.2-1. As can be seen, there is little flow for much of the year. The periods of no flow can be contrasted against the peaks resulting from surface runoff from snowmelt and storms. Storm activity results in "flashy" peaks; that is, the storms result in a rapid rise in streamflow to the peak, followed by a rapid decrease in flow.

The monthly mean, maximum, and minimum for flows on the Rio San Jose and Zuni River for the period of record are summarized in figure 3.2-2. A majority of the annual discharge occurs from March through August in response to snowmelt and storms. Differences between the maximum and minimum flows are variable from month to month. Maximum discharges vary greatly between months, while the minimum discharges are zero for most months. For contrast, the maximum and minimum flows are summarized below for the Zuni River and Rio San Jose.

Map No.	Station Name	Maximum average flow		Minimum average flow		Average flow
		Flow	Water year	Flow	Water year	
15	Zuni River above Black Rock Reservoir, N. Mex.	46.9	1973	1.39	1972	13.0
6	Rio San Jose at Grants, N. Mex.	28.7	1916	0.01	1961	3.22

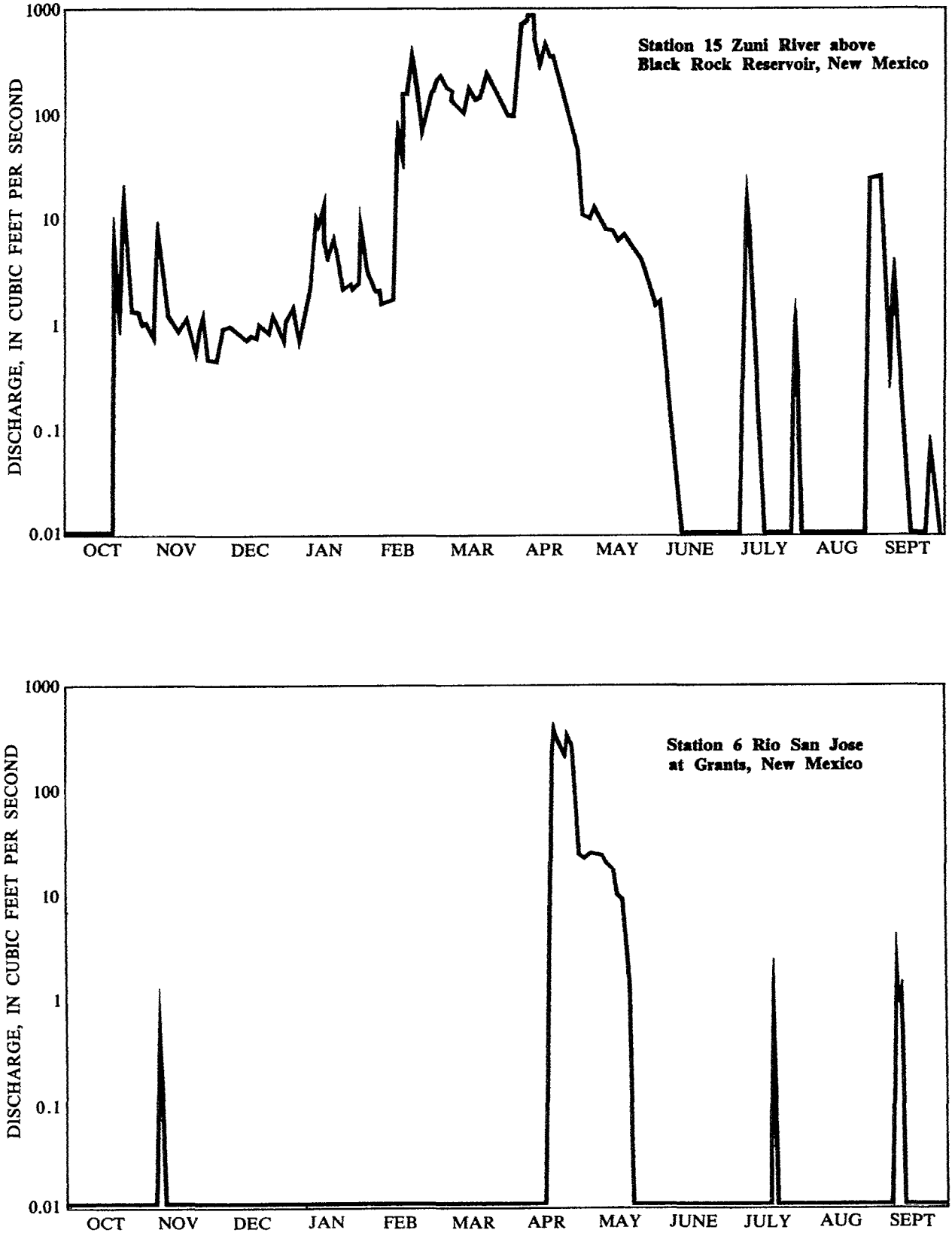
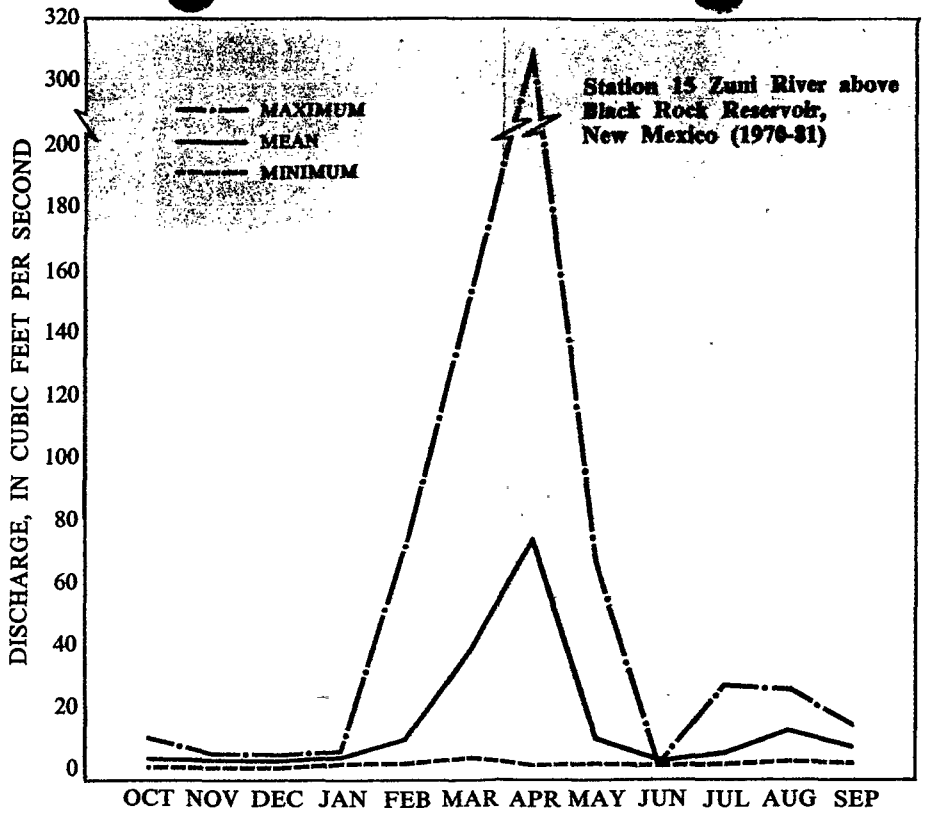


Figure 3.2-1 Daily mean discharge hydrographs (1980 water year) for Zuni River and Rio San Jose.



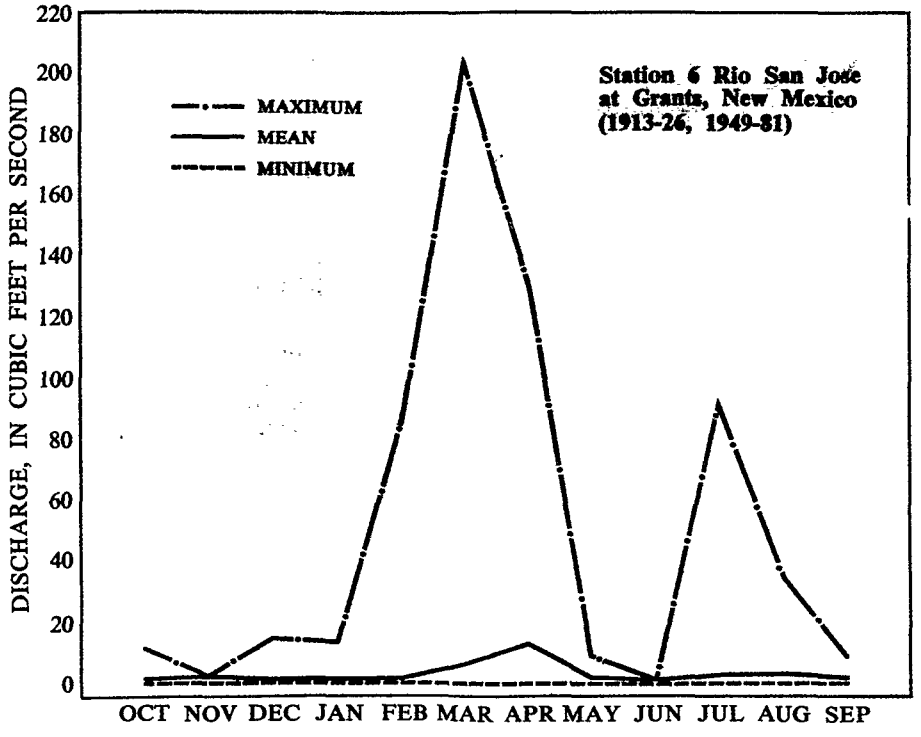


Figure 3.2-2 Maximum, mean, and minimum monthly mean discharges for the Zuni River and Rio San Jose.

Mean Annual Runoff is 1.0 Inch or Less

Mountainous areas contribute the most runoff; base flows are indicative of no ground-water contribution.

A map delineating the distribution of mean annual unit runoff (mean annual runoff divided by drainage area) in Area 62 is shown in figure 3.3-1. The map, modified from one published by the U.S. Department of Agriculture (1981b), represents runoff in terms of average depth of yearly runoff in inches. Mountainous areas contribute the highest runoff value of 1.0 inch with the lower altitudes contributing less runoff. As pointed out in the U.S. Department of Agriculture publication, for streams draining the mountainous areas, unit runoff decreases downstream.

Base flow is defined as streamflow that is composed of only ground-water discharge. Most unregulated streams in Area 62 are ephemeral, flowing only in response to storms and snowmelt. Base flow for these streams is zero indicating no significant ground-water discharge. Streams that continue to flow when the ephemeral streams have gone dry, do so as a result of spring discharge or man-made discharge, such as from treatment plants or reservoirs. For example, the Rio San Jose near Grants continues to flow due to discharges from Horace Springs and the Grants sewage treatment plant.

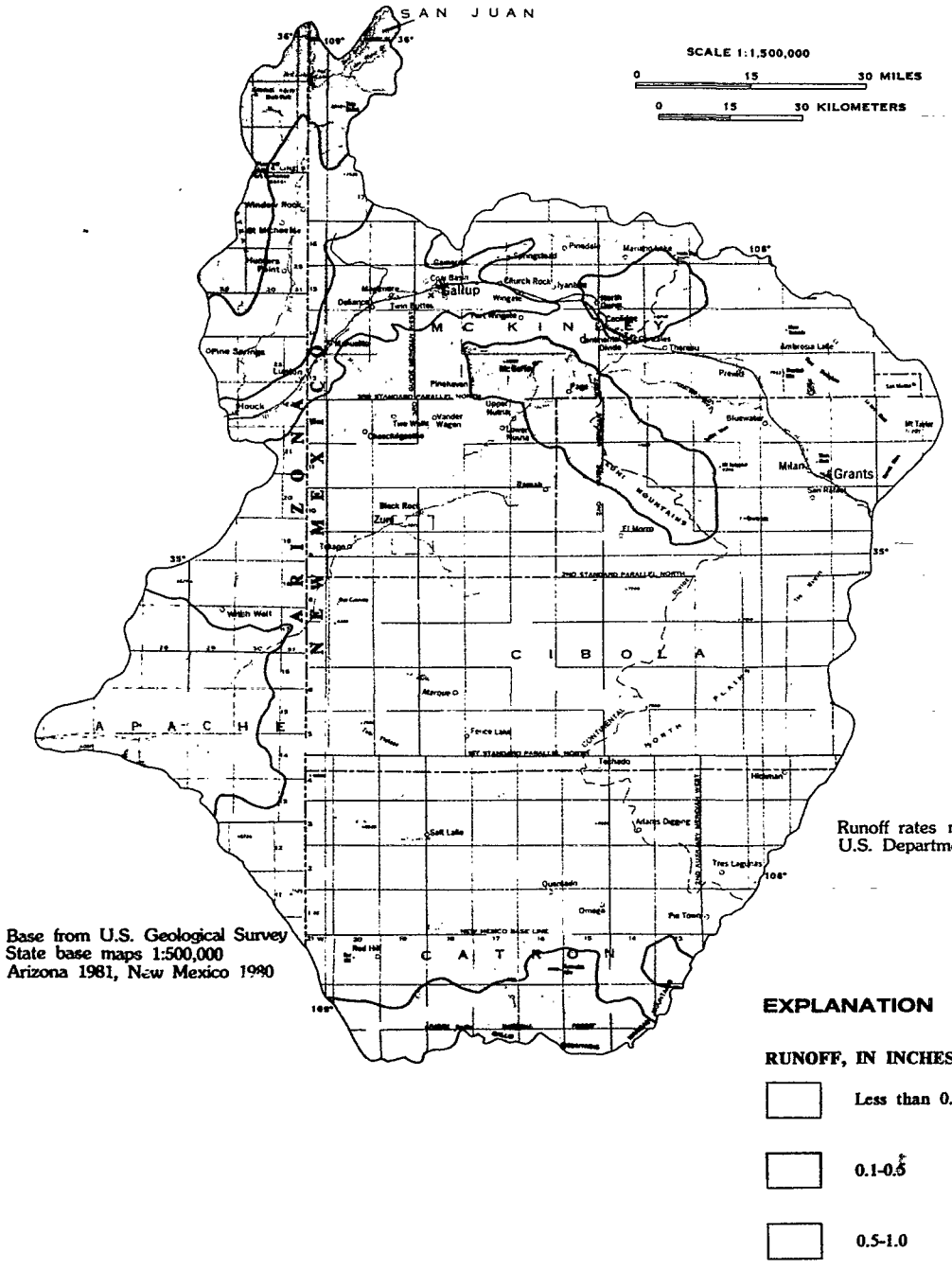


Figure 3.3-1 Mean annual unit runoff.

Flood Magnitude and Frequency Values Computed for Selected Streams

Technique available to estimate peak flood flows for ungaged streams.

Flood magnitude and frequency data for gaged streams having more than 10 years of peak-discharge record are listed in table 3.4-1. The flood values were computed using the station record according to guidelines outlined by the U.S. Water Resources Council (1981).

A multiple regression model was used by Thomas and Gold (1982) to develop flood-estimating equations for ungaged streams in New Mexico. The equations were developed using data from stations throughout New Mexico, as well as in Arizona bordering New Mexico; thus, the equations are applicable to all parts of Area 62. Basin characteristics, such as station altitude, rainfall, and drainage area were used as the independent variables, with flood flows at each gaged station used as the dependent variables. A complete description of the development of the equations can be found in Thomas and Gold (1982). The equations for estimating peak flood magnitudes for return intervals of 10 years (Q_{10}), 50 years (Q_{50}), and 100 years (Q_{100}) are presented below.

Estimating equation	Interval covered by standard error of estimate (percent)
$Q_{10} = 3.88 \times 10^4 A^{0.444} (Sa/1{,}000)^{-2.78}$	+124 -55
$Q_{50} = 2.01 \times 10^5 A^{0.403} (Sa/1{,}000)^{-3.18}$	+140 -58
$Q_{100} = 3.54 \times 10^5 A^{0.389} (Sa/1{,}000)^{-3.32}$	+145 -59

In the equations, A is the contributing drainage area in square miles and Sa is site altitude in feet above sea level. For example, the 100-year recurrence flood at a site having an altitude of 6,300 feet and a drainage area of 6.76 square miles would be estimated by the following calculations: $(3.54 \times 10^5)(6.76)^{0.389}(6{,}300/1{,}000)^{-3.32} = 1{,}700$ cubic feet per second. This value is subject to the large interval of standard error listed with the estimating equations.

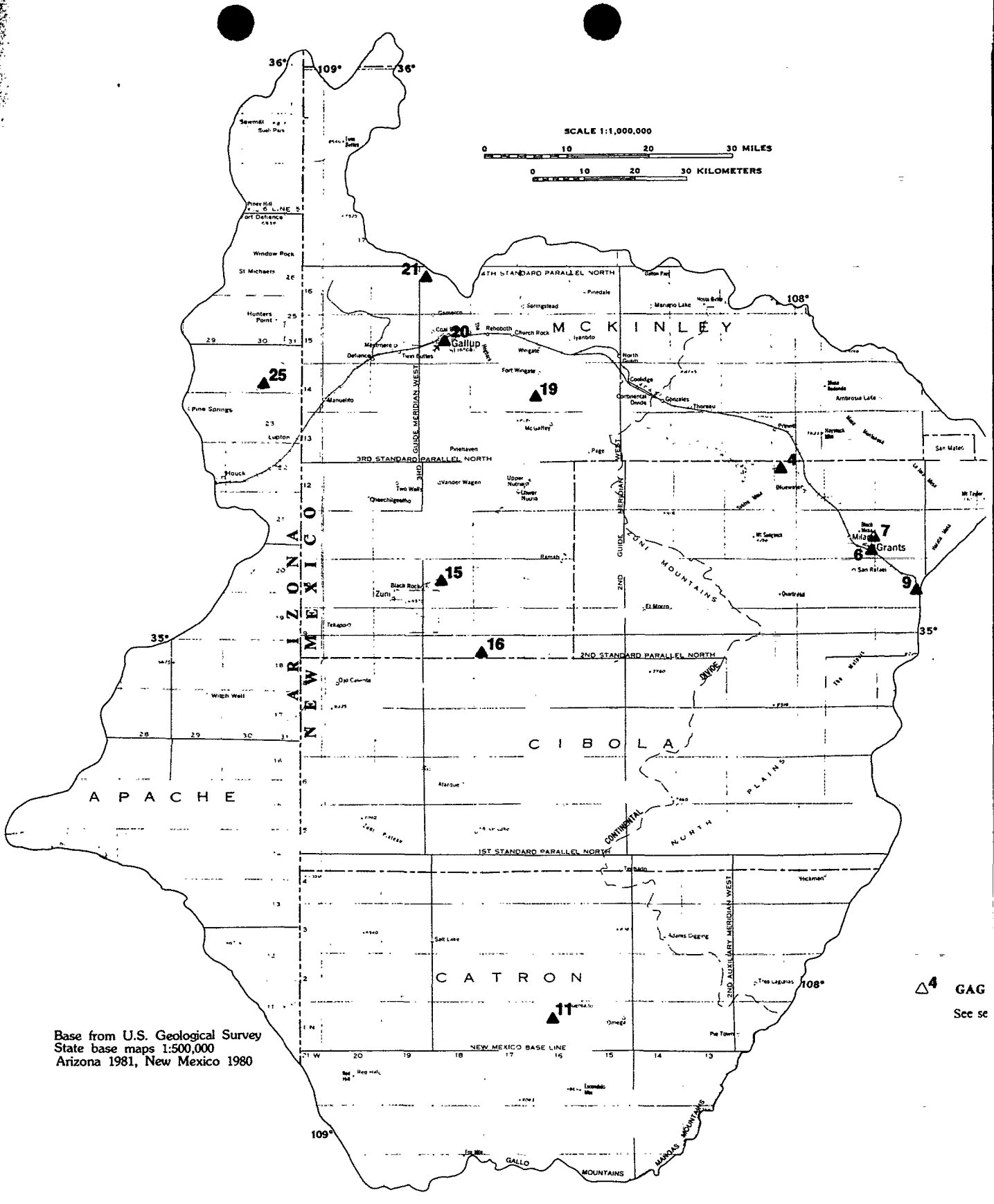


Figure 3.4-1 Locations of stations where flood magnitude and frequency have been computed.

Table 3.4-1 Flood magnitude and frequency at selected

Station number	Station name	Discharge, in cubic feet per second, for indicated recurrence interval (years)
4[1]	Bluewater Creek near Bluewater, N. Mex.	
6[2]	Rio San Jose at Grants, N. Mex.	
7	Grants Canyon at Grants, N. Mex.	
9[2]	Rio San Jose near Grants, N. Mex.	
11	Largo Creek near Quemado, N. Mex.	
15[3]	Zuni River above Black Rock Reservoir, N. Mex.	
16	Galestena Canyon Tributary near Black Rock, N. Mex.	
19	Milk Ranch Canyon near Fort Wingate, N. Mex.	
20	Puerco River at Gallup, N. Mex.	
21	Wagon Trail Wash near Gomerco, N. Mex.	
25	Black Creek near Lupton, Ariz.	

[1] Flow regulated by Bluewater Dam
[2] Some withdrawals, diversions, and regulation upstream from station
[3] Some regulation from upstream reservoirs

LANATION

TION AND NUMBER

6.1 for detailed site description

3.0 SU

Streamflow is Poorly Sustained

Duration curves indicate little, if any, contribution from ground-water sources.

The flow duration curve is a cumulative frequency curve of daily discharges showing the percent of time that specified discharges were equaled or exceeded during a given period.

The data presented in the duration curves (fig. 3.5-1) for 6 stations in Area 62 were computed using a Geological Survey computer program (Hutchison, 1975). The curves may be interpreted using the following guidelines. A steep slope indicates poorly sustained flow. For example, a steep slope at the lower end indicates that streamflow is not sustained by ground-water discharge and tends rapidly toward zero during periods of low precipitation. Gentler slopes indicate a more sustained streamflow such as would occur if ground-water or other stored water were discharged to the stream.

The duration curves for several representative stations presented in figure 3.5-1, have, with one exception, steep slopes throughout the lengths of those curves. The only exception, Rio Nutria, displays a moderate slope, and therefore a well sustained condition for flows less than 0.1 cubic foot per second. Streamflows recorded at the stations on the Rio San Jose, San Mateo Creek, Puerco River, and the Zuni River are subject to regulation which will cause the shape of their duration curves to differ from curves representing natural flow. Duration of flow figures for other streamflow stations are contained in table 3.5-1. The tabulated data can be used to draw duration curves for those stations.

Table 3.5-1 Flow-duration data at selected stations.

Station number	Station name	Flow, in cubic feet per second, which was equaled or exceeded for percentage of time indicated								
		99.5	95	90	75	50	25	10	5	1
3[1]	Bluewater Creek below Bluewater Dam, N. Mex.	0.21	0.27	0.29	0.38	0.42	3.8	20	25	31
4[1]	Bluewater Creek near Bluewater, N. Mex.	0.38	0.62	0.76	1.1	1.2	3.2	18.6	24	33
9[2]	Rio San Jose near Grants, N. Mex.	3.5	4.2	4.4	4.7	5.3	6.0	7.6	9.3	32
10	Largo Creek near Mangas, N. Mex.	0.04	0.09	0.09	0.1	0.21	0.38	0.62	1.5	20
25	Black Creek near Lupton, Ariz.	0.0	0.0	0.03	0.07	0.19	1.9	10.7	31	130

[1] Flow regulated by Bluewater Dam
[2] Affected by diversions and discharges from city of Grants

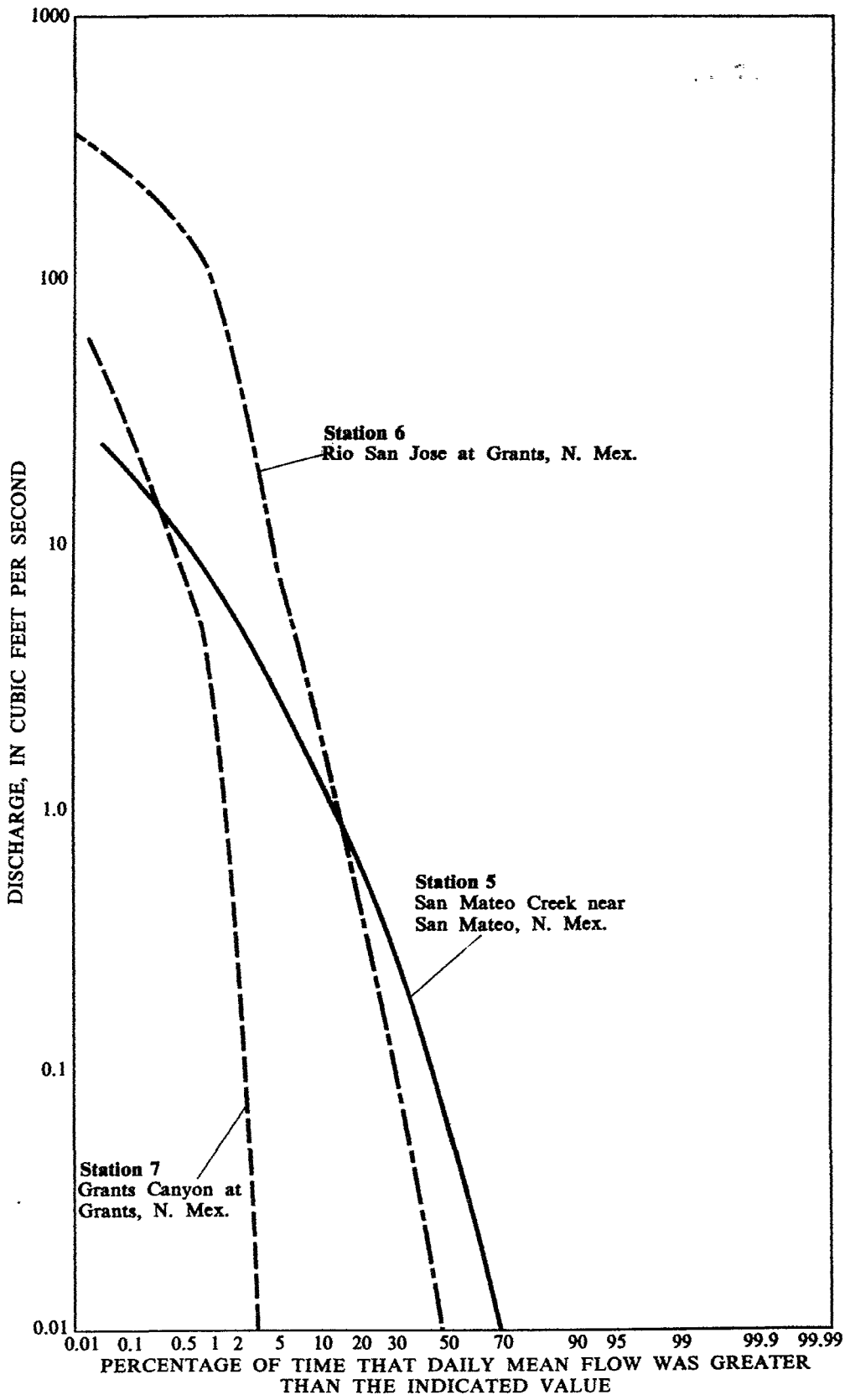
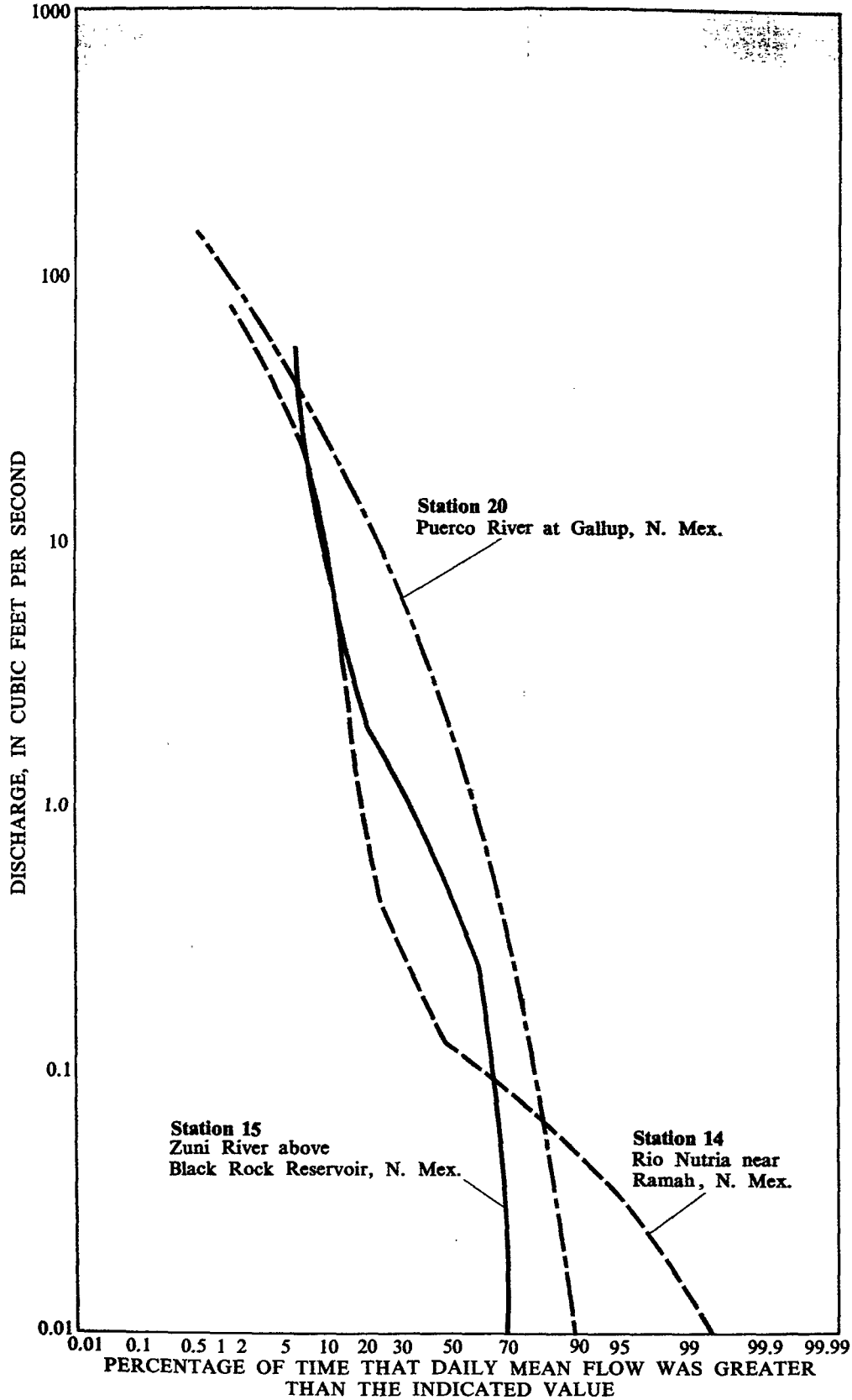


Figure 3.5-1 Flow-d



ıtion curves for selected stations.

Annual Erosion Rates Generally Less Than 1 Acre-Foot per Square Mile

Sediment yield is dependent on topographic setting, soil type, climatic factors, and land uses.

Erosion potential and the resulting sediment yield are of great interest in Area 62. The effects of erosion may include degradation of water quality, deposition of sediments in streambeds and reservoirs, decreased reservoir capacity, and removal of soils and nutrients. All aspects of erosion may result in an economic loss to the inhabitants of the area who use streams as water supplies, use the land for stock grazing or farming, or build structures. Area 62 is marked by areas where extreme erosion has occurred in the past and is continuing. The effects of erosion (fig. 3.7-2) can be observed in the alluvial valleys of the Puerco and Zuni Rivers and in numerous washes throughout the area.

The extent of erosion of the land by wind and water varies greatly within the area, mostly in response to a combination of factors. Specifically, surface geology, soil types, climate, runoff, topography, vegetative cover, land use, and upland drainage pattern all affect erosion rates. Erosion rates can be increased by some uses of the land, such as unimproved roads, construction sites, and by livestock grazing. High rates are also a result of geologic conditions within the area. Specifically, badland areas, sites of substantial erosion, are a result of the significant erosion potential of the relatively unconsolidated shales, mudstones, and claystones cropping out in those areas. Low erosion rates occur in areas having good grass cover and in forested areas.

Estimated erosion rates for Area 62 are shown in figure 3.7-1. Summaries of suspended-sediment data collected at gaging stations are given in table 3.7-1. The location of the gaging stations is shown in figure 3.7-1.

The suspended particles may contain certain chemical constituents in quantities greater than that found in the water surrounding those particles. The samples for the two Rio San Jose stations were collected when large quantities of water were released to relieve pressure on an upstream dam. The samples for the stations Puerco River near Church Rock (18) and Puerco River at Gallup (20), resulting in the maximum values, were collected after a dam failure at an upstream uranium-milling operation.

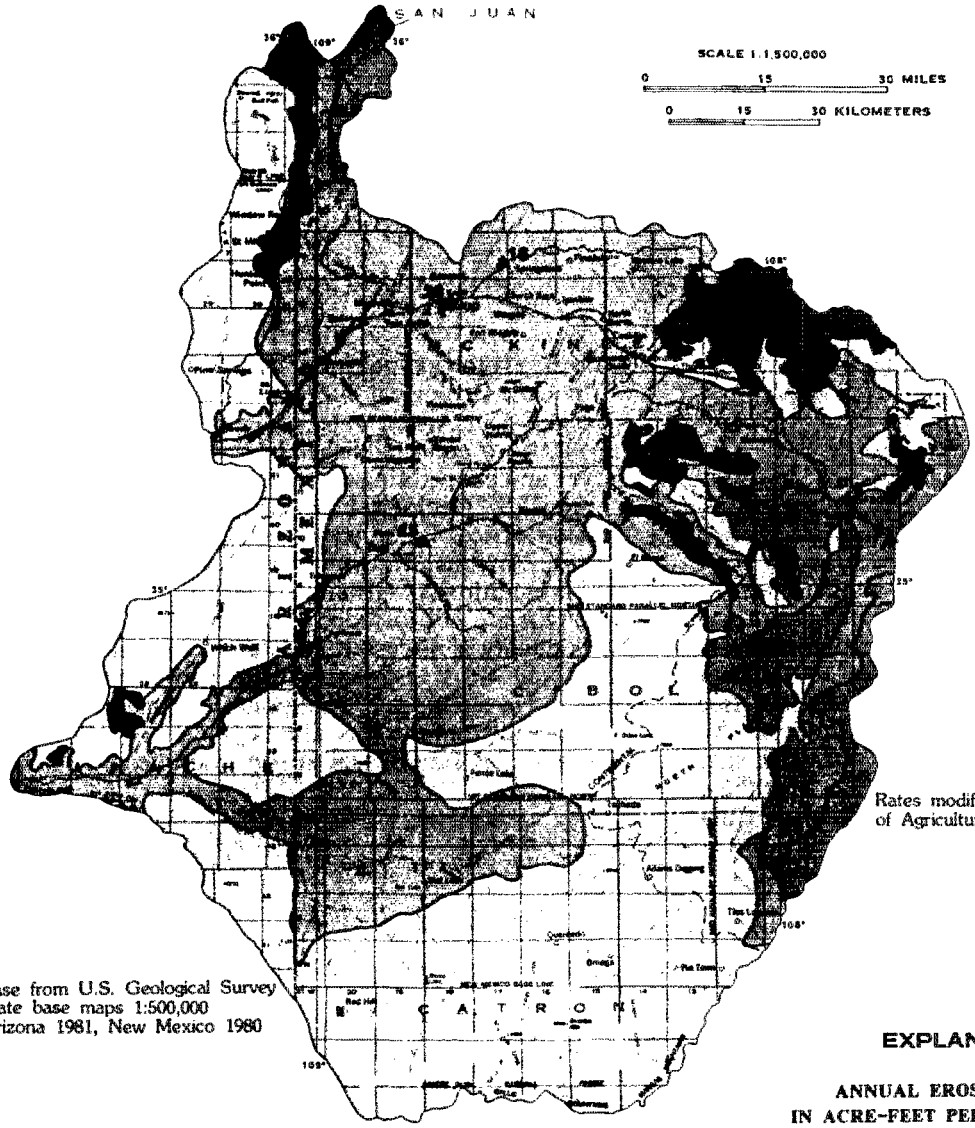


Figure 3.7-1 Soil erosion rates.

Figure 3.7-2 Effects of erosion in the alluvial valley (east of Gallup, New Mexico).

Table 3.7-1 Suspended sediment at gaging stations.

Station number	Station name	Number of samples taken	Suspended sediment concentration (mg/L)		
			Mean	Minimum	Maximum
6	Rio San Jose at Grants, N. Mex.	4	3,540	523	8,300
9	Rio San Jose near Grants, N. Mex.	4	315	19.0	672
15	Zuni River above Black Rock Res., N. Mex.	35	345	18.0	2,090
18	Puerco River near Church Rock, N. Mex.	2		17,100	18,000
20	Puerco River at Gallup, N. Mex.	6	24,440	3,360	70,100

Ground-Water Recharge Occurs Primarily Above 6,000 Feet and Where Geology and Topography are Conducive to Infiltration

Major spring discharge occurs in the northwest and central parts of the study area.

Recharge to ground-water aquifers occurs primarily from infiltration of runoff from precipitation in the mountainous areas and on the flanks of structural basins (U.S. Department of Agriculture, 1981a, p. 5-22) (fig. 4.2-1). These highland areas, which account for as much as 80 percent of the ground-water recharge, are generally at an altitude greater than 6,000 feet above sea level and receive more than 15 inches of precipitation annually (Lower Colorado Region State-Federal Interagency Group for the Pacific Southwest Interagency Committee, 1971, p. V-21). Recharge probably occurs also on Mt. Taylor, along the Continental Divide, and in the Gallo and Mangas Mountains although it has not been mapped in these areas. Minor recharge also occurs from infiltration of excess irrigation water and canal seepage from surface-water sources and from infiltration of precipitation in the center of the basins. Infiltration in the center of the basin is generally negligible as a result of the arid to semiarid climate but may be affected by both topography and geology.

Ground water is discharged by four natural processes: (1) Evaporation in areas where the water table is near to the land surface; (2) transpiration by vegetation; (3) seepage into stream channels in places where the streambed (or channel) intersects the water table; and, (4) spring discharge (Lower Colorado Region State-Federal Interagency Group for the Pacific Southwest Interagency Committee, 1971, p. V-22).

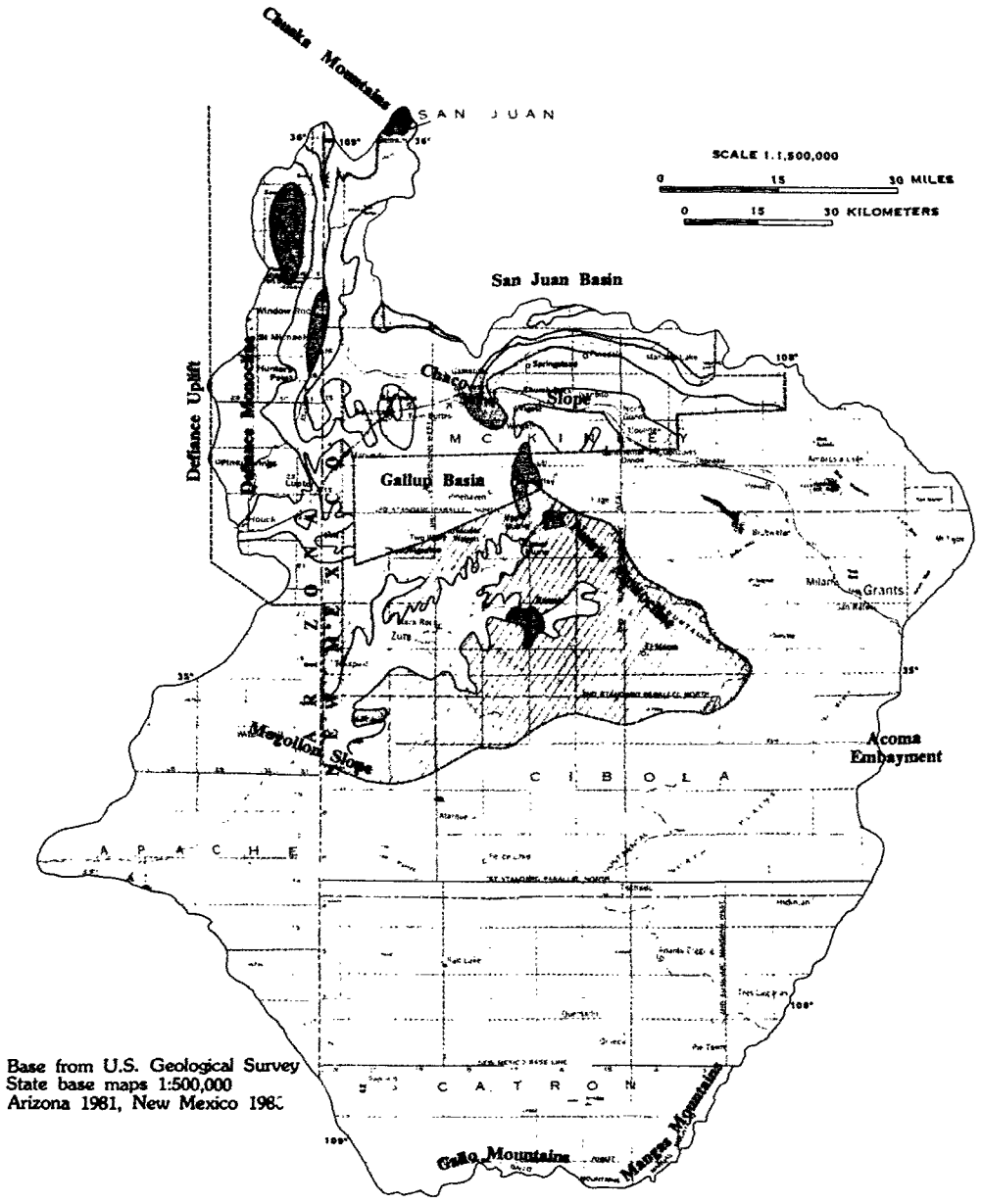
Only small amounts of ground water are discharged by evaporation in areas where the water table is near the surface (as the depth to the water table reaches 10 feet, discharge by evaporation becomes negligible). Large amounts of ground water are transpired from ground-water aquifers by vegetation.

Spring discharge occurs where the water table intersects the land surface or where water from artesian aquifers flows through fractures or fault zones in the rock (Lower Colorado Region State-Federal Interagency Group for the Pacific Southwest Interagency Committee, 1971, p. V-22). Major areas for spring discharge are in the vicinity of Ojo Caliente and Ramah. The combined discharge for springs near Ojo Caliente is about 1 cubic foot per second and for springs near Ramah combined discharge is about 1.1 cubic feet per second (Orr, 1982, p. 46, 90). Studies by Risser (1982) describe a spring called Ojo del Gallo located southwest of Grants, New Mexico. Ojo del Gallo yielded as much as 5 to 7 cubic feet per second in the 1930's, ceased flowing in the 1950's (Risser, 1982, p. 29), but has begun to flow again (J.A. Baldwin, oral communication, 1983). Springs on the southwest side of the San Juan Basin, around Window Rock, and in the Chuska Mountains usually do not yield any more than .02 cubic foot per second (Cooley and others, 1969, p. A-44). Other springs discharge near Black Rock Village, along outcrops of the Glorieta Sandstone and San Andres Limestone in the Zuni Mountains (Orr, 1982), and along the Zuni River in McKinley and Cibola Counties (Summers, 1972, p. 83).

Induced ground-water discharge takes place as ground-water pumpage from wells. Pumpage removes water from the flow system and thus diverts ground water from some of its natural points of discharge. This type of discharge will be discussed in more detail in Section 4.4.

The areas of ground-water recharge which have been mapped, and locally, areas of spring discharge are shown in figure 4.2-1. Several publications discuss ground-water recharge and discharge in specific aquifers but do not include maps. These publications include studies about the San Juan Basin (Lyford, 1979), Apache County (Akers, 1964), the Rio San Jose (Risser, 1982),and McKinley and Cibola Counties (Orr, 1982). Other information from some of these references describes gaining and losing reaches along some of the intermittent streams. In general ground water may be discharged to the stream (the stream gains) or the stream water may be recharged to the adjacent aquifer (the stream loses).

Ground-water movement in Area 62 is generally from recharge areas in the highlands to the central parts of the basins. Movement of ground water in central Apache County, Arizona, mainly is southward toward the Little Colorado River (Lower Colorado Region State-Federal Interagency Group for the Pacific Southwest Interagency Committee, 1970, p. V-21). Ground-water movement in New Mexico is toward the Puerco River in aquifers near Gallup (Lyford, 1979) and near Zuni; in Cibola County ground-water movement in the Glorieta-San Andres aquifer, the Chinle Formation, the Zuni-Dakota aquifer, and Bidahochi Formation is generally to the west (Orr, 1982). Locally, along the Nutria monocline, ground water in the Gallup Sandstone and Crevasse Canyon Formation moves toward the Rio Nutria and Rio Pescado, but ground water in more deeply buried Gallup and Crevasse Canyon rocks probably moves northward to join the flow system near Gallup (Orr, 1982, p. 77, 114).



EXPLANATION

RECHARGE AREA, *Modified from area mapped by Cooley and others (1969).*

RECHARGE AREA, *Modified from area mapped by Summers (1972).*

AREA OF PROBABLE GROUND-WATER DISCHARGE FROM SPRINGS

AREA MAPPED FOR GROUND WATER RECHARGE
Note: Recharge areas in other parts of Area 62 have not been mapped.

Figure 4.2-1 Location of recharge areas and spring discharge areas.

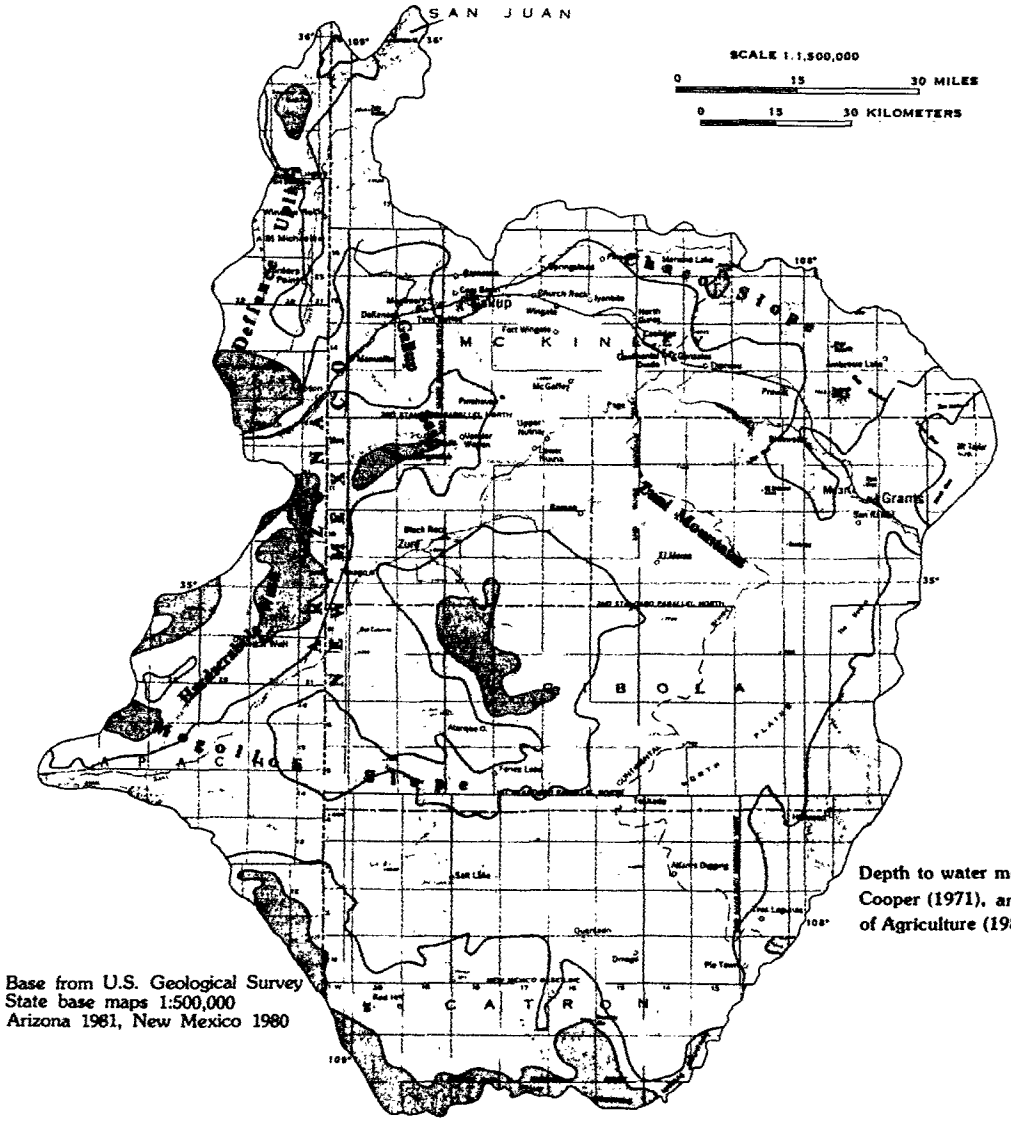
Depth to Water Below Land Surface Generally Less than 200 Feet

Depth to water varies because of complex geology and large topographic relief.

Depth to water ranges from only a few feet, especially along the major streams and rivers to about 500 feet along parts of the Defiance uplift, near Hardscrabble Wash south of the Defiance uplift, in the Gallup sag, and along the Mogollon slope on the southern boundary of the study area. Depths to water of less than 100 feet commonly occur in alluvial channels and in a few areas in Precambrian granite exposed southeast of Gallup, New Mexico, in the Zuni Mountains (fig. 2.6-1). Depth to water varies throughout the area because of the structural complexity of the geology and the substantial topographic relief. Generally, areas with similar depths to water roughly follow the physiographic and structural features of the area (Cooley and others, 1969, p. A-22).

Both artesian (confined) and water-table (unconfined) conditions occur in Area 62. Artesian conditions occur throughout the area and artesian springs and wells have been utilized in many areas (refer to figure 4.2-1 for the locations of major springs). Water-table conditions are present in the principal recharge areas (fig. 4.2-1), in the flat-lying rocks between major uplifts, and in the shallow alluvial aquifers along the major streams and rivers.

A generalized map of the depth to water in Area 62 is shown in figure 4.3-1. In specific areas, depth to water may differ considerably from the ranges indicated in this generalized map. The depth to water shown in figure 4.3-1 is the depth in feet below land surface, at which water is first penetrated, regardless of the quality, and is not the altitude to which the water will rise in a well. Data for figure 4.3-1 are from wells completed in the major aquifers (see section 4.5) and include data through 1980 for Apache County, Arizona (U.S. Department of Agriculture, 1981b), and through 1971 (Cooper, 1971) for counties in the New Mexico portion of Area 62.



Depth to water modified from:
Cooper (1971), and U.S. Department of Agriculture (1981b).

EXPLANATION

DEPTH TO WATER, IN FEET BELOW LAND SURFACE

- Less than 200
- 200 to 500
- More than 500

Figure 4.3-1 General depth to ground water.

Water in Permian Aquifers has the Largest Median Concentrations of Dissolved Solids, Calcium, Sulfate, and Hardness

Water-quality data are summarized for 38 Jurassic sites, 68 Triassic sites, and 69 Permian sites.

Throughout much of Area 62, Jurassic through Permian aquifers underlie the coal-bearing rocks (fig. 4.5.3-1). The location of sampling sites for these aquifers is shown in figure 4.5.3-2; because of the map scale, one sampling site may represent several closely spaced wells or springs. A summary of the chemical analyses for samples is given in table 4.5.3-1.

The National Water Data Storage and Retrieval System (WATSTORE) lists 38 sites at which samples have been collected from Jurassic aquifers: 25 for the Morrison Formation, 8 for the combined Zuni Sandstone-Cow Springs Sandstone, and 5 for the Entrada Sandstone. Compared to other aquifers in Area 62, Jurassic aquifers exhibit small median concentrations of hardness and chloride.

Of the 68 Triassic sampling sites, 61 derive water from the Chinle Formation, 5 from the Wingate Sandstone, and 2 from the Moenkopi Formation. The water typically is enriched with bicarbonate and sodium but has small median concentrations of calcium and calcium carbonate hardness.

The summary of chemical analyses for Permian aquifers in table 4.5.3-1 is based on samples from two aquifer systems: the undifferentiated San Andres Limestone-Glorieta Sandstone in New Mexico (51 sites) and the undifferentiated Kaibab Limestone-Coconino Sandstone in Arizona (18 sites). As a group, the Permian aquifers have the most mineralized water in Area 62, with the largest median concentrations of hardness, calcium, sulfate, and dissolved solids; however, the sodium and chloride concentrations are rather small. Although the San Andres-Glorieta and Kaibab-Coconino are stratigraphically lateral equivalents, the available data indicate that water quality is markedly different in the units. Median concentrations of all constituents in the San Andres-Glorieta are much smaller than in the Kaibab-Coconino; especially notable are the concentrations of sodium (60 versus 360 milligrams per liter), chloride (22 versus 430 milligrams per liter), and dissolved solids (740 versus 1,750 milligrams per liter). These differences may be an aberration caused by the few samples available or the location of the sampling sites. However, the water-quality differences could be caused by differences in composition of the rocks or the chemical composition of the recharge to the aquifers.

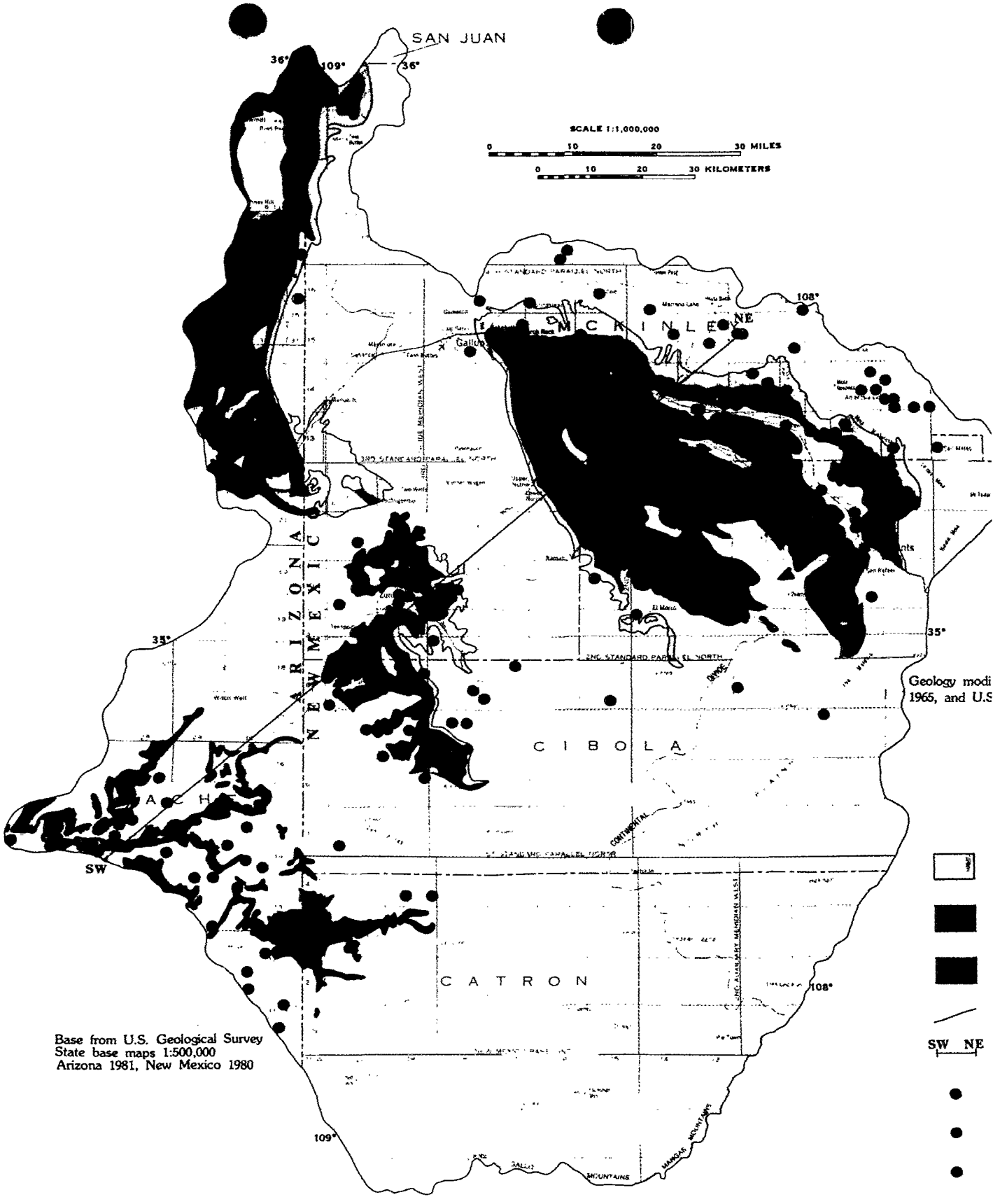


Figure 4.5.3-2 Sites of water samples from Jurassic, Triassic, and Permian aqu

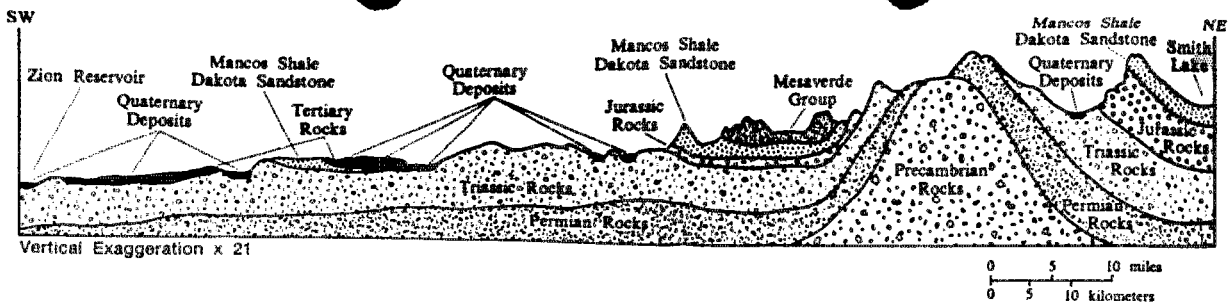


Figure 4.5.1-1 Schematic diagram showing stratigraphic relationship of Quaternary and Tertiary rocks to underlying rocks between Zion Reservoir and Smith Lake.

Table 4.5.1-1 Summary of chemical analyses of water samples from Quaternary and Tertiary aquifers.

Concentrations of dissolved constituents reported in milligrams per liter, except as indicated. Micromhos, micromhos per centimeter at 25° Celsius. < , less than.

Constituent or property	Range	Median	Number of samples
Specific conductance (micromhos)	308-5,080	835	60
pH (units)	6.8-9.5	7.8	57
Bicarbonate (HCO_3)	140-670	320	41
Hardness ($CaCO_3$)	7-2,700	180	60
Calcium (Ca)	2.4-530	54	60
Sodium (Na)	8.5-1,000	120	50
Chloride (Cl)	2.9-1,100	26	60
Sulfate (SO_4)	0.8-2,600	84	60
Iron (Fe)	0-3.2	.024	50
Manganese (Mn)	<1-1.0	..003	16
Dissolved solids	178-3,600	479	59

Constituent or property	Range	Median	Number of samples
Specific conductance (micromhos)	270-1,000	420	29
pH (units)	7.1-10.0	8.0	25
Bicarbonate (HCO_3)	82-330	153	19
Hardness ($CaCO_3$)	82-262	150	23
Calcium (Ca)	2.8-69	34	30
Sodium (Na)	8.0-230	40	30
Chloride (Cl)	4.2-130	14	30
Sulfate (SO_4)	4.8-95	14	30
Iron (Fe)	0-0.530	.020	29
Manganese (Mn)	0-0.120	.006	11
Dissolved solids	153-625	262	30

PLANATION

C IP AREA OF QUATERNARY ROCKS

CROP AREA OF TERTIARY ROCKS

TACT

F SECTION (see figure 4.5.1-1)

OF WATER SAMPLE FROM TERNARY AQUIFER

WATER SAMPLE FROM RY AQUIFER

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Well Yields Commonly as Much as 100 Gallons per Minute in Most of the Area

Consolidated sedimentary rocks store most of the ground water; permeability and depth to water affect the availability of ground water.

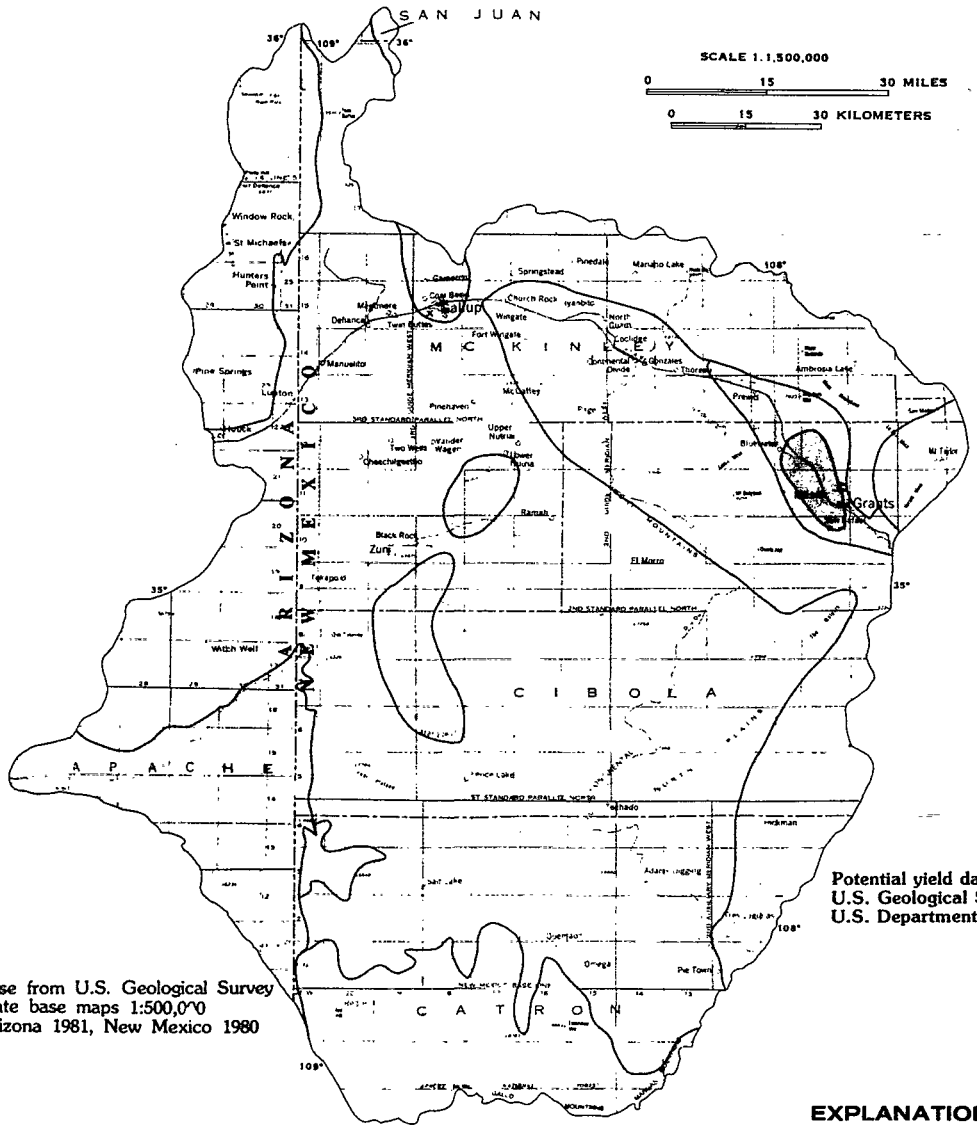
Wells completed in aquifers containing fresh to slightly saline water (dissolved solids concentration of less than 3,000 milligrams per liter) commonly yield as much as 100 gallons per minute. Yields of this magnitude can be obtained in more than one-half of the area (fig. 4.4-1). Water is obtained primarily from both consolidated sedimentary rocks and from unconsolidated stream-valley sediments and alluvium. Only a small amount of unconsolidated rocks are present in the area; therefore, the consolidated rocks store most of the ground water. Well yields in the unconsolidated rocks generally range from 100 to 500 gallons per minute. Yields in the consolidated rocks vary greatly because of differences in rock permeability. Most of the consolidated rocks yield from 25 to 100 gallons per minute. The use of ground water is affected economically by the depth from which it must be pumped.

Principal aquifers in the study area include the Permian Kaibab Limestone and Coconino Sandstone in Arizona, which grade laterally eastward to the San Andres Limestone and Glorieta Sandstone; the Triassic Chinle Formation; the Zuni Sandstone, members of the Morrison Formation, and the Entrada Sandstone and Summerville Formation of the San Rafael Group, all of Jurassic age; the Cretaceous Dakota Sandstone, Mancos Shale, Gallup Sandstone and formations in the Mesaverde Group; the Tertiary sediments of the Bidahochi Formation; and the stream-valley sediments of Tertiary to Quaternary age (table 2.7-1). Permeable volcanic rocks of Tertiary to Quaternary age yield water to wells locally.

The estimated potential yield for wells in Catron County is generally as much as 100 gallons per minute. Yields in Cibola and McKinley Counties are similar. Greater yields of as much as 500 gallons per minute are found around Gallup, north of Black Rock, and along the western edges of Cibola and Catron Counties. Well yields may exceed 500 gallons per minute around Bluewater in Cibola County. Studies by Mercer and Cooper (1970), Hiss and Marshall (1975), and McLean (1980) provide more detailed evaluations concerning the availability of ground water and potential yields in the Gallup area. Estimated potential yields in Apache County range widely from about 25 gallons per minute in the north to about 500 gallons per minute in the south.

Estimates for the volume of recoverable ground water are not available for the entire study area. The general location and estimated potential yields of ground water are shown in figure 4.4-1. Detailed investigations locally provide some information, but more data are needed to realize actual development of ground-water supplies (U.S. Department of Agriculture, 1981b).

Although the major water supply for rural-domestic, municipal, and industrial uses is ground water, water supply for livestock use is from both surface water and ground water (U.S. Department of Agriculture, 1981b, p.3-2). The U.S. Department of Agriculture (1981b, p. 3-14--3-20) estimated that future livestock water requirements will be increasing and that development of ground water is the best future source of water supply. Irrigation needs are served mostly by surface-water sources. In New Mexico and Arizona some of the wells for municipal, industrial, irrigation, rural domestic, and livestock use are completed in alluvial aquifers. Because these aquifers are generally thin and of limited saturated thickness, aquifers of Cretaceous age and older have been developed (refer to section 4.5 for major aquifers).



Base from U.S. Geological Survey
State base maps 1:500,000
Arizona 1981, New Mexico 1980

Potential yield data from:
U.S. Geological Survey (1972), and
U.S. Department of Agriculture (1981b).

EXPLANATION

MAXIMUM POTENTIAL YIELDS OF PROPERLY CONSTRUCTED WELLS, IN GALLONS PER MINUTE

- Less than 25
- 25 to 100
- 100 to 500
- More than 500

Figure 4.4-1 Estimated potential yield of water wells.

NAWDEX, WATSTORE, and OWDC Have Water Data Information

Water data are collected in coal areas by large number of organizations in response to a wide variety of missions and needs.

Within the U.S. Geological Survey there are three activities that help to identify and improve access to the vast amount of existing water data. These activities are:

(1) The National Water Data Exchange (NAWDEX), which indexes the water data available from over 400 organizations and serves as a central focal point to help those in need of water data to determine what information is available.

(2) The National Water Data Storage and Retrieval System (WATSTORE), which serves as the central repository of water data collected by the U.S. Geological Survey and which contains large volumes of data on the quantity and quality of both surface and ground waters.

(3) The Office of Water Data Coordination (OWDC), which coordinates Federal water-data acquisition activities and maintains a "Catalog of Information on Water Data." To assist in identifying available water-data activities in coal provinces of the United States, special indexes to the Catalog are being printed and made available to the public.

A more detailed explanation of these three activities are given in sections 5.2, 5.3, and 5.4.

REFERENCE # 6

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

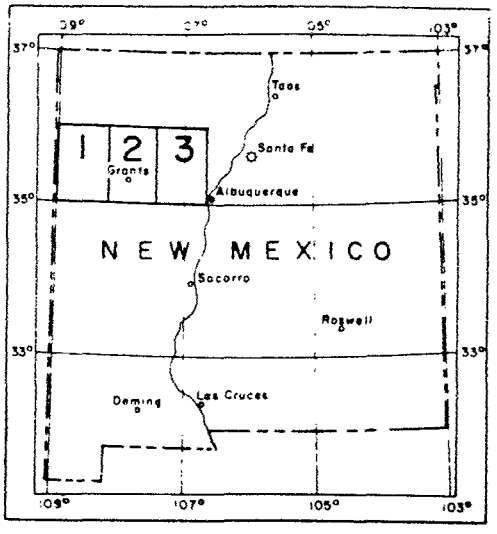
MAY,'90 P. MOLLOY

17:6

$5.00

Geologic Map of Grants Uranium Region

Maps #1 & 2 Frame in Plains Electric



GEOLOGIC MAP 31 New Mexico Bureau of Mines & Mineral Resources 1974

A DIVISION OF

NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

Jm
Kdm
J
ANDREWS
Q
O
P
Kgc
Kdm
24
25
Jm
Prewitt
COMPANY
Haystack Mtn
Kdm
7832
40
66
412
LAVA
FLOW
Qv
NAVAJO INDIAN LAND
NAVAJO INDIAN LAND
BLUE WATER STATE PARK
Bluewater
U D
P
U D
66
Bluewater
56
Anaconda
334
Qv
Broadview
BLACK TANK
SILVER TANK
53
ATIONAL
FOREST
Canyon
Prop
Pole
Canyon
D
Tv

EOLOGIC MAP 31 [1] [2] [3] SHEET 3 OF 3

R.2E. R. 3E.

EXPLANATION

Qv / Tv	*Undifferentiated volcanic rocks, mostly basaltic; locally includes intrusive rocks*	TERTIARY & QUATERNARY
	UNCONFORMITY	
Tb	*Continental strata; Bidahochi Formation and Chuska Sandstone*	TERTIARY
	UNCONFORMITY	
Kcl	*Cliff House Sandstone, Lewis Shale, Pictured Cliffs Sandstone, Fruitland Formation, and Kirtland Shale; includes Tertiary strata in T. 20 N.*	CRETACEOUS
Kpm	*Point Lookout Sandstone and Menefee Formation; includes Hosta Sandstone and Satan Tongue of Mancos Shale, where present*	CRETACEOUS
	Gallup Sandstone and overlying Crevasse Canyon Formation (in south part of map area) and Mulatto Tongue of Mancos Shale (in north part of map area)	CRETACEOUS

Mesaverde Group

T.20N.

T.19N.

T.18N.

Dakota Formation and lower Mancos Shale

UNCONFORMITY

T.17N.

Jmj / Jm

Morrison Formation. In ascending order: Recapture Shale Member (at base), Westwater Canyon Member, and Brushy Basin Member. Jackpile Sandstone (Jmj) of Brushy Basin Member mapped separately in Laguna area

Jurassic strata beneath Morrison Formation. Includes Entrada Sandstone, Todilto Formation, and Summerville Formation of San Rafael Group and overlying Cow Springs Sandstone with its lateral equivalents, Zuni Sandstone and Bluff Sandstone

UPPER JURASSIC

UNCONFORMITY

T.16N.

R

Triassic strata, undifferentiated. Includes Chinle Formation and Wingate Sandstone

TRIASSIC

UNCONFORMITY

P

Permian strata, undifferentiated. Includes Abo Formation, Yeso Formation, Glorieta Sandstone, and San Andres Limestone

PERMIAN

T.15N.

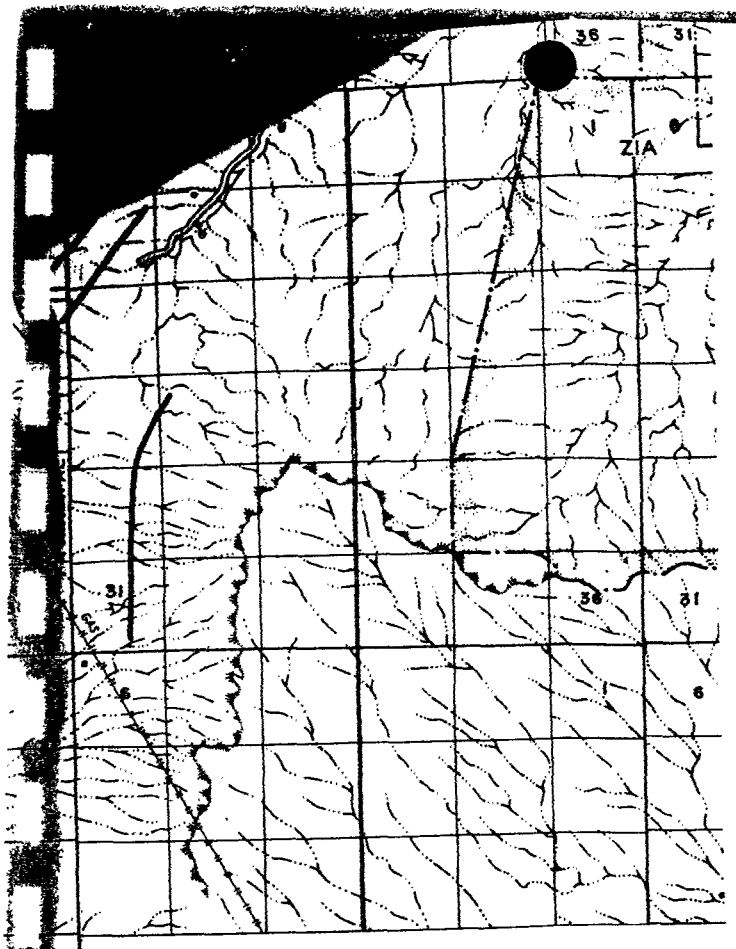
P

Pennsylvanian rocks, undifferentiated. Includes Sandia Formation and Madera Limestone

PENNSYLVANIAN

UNCONFORMITY

AN



UNCONFORMITY

PRECAMBRIAN

Precambrian rocks, undifferentiated. Includes granitic rocks and, in Zuni Mountains, several types of metamorphic rocks

Contacts, dashed where approximate

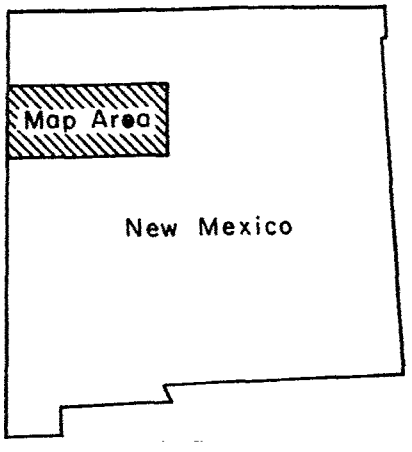
U
D

Fault or fault zone, dashed where approximate

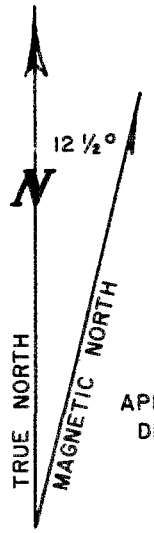
Uranium deposits in Morrison Fm, of known shape and extent

Locality of close-spaced drilling indicating uranium mineralization in Morrison Formation

623-690'



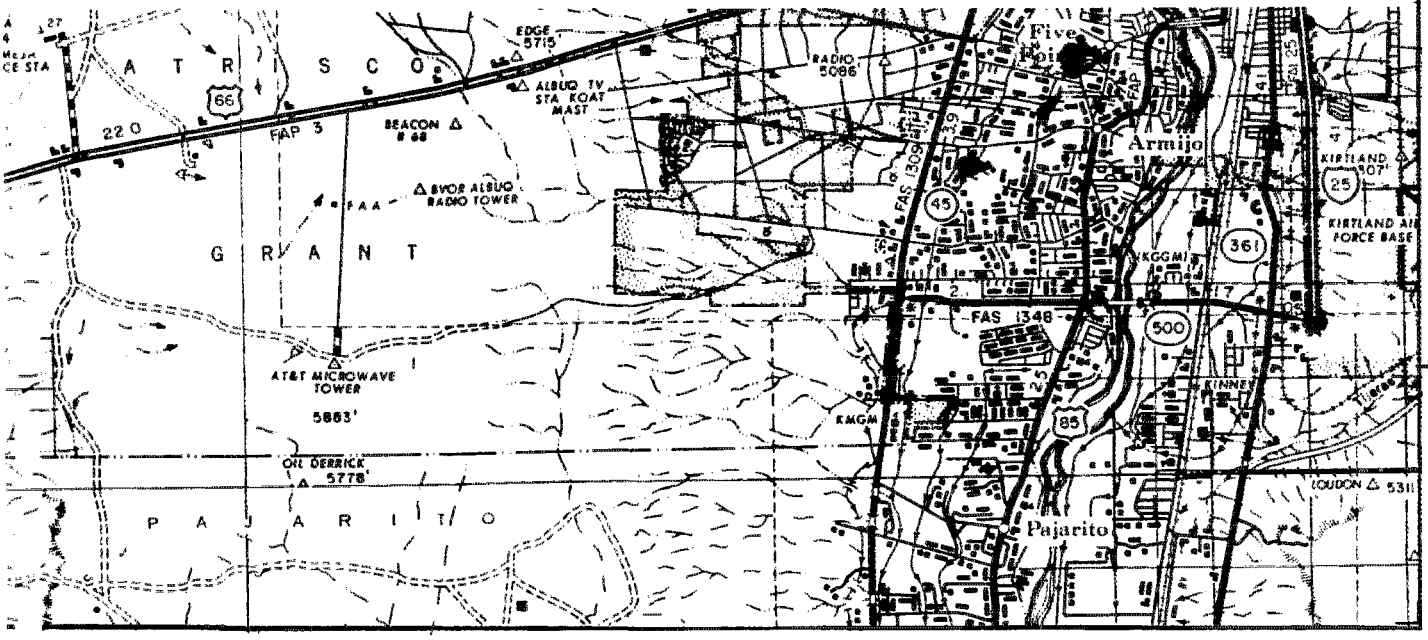
Base map by New Mexico State Highway Department. Geology compiled from sources listed on Sheet 1.



APPROXIMATE MEAN
DECLINATION, 1972

T.11N.

T.10N.



T.9N.

R.1E. R.2E. R.3E.

GEOLOGIC MAP 31 [1][2][3] · SHEET 3 OF 3

R.1E. R.2E. R.3E.

R.8W. R.7W. R.6W.

DICATED SUBSTANTIAL URANIUM
RALIZATION IN MORRISON FORMATION

NAME	OWNER
----------	Gulf
Section 24	Gulf
Fernandez	Gulf
Ulrich	Homestake
----------	Enerdyne
Johnny M	Ranchers
Section 19	Keradamex/Gulf
Walker Dome	Gulf
----------	DeVilliers
----------	DeVilliers
----------	United Nuclear
----------	Western Nuclear/N. M. Ariz. Land
Ruby Wells	Western Nuclear/N. M. Ariz. Land
----------	Western Nuclear/N. M. Ariz. Land

(continued on sheets 1 and 3)

SEE SHEET 3 FOR EXPLANATION

SEE BACK OF SHEET 3 FOR TEXT

MAJOR MORRISON FORMATION URANIUM MINES

MAP NO.	NAME	OPERATOR
1	Poison Canyon	(First sandstone uranium discovery in region, 1951)
2	Dysart No. 1	(First Westwater Sandstone uranium discovery, 1955)
7	San Mateo	United Nuclear
8	Cliffside	Kerr-McGee
9	Elizabeth	Kerr-McGee
10	Marquez	Kerr-McGee
11	Section 27	United Nuclear
12	Section 27 #2	United Nuclear
13	Sandstone	Kerr-McGee
14	Ann Lee	United Nuclear
15	Section 33	Kerr-McGee
16	Section 17	Kerr-McGee
17	Section 32	United Nuclear-Homestake
18	Section 19	Kerr-McGee
19	Section 30 West	Kerr-McGee
20	Section 30	Kerr-McGee
21	Section 24	Kerr-McGee
22	Section 25	United Nuclear-Homestake
23	Section 23	United Nuclear-Homestake
24	Section 15	United Nuclear-Homestake
25	Section 22	Kerr-McGee
26	Black Jack #1	United Nuclear-Homestake

(continued on sheets 1 and 3)

T.20N.

T.19N.

T.18N.

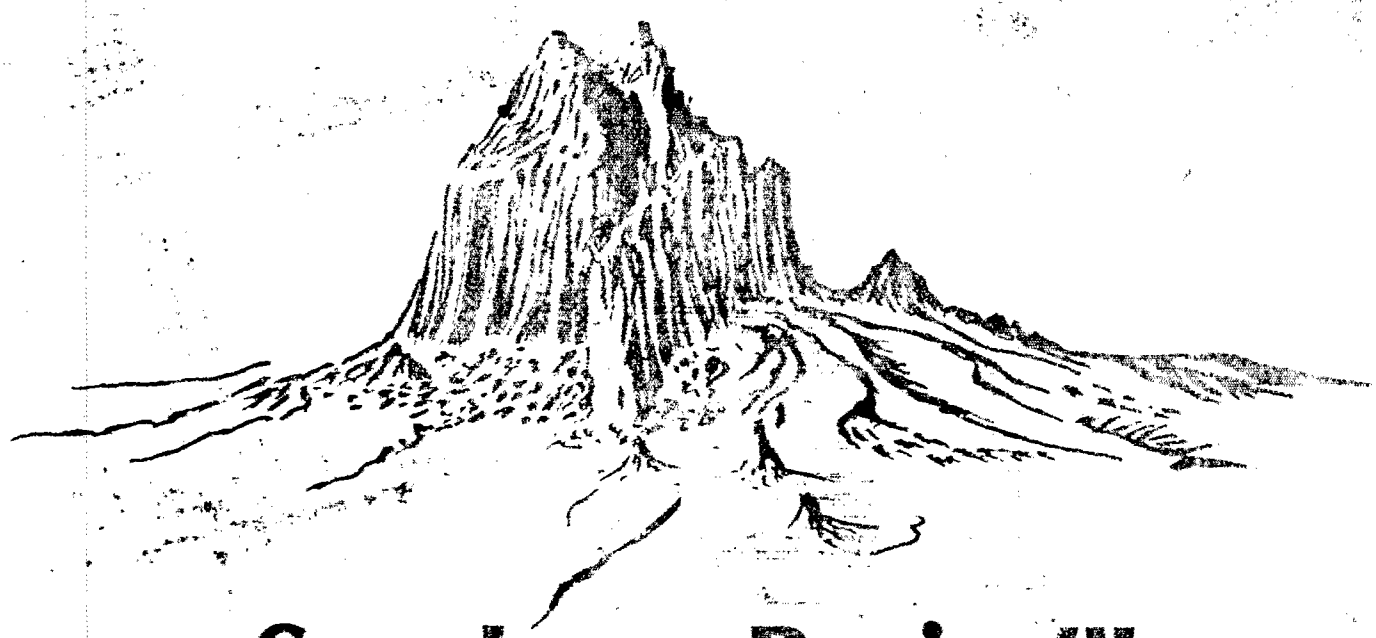
REFERENCE # 8

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

NEW MEXICO GEOLOGICAL SOCIETY



San Juan Basir III

1977

Guidebook of

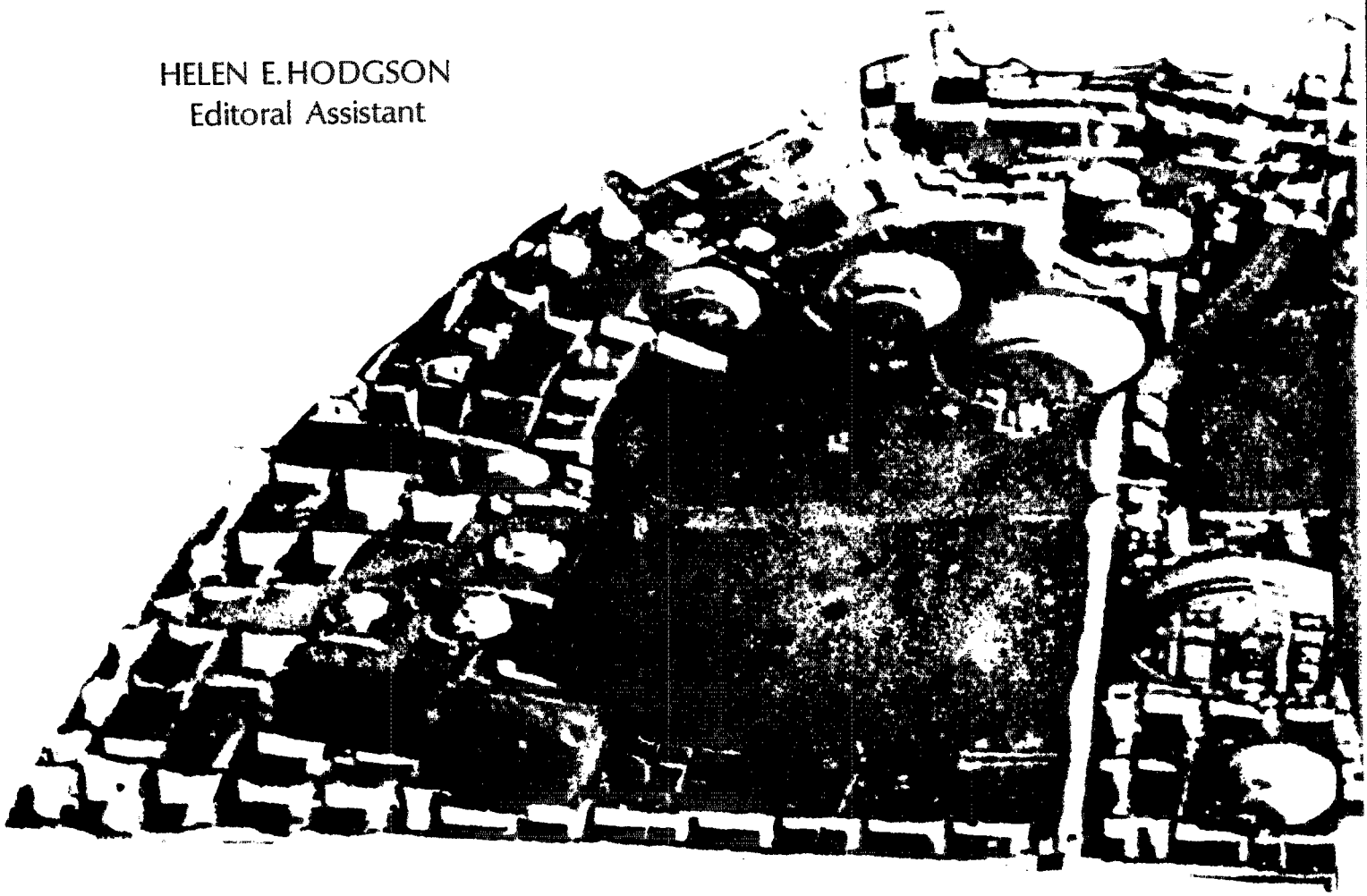
San Juan Basin III

NORTHWESTERN NEW MEXICO

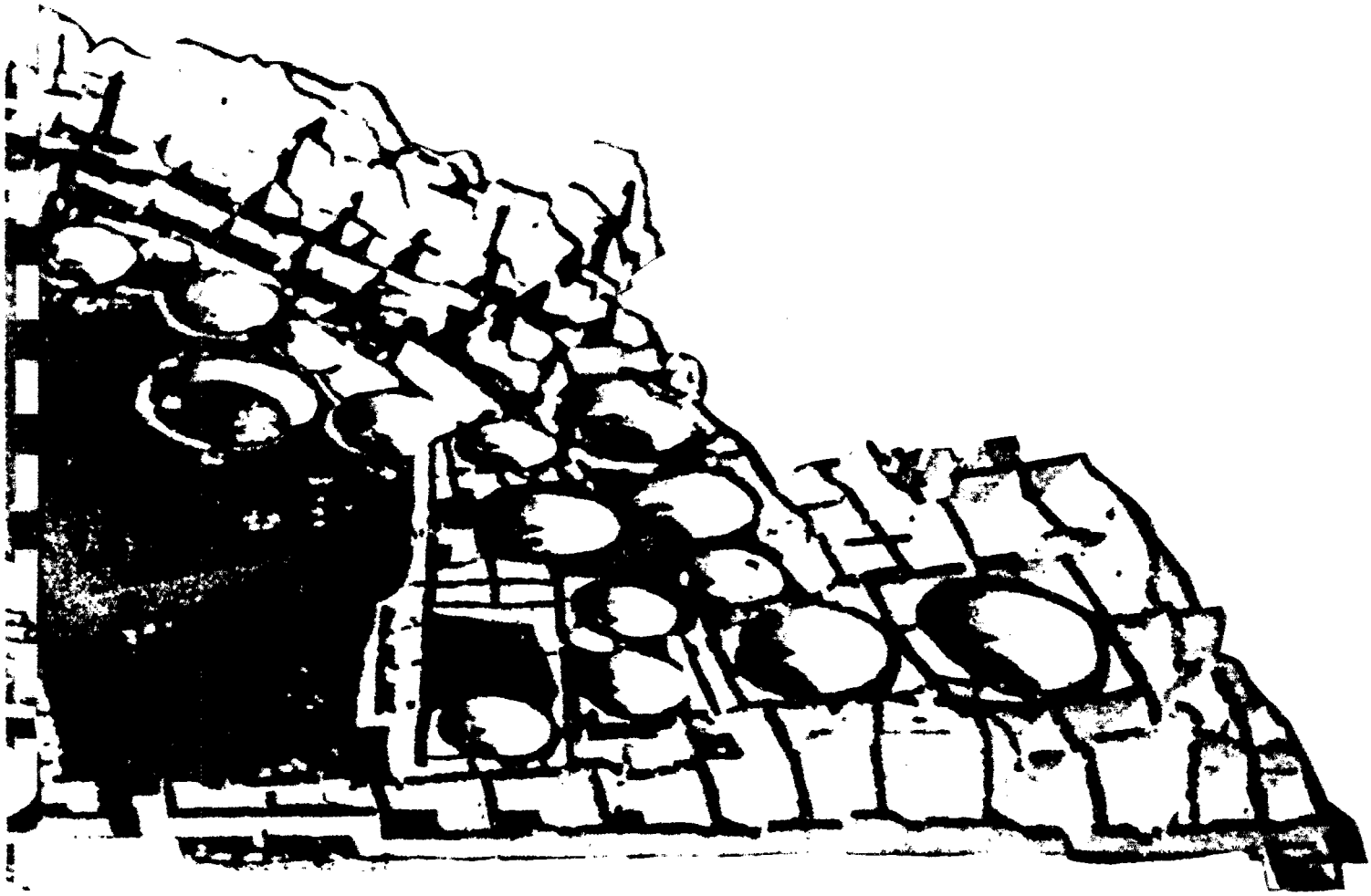
J. E. FASSETT
EDITOR

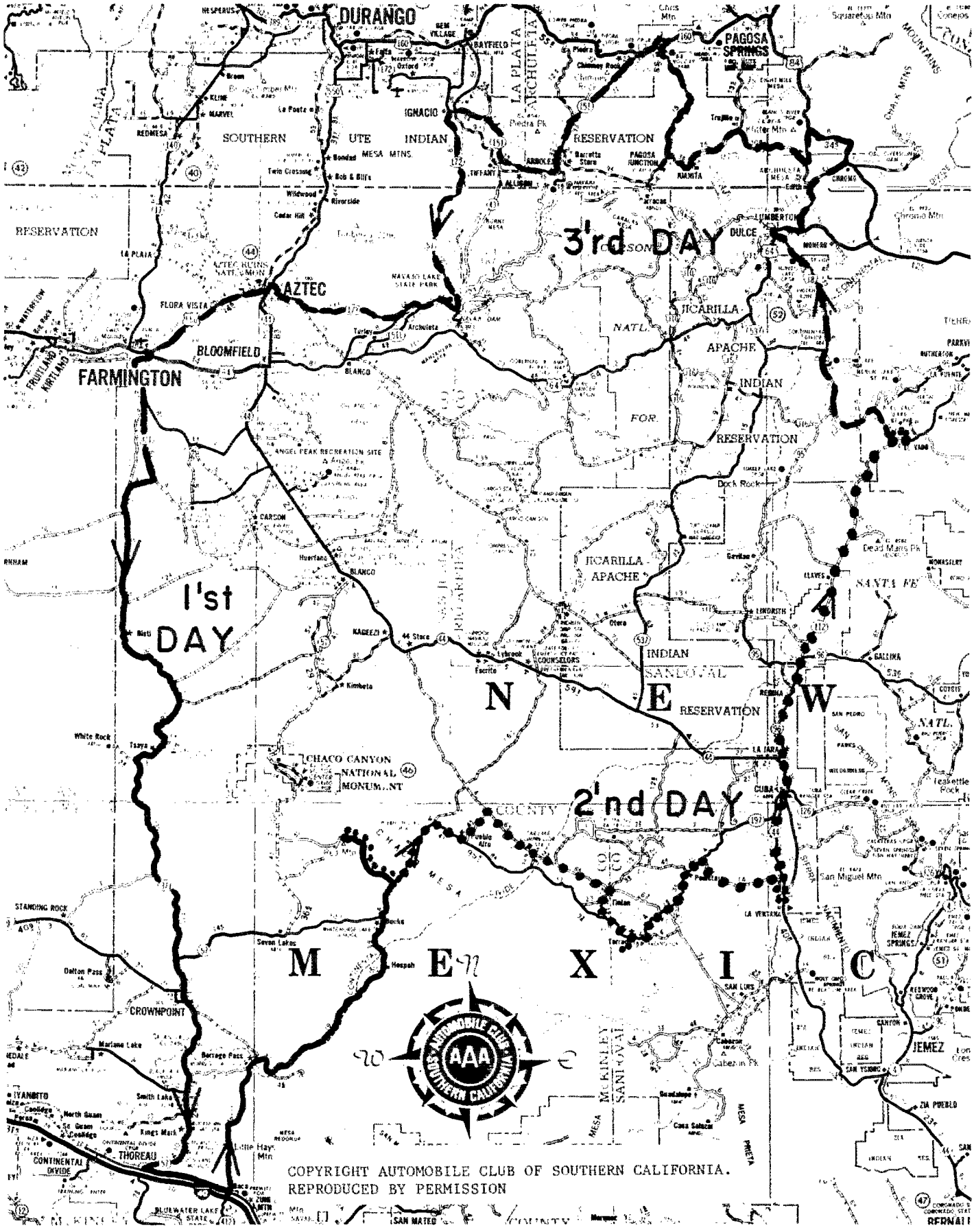
H. L. JAMES
MANAGING EDITOR

HELEN E. HODGSON
Editoral Assistant



New Mexico Geological Society
Twenty-Eighth Field Conference
September 15-17, 1977





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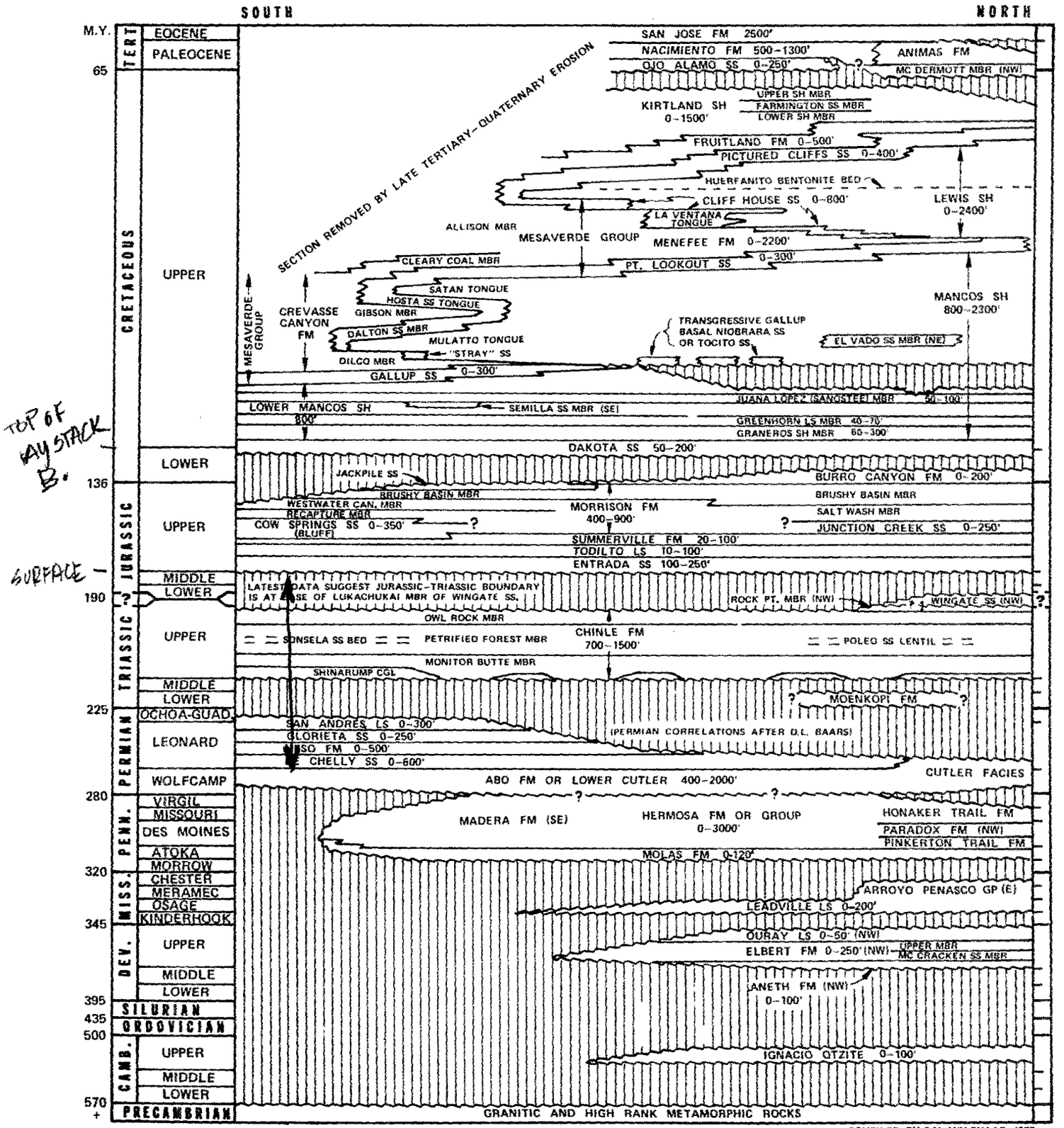
SAN JUAN BASIN TIME-STRATIGRAPHIC NOMENCLATURE CHART



COMPILED BY C.M. MOLENAAR 1977

101.0 Dakota-Morrison contact on right.

0.6

101.6 On left ahead is the Todilto Limestone overlying the Entrada Sandstone.

0.5

102.1 Road to the left leads to a quarry in the Todilto Limestone. The limestone is mined or quarried for aggregate which was used for construction of Interstate Highway 40 in eastern Arizona. The Todilto outcrop immediately right (west) of the road is the type locality for the ostracode *Metacypris todiltensis*. This new species is said to be definitely nonmarine and have the following dimensions: 0.65 mm. long, 0.50 mm. high, and 0.35 mm. thick. Road ahead cuts down through the Entrada.

1.0

103.1 Contact of the Entrada Sandstone and Chinle Formation is exposed at the base of the hill at 2:00. The Chinle is the soft-weathering, purplish shaly unit.

2.5

105.6 **STOP 3**—Discussion of the Mesozoic section exposed on cliffs. The Owl Rock Member of the Chinle Formation (Upper Triassic) is poorly exposed at the base of the cliff. The Owl Rock is unconformably overlain by the Entrada Sandstone of Late Jurassic age. The Entrada is about 250 feet thick here and has been divided into three parts on U.S.G.S. quadrangle maps in this area. The lower 50± feet is called the Iyanbito Member and is a cross-bedded sandstone unit that formerly was considered to be Wingate Sandstone. Above this is a 50±-foot-thick medial silt-

Figure 105.6. View to southwest near Stop 3 illustrating the contacts of the Entrada Sandstone (Je) with the Todilto Limestone (Jt) and the underlying Chinle Formation (Trc)—H. L. James photo.

stone member, and then the main thick upper sandstone member. The Entrada is an eolian deposit.

The Entrada is overlain by the 10 to 40-foot-thick Todilto Limestone. The slope-former above this is the Summerville Formation which is about 60 feet thick and consists of reddish brown to orange silty sandstone and siltstone. The overlying Cow Springs Sandstone is divided into a lower unit made up of cosets of medium scale cross-bedded sandstone and flat bedded silty sandstone and an upper thick, light greenish gray unit consisting of large scale, eolian cross-bedded sandstone. The Cow Springs has also been called Bluff or Zuni Sandstone and Thoreau Formation.

The Morrison conformably overlies the Cow Springs and is divided into three members which in ascending order are: (1) Recapture Member, an interbedded reddish brown siltstone and light gray sandstone unit; (2) Westwater Canyon Member a thick, light red fluvial sandstone unit; and (3) Brushy Basin Member, a slope forming unit of greenish to purplish gray shale and sandstone. In earlier mapping, Clay Smith named these three members, in ascending order: Chavez, Prewitt and Casamero members. An unconformity is present either at the base of the Morrison or within the Recapture Member. The Westwater Canyon Member is the major uranium producer in the Grants mineral belt. The Todilto Limestone and fluvial sands in the Brushy Basin are also productive.

The brown unit capping the hill is the basal fluvial sandstone of the Dakota, which unconformably overlies the Morrison. The Dakota truncates the section to the south overlying the Chinle Formation south of the Zuni uplift.

The unconformity at the base of the Entrada is a regional unconformity in which the Entrada and associated Carmel Formation overlie progressively older strata from west to east across the Colorado Plateau; one might call this the craton's response to early Nevadan orogeny.

An interesting bit of nomenclatural history concerns the type area of the Wingate Sandstone. This is at the Wingate cliffs; a continuation of these cliffs extend about 22 miles to the west near Fort Wingate, New Mexico. After the Wingate place name was applied in New Mexico, the Wingate nomenclature became firmly entrenched in the literature of southeastern Utah for a sandstone bed which apparently does not exist at the type locality. When it was realized that the type Wingate was actually the Entrada Sandstone of southeastern Utah, for some reason, the first reference and type locality did not take precedence. Ever since, some workers have tried to include a part of the Wingate in the original Wingate (now Entrada) cliffs, but regional correlations show the Wingate truncated edge is far to the west near the Arizona-New Mexico border. The Wingate is present in the northwest corner of New Mexico. Incidentally, the Wingate, which was originally considered to be Early Jurassic in age and later was thought to be Late Triassic, is now considered Early Jurassic in age on the basis of palynomorphs found in the time-equivalent Moenave Formation in south-central Utah. Those paleontologists are a shifty bunch!

1.5

107.1 Thoreau Chapter House on right.

1.3

108.4 Cross Santa Fe Railroad tracks.

0.2

108.6 **Turn left** on frontage road; **do not go under I-40!** After turn, Mt. Taylor is straight ahead. On right is dip slope of Chinle (largely Sonsela Sandstone Bed) off Zuni uplift to southwest.

2.8

111.4 On left at 9:00 is good view of cliff exposures from Chinle to Dakota. Light green, massive sandstone about half way up is eolian Cow Springs Sandstone. **Refer to mile 105.6 for discussion.**

2.2

113.6 Roadcut in Chinle. Haystack Butte is straight ahead. This is the location where Paddy Martinez, a Navajo sheepherder, collected samples of the Todilto Limestone containing yellow uranium minerals. Publicity associated with the find started the uranium boom in the Grants area in the fall of 1950.

3.7

117.3 Roadcut in Chinle (Sonsela Sandstone Bed).

1.0

118.3 Road junction with N.M. 412; **continue straight ahead.**

0.5

118.8 KOA Campground on right and road junction on left; **turn left** toward Borrego Pass. This is Baca—the point where a proposed railroad spur will head north to Star Lake to bring down coal to the Santa Fe's main line from

REFERENCE # 9

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

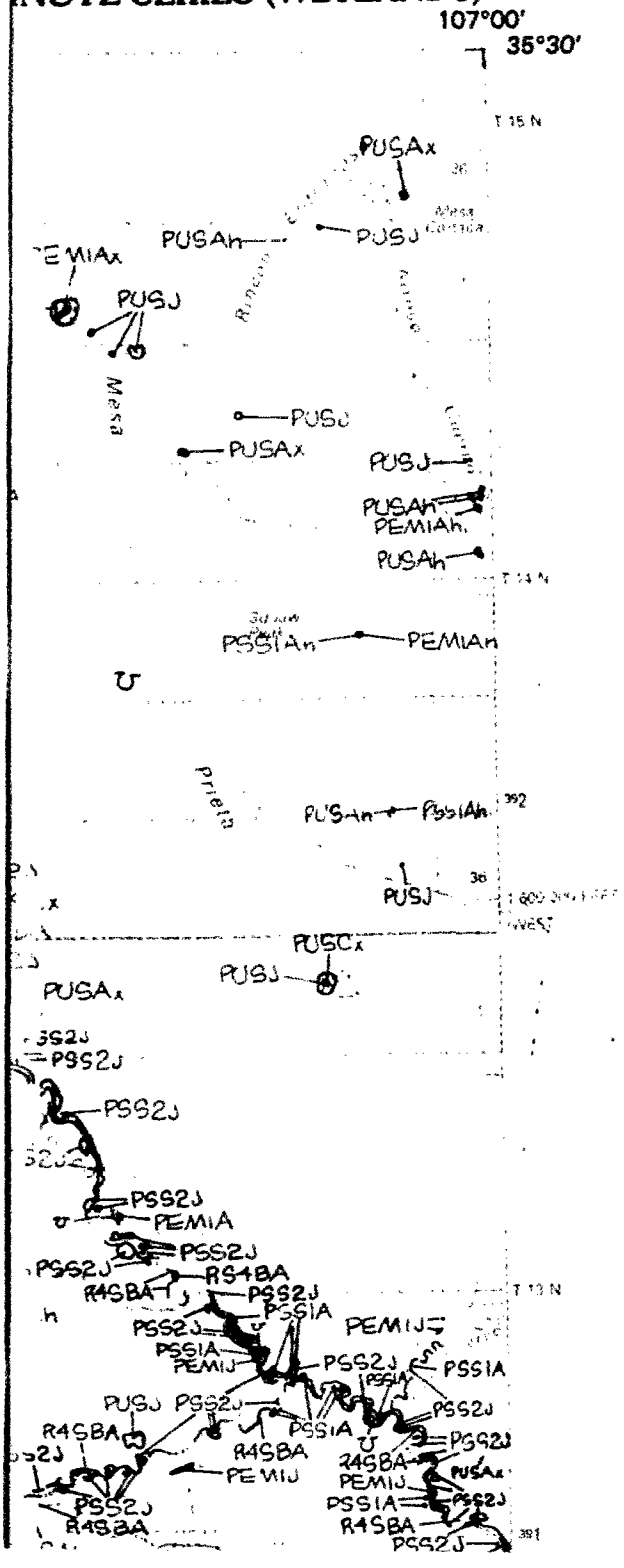
MAY, '90 P. MOLLOY

Grants
NEW MEXICO

1:100 000 — Scale Map of

National Wetlands Inventory

- **Wetland classifications**
- **Highways, roads and other manmade structures**
- **Water features**
- **Geographic names**



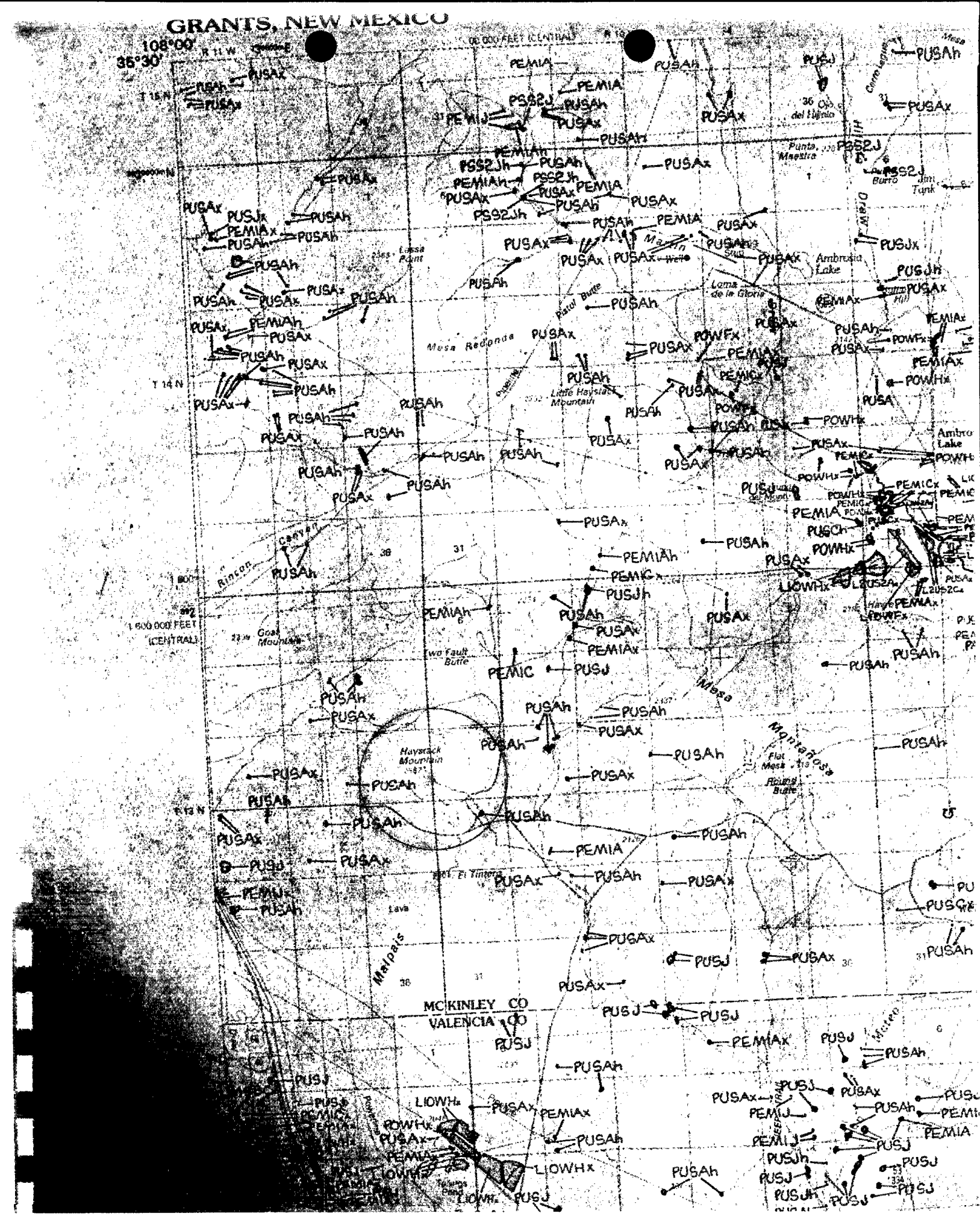
FISH & WILDLIFE SERVICE

1984

Produced by the United States Fish and Wildlife Service

Wetland classifications from 1:58,000 scale color infrared aerial photographs taken 1981 and other source data.

Projection and 10,000 meter, zone 12
Universal Transverse Mercator


GRANTS, NEW MEXICO
108°00'
35°30'
R 11 W
T 15 N
T 14 N
T 13 N
1 600 000 FEET (CENTRAL)
Mesa Redonda
Pistol Butte
Little Haystack Mountain
Ambrosia Lake
Loma de la Gloria
Punta Maestra
Rincon Canyon
Goat Mountain
Two Fault Butte
Haystack Mountain
Mesa Montañosa
Flat Mesa
Round Butte
El Tintero
Malpais
Lava
MC KINLEY CO
VALENCIA CO
PEMIA
PEMIAx
PEMIAh
PEMIJ
PEMIC
PEMICx
PEMIJx
PEMIJh
PSS2J
PSS2Jh
PUSAx
PUSAh
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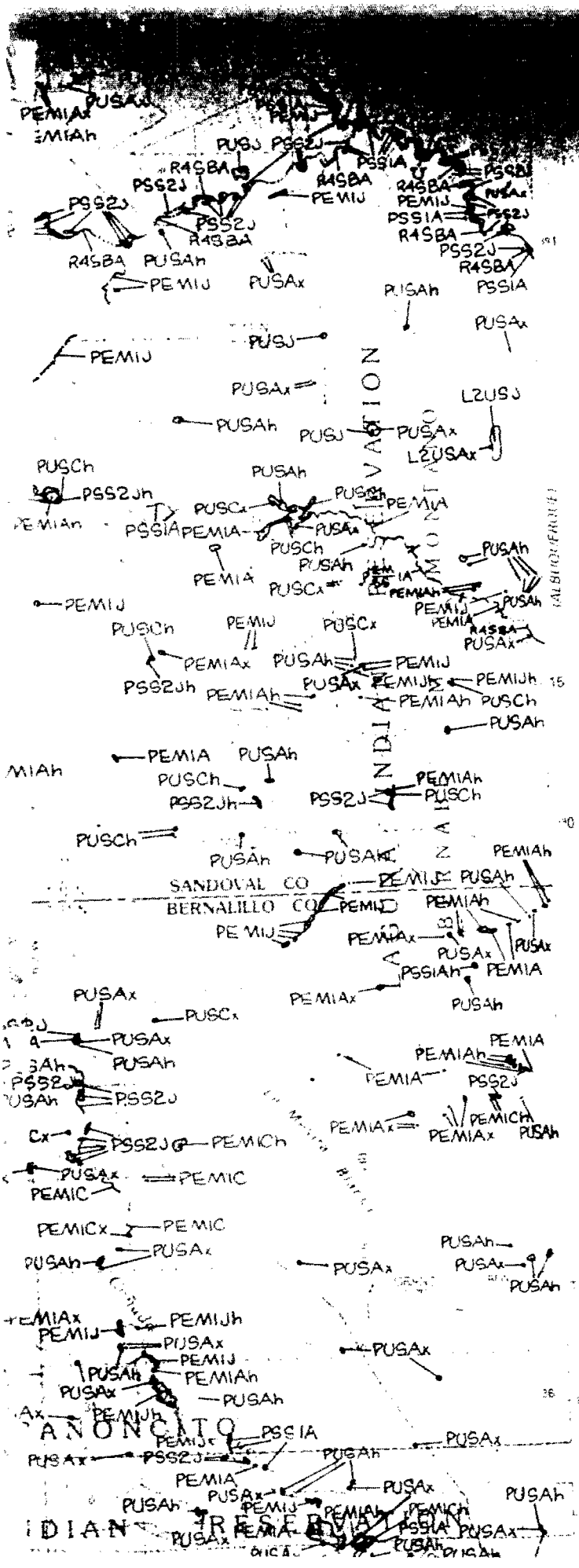
POWHx
LIOWHx
L2US2Ax
L2US2Cx
PUSCx



Projection and 10,000 meter, zone 12 Universal Transverse Mercator
25,000-foot grid ticks based on New Mexico coordinate system, central and east zones 1927 North American datum
To place on the predicted North American Datum 1983 move the projection line 1 meter south and 54 meters east

SPECIAL NOTE

This document was prepared primarily by stereoscopic analysis of high altitude aerial photographs. Wetlands were identified on the photographs based on vegetation, visible hydrology, and geography in accordance with **Classification of Wetlands and Deep Water Habitats of the United States** (An Operational Draft) Cowardin, et al, 1977. The aerial photographs typically reflect conditions during the specific year and season when they were taken. In addition, there is a margin of error inherent in the use of the aerial photographs. Thus, a detailed on the ground and historical analysis of a single site may result in a revision of the wetland boundaries established through photographic interpretation. In addition, some small wetlands and those obscured by dense forest cover may not be included on this document.

Federal, State and local regulatory agencies with jurisdiction over wetlands may define and describe wetlands in a different manner than that used in this inventory. There is no attempt, in either the design or products of this inventory, to define the limits of proprietary jurisdiction of any Federal, State or local government or to establish the geographical scope of the regulatory programs of government agencies. Persons intending to engage in activities involving modifications within or adjacent to wetland areas should seek the advice of appropriate Federal, State or local agencies concerning specific agency regulatory programs and proprietary jurisdictions that may affect such activities.

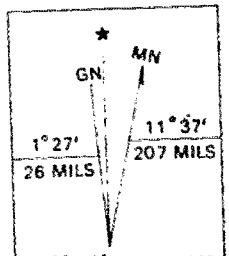
CONVERSION TABLE

Meters	Feet
1	3.2808
2	6.5617
3	9.8425
4	13.1234
5	16.4042
6	19.6850
7	22.9658
8	26.2467
9	29.5276
10	32.8084

To convert meters to feet multiply by 3.2808

To convert feet to meters multiply by 0.3048

DECLINATION DIAGRAM



UTM grid convergence (GN) and 1984 magnetic declination (MN) at center of map
Diagram is approximate

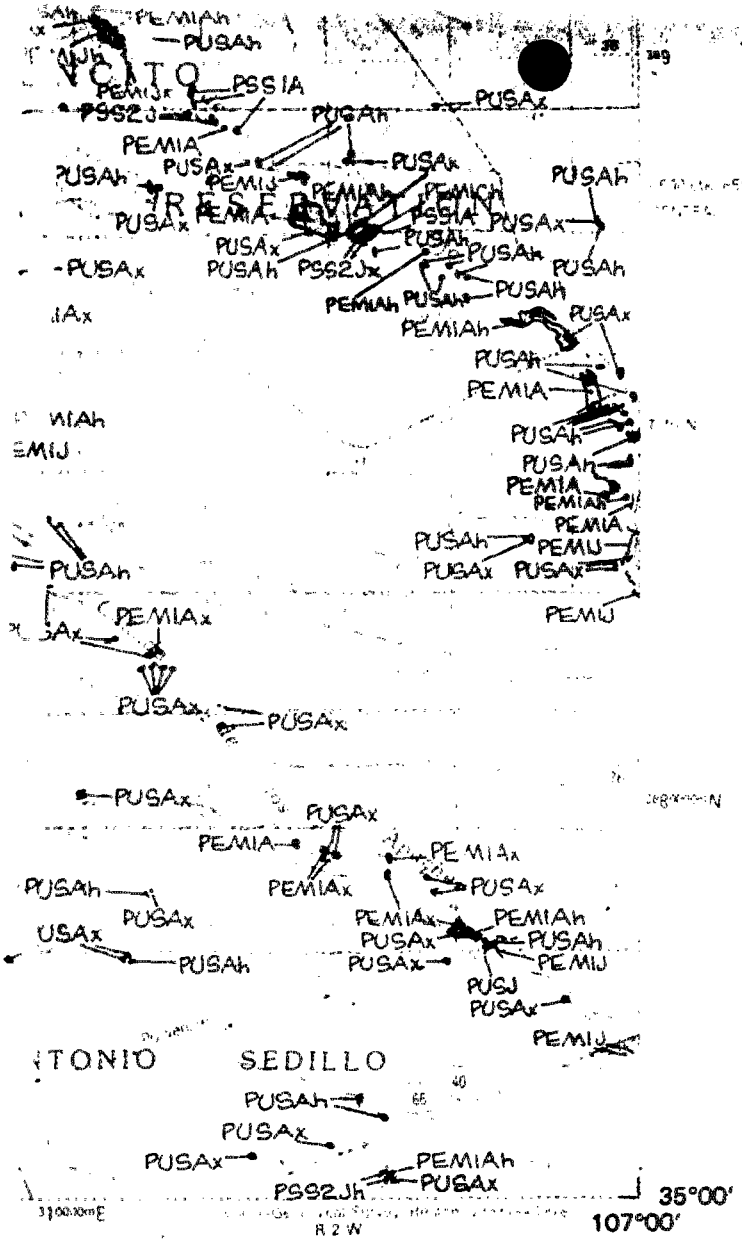
ADJOINING MAPS

1	2	3
4		5
6	7	8

1. Gallup
2. Chaco Mesa
3. Los Alamos
4. Zuni
5. Albuquerque
6. Fence Lake
7. Acoma Pueblo
8. Belen

NOTES TO THE USER

- Wetlands which have been field examined are indicated on the map by an asterisk (*).
- Additions or corrections to the wetlands information displayed on this map are solicited. Please forward such information to the address indicated.
- Subsystems, Classes, Subclasses, and Water Regimes in *italics* were developed specifically for NATIONAL WETLANDS INVENTORY mapping.
- Some areas designated as R4SB, R4SBW, OR R4SBJ (INTERMITTENT STREAMS) may not meet the defini-



GRANTS, NEW MEXICO
(SW ¼ of Albuquerque 1:250,000)

NOTES TO THE USER

- Wetlands which have been field examined are identified on the map with an asterisk (*).
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- Subsystems, Classes, Subclasses, and Water Regimes in *Italics* were developed specifically for NATIONAL WETLANDS INVENTORY mapping.
- Some areas designated as R4SB, R4SBW, OR R4SBJ (INTERMITTENT STREAMS) may not meet the definition of wetland.
- This map uses the class Unconsolidated Shore (US). On earlier NWI maps that class was designated Beach/Bar (BB), or Flat (FL). Subclasses remain the same in both versions.

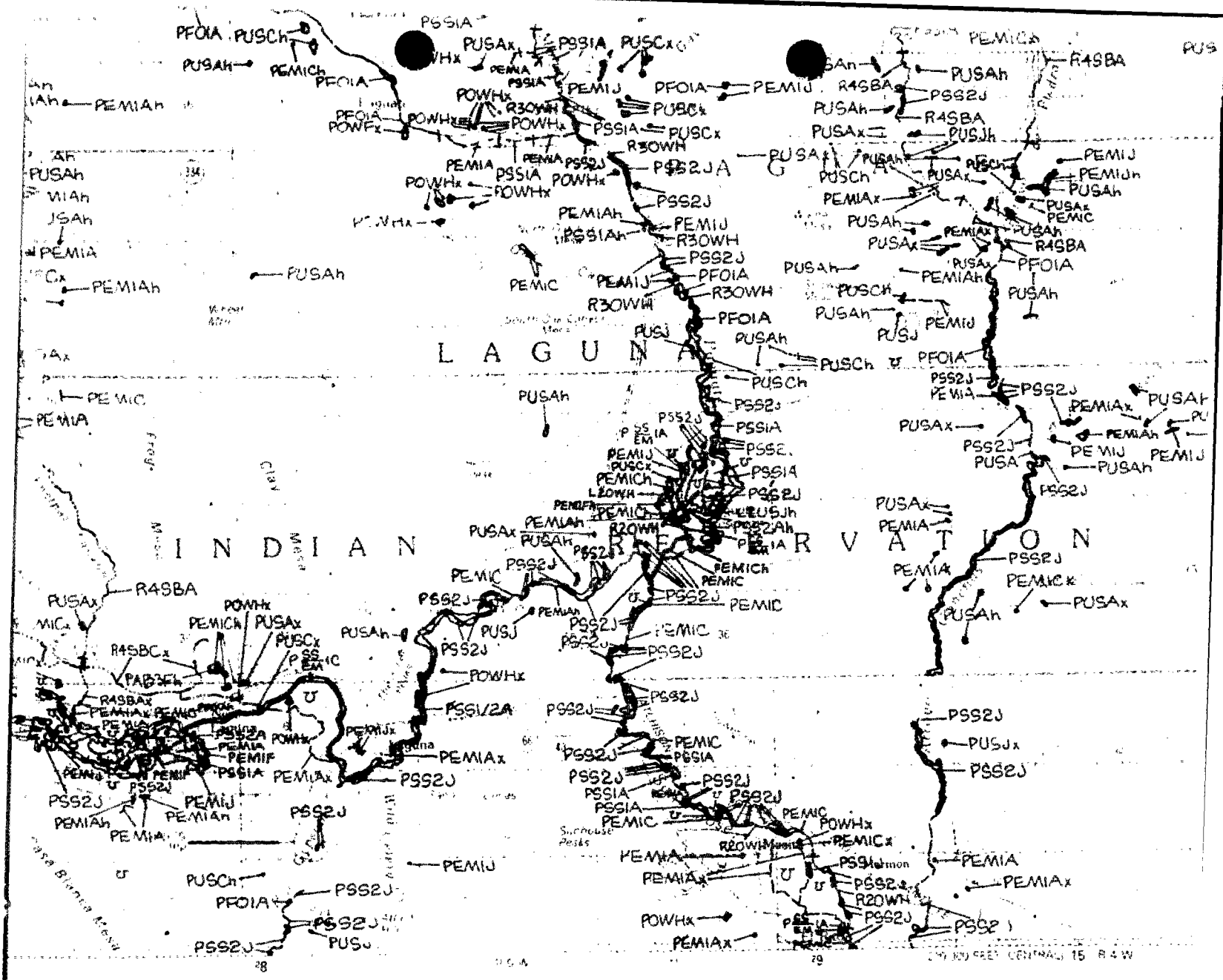
Other information including a narrative report concerning the wetland resources depicted on this document may be available. For information, contact:

Regional Director (ARDE) Region II U.S. Fish and Wildlife Service
P.O. Box 1306 Albuquerque, New Mexico 87103

GRANTS, NEW MEXICO
(SW ¼ of Albuquerque 1:250,000)

SYMBOLOGY EXAMPLE

Ʊ — Primarily represents upland areas, but may include unclassified wetlands such as man-modified areas, non photo-identifiable areas and/or unintentional omissions.



L — LACUSTRINE

1 — LIMNETIC

RB — ROCK BOTTOM	UB — UNCONSOLIDATED BOTTOM	AB — AQUATIC BED	OW — *OPEN WATER/ Unknown Bottom*
1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Algal 2 Aquatic Moss 3 Rooted Vascular 4 Floating Vascular 5 *Unknown Submergent* 6 *Unknown Surface*	

2 — LITTORAL

RB — ROCK BOTTOM	UB — UNCONSOLIDATED BOTTOM	AB — AQUATIC BED	RS — ROCKY SHORE	US — UNCONSOLIDATED SHORE	EM — EMERGENT
1 Bedrock 2 Rubble	1 Cobble-Gravel 2 Sand 3 Mud 4 Organic	1 Algal 2 Aquatic Moss 3 Rooted Vascular 4 Floating Vascular 5 *Unknown Submergent* 6 *Unknown Surface*	1 Bedrock 2 Rubble	1 Cobble Gravel 2 Sand 3 Mud 4 Organic 5 Vegetated	2 Nonpersistent

MODIFIERS

In order to more adequately describe wetland and deepwater habitats one or more of the water regime, water chemistry, soil, or special modifiers may be applied at the class or lower level in the hierarchy. The formed modifier may also be applied to the ecological system.

WATER REGIME

Non-Tidal

A Temporarily Flooded	H Permanently Flooded
B Saturated	J Intermittently Flooded
C Seasonally Flooded	K Artificially Flooded
D *Seasonally Flooded/ Well Drained*	W Intermittently Flooded/Temporary
E Seasonally Flooded/ Saturated	Y Saturated/Semipermanent/ Seasonal
F Semipermanently Flooded	Z Intermittently Flooded/Permanent
G *Intermittently Exposed*	U *Unknown*

Tidal

E *Artificially Flooded*	*S Temporary Tidal
L Subtidal	*R Seasonal Tidal
M Irregularly Exposed	*T Semipermanent Tidal
N Regularly Flooded	*V Permanent Tidal
P Irregularly Flooded	U *Unknown*

*These water regimes are only used in saline estuarine and/or oceanic regimes.

WATER CHEMISTRY

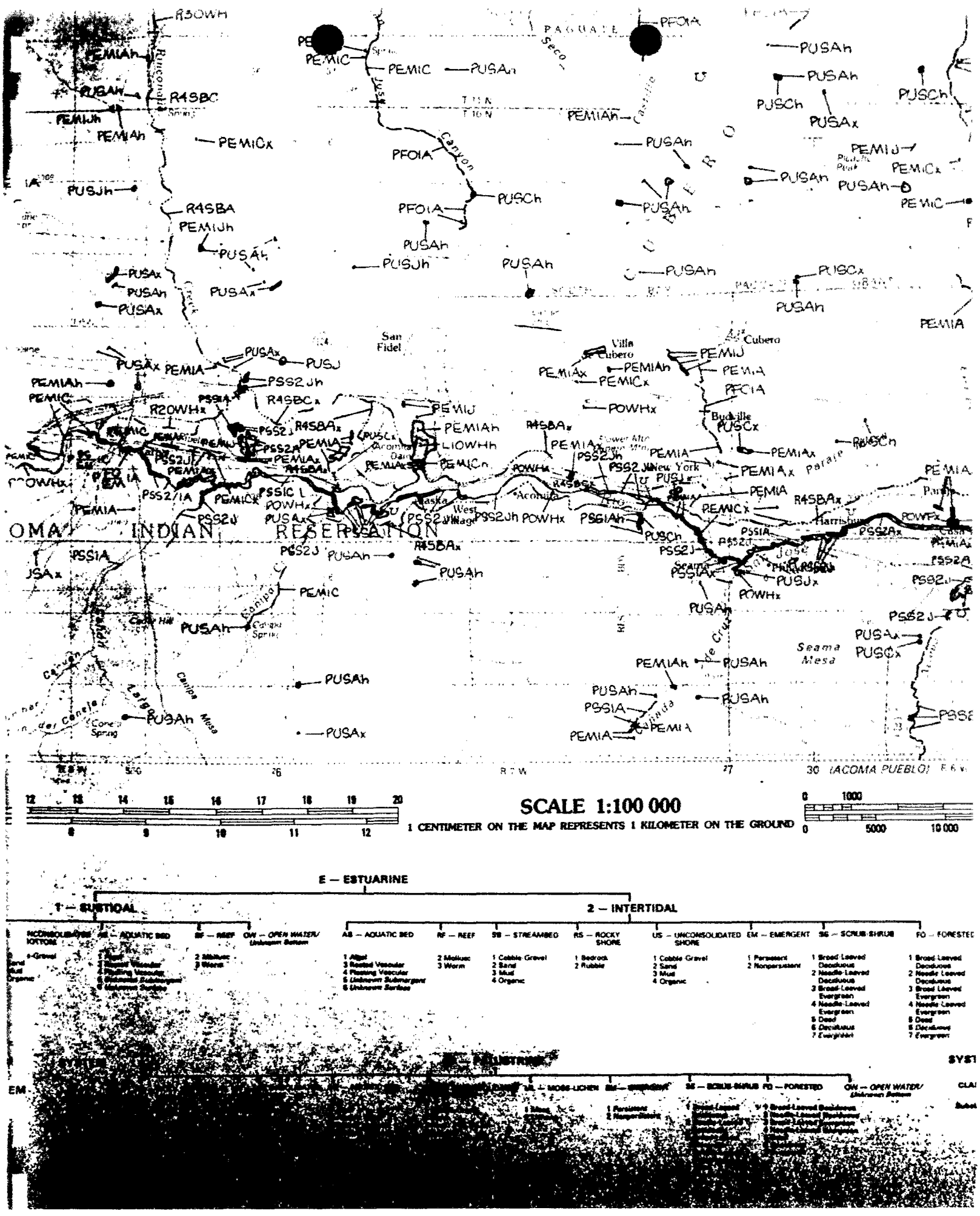
Coastal Salinity	Inland Salinity	pH Modifiers for all Fresh Water
1 Hyperhaline	7 Hypersaline	
2 Euhaline	8 Eusaline	a Acid
3 Mixohaline (Brackish)	9 Mixosaline	i Circumneutral
4 Polyhaline	0 Fresh	b Alkaline
5 Mesohaline		
6 Oligohaline		
0 Fresh		

SOIL

9 Organic	
0 Mineral	

SPECIAL

[illegible] is limited to TIDAL and INTERMITTENT SUBSYSTEMS, and comprises the only CLASS in the INTERMITTENT SUBSYSTEM
[illegible] SUBSYSTEMS. The remaining CLASSES are found in all SUBSYSTEMS.



PAGUATE
Seco
Canyon
San Fidel
Villa Cubero
Cubero
Budville
New York
Acomita
West Village
Harrisburg
Seama Mesa
Cedar Hill
Canipa Spring
Canipa Mesa
Cone Spring
OMA INDIAN RESERVATION
(ACOMA PUEBLO)
R 7 W
SCALE 1:100 000
1 CENTIMETER ON THE MAP REPRESENTS 1 KILOMETER ON THE GROUND
E — ESTUARINE
1 — SUBTIDAL
2 — INTERTIDAL
AS — AQUATIC BED
RF — REEF
OW — OPEN WATER/ Unknown Bottom
SB — STREAMBED
RS — ROCKY SHORE
US — UNCONSOLIDATED SHORE
EM — EMERGENT
SS — SCRUB-SHRUB
FO — FORESTED
1 Algal
3 Rooted Vascular
4 Floating Vascular
5 Unknown Submergent
6 Unknown Surface
2 Mollusc
3 Worm
1 Cobble-Gravel
2 Sand
3 Mud
4 Organic
1 Bedrock
2 Rubble
1 Persistent
2 Nonpersistent
1 Broad-Leaved Deciduous
2 Needle-Leaved Deciduous
3 Broad-Leaved Evergreen
4 Needle-Leaved Evergreen
5 Dead
6 Deciduous
7 Evergreen

REFERENCE # 10

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

Uranium Geology Exploration

Richard H. De Voto

Colorado School of Mines
Golden, Colorado

URANIUM GEOLOGY
AND EXPLORATION

BY

RICHARD H. DE VOTO

LECTURE NOTES AND REFERENCES

COLORADO SCHOOL OF MINES

GOLDEN, COLORADO 80401

MARCH, 1978

GEOCHEMISTRY OF URANIUM

I. Atomic Chemistry of Uranium

A. Atomic Number: 92, heaviest naturally occurring element.

B. Atomic Weight: 238.03

C. Naturally Occurring Isotopes

Mass No.	Abundance Wt. %	Activity % (radioactive decay events per unit of time)
238	99.28	48.9
235	0.71	2.2
234	0.0054	48.9

D. Nuclear Properties

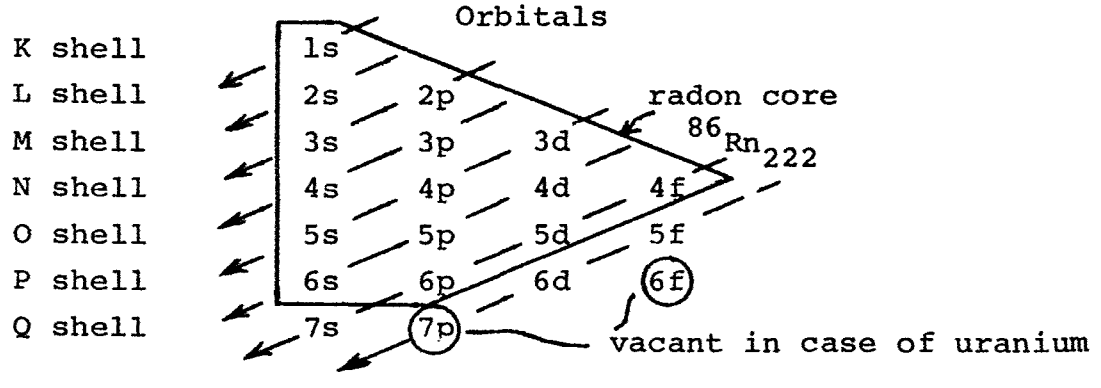
1. All isotopes of uranium are radioactive.

2. U-235 is readily fissionable.

3. All isotopes of all elements above Bismuth (83) are radioactive.

Isotope	Half Life
U^{238}	4.51×10^9 years
U^{235}	7.1×10^8 years
U^{234}	2.48×10^5 years

E. Electronic Structure and Valence States



2. Energy of decay process often results in oxidation, therefore U^{234} may be U^{+6} from U^{238} in UO_2 (uraninite) Note: U^{238} and U^{235} always in fixed ratio in nature.

VI. Measurement of Nuclear Radiation

A. Alpha (α) radiation measured by

1. proportional counters (gross α radioactivity)

2. semiconductor detectors, for α energy spectrometry

3. photographic techniques (track etch) radon α particularly

4. helium analysis with mass spectrometer

B. Beta (β) radiation

1. measured with proportional counter

2. not very useful, except for ore grade control

C. Gamma (γ) radiation

1. Because of high range and discrete energy levels, most frequently measured radiation

2. Geiger counter

a. inexpensive, measures total γs from all sources, non energy selective

b. γs enter gas-filled tube, ionize gas, giving electrical impulse

3. Scintillation counter

a. medium resolution γ energy spectra

b. medium cost $2000 - 20,000

c. γ strikes NaI crystal, converts energy to light. Sorts light intensity for different energies

4. Semiconductor detector (germanium)

   a. high resolution γ spectra

   b. high cost

D. Uranium Analysis by Gamma Spectrometry

1. U^{238} series

   a. U^{238}, U^{235}, U^{234} γ energies are too low for practical measurement

   b. Bi^{214}, daughter in U^{238} series, has γ energies of 0.61 MeV and 1.76 MeV which are readily measured. Figure 28

   c. Bi^{214} is good measure of Rn^{222}

   d. Bi^{214} activity is reliable measure of U^{238}-U^{235} activity only if sample has not weathered for 1 million years, and radon has not escaped for 3 weeks

   e. Bi^{214} is the mechanism of "radiometric assaying" for uranium

2. Th^{232} series

   a. Tl^{208} daughter has high energy 2.615 MeV γ (Figure 29)

   b. Th^{232} analysis by measuring Tl^{208} activity because short-lived daughters

   c. Some Th^{232} series γs interfere with 1.76 MeV γ from Bi^{214}, so need to know Th content when measure Bi^{214} activity

3. K^{40} gamma spectrum

   a. high energy 1.46 MeV γ (Figure 30)

4. Superimpose U^{238}, Th^{232}, and K^{40} γ spectra

   a. 2.615 MeV, Tl^{208} from Th^{232}

   b. 1.76 MeV, Bi^{214} from U^{238}

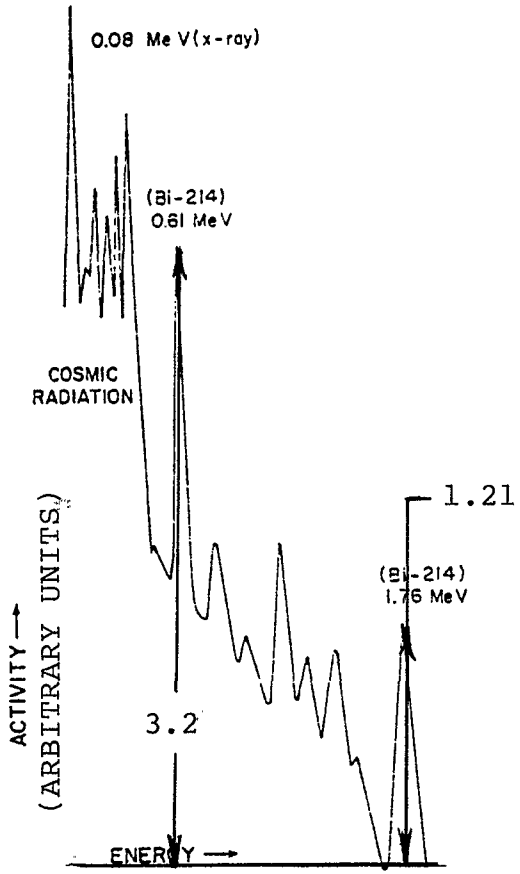


Fig. 28. Gamma spectrum of equilibrium U-238, U-235 series.

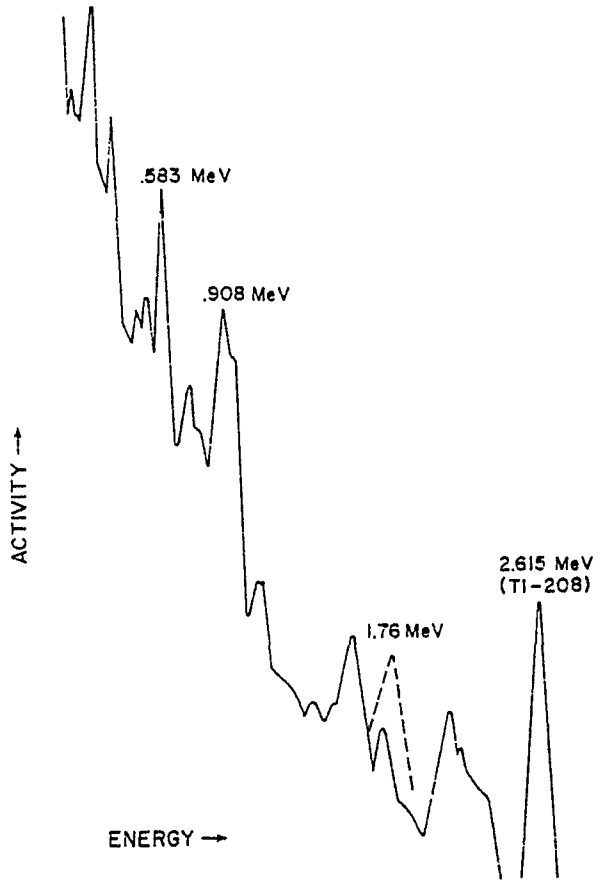


Fig. 29. Gamma spectrum of equilibrium Th-232 series.

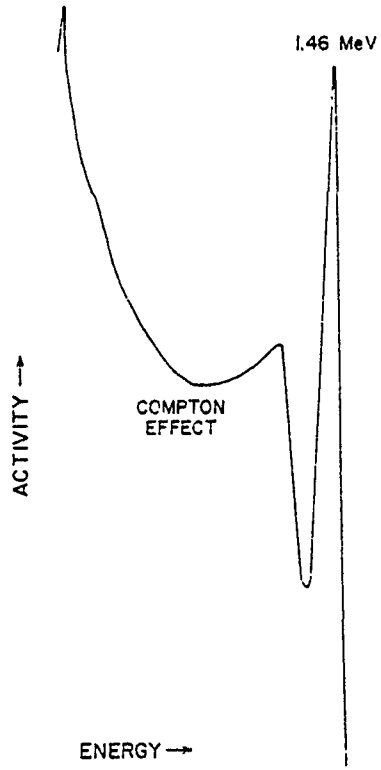


Fig. 30. K-40 gamma spectrum.

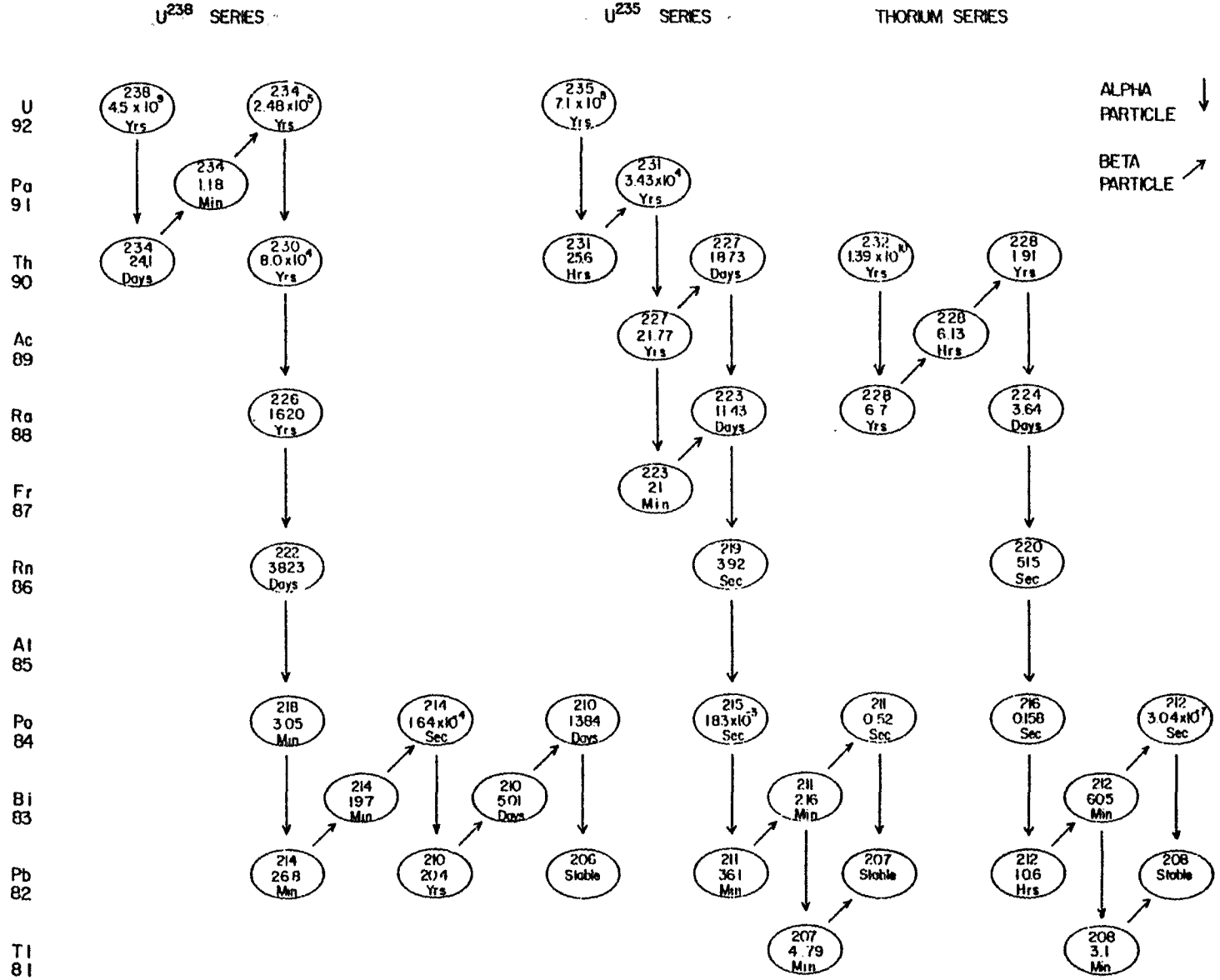


Fig. 27. U^{238}, U^{235}, and Th^{232} natural radioactivity decay series, particles emitted, and half lives. (Friedlander, Kennedy, and Miller, 1964)

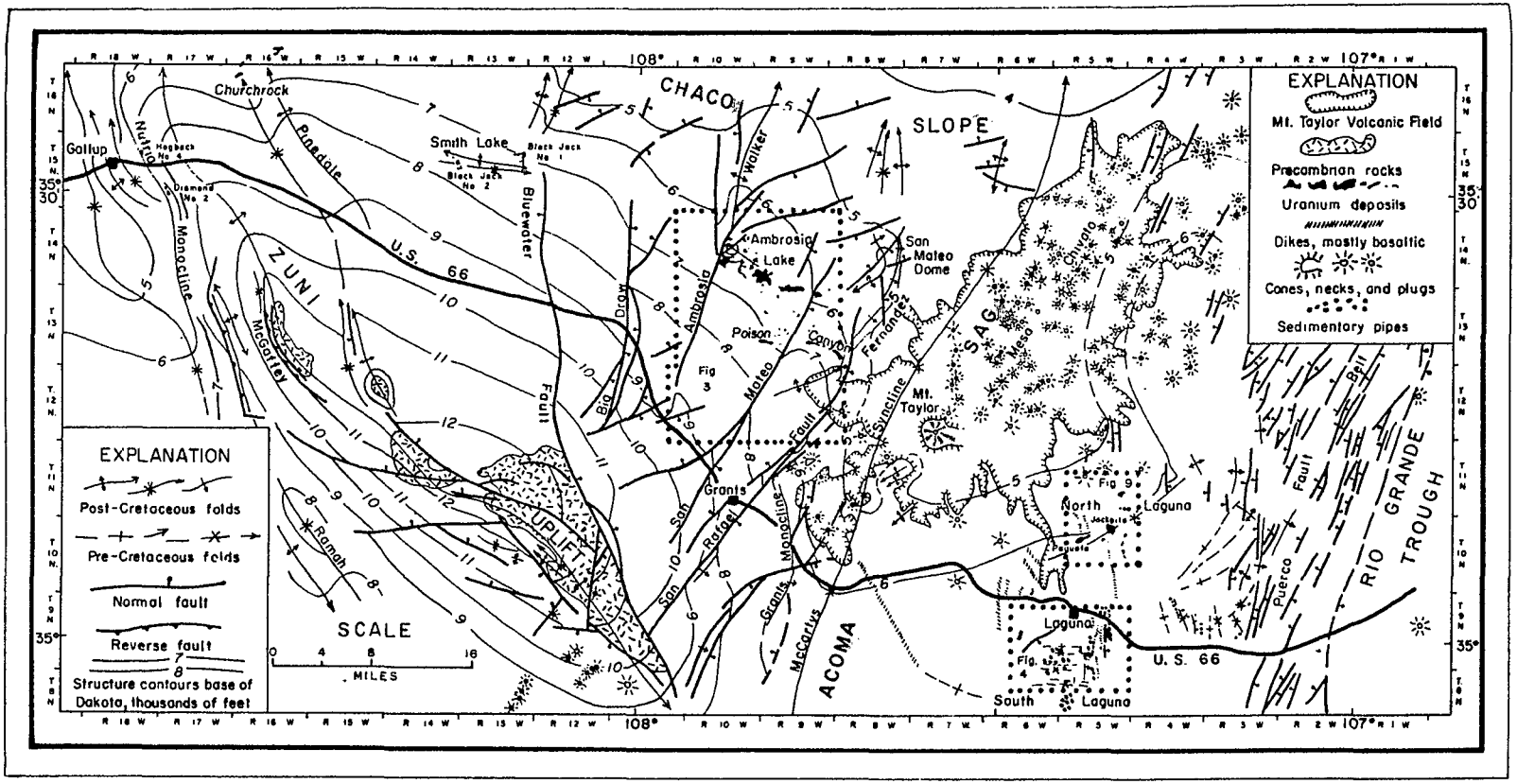


Fig. 126. *Geologic features of the Grants Region.* (Kelley, and others, 1968)

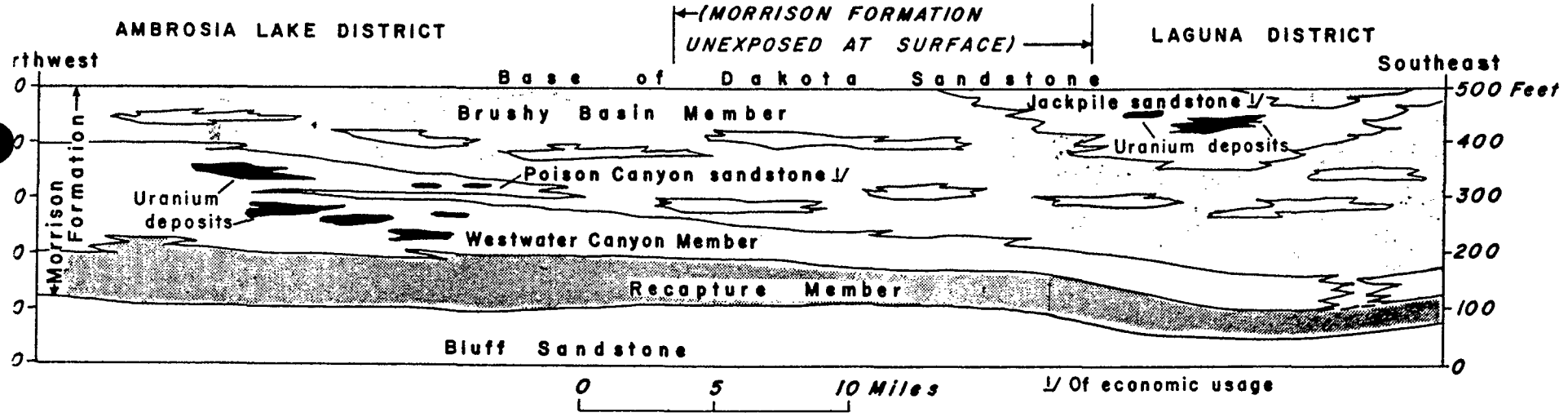


Figure 127

GENERALIZED GEOLOGIC SECTION SHOWING THE STRATIGRAPHIC RELATIONS OF THE MORRISON FORMATION BETWEEN AMBROSIA LAKE AND LAGUNA

(Hilpert, 1963)

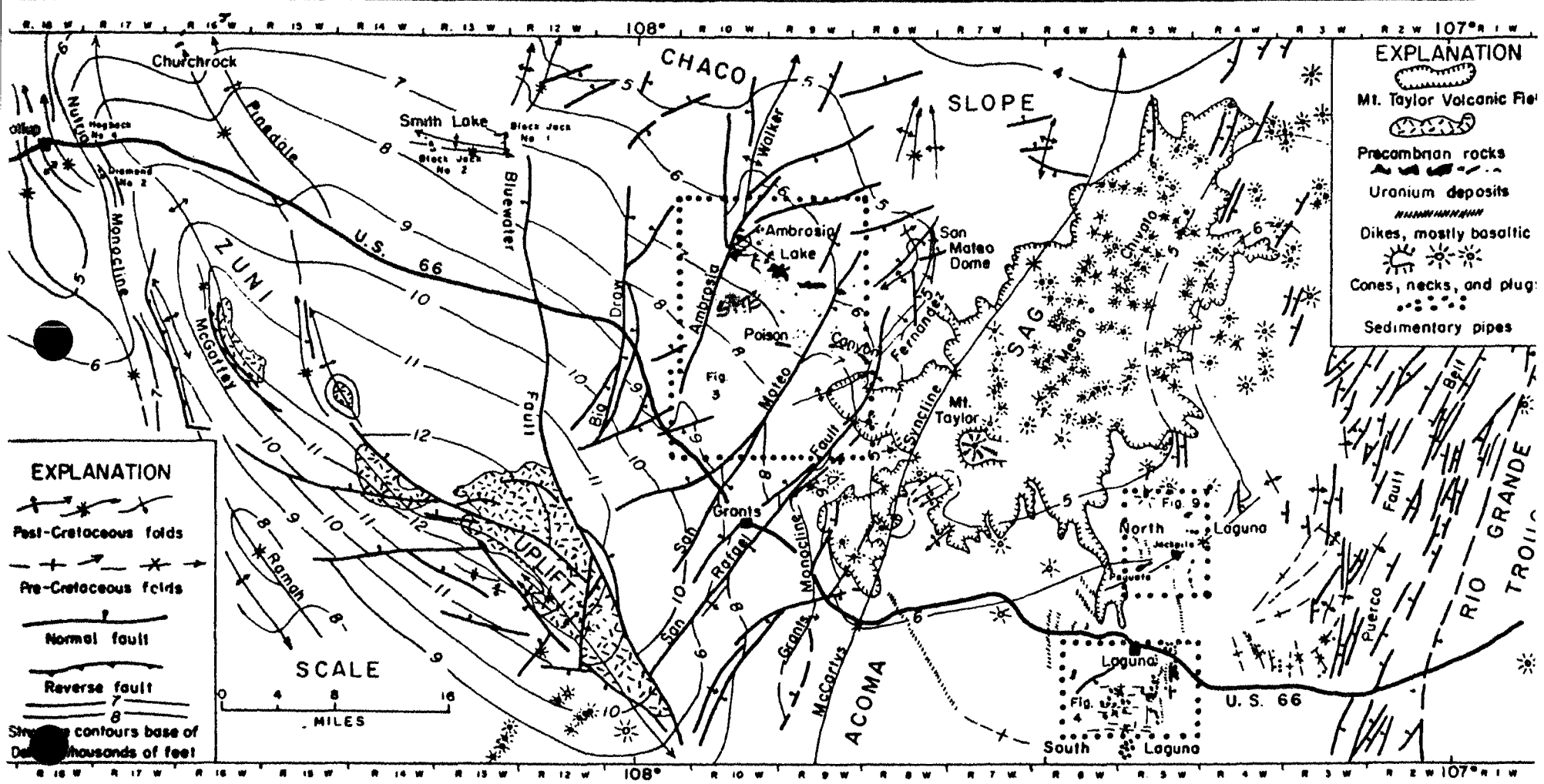
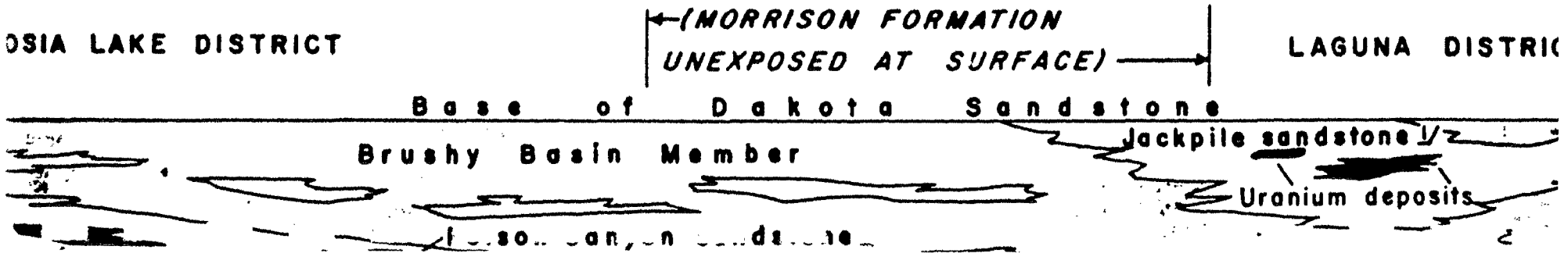


Fig. 126. *Geologic features of the Grants Region.* (Kelley, and others, 1968)



F. Organic-rich limestones (epigenetic)

1. Dynamic ground water system

2. Ocean water (2ppb U) or oxidizing uraniferous ground water by evaporitic pumping (Fig. 139)

3. Todilto U deposits, Grants, New Mexico

a. Algal stromatolites, organic rich

b. Rest on red, hematitic Entrada Sandstone

c. U probably derived from Fe-Mg silicates in Entrada

d. Evaporitic pumping of uraniferous ground water to organic-rich reducing environment in Todilto

G. Coals (epigenetic)

1. Uranium accumulation principally in low-rank coals

2. Beneath unconformity with overlying tuffaceous oxidized rocks

3. Black Hills example (Fig. 140)

H. Sulfide-bearing veins (epigenetic)

1. Beneath an unconformity (Fig. 141), or

2. at the ground surface

I. Reducing gas moving to uraniferous oxidizing water

1. H_2S, methane, or other volatile hydrocarbons move upward, through ground water

a. U and pyrite precipitation at ground water table (Fig. 31r)

b. U and pyrite precipitation at positions of maximum reduction, at or near point of introduction of reductant into oxidizing ground waters (Fig. 142):

1. along faults (S. Texas, NW Colorado)

2. above subcrop positions of petroliferous aquifers

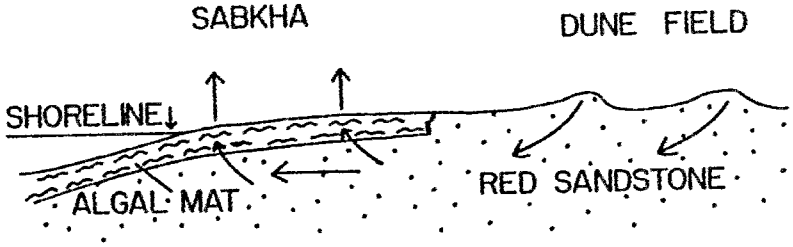


Fig. 139 Evaporitic pumping bringing oxidizing uraniferous ground water through underlying sandstone (Entrada) into reducing environment of algal stromatolitic limestones (Todilto Limestone).

REFERENCE # 11

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

Uranium Resources of Northwestern New Mexico

GEOLOGICAL SURVEY PROFESSIONAL PAPER 603

Prepared on behalf of the U.S. Atomic Energy Commission

Uranium Resources of Northwestern New Mexico

By LOWELL S. HILPERT

GEOLOGICAL SURVEY PROFESSIONAL PAPER 603

Prepared on behalf of the U.S. Atomic Energy Commission

A description of the stratigraphic and structural relations of the various types of uranium deposits in one of the world's great uranium-producing regions

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1969

TABLE 4.—*Uranium deposits, by county, in northwestern New Mexico*—Continued

Name of deposit	Location			Description of deposit and sample	Source of data
	Sec.	T.	R.		
McKinley County—Continued					
Junior (*4*)	NE¼ 4	13 N.	10 W.	Mineralized zone in carbonaceous sandstone near base of Dakota Sandstone. Ore mined from opencut, 1953.	FN, November 1954
Pat (Dakota) (*64*)	SE¼NE¼ 4 (about 300 ft from ¼ cor. secs. 3 and 4).	13 N.	10 W.	Several lenses of dark-gray radioactive material in zone about 15 ft thick in upper part of 60- to 80-ft-thick sandstone. This sandstone may be at base of Jmb or at top of Jmw. The lenses are in buff to gray crossbedded sandstone and range in thickness from a few inches to about 1 ft. In 1954, the workings were four short partly connected adits, all within an outcrop distance of about 100 ft. Mined in 1952–63 but most of ore mined since 1958.	Do.
Section 5 (Westvaco; Febco(?)) (*6*)	5	13 N.	10 W.	Probably in Dakota Sandstone, but some may occur in Jmb. Ore was mined from adit, 1958.	AEC.
Sections 10 and 11	10 and 11	13 N.	10 W.	Mineralized material in sandstone in Jmb and possibly in Jmw.	AEC, DH.
Sections 12 and 13	12 and 13	13 N.	10 W.	Mineralized material in sandstone in Jmb and possibly in Jmw. Locality is near western limit of Jmpc. Relations of the deposits to Jmpc are not known.	Do.
Section 14	NE¼ 14	13 N.	10 W.	Some mineralized sandstone and a few scattered mineralized fossil logs at outcrop, probably in Jmpc.	Mathewson (1953, p. 11).
Red Point Lode (*28*)	SW¼SW¼ NW¼ 16.	13 N.	10 W.	Small deposit in middle and lower parts of Todilto Limestone, associated with eastward-trending intraformational anticlinal fold in limestone. Deposit mined from open pit, 1952–55.	Gabelman (1956b, p. 394); McLaughlin (1963, p. 146).
Section 17	NW¼ 17	13 N.	10 W.	Several small deposits in Todilto Limestone	Food Machinery and Chemical Corp., DH, July 1955; and AEC, DH.
Do	NW¼NW¼ SW¼ 17.	13 N.	10 W.	Small deposit in Todilto Limestone	Do.
Section 18, NE¼	S½NE¼ 18	13 N.	10 W.	Northward extension of several medium deposits from SE¼ of section and several other scattered small deposits in Todilto Limestone.	AEC, DH.
Section 18, SW¼ (Williams and Thompson) (*32*)	SW¼ 18	13 N.	10 W.	Cluster of medium and small irregularly shaped deposits in Todilto Limestone. Several deposits mined from inclined shaft, others from opencuts, 1952–64.	Federal Uranium Corp., DH, June 1956; AEC.
Section 18, SE¼ (Williams) (*33*)	SE¼ 18	13 N.	10 W.	Cluster of medium and small irregularly shaped deposits in Todilto Limestone. Deposits mined from open pits, 1953.	AEC, DH.
Haystack (Haystack Butte; Section 19, NW¼) (*16*)	NW¼ 19	13 N.	10 W.	Large, irregularly shaped, roughly tabular, partly oxidized deposit approximately in middle part of Todilto Limestone. Deposit is elongate northward and associated with numerous intraformational folds in limestone, some of which include the top few feet of the Entrada Sandstone These folds have diverse trends, but the dominant trends are northward and eastward. Ore mined from opencut, 1952–57.	FN, July 1955; Haystack Mountain and Development Co., DH, 1955; Gabelman (1956b, p. 393–396).
Section 19, NE¼ (*54*)	N½N½NE¼ 19	13 N.	10 W.	Several small or medium deposits, near or at outcrop of Todilto Limestone. Deposits mined in 1959–64.	AEC.
Section 22, NE¼	NE¼ 22	13 N.	10 W.	Small deposit in Todilto Limestone. Deposit worked by open pit, but no shipments reported.	McLaughlin (1963, p. 146).
Section 23 (*58*)	S½SE¼ 23	13 N.	10 W.	Cluster of small and medium irregularly shaped deposits in middle and lower parts of Todilto Limestone. Cluster is in elongate zone about 300 ft wide that trends eastward along southern margin of SE¼ of section and into adjoining secs. 25 and 26. Ore mined from opencuts, 1957–58.	Haystack Mountain and Development Co., DH, June 195 and January 1954.
Bob Cat (*11*)	NE¼NE¼(?) 24	13 N.	10 W.	Deposit probably in Jmpc. Ore shipped in 1955	AEC.

The high uranium content of the host rock is demonstrated by a suite of 10 samples collected between Abiquiu and Santa Fe (fig. 18). Uranium content of these samples ranged from 2 to 12 ppm (parts per million) and averaged >5 ppm. Eight of the samples were sandstone and two were siltstone. Although they were collected roughly parallel to the strike of the beds, they likely represent several hundred feet of stratigraphic section, including the part that contains the uranium deposits, because the coverage is about 40 miles.

The high uranium content of the Tesuque Formation can most likely be attributed to the high uranium concentrations in the volcanic ash, as shown by the following five samples:

Sample	Locality	Description	Uranium content (ppm)	
			U	eU [1]
2A [2]	Center E½ sec. 33, T. 19 N., R. 9 E. (≈1 mile south of locality of sample 252605, fig. 18).	Top 3 in. of 42-in.-thick exposure of ash bed.	18.1	([3])
2B [2]	do	28 in. above base of ash bed described for sample 2A.	10.7	([3])
2 [2]	do	6 in. above base of ash bed described for sample 2A.	5.6	([3])
239584	NW¼SE¼ sec. 17, T. 20 N., R. 9 E.	Channel across 4-ft-thick white tuff bed.	([3])	20
239585	Center SW¼ sec. 17, T. 20 N., R. 9 E. (≈3,500 ft northeast of locality of sample 252603, fig. 18, and 1,700 ft west of locality of sample 239584 (see above).	do	([3])	30

[1] Analyst, C. G. Angelo.
[2] Data from R. L. Cannon (oral commun., 1965).
[3] No data.

These samples show a range in content of 5.6–30 ppm U or eU and, although the eU values may be high because of disequilibrium, the tuffs probably average more than the entire host rock.

The uranium deposits postdate the Tesuque Formation. Their surficial relations and envelopment within radioactive opal, which also coats surficial debris, indicate that they were probably formed in the present cycle of weathering.

PENECONCORDANT DEPOSITS IN TODILTO LIMESTONE AND ADJACENT FORMATIONS

About 100 deposits or clusters of deposits are listed in the Todilto Limestone, of Jurassic age, on plate 1. Deposits occur in other limestone units, but are uncommon; nearly all of them are associated with faults and are classified as vein deposits. A few others are segments of deposits that are primarily in sandstone; they have been described previously. Most of the deposits in the Todilto Limestone are in the Ambrosia Lake and Laguna districts, McKinley and Valencia Counties. A few are scattered in the southern part of the Chama Basin, Rio Arriba County, and in the Chuska district, San Juan County.

From 1950 to 1964, about 980,000 tons of ore was produced from 52 mines in the Todilto Limestone. This ore had an average grade of 0.22 percent U_3O_8 but ranged from 0.10 to 0.43 percent U_3O_8 among the mines. Prior to 1959, 445,000 tons of this ore averaged 0.14 percent V_2O_5 and had a U : V ratio of about 5 : 2, similar to that of most of the deposits in sandstone. All but a few thousand tons was mined in the Ambrosia Lake District; the remainder came from three mines in the Laguna district and one mine in Rio Arriba County.

The ores ranged fro 25 to 98 percent lime and averaged 80 percent. Ores from only a few mines averaged less than 50 percent $CaCO_3$; these were mostly mixed ores that came from deposits that extended into the underlying Entrada Sandstone or overlying Summerville Formation, such as the Sandy, Zia, and Haystack 2.

STRATIGRAPHY

Regional stratigraphy of the Todilto Limestone and its relations to the underlying Entrada Sandstone and overlying Summerville Formation were outlined previously (p. 18), but the local stratigraphy in the Ambrosia Lake and Laguna districts will be discussed in more detail to explain the relationships of the deposits.

In the Ambrosia Lake district only the limestone member crops out, but the gypsum-anhydrite member has been penetrated by drill holes about 8 miles north of the outcrop (J. C. Wright, written commun., 1957). The limestone member, which contains all the deposits, ranges in thickness from about 5 to 30 feet and averages about 15 feet. It comprises three units which are referred to locally as the basal "platy," medial "crinkly," and the upper "massive" zones. The platy and crinkly zones are about equal in thickness and compose about half the total thickness of the member. They consist of fine-grained laminated and thin-bedded limestone, which contains thin siltstone partings and locally seams of gypsum. Black fine-grained films of carbon-rich material are conspicuous locally, especially along the partings in the crinkly unit. Bedding in the platy unit is undisturbed, but in the crinkly unit is intensely crenulated. The massive unit is more coarsely crystalline and indistinctly bedded limestone, and it varies markedly in thickness from place to place.

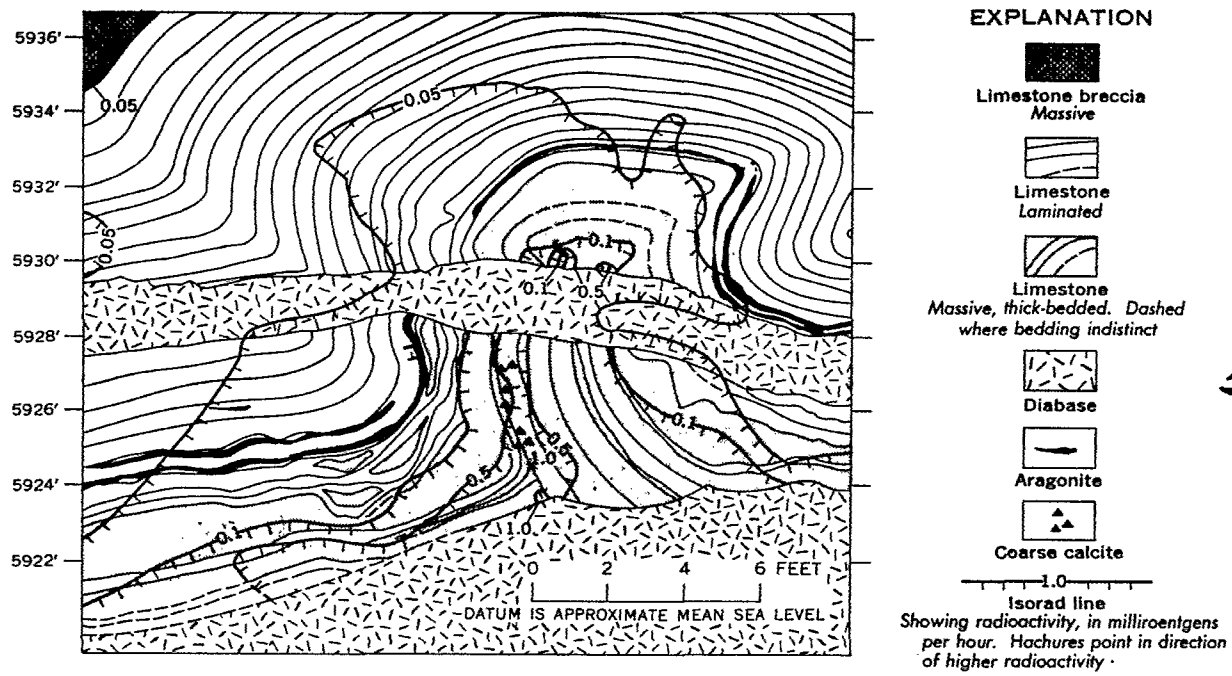


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FIGURE 19.—Geologic section across uranium deposit in Todilto Limestone, showing displacement by diabase intrusive, Sandy mine area. Geology by Frank Hensley.

intersect deposits, the deposits are displaced and therefore must be older.

Gabelman (1956b, p. 391–392, fig. 132), however, implied that the deposits may be younger than the faults and folds by noting that the deposits occur within the area of strongest faulting and along the axes of northeastward-trending folds, both of which are on the flank of the Zuni uplift and within the sharpest bend of the strike of the Thoreau homocline (meaning the bend of the Chaco slope southeastward around the Zuni uplift and southward along the west flank of the McCartys syncline).

Gabelman's northeastward-trending folds probably are related to the subparallel faults (see p. 61), and both probably are the same age. Because the faults displace the deposits, both the folds and the faults must be younger than the deposits and could not have influenced their emplacement.

The oldest recognizable structural features that are certainly younger than the deposits are the fractures in the Laguna district that formed contemporaneously with the Rio Grande trough during the third period of deformation. These fractures are intruded by diabasic dikes and sills which, in turn, are broken by the same set of fractures, a relation that indicates their contemporaneity. The deposits show no relation to the fractures, and the diabasic intrusives displace and metamorphose the uranium deposits (Moench, 1962; 1963c, p. 161) (fig. 19). These facts demonstrate that the deposits are clearly older than the fractures and the intrusives.

Field relations indicate the fractures and intrusives probably formed mostly in middle to late Tertiary time, and probably prior to the Mount Taylor eruptions. Inclusions of the diabase were found in a volcanic pipe that probably supplied one of the earliest basaltic flows (Hilpert and Moench, 1960, p. 444). The fact that these flows were extruded during the latest stages of the Mount Taylor eruptions indicates the diabasic rocks are at least older than what may be the oldest basaltic flows. Because the entire sequence of Mount Taylor probably formed during an eruptive cycle, a relatively short period of time, the diabasic intrusions probably took place before the Mount Taylor cycle, as well as before the basaltic extrusions. Conclusions are that the deposits are older than any of the intrusive igneous rocks within the Laguna and Ambrosia Lake districts and that their emplacement could not have been influenced by them.

PENECONCORDANT DEPOSITS IN SHALE AND COAL

Deposits in shale and coal are quite similar in mineralogy and form to those in sandstone and, in some instances, where they occur in nearly equal proportions in both rock types, are classified rather arbitrarily. The host rocks, however, are different, so the deposits are separated for descriptive purposes. The deposits occur in shale and coal of Permian, Cretaceous, and Tertiary

Rapaport, Hadfield, and Olson (1952) first described the intraformational folds and dated their development as shortly after deposition of the Todilto sediments. Gabelman (1956b) described some of them in detail and drew similar conclusions regarding the age of their formation, and Hilpert and Moench (1960) described their association and probable contemporaneity with the larger pre-Dakota folds in the Ambrosia Lake and Laguna districts.

The intraformational folds occur in a great variety of shapes, ranging from open and closed anticlines to recumbent folds, chevron folds, and fan folds. They are mostly anticlinal and asymmetric, but some are synclinal, open, and symmetrical. Most of the folds are small, pronounced structural features that have amplitudes generally less than their breadths. The largest have a breadth of as much as 50 feet and an amplitude of about 25 feet and involve the entire thickness of the Todilto and basal part of the overlying Summerville Formation. The smallest are measured in inches or fractions of an inch and commonly bear a drag relation to larger folds. In length the folds range from a few feet to hundreds of feet. They mostly are somewhat sinuous and elongate, but some are rather tortuous in plan or are simply domal.

The folds generally tend to be concentrated or clustered, and in both the Ambrosia Lake and Laguna districts the fold axes in the clusters generally trend eastward or northward. Others show an almost random arrangement.

All the folds are fractured or jointed and some are faulted. The associated faults, however, are almost invariably intraformational and die out within the folds or within the Todilto Limestone and basal part of the Summerville Formation. Many faults are reverse type and closely follow the axial plane of tight or recumbent folds. All the related faults, however, show little displacement, seldom more than a foot or so and generally not more than a few inches.

Most joints are nearly vertical and comprise many sets. The principal set is longitudinal to the folds and probably formed with the folds or shortly after, similar to the intraformational faults. Other subsidiary joints make up an almost random pattern, although in some deposits in the Ambrosia Lake district a minor set is roughly normal to the fold axes. Many of the joints probably formed during later periods of deformation. The complexity of the fold and fracture patterns is illustrated by the structures in the Haystack, Gay Eagle, and Black Hawk deposits (Gabelman, 1956b, figs. 135–137).

In the Laguna district the intraformational folds are localized along the flanks and troughs of broad eastward- and northward-trending pre-Dakota synclines, and the dominant trends of the axes of the intraformational folds are likewise eastward and northward (Moench, 1963c, p. 159). (See fig. 9, this report.)

The Todilto Limestone in the Laguna district is also somewhat thicker in the synclines than on the crests of the adjoining folds. This fact suggests that the intraformational folds formed by flowage down the limbs of the pre-Dakota folds. This flowage apparently occurred under cover in post-Todilto time because the intraformational folds are not truncated by bedding planes.

Similar relations are indicated in the Ambrosia Lake district. Where data are available, particularly where uranium deposits have been mined, the intraformational folds also tend to trend eastward and northward and to make up clusters with similar trends (Gabelman, 1956b, figs. 134–138; Hilpert and Moench, 1960, p. 460–461, fig. 18). The pre-Dakota folds in the overlying rocks likewise trend eastward; others might also trend northward, as in the Laguna district, but more detailed information is needed to determine this.

In the Chuska district small anticlinal intraformational folds occur along a 4-mile strip of outcrop west of Sanostee in the upper part of the Todilto. The largest folds have amplitudes of as much as 2 feet, a width of 3 feet, and a length of 15 feet. Where concentrated or most highly developed they are subparallel, but show no relation to Laramide structures (J. W. Blagbrough, D. A. Thieme, B. J. Archer, Jr., and R. W. Lott, written commun., 1959).

In the south part of the Chama Basin, similar intraformational folds have been noted in the Todilto Limestone at the outcrop south and east of Coyote. Some of these folds have amplitudes of as much as several feet and widths of as much as 25 or 30 feet, but their lengths and trends are not known.

Structural features that formed principally during the second period of deformation in the Ambrosia Lake district consist of the Chaco slope or homocline, west flank of the McCartys syncline, a set of fractures and folds that range in trend from northeast to north, and some domal and anticlinal structures. (See p. 61–62). In the Laguna district they consist of the east limb of the McCartys syncline, a north-trending faulted monocline, and a set of faults and fractures that were intruded in many places by diabasic dikes and sills. (See p. 72).

MINERALOGY AND FORM

Mineralogy of the uranium deposits in the Todilto Limestone has been partly described by Rapaport, Hadfield, and Olson, (1952, p. 9–12), Laverty and Gross (1956, p. 200), and Truesdell and Weeks (1960), and

as been summarized by Granger (1963, p. 33–35) and by McLaughlin (1963, p. 140).

The deposits in the Todilto differ from the ones in sandstone principally in their relative sparseness of metallic sulfide minerals and in the occurrence of fluorite.

Unoxidized minerals that have been identified are uraninite, coffinite, paramontroseite, haggite, fluorite, pyrite, marcasite, and galena. Barite, specular hematite, vanadium clay, and recrystallized calcite are closely associated with these minerals and probably are also primary.

Uraninite is more abundant than coffinite and occurs as colloform coatings on grain boundaries, as veinlets in limestone, and as replacements of the limestone grains along bedding planes and along the walls of veinlets. Coffinite at least locally coats uraninite and fills shrinkage cracks in uraninite.

The formation of haggite, paramontroseite, and vanadium clay generally preceded that of uraninite. The haggite occurs as fine blades and fibers along grain boundaries and solution channels in limestone, and some as intergrowths with paramontroseite. The vanadium clay in some places forms irregular spherical aggregates.

Fluorite has been observed in several deposits and likely is a constituent of most of them. It generally is purple and occurs as a fine-grained replacement of the limestone along bedding surfaces, as veinlets, and locally as irregular replacements of limestone that form masses as much as 6 inches in diameter. The fluorite generally is closely associated with and in places is replaced by uraninite.

Pyrite, marcasite, and galena are the only sulfide minerals identified in the deposits in the Todilto. Pyrite occurs as an early mineral which is generally corroded and replaced by later minerals but is most abundant as a late mineral which fills solution cavities and fractures and which replaces detrital grains. Marcasite has been identified only as a late mineral. Galena occurs as fine-grained cubes deposited with and after uraninite and coffinite and as a replacement of early pyrite and haggite.

Coarse-grained calcite occurs along bedding planes, fractures, and solution cavities as a replacement of limestone or as recrystallized limestone in and near the uranimum deposits. The coarse-grained calcite is both earlier and later than most other minerals.

Fine-grained hematite occurs in most of the deposits and generally is associated with the uraniferous zones. Specular hematite has been noted with vanadium clay. Hematite also occurs as pseudomorphs after pyrite and as stains along fractures and bedding planes in oxidized zones.

Barite occurs in most deposits as a resinous yellow to clove-brown tabular mineral that lines solution cavities and forms veinlets or irregular globelike replacements of coarse-grained calcite or local disseminations along the bedding.

Most of the deposits in the Todilto occur at or near the surface and so have been subjected to oxidation which has led to the rather widespread occurrence of the conspicuous yellow and green secondary minerals tyuyamunite, metatyuyamunite, uranophane, and probably sklodowskite. Less common secondary minerals are carnotite, cuprosklodowskite, gummite, santafeite, liebigite, and various oxides of manganese and iron. Also, the dark-olive green fibrous vanadyl vanadate, grantsite, was identified in the F-33 mine (Weeks and others, 1961) and probably occurs in other deposits in the Todilto.

Early field-examination reports generally mentioned carnotite as a constituent of most deposits and created the impression that the mineral was one of the more common ones. Most of the reported occurrences, however, were probably tyuyamunite, which is more likely to form in limestone in which calcium is in excess of sodium. Tyuyamunite and carnotite are both canary yellow and difficult to distinguish in the field.

Uranium deposits in the Todilto are roughly tabular bodies having an irregular form similar to the forms of the deposits in sandstone. Most of them occur along the flanks of the folds and some along the fold axes roughly parallel to the bedding, but locally the deposits cut across the bedding. Many of them are near the base of the Todilto, but others are near the middle or top, and a few occupy the entire limestone interval. Many are not confined to the limestone, but extend a few inches and in some places several feet into the underlying Entrada Sandstone, and in many deposits as much as several feet into the overlying siltstone of ths Summerville Formation. A few deposits are mostly, or entirely, in the basal part of the Summerville or top of the Entrada Sandstone. Although these deposits have a relationship to bedding that is similar to that of deposits in other sandstones, they are dissimilar in their association with folds in the overlying or underlying Todilto Limestone.

Dimensions of the deposits in the Todilto range from a few feet in width and length to several hundred feet in width and more than 1,000 feet in length, and in thickness from mere seems to as much as 20 feet. They probably average a few tens of feet in width, a hundred feet or so in length, and about 10 feet in thickness.

The largest deposits occur where the folds in the limestone are clustered and have a similar trend. Because of the clustering, the deposits associated with individual folds interconnect or merge into relatively large masses that in some places are rather irregular or oblong, such as the Haystack (Gabelman, 1956b, figs. 133, 135) and Flat Top 4-Vilatie Hyde deposits. Others merge and interconnect to form stringlike masses having a length many times their width, such as the F-33 (Hilpert and Moench, 1960, fig. 18), the Faith (McLaughlin, 1963, fig. 6), and the Section 25. The dominant trends of these masses are eastward or northward, similar to the trends of the intraformational folds, but many are heterogeneous.

Ore bodies generally constitute the central parts of the deposits where the deposits are thicker and higher in grade. Away from ore, the deposits feather out or grade into barren host rock along rather irregular or vaguely defined zones. Ore bodies range from masses with dimensions of only a few feet that contain several tons of ore to masses that are hundreds of feet wide, more than 1,000 feet long, and several feet thick, and contain as much as 100,000 tons of ore. Most ore bodies, however, average about 25 feet in width, 100 feet in length, and 5–7 feet in thickness, and contain about 1,000 tons of ore. McLaughlin's (1963, fig. 6) map of the Faith deposit is a good example of the general relations of ore to mineralized ground.

Grade of the ore ranges from 0.10 U_3O_8 to at least 10.0 percent U_3O_8.

STRATIGRAPHIC RELATIONS OF THE DEPOSITS

Uranium deposits in the Todilto Limestone show no direct relation to the stratigraphy of the formation but possibly are indirectly related to the gypsum-anhydrite member and probably are indirectly related to the original thickness of the limestone member.

From place to place the deposits occur at the base, middle, top, or throughout the limestone member and, in many places, extend into the top of the underlying Entrada Sandstone or base of the overlying Summerville Formation. No known deposits occur in the gypsum-anhydrite member, but all the principal deposits are near its outcrop. (See pl. 3.) This position of the deposits in relation to the member probably stems from chance exposure, but for some unknown physical or chemical reason, the gypsum-anhydrite member may have influenced the emplacement of the deposits near its margin.

Near the principal deposits the limestone member is about 15–25 feet thick (pl. 3). Elsewhere it is generally less than 15 feet thick. This occurrence of deposits near thicker limestone may also be a result of fortuitous exposure—the Todilto Limestone has been explored at most only a few miles from the outcrop—but more probably it expresses some relation of the deposits to the original thickness of the limestone.

STRUCTURAL RELATIONS OF THE DEPOSITS

Primary uranium deposits in the Todilto were directly controlled by structures that resulted from the first period of deformation (Late Jurassic to Early Cretaceous), but show few effects, except secondary ones, from later deformation.

The deposits are closely related to intraformational folds in the limestone and these folds are related to broader open folds in the Jurassic rocks, which are dated as post-Todilto and pre-Dakota. The deposits are postsyngenetic because they cross the limestone bedding (fig. 19), and are postintraformational folding because they transect the intraformational folds (Gabelman, 1956b, fig. 136, cross section *L–K*) and at least locally transect the broader pre-Dakota folds (Hilpert and Moench, 1960, p. 458, fig. 15; Moench, 1963c, p. 163–164).

The original thickness of the limestone (see above) probably had a direct bearing on the localization and development of the intraformational folds. Confinement of the folds largely within the limestone indicates its relative incompetence; it should follow that where the limestone is thickest it would have a tendency to absorb a greater percentage of the stresses exerted on the rock column. Thus, the degree of deformation expressed by the folds would most likely be a direct result of the original thickness of the limestone member. The deposits are directly related to the folds and generally to their degree or intensity of development: thus they are indirectly related to the original thickness of the limestone.

No convincing evidence supports the possibility that localization of the primary deposits was influenced by the second (Late Cretaceous to middle Tertiary) or third (middle Tertiary to late Tertiary or Quaternary) periods of deformation. Present information indicates that the oldest structural features resulting from these periods of deformation are the faults and folds that formed contemporaneously with the development of the McCartys syncline. As indicated above, the syncline and the associated smaller features probably formed during development of the Zuni and Lucero uplifts and the Ácoma sag, and probably prior to the northward tilting of the San Juan Basin (pre-San Jose, or pre-early Eocene time).

In the Ambrosia Lake district, deposits do not occupy fault zones except for the intraformational faults within the Todilto Limestone. Where faults

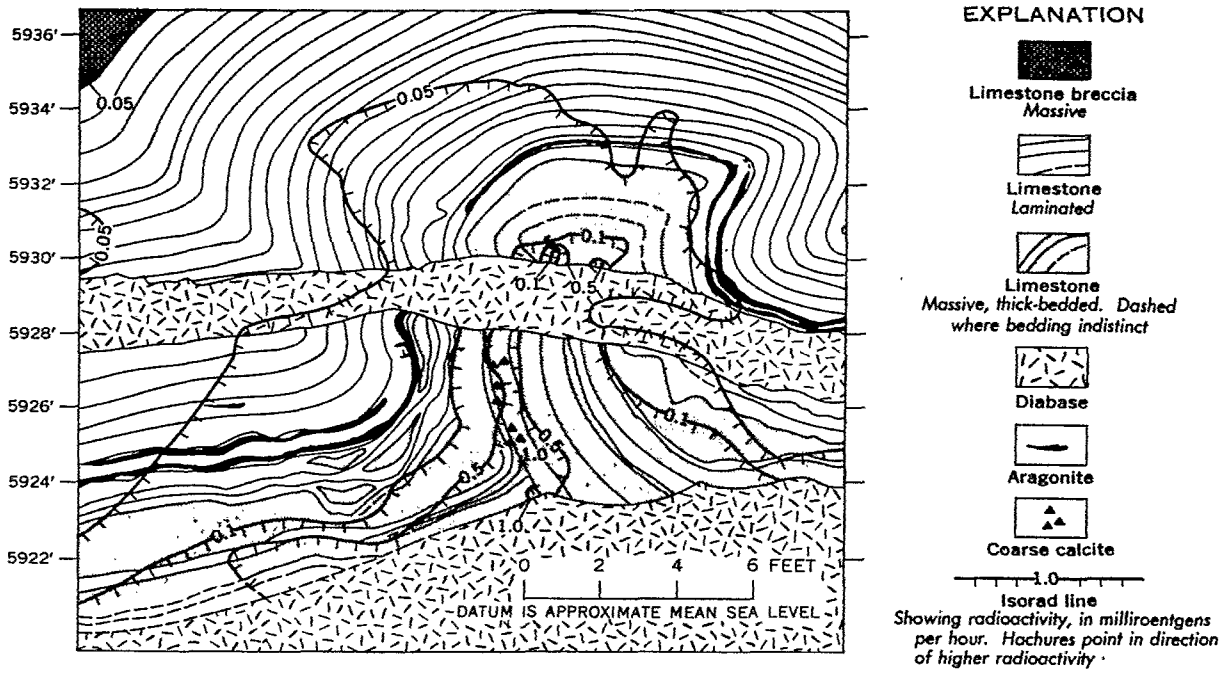


FIGURE 19.—Geologic section across uranium deposit in Todilto Limestone, showing displacement by diabase intrusive, Sandy mine area. Geology by Frank Hensley.

intersect deposits, the deposits are displaced and therefore must be older.

Gabelman (1956b, p. 391–392, fig. 132), however, implied that the deposits may be younger than the faults and folds by noting that the deposits occur within the area of strongest faulting and along the axes of northeastward-trending folds, both of which are on the flank of the Zuni uplift and within the sharpest bend of the strike of the Thoreau homocline (meaning the bend of the Chaco slope southeastward around the Zuni uplift and southward along the west flank of the McCartys syncline).

Gabelman's northeastward-trending folds probably are related to the subparallel faults (see p. 61), and both probably are the same age. Because the faults displace the deposits, both the folds and the faults must be younger than the deposits and could not have influenced their emplacement.

The oldest recognizable structural features that are certainly younger than the deposits are the fractures in the Laguna district that formed contemporaneously with the Rio Grande trough during the third period of deformation. These fractures are intruded by diabasic dikes and sills which, in turn, are broken by the same set of fractures, a relation that indicates their contemporaneity. The deposits show no relation to the fractures, and the diabasic intrusives displace and metamorphose the uranium deposits (Moench, 1962; 1963c, p. 161) (fig. 19). These facts demonstrate that the deposits are clearly older than the fractures and the intrusives.

Field relations indicate the fractures and intrusives probably formed mostly in middle to late Tertiary time, and probably prior to the Mount Taylor eruptions. Inclusions of the diabase were found in a volcanic pipe that probably supplied one of the earliest basaltic flows (Hilpert and Moench, 1960, p. 444). The fact that these flows were extruded during the latest stages of the Mount Taylor eruptions indicates the diabasic rocks are at least older than what may be the oldest basaltic flows. Because the entire sequence of Mount Taylor probably formed during an eruptive cycle, a relatively short period of time, the diabasic intrusions probably took place before the Mount Taylor cycle, as well as before the basaltic extrusions. Conclusions are that the deposits are older than any of the intrusive igneous rocks within the Laguna and Ambrosia Lake districts and that their emplacement could not have been influenced by them.

PENECONCORDANT DEPOSITS IN SHALE AND COAL

Deposits in shale and coal are quite similar in mineralogy and form to those in sandstone and, in some instances, where they occur in nearly equal proportions in both rock types, are classified rather arbitrarily. The host rocks, however, are different, so the deposits are separated for descriptive purposes. The deposits occur in shale and coal of Permian, Cretaceous, and Tertiary

BLE 6.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from limestone, northwestern New Mexico*

erial within brackets is descriptive, not part of mine name. Italic numbers are mine numbers shown on plate 1. Spectrographic determinations are semiquantitative and were made by the rapid visual comparison method. Comparisons of similar data with those obtained by quantitative methods show that the assigned semiquantitative class interval includes the quantitative value in about 60 percent of the determinations. Figures are reported to the nearest number in the series >10, 7, 3, 1.5, 0.7, 0.3, 0.15, and are coded as follows: >10=1, 7=2, 3=3, 1.5=4, 0.7=5, 0.3=6, 0.15=7, 0.07=8, 0.03=9, 0.015=10, 0.007=11, 0.003=12, 0.0015=13, 0.0007=14, 0.0003=15. Figures reported as less than (<) are coded: <1.0=a, <0.05=b, <0.02=c, <0.005=d, <0.002=e, <0.001=f, <0.0005=g, <0.0002=h, <0.00005=i. 0, looked for but not found; <, less than amount shown, standard detectability does not apply; Tr., trace; leaders (....), not looked for; number enclosed in parentheses is near threshold of detectability; ND, no data

[Spectrographic analyses are in percent, coded; other analyses are in percent or parts per million, as indicated, and are not coded]

Sample [1]	Name of mine or prospect	Spectrographic [2]																
		Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er
Ore in the Todilto Limestone																		
24	Barbara J 1 (*1*)	0	3	0	0	0	9	0	0	1	0	b	14	13	.....	12	0	0
25	Billy The Kid (*3*)	0	4	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
26	Black Hawk (*4*)	0	4	0	0	0	9	0	0	1	0	b	14	14	.....	12	0	0
27	Bunney (*4*)	0	4	0	0	0	9	0	0	1	0	b	14	14	.....	12	0	0
90	Cedar 1 (*5*)	i	5	0	0	b	9	0	0	1	0	b	(15)	12	ND	13	0	0
28	Christmas Day (*6*)	0	5	0	0	0	9	0	0	1	0	b	14	14	.....	13	0	0
28	Crackpot (*7*)	0	4	0	0	0	10	0	0	1	0	.....	0	13	.....	12	0	0
29	Flat Top 4 (*12*)	0	3	0	0	0	9	0	0	1	0	b	15	13	.....	13	0	0
30	Gay Eagle (*15*)	0	4	0	0	0	9	0	0	1	0	b	15	14	.....	13	0	0
93	Hanosh (Section 26) (*15*)	i	4	0	0	b	9	0	0	1	0	b	(15)	13	ND	13	0	0
[redacted]	Haystack 2 (*17*)	0	3	0	0	0	8	0	0	1	0	b	15	13	.....	13	0	0
32	Last Chance (*19*)	0	4	0	0	0	8	0	0	1	0	b	14	14	.....	12	0	0
33	Red Bluff 3 (*24*)	0	5	0	0	0	9	0	0	1	0	b	14	15	.....	13	0	0
34	Red Bluff 5 (*25*)	0	4	0	0	0	8	0	0	1	0	b	14	14	.....	13	0	0
35	Red Bluff 7 (*26*)	0	4	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
36	Red Bluff 8 (*15*)	0	3	0	0	0	8	0	0	1	0	b	14	13	.....	12	0	0
91	Red Bluff 10 (*15*)	i	4	0	0	b	9	0	0	1	0	b	(15)	14	ND	13	0	0
37	Red Point Lode (*28*)	0	5	0	0	0	8	0	0	1	0	b	15	14	.....	13	0	0
91	Reed Henderson	0	5	0	0	0	9	0	0	1	0	.....	0	13	.....	13	0	0
38	Rimrock (*29*)	0	5	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
39	Section 18 (*32*)	Tr.	3	0	0	0	7	0	0	1	0	b	14	13	.....	12	0	0
40	Section 18 (*33*)	0	3	0	0	0	8	0	0	1	0	b	15	13	.....	12	0	0
95	Section 19 (*34*)	i	5	0	0	b	11	0	0	1	12	b	g	15	ND	13	0	0
41	Section 21 (*37*)	0	2	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
42	Section 24 (*39*)	0	3	0	0	0	8	0	0	1	0	b	15	14	.....	12	0	0
92	Manol (Section 30) (*22*)	i	4	0	0	b	10	0	0	1	0	b	(15)	12	ND	13	0	0
43	Manol (Section 30, T-8) (*22*)	0	4	0	0	0	9	0	0	1	0	b	15	13	.....	12	0	0
44	Manol (Section 30, T-19) (*22*)	0	3	0	0	0	9	0	0	1	0	b	14	13	.....	12	0	0
94	T 2 (*45*)	i	5	0	0	b	10	0	0	1	(12)	b	g	14	ND	13	0	0
45	Tom Elkins (*48*)	0	2	0	0	0	7	0	0	1	0	b	15	14	.....	12	0	0
46	UDC 5 (*49*)	0	4	0	0	0	9	0	0	1	0	b	14	14	.....	12	0	0
Ore in the Todilto Limestone and Entrada Sandstone																		
29	Sandy (*76*)	0	3	0	0	Tr.	9	0	0	1	0	0	13	12	.....	12	0	0

			T				T		T?						T?
	NT		NT	DD		NT	NT	NT	NT		9	NT			NT
ELEM	Al	Ba	Ca	Co	Cr	Cu	Fe	K	[illegible]	[illegible]	[illegible]	Na	Ni	[illegible]	Si	Sr	Ti	[illegible]	V	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Zn
CODE	3	8	1	15	13	13	5	3	[illegible]	[illegible]	[illegible]	5	15	[illegible]	1	10	[illegible]	[illegible]	[illegible]	10			[illegible]	[illegible]	
PPM		700			15				[illegible]	[illegible]	[illegible]			70		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.8	60	[illegible]	100	PPM

1 :
3 :
5 :

PPM

6 : .3% → 3000
7 : .15% → 1500
8 : .07% → 700
9 : .03% → 300
10 : .015% → 150
11 : .007% → 70
[illegible] : .0015% → 15
15 :

NT - NOT TOXIC

T - TRACER

DD - DOWN IN THE DIRT

TABLE 6.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from limestone, northwestern New Mexico*

Material within brackets is descriptive, not part of mine name. Italic numbers are mine numbers shown on plate 1. Spectrographic determinations are semiquantitative and were made by the rapid visual comparison method. Comparisons of similar data with those obtained by quantitative methods show that the assigned semiquantitative class interval includes the quantitative value in about 60 percent of the determinations. Figures are reported to the nearest number in the series >10, 7, 3, 1.5, 0.7, 0.3, .15, and are coded as follows: >10=1, 7=2, 3=3, 1.5=4, 0.7=5, 0.3=6, 0.15=7, 0.07=8, 0.03=9, 0.015=10, 0.007=11, 0.003=12, 0.0015=13, 0.0007=14, 0.0003=15. Figures reported as less than (<) are coded: <1.0=a, <0.05=b, <0.02=c, <0.005=d, <0.002=e, <0.001=f, <0.0005=g, <0.0002=h, <0.00005=i. 0, looked for but not found; <, less than amount shown, standard detectability does not apply; Tr., trace; leaders (.....), not looked for; number enclosed in parentheses is near threshold of detectability; ND, no data

[Spectrographic analyses are in percent, coded; other analyses are in percent or parts per million, as indicated, and are not coded]

Sample [1]	Name of mine or prospect	Spectrographic [2]																
		Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er
Ore in the Todilto Limestone																		
256424	Barbara J 1 (*1*)	0	3	0	0	0	9	0	0	1	0	b	14	13	.....	12	0	0
256425	Billy The Kid (*3*)	0	4	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
256426	Black Hawk (*4*)	0	4	0	0	0	9	0	0	1	0	b	14	14	.....	12	0	0
25[illegible]7	Bunney (*4*)	0	4	0	0	0	9	0	0	1	0	b	14	14	.....	12	0	0
22 0	Cedar 1 (*5*)	i	5	0	0	b	9	0	0	1	0	b	(15)	12	ND	13	0	0
25 8	Christmas Day (*6*)	0	5	0	0	0	9	0	0	1	0	b	14	14	.....	13	0	0
24 8	Crackpot (*7*)	0	4	0	0	0	10	0	0	1	0	.....	0	13	.....	12	0	0
256429	Flat Top 4 (*12*)	0	3	0	0	0	9	0	0	1	0	b	15	13	.....	13	0	0
256430	Gay Eagle (*15*)	0	4	0	0	0	9	0	0	1	0	b	15	14	.....	13	0	0
229393	Hanosh (Section 26) (*16*)	i	4	0	0	b	9	0	0	1	0	b	(15)	13	ND	13	0	0
25 1	Haystack 2 (*17*)	0	3	0	0	0	8	0	0	1	0	b	15	13	.....	13	0	0
25 2	Last Chance (*19*)	0	4	0	0	0	8	0	0	1	0	b	14	14	.....	12	0	0
25 3	Red Bluff 3 (*24*)	0	5	0	0	0	9	0	0	1	0	b	14	15	.....	13	0	0
25 4	Red Bluff 5 (*25*)	0	4	0	0	0	8	0	0	1	0	b	14	14	.....	13	0	0
256435	Red Bluff 7 (*26*)	0	4	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
256436	Red Bluff 8 (*13*)	0	3	0	0	0	8	0	0	1	0	b	14	13	.....	12	0	0
229391	Red Bluff 10 (*13*)	i	4	0	0	b	9	0	0	1	0	b	(15)	14	ND	13	0	0
25 7	Red Point Lode (*28*)	0	5	0	0	0	8	0	0	1	0	b	15	14	.....	13	0	0
24 1	Reed Henderson	0	5	0	0	0	9	0	0	1	0	.....	0	13	.....	13	0	0
25 8	Rimrock (*29*)	0	5	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
256439	Section 18 (*32*)	Tr.	3	0	0	0	7	0	0	1	0	b	14	13	.....	12	0	0
256440	Section 18 (*35*)	0	3	0	0	0	8	0	0	1	0	b	15	13	.....	12	0	0
229395	Section 19 (*34*)	i	5	0	0	b	11	0	0	1	12	b	g	15	ND	13	0	0
25[illegible]11	Section 21 (*37*)	0	2	0	0	0	9	0	0	1	0	b	15	14	.....	12	0	0
21 12	Section 24 (*39*)	0	3	0	0	0	8	0	0	1	0	b	15	14	.....	12	0	0
2[illegible]2	Manol (Section 30) (*22*)	i	4	0	0	b	10	0	0	1	0	b	(15)	12	ND	13	0	0
21 13	Manol (Section 30, T-8) (*22*)	0	4	0	0	0	9	0	0	1	0	b	15	13	.....	12	0	0
256444	Manol (Section 30, T-19) (*22*)	0	3	0	0	0	9	0	0	1	0	b	14	13	.....	12	0	0
229394	T 2 (*45*)	i	5	0	0	b	10	0	0	1	(12)	b	g	14	ND	13	0	0
256445	Tom Elkins (*48*)	0	2	0	0	0	7	0	0	1	0	b	15	14	.....	12	0	0
2 46	UDC 5 (*49*)	0	4	0	0	0	9	0	0	1	0	b	14	14	.....	12	0	0
Ore in the Todilto Limestone and Entrada Sandstone																		
245229	Sandy (*76*)	0	3	0	0	Tr.	9	0	0	1	0	0	13	12	.....	12	0	0
Ore in the San Andres Limestone																		
245227	Lucky Don (*1*)	0	4	0	0	Tr.	11	0	0	1	0	0	13	12	.....	12	0	0
Ore in the Madera Limestone																		
254110	Agua Torres (*1*)	0	3	0	0	12	7	0	0	3	0	0	14	12	.....	11	0	0
254109	Marie (*2*)	14	3	5	0	12	8	0	0	2	0	0	12	11	.....	9	0	0

See footnotes at end of table.

TABLE 6.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from limestone, northwestern New Mexico*—Continued

Sample [1]	Name of mine or prospect	Spectrographic [2]—Continued															
		Eu	F	Fe	Ga	Gd	Ge	Hf	Hg	Ho	In	Ir	K	La	Li	Lu	Mg	Mn
Ore in the Todilto Limestone																		
256424	Barbara J 1 (1)	0	-------	6	0	0	0	0	0	0	0	0	4	0	0	0	6	8
256425	Billy The Kid (3)	0	-------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
256426	Black Hawk (4)	0	-------	5	0	0	0	0	0	0	0	0	0	0	0	0	6	8
256427	Bunney (4)	0	-------	6	0	0	0	0	0	0	0	0	5	0	0	0	6	8
229390	Cedar 1 (5)	ND	ND	5	h	0	0	0	0	ND	0	0	a	0	0	ND	6	9
256428	Christmas Day (6)	0	-------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
245228	Crackpot (7)	-------	-------	6	0	0	0	0	0	-------	0	0	4	0	0	-------	6	9
256429	Flat Top 4 (12)	0	-------	6	0	0	0	0	0	0	0	0	5	0	0	0	6	8
256430	Gay Eagle (13)	0	-------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
229393	Hanosh (Section 26) (15)	ND	ND	6	h	0	0	0	0	ND	0	0	(5)	0	0	ND	6	8
256431	Haystack 2 (17)	0	-------	5	0	0	0	0	0	0	0	0	3	0	0	0	6	8
256432	Last Chance (19)	0	-------	6	0	0	0	0	0	0	0	0	5	0	0	0	6	7
256433	Red Bluff 3 (24)	0	-------	5	0	0	0	0	0	0	0	0	0	0	0	0	7	7
256434	Red Bluff 5 (25)	0	-------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	7
256435	Red Bluff 7 (26)	0	-------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
256436	Red Bluff 8 (15)	0	-------	5	0	0	0	0	0	0	0	0	5	0	0	0	6	8
229391	Red Bluff 10 (17)	ND	ND	6	h	0	0	0	0	ND	0	0	a	0	0	ND	6	8
256437	Red Point Lode (28)	0	-------	6	0	0	0	0	0	0	0	0	0	0	0	0	7	9
246891	Reed Henderson	-------	-------	7	0	0	0	0	0	-------	0	0	4	0	0	-------	5	8
256438	Rimrock (29)	0	-------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
256439	Section 18 (32)	0	-------	6	0	0	0	0	0	0	0	0	4	0	0	0	6	8
256440	Section 18 (35)	0	-------	5	0	0	0	0	0	0	0	0	3	0	0	0	5	8
229395	Section 19 (34)	ND	ND	7	h	0	0	0	0	ND	0	0	(5)	0	0	ND	6	6
256441	Section 21 (37)	0	-------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
256442	Section 24 (39)	0	-------	6	0	0	0	0	0	0	0	0	4	0	0	0	6	8
229392	Manol (Section 30) (22)	ND	ND	6	h	0	0	0	0	ND	0	0	(5)	0	0	ND	6	8
256443	Manol (Section 30, T-8) (22)	0	-------	6	0	0	0	0	0	0	0	0	5	0	0	0	6	8
256444	Manol (Section 30, T-19) (22)	0	-------	6	0	0	0	0	0	0	0	0	4	0	0	0	6	8
229394	T 2 (45)	ND	ND	6	h	0	0	0	0	ND	0	0	a	0	0	ND	6	8
256445	Tom Elkins (48)	0	-------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
256446	UDC 5 (49)	0	-------	6	0	0	0	0	0	0	0	0	0	0	0	0	6	8
Ore in the Todilto Limestone and Entrada Sandstone																		
245229	Sandy (76)	-------	-------	5	Tr.	0	0	0	0	-------	0	0	3	0	0	-------	5	8
Ore in the San Andres Limestone																		
245227	Lucky Don (1)	-------	-------	5	0	0	0	0	0	-------	0	0	4	0	0	-------	2	
Ore in the Madera Limestone																		
254110	Agua Torres (1)	0	-------	4	Tr.	0	0	0	0	0	0	0	4	0	0	0	5	8
254109	Marie (8)	0	-------	2	14	0	0	0	0	0	0	0	3	0	0	0	6	9

See footnotes at end of table.

BLE 6.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from limestone, northwestern New Mexico*—Continued

Sample [1]	Name of mine or prospect	Spectrographic [2]—Continued															
		Mo	Na	Nb	Nd	Ni	Os	P	Pb	Pd	Pr	Pt	Rb	Re	Rh	Ru	Sb	Sc
Ore in the Todilto Limestone																		
256424	Barbara J 1 (*1*)	13	5	0	0	13	0	0	11	0	0	0	------	0	0	0	0	0
125	Billy The Kid (*3*)	0	6	0	0	14	0	0	12	0	0	0	------	0	0	0	0	0
126	Black Hawk (*4*)	14	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
127	Bunney (*4*)	14	6	0	0	14	0	0	12	0	0	0	------	0	0	0	0	0
190	Cedar 1 (*5*)	14	6	0	0	14	0	0	11	0	ND	0	ND	0	0	0	0	f
256428	Christmas Day (*6*)	14	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
245228	Crackpot (*7*)	0	6	0	0	14	0	0	12	0	------	0	------	0	0	0	0	0
256429	Flat Top 4 (*12*)	0	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
130	Gay Eagle (*13*)	14	6	0	0	15	0	0	11	0	0	0	------	0	0	0	0	0
393	Hanosh (Section 26) (*15*)	12	6	0	0	14	0	0	10	0	ND	0	ND	0	0	0	0	f
131	Haystack 2 (*17*)	13	5	0	0	15	0	0	11	0	0	0	------	0	0	0	0	0
132	Last Chance (*19*)	0	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
256433	Red Bluff 3 (*24*)	13	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
256434	Red Bluff 5 (*25*)	12	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
256435	Red Bluff 7 (*26*)	0	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
136	Red Bluff 8 (*13*)	14	6	0	0	13	0	0	11	0	0	0	------	0	0	0	0	0
391	Red Bluff 10 (*15*)	13	6	0	0	14	0	0	11	0	ND	0	ND	0	0	0	0	f
137	Red Point Lode (*28*)	0	6	0	0	15	0	0	12	0	0	0	------	0	0	0	0	0
256391	Reed Henderson	0	6	0	0	14	0	0	14	0	------	0	------	0	0	0	0	0
256438	Rimrock (*29*)	0	6	0	0	14	0	0	13	0	0	0	------	0	0	0	0	0
256439	Section 18 (*32*)	0	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
140	Section 18 (*33*)	0	5	0	0	14	0	0	12	0	0	0	------	0	0	0	0	0
395	Section 19 (*34*)	f	7	0	0	15	0	0	13	0	ND	0	ND	0	0	0	0	f
441	Section 21 (*37*)	0	6	0	0	15	0	0	13	0	0	0	------	0	0	0	0	0
442	Section 24 (*39*)	0	6	0	0	15	0	0	11	0	0	0	------	0	0	0	0	0
229392	Manol (Section 30) (*22*)	f	6	0	0	14	0	0	11	0	ND	0	ND	0	0	0	0	f
256443	Manol (Section 30, T–8) (*22*)	0	6	0	0	13	0	0	11	0	0	0	------	0	0	0	0	0
256444	Manol (Section 30, T–19) (*22*)	14	6	0	0	13	0	0	10	0	0	0	------	0	0	0	0	0
394	T 2 (*45*)	f	7	0	0	14	0	0	13	0	ND	0	ND	0	0	0	0	f
445	Tom Elkins (*48*)	0	6	0	0	14	0	0	12	0	0	0	------	0	0	0	0	0
446	UDC 5 (*49*)	13	6	0	0	14	0	0	11	0	0	0	------	0	0	0	0	0
Ore in the Todilto Limestone and Entrada Sandstone																		
229	Sandy (*76*)	13	4	0	0	14	0	0	12	0	------	0	------	0	0	0	0	0
Ore in the San Andres Limestone																		
227	Lucky Don (*1*)	13	6	0	0	11	0	0	11	0	------	0	------	0	0	0	0	0
Ore in the Madera Limestone																		
110	Agua Torres (*1*)	12	7	0	0	12	0	0	12	0	0	0	------	0	0	0	0	14
109	Marie (*2*)	10	6	0	0	12	0	0	5	0	0	0	------	0	0	0	10	14

See footnotes at end of table.

TABLE 6.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from limestone, northwestern New Mexico*—Continued

Sample [1]	Name of mine or prospect	Spectrographic [2]—Continued																
		Si	Sn	Sr	Sm	Ta	Tb	Te	Th	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
Ore in the Todilto Limestone																			
256424	Barbara J 1 (*1*)	1	0	9	0	0	0	0	0	8	0	0	6	9	0	14	d	0	11
256425	Billy The Kid (*3*)	3	0	8	0	0	0	0	0	9	0	0	8	7	0	0	d	0	12
256426	Black Hawk (*4*)	2	0	9	0	0	0	0	0	8	0	0	7	9	0	Tr.	d	0	11
256427	Bunney (*4*)	2	0	9	0	0	0	0	0	8	0	0	8	8	0	0	d	0	12
229390	Cedar 1 (*5*)	3	0	10	0	0	ND	0	0	9	0	ND	6	9	0	0	h	0	12
256428	Christmas Day (*6*)	3	0	9	0	0	0	0	0	9	0	0	7	8	0	0	d	0	12
245228	Crackpot (*7*)	3	0	9	0	0	------	0	0	11	0	------	8	7	0	0	e	0	12
256429	Flat Top 4 (*12*)	2	0	9	0	0	0	0	0	8	0	0	7	8	0	0	d	0	11
256430	Gay Eagle (*15*)	3	0	9	0	0	0	0	0	9	0	0	7	8	0	0	d	0	11
229393	Hanosh (Section 26) (*15*)	7	0	10	0	0	ND	0	0	8	0	ND	6	8	0	14	f	0	11
256431	Haystack 2 (*17*)	1	0	10	0	0	0	0	0	8	0	0	7	9	0	0	d	0	10
256432	Last Chance (*19*)	2	0	9	0	0	0	0	0	9	0	0	7	7	0	0	d	0	12
256433	Reb Bluff 3 (*24*)	3	0	9	0	0	0	0	0	10	0	0	7	10	0	0	0	0	13
256434	Reb Bluff 5 (*25*)	2	0	8	0	0	0	0	0	9	0	0	7	9	0	0	0	0	12
256435	Red Bluff 7 (*26*)	2	0	9	0	0	0	0	0	9	0	0	7	8	0	0	d	0	12
256436	Red Bluff 8 (*13*)	1	0	8	0	0	0	0	0	8	0	0	7	7	0	0	d	0	11
229391	Red Bluff 10 (*13*)	3	0	10	0	0	ND	0	0	9	0	ND	7	8	0	0	f	0	12
256437	Red Point Lode (*28*)	3	0	9	0	0	0	0	0	8	0	0	8	8	0	0	d	0	12
246891	Reed Henderson	3	0	9	0	0	------	0	0	9	0	------	0	8	0	0	------	0	12
256438	Rimrock (*29*)	3	0	8	0	0	0	0	0	9	0	0	8	7	0	0	d	0	11
256439	Section 18 (*52*)	1	0	8	0	0	0	0	0	9	0	0	7	7	0	0	d	0	11
256440	Section 18 (*53*)	1	0	9	0	0	0	0	0	8	0	0	8	7	0	14	d	0	11
229395	Section 19 (*54*)	4	0	10	0	0	ND	0	0	10	0	ND	7	7	0	0	f	0	13
256441	Section 21 (*57*)	3	0	8	0	0	0	0	0	9	0	0	7	7	0	0	d	0	13
256442	Section 24 (*59*)	1	0	9	0	0	0	0	0	8	0	0	7	8	0	0	d	0	10
229392	Manol (Section 30) (*22*)	3	0	10	0	0	ND	0	0	9	0	ND	6	7	0	0	f	0	12
256443	Manol (Section 30, T–8) (*22*)	1	0	9	0	0	0	0	0	8	0	0	7	8	0	0	d	0	12
256444	Manol (Section 30, T–19) (*22*)	1	0	9	0	0	0	0	0	8	0	0	6	9	0	Tr.	d	0	11
229394	T 2 (*45*)	3	0	10	0	0	ND	0	0	10	0	ND	7	7	0	0	f	0	12
256445	Tom Elkins (*48*)	3	0	8	0	0	0	0	0	9	0	0	7	7	0	0	d	0	12
256446	UDC 5 (*49*)	2	0	9	0	0	0	0	0	8	0	0	7	8	0	0	d	0	12
Ore in the Todilto Limestone and Entrada Sandstone																			
245229	Sandy (*76*)	1	0	10	0	0	------	0	0	8	0	------	8	9	0	13	15	0	11
Ore in the San Andres Limestone																			
245227	Lucky Don (*1*)	1	0	11	0	0	------	0	0	8	0	------	7	7	0	0	e	7	11
Ore in the Madera Limestone																			
254110	Agua Torres (*1*)	1	0	7	0	0	0	0	0	7	0	0	8	9	ND	13	15	9	11
254109	Marie (*2*)	1	0	9	0	0	0	0	0	6	10	0	7	9	ND	13	15	7	10

See footnotes at end of table.

TABLE 6.—*Semiquantitative spectrographic, radiometric, and chemical analyses of mill pulp samples of uranium ores from limestone, northwestern New Mexico*—Continued

Sample [1]	Name of mine or prospect	Radiometric	Chemical								
		eU [3]	U [4]	V_2O_5 [5]	S [6]	P_2O_5 [7]	C [8] (organic)	As [9]	F [10]	Se [11]	Zn [12]
		Percent						Parts per million			
Ore in the Todilto Limestone											
6424	Barbara J 1 (*1*)	0.23	0.23	0.09	0.07	0.026	0.11	16	50	5	20
246425	Billy The Kid (*3*)	.09	.09	.30	.03	.003	.08	3	50	1	10
256426	Black Hawk (*4*)	.12	.12	.08	.04	.015	.07	23	340	3	10
256427	Bunney (*4*)	.08	.08	.11	.03	.003	.08	11	30	2	10
229390	Cedar 1 (*5*)	.21	.24			.024		60	290	5	20
6428	Christmas Day (*6*)	.16	.16	.13	.04	.003	.10	18	290	4	10
5228	Crackpot (*7*)	.07	.10	.33	.11	.011		18	160	3	7
6429	Flat Top 4 (*12*)	.19	.20	.13	.03	.003	.09	18	630	3	10
256430	Gay Eagle (*13*)	.16	.18	.15	.03	.003	.06	20	190	4	10
229393	Hanosh (Section 26) (*16*)	.31	.34			.031		50	1,700	5	20
256431	Haystack 2 (*17*)	.15	.16	.13	.08	.015	.14	8	60	8	10
5432	Last Chance (*19*)	.12	.13	.23	.03	.003	.06	6	50	2	10
5433	Red Bluff 3 (*24*)	.17	.16	.05	.04	.015	.05	33	90	4	10
5434	Red Bluff 5 (*25*)	.16	.16	.05	.03	.018	.06	21	90	3	10
5435	Red Bluff 7 (*26*)	.13	.13	.09	.04	.003	.07	12	120	2	10
256436	Red Bluff 8 (*15*)	.13	.14	.14	.03	.003	.08	19	150	3	10
229391	Red Bluff 10 (*15*)	.17	.18			.017		60	440	5	10
256437	Red Point Lode (*28*)	.11	.11	.07	.03	.005	.06	20	30	3	10
5891	Reed Henderson	.03	.03	.12	.05	.015	.92	8	80	.5	4
5438	Rimrock (*29*)	.10	.11	.28	.03	.003	.06	8	110	3	10
5439	Section 18 (*32*)	.15	.16	.33	.03	.003	.06	9	20	5	20
256440	Section 18 (*35*)	.10	.10	.23	.03	.003	.07	8	20	4	10
229395	Section 19 (*34*)	.14	.14			.004		10	160	5	10
256441	Section 21 (*37*)	.10	.11	.30	.03	.003	.06	2	20	2	10
5442	Section 24 (*39*)	.19	.18	.15	.03	.003	.06	2	20	1	30
5892	Manol (Section 30) (*22*)	.19	.23			.019		50	460	2	10
5443	Manol (Section 30, T–8) (*22*)	.17	.19	.11	.04	.007	.12	19	240	3	10
5444	Manol (Section 30, T–19) (*22*)	.28	.31	.07	.04	.029	.10	16	130	3	10
229394	T 2 (*45*)	.12	.13			.004		10	130	1	20
256445	Tom Elkins (*48*)	.12	.11	.19	.04	.003	.06	4	20	3	10
256446	UDC 5 (*49*)	.14	.14	.06	.04	.011	.06	29	370	5	10
Ore in the Todilto Limestone Limestone and Entrada Sandstone											
245229	Sandy (*76*)	0.09	0.10	0.13	0.08	0.024		15	60	15	12
Ore in the San Andres Limestone											
245227	Lucky Don (*1*)	0.17	0.22	0.43	0.06	0.011		41	240	10	830
Ore in the Madera Limestone											
254110	Agua Torres (*1*)	0.06	0.08	0.11	0.46			172		50	37
254109	Marie (*2*)	.17	.17	.05	3.27			6,200	890	75	2,100

[1] Spectrographic analyses, chemical analyses for As, Se, U, and Zn, and radiometric analyses for U for samples 229390–229395 inclusive requested by A. T. Miesch.
[2] Analysis of sample 246891 by N. M. Conklin; all others by R. G. Havens.
[3] Analysts: C. G. Angelo, R. P. Cox, G. S. Erickson, Mary Finch, W. D. Goss, H. H. Lipp, T. Miller, and J. S. Wahlberg.
[4] Analysts: C. G. Angelo, R. P. Cox, E. J. Fennelly, D. L. Ferguson, Mary Finch, W. D. Goss, H. H. Lipp, T. Miller and J. S. Wahlberg. Fluorimetric method.
[5] Analysts: W. D. Goss, H. H. Lipp, and J. S. Wahlberg. Volumetric method.
[6] Analysts: G. T. Burrow, D. L. Ferguson, and E. C. Mallory. Gravimetric method.
[7] Analysts: D. L. Ferguson and L. F. Rader, Jr. Volumetric method.
[8] Analysts: Wayne Mountjoy and J. P. Schuch. Rapid scanning, CO_2 method.
[9] Analysts: R. R. Beins, H. E. Crowe, E. J. Fennelly, Claude Huffman, J. P. Schuch, and J. E. Wilson. Colorimetric method.
[10] Analysts: R. P. Cox, W. D. Goss, and L. F. Rader, Jr. Colorimetric method.
[11] Analysts: C. G. Angelo, G. T. Burrow, R. P. Cox, Mary Finch, W. D. Goss, H. H. Lipp, T. Miller, and J. S. Wahlberg. Colorimetric method.
[12] Analysts: R. R. Beins, G. T. Burrow, and H. E. Crowe. Colorimetric method

TABLE 8.—*Ranges of the geometric means of 19 minor elements in 12 sample groups of the uranium ores, northwestern New Mexico*

[All analyses are spectrographic. Numbers in parentheses are samples below limit of detection]

Ore sample groups (By formation, type of host rock [ ], and distinctive structure*)	No. of samples	SILVER (Ag) Percent 0.000015 0.00003 0.00007 0.00015 0.0003 0.0007 0.0015 0.003 0.007 0.015 0.03 0.07 0.15 0.3 0.7 1.5	No. of samples	COBALT (Co) Percent 0.000015 0.00003 0.00007 0.00015 0.0003 0.0007 0.0015 0.003 0.007 0.015 0.03 0.07 0.15 0.3 0.7 1.5	No. of samples	LANTHANUM (La) Percent 0.000015 0.00003 0.00007 0.00015 0.0003 0.0007 0.0015 0.003 0.007 0.015 0.03 0.07 0.15 0.3 0.7 1.5
Espinaso Volcanics of Stearns (1943) [●]*	2		2		2	
Popotosa Formation [○]*	2 (1)		2		2	
Baca Formation [○]	1		1		1 (1)	
Dakota Sandstone [◑]	5 (5)		5		5 (4)	
Dakota Sandstone (shale) [◒]	1 (1)		1		1	
Morrison Formation [●]	18(18)		18 (1)		18(16)	
Morrison Formation (Woodrow deposit) [●]*	1		1		1 (1)	
Todilto Limestone [▲]*	[1]31(30)		31 (4)		31(31)	
Todilto Limestone and Entrada Sandstone [▲●]*	1 (1)		1		1 (1)	
Cutler Formation [◍]	3 (1)		3		3	
San Andres Limestone [▽]*	1 (1)		1		1 (1)	
Madera Limestone [△]*	2 (1)		2		2 (2)	
		BORON (B)		CHROMIUM (Cr)		MOLYBDENUM (Mo)
Espinaso Volcanics of Stearns (1943) [●]*	2 (2)		2		2	
Popotosa Formation [○]*	[2]2 (1)		2		2	
Baca Formation [○]	[2]1 (1)		1		1	
Dakota Sandstone [◑]	5 (1)		5		5 (1)	
Dakota Sandstone (shale) [◒]	1		1		1	
Morrison Formation [●]	18 (6)		18		18 (1)	
Morrison Formation (Woodrow deposit) [●]*	1 (1)		1		1	
Todilto Limestone [▲]*	31(31)		31		31(17)	
Todilto Limestone and Entrada Sandstone [▲●]*	[2]1 (1)		1		1	
Cutler Formation [◍]	3		3		3 (1)	
San Andres Limestone [▽]*	[2]1 (1)		1		1	
Madera Limestone [△]*	2		2		2	
		BARIUM (Ba)		COPPER (Cu)		NIOBIUM (Nb)
Espinaso Volcanics of Stearns (1943) [●]*	2		2		2	
Popotosa Formation [○]*	2		2		2	
Baca Formation [○]	1		1		1 (1)	
Dakota Sandstone [◑]	5		5		5 (4)	
Dakota Sandstone (shale) [◒]	1		1		1 (1)	
Morrison Formation [●]	18		18		18(12)	
Morrison Formation (Woodrow deposit) [●]*	1		1		1 (1)	
Todilto Limestone [▲]*	31		31		31(31)	
Todilto Limestone and Entrada Sandstone [▲●]*	1		1		1 (1)	
Cutler Formation [◍]	3		3		3 (2)	
San Andres Limestone [▽]*	1		1		1 (1)	
Madera Limestone [△]*	2		2		2 (2)	
		BERYLLIUM (Be)		GALLIUM (Ga)		NEODYMIUM (Nd)
Espinaso Volcanics of Stearns (1943) [●]*	2 (2)		[5]2		[9]2	
Popotosa Formation [○]*	2		2		2 (2)	
Baca Formation [○]	1		1		1 (1)	
Dakota Sandstone [◑]	5 (5)		5 (5)		5 (5)	
Dakota Sandstone (shale) [◒]	1		1		1 (1)	
Morrison Formation [●]	18 (5)		[6]18 (5)		18 (17)	
Morrison Formation (Woodrow deposit) [●]*	[4]1		[7]1		1 (1)	
Todilto Limestone [▲]*	31(31)		31 (31)		31(31)	
Todilto Limestone and Entrada Sandstone [▲●]*	1 (1)		[7]1		1 (1)	
Cutler Formation [◍]	3		3		[8]3 (1)	
San Andres Limestone [▽]*	1 (1)		1 (1)		1 (1)	
Madera Limestone. [△]*	2 (2)		[5]2		2 (2)	

[1] One sample reported as trace, assumed to be 0.00005.
[2] One sample reported as 0.001.
[3] One sample reported as trace, assumed to be 0.002.
[4] Sample reported as trace, assumed to be 0.0001.
[5] Both samples reported as trace and assumed to be 0.0002.
[6] Includes 2 samples reported as trace and assumed to be 0.0002.
[7] Sample reported as trace, assumed to be 0.0002.
[8] Includes 1 sample reported as trace and assumed to be 0.0002.
[9] Includes 1 sample reported as trace and assumed to be 0.01.

TABLE 8.—*Ranges of the geometric means of 19 minor elements in 12 sample groups of the uranium ores, northwestern New Mexico*—Continued

Ore sample groups (By formation, type of host rock [ ], and distinctive structure*)	No. of samples	Percent: 0.000015 0.00003 0.00007 0.00015 0.0003 0.0007 0.0015 0.003 0.007 0.015 0.03 0.07 0.15 0.3 0.7 1.5
		NICKEL (Ni)
Espinaso Volcanics of Stearns (1943) [⊕]*	2	
Popotosa Formation [○]*	2	
Baca Formation [○]	1	
Dakota Sandstone [◑]	5	
Dakota Sandstone (shale) [◒]	1	
Morrison Formation [●]	18	
Morrison Formation (Woodrow deposit) [●]*	1	
Todilto Limestone [▲]*	31	
Todilto Limestone and Entrada Sandstone [▲●]*	1	
Cutler Formation [⊖]	3	
San Andres Limestone [▽]*	1	
Madera Limestone [△]*	2	
		LEAD (Pb)
Espinaso Volcanics of Stearns (1943) [⊕]*	2	
Popotosa Formation [○]*	2	
Baca Formation [○]	1	
Dakota Sandstone [◑]	5 (2)	
Dakota Sandstone (shale) [◒]	1	
Morrison Formation [●]	18	
Morrison Formation (Woodrow deposit) [●]*	1	
Todilto Limestone [▲]*	31	
Todilto Limestone and Entrada Sandstone [▲●]*	1	
Cutler Formation [⊖]	3	
San Andres Limestone [▽]*	1	
Madera Limestone [△]*	2	
		SCANDIUM (Sc)
Espinaso Volcanics of Stearns (1943) [⊕]*	2	
Popotosa Formation [○]*	2	
Baca Formation [○]	1	
Dakota Sandstone [◑]	5 (3)	
Dakota Sandstone (shale) [◒]	1	
Morrison Formation [●]	18(12)	
Morrison Formation (Woodrow deposit) [●]*	1	
Todilto Limestone [▲]*	31(31)	
Todilto Limestone and Entrada Sandstone [▲●]*	1 (1)	
Cutler Formation [⊖]	3	
San Andres Limestone [▽]*	1 (1)	
Madera Limestone [△]*	2	
		STRONTIUM (Sr)
Espinaso Volcanics of Stearns (1943) [⊕]*	2	
Popotosa Formation [○]*	2	
Baca Formation [○]	1	
Dakota Sandstone [◑]	5	
Dakota Sandstone (shale) [◒]	1	
Morrison Formation [●]	18	
Morrison Formation (Woodrow deposit) [●]*	1	
Todilto Limestone [▲]*	31	
Todilto Limestone and Entrada Sandstone [▲●]*	1	
Cutler Formation [⊖]	3	
San Andres Limestone [▽]*	1	
Madera Limestone [△]*	2	

Ore sample groups (By formation, type of host rock [ ], and distinctive structure*)	No. of samples	Percent: 0.000015 0.00003 0.00007 0.00015 0.0003 0.0007 0.0015 0.003 0.007 0.015 0.03 0.07 0.15 0.3 0.7 1.5
		YTTRIUM (Y)
Espinaso Volcanics of Stearns (1943) [⊕]*	2	
Popotosa Formation [○]*	2	
Baca Formation [○]	1	
Dakota Sandstone [◑]	5	
Dakota Sandstone (shale) [◒]	1	
Morrison Formation [●]	18 (2)	
Morrison Formation (Woodrow deposit) [●]*	1	
Todilto Limestone [▲]*	[10]31(26)	
Todilto Limestone and Entrada Sandstone [▲●]*	1	
Cutler Formation [⊖]	3	
San Andres Limestone [▽]*	1 (1)	
Madera Limestone [△]*	2	
		YTTERBIUM (Yb)
Espinaso Volcanics of Stearns (1943) [⊕]*	2	
Popotosa Formation [○]*	2 (1)	
Baca Formation [○]	1 (1)	
Dakota Sandstone [◑]	5 (5)	
Dakota Sandstone (shale) [◒]	1	
Morrison Formation [●]	17(17)	
Morrison Formation (Woodrow deposit) [●]*	1 (1)	
Todilto Limestone [▲]*	30(30)	
Todilto Limestone and Entrada Sandstone [▲●]*	1	
Cutler Formation [⊖]	3 (2)	
San Andres Limestone [▽]*	1 (1)	
Madera Limestone [△]*	2	
		ZIRCONIUM (Zr)
Espinaso Volcanics of Stearns (1943) [⊕]*	2	
Popotosa Formation [○]*	2	
Baca Formation [○]	1	
Dakota Sandstone [◑]	5	
Dakota Sandstone (shale) [◒]	1	
Morrison Formation [●]	18	
Morrison Formation (Woodrow deposit) [●]*	1	
Todilto Limestone [▲]*	31	
Todilto Limestone and Entrada Sandstone [▲●]*	1	
Cutler Formation [⊖]	3	
San Andres Limestone [▽]*	1	
Madera Limestone [△]*	2	

EXPLANATION

Range in content of samples — Dashed where uncertain

Geometric mean of all samples reported as trace or more. Questioned where doubtful

−○

Approximate limit of sensitivity where the element is undetected in all samples

−○ −○

Approximate limits of sensitivities where they vary between samples. All samples undetected and below either or both limits

Ore sample groups

[⊕]* Tertiary igneous breccia; in footwall of igneous dike

[○]* Tertiary sandstone; in hanging wall of low-angle fault

[○] Tertiary sandstone

[◑] Cretaceous sandstone

[◒] Cretaceous shale

[●] Jurassic sandstone

[●]* Jurassic sandstone (Woodrow deposit); in near-vertical breccia pipe

[▲]* Jurassic limestone

[▲●]* Jurassic limestone and sandstone

[⊖] Permian sandstone

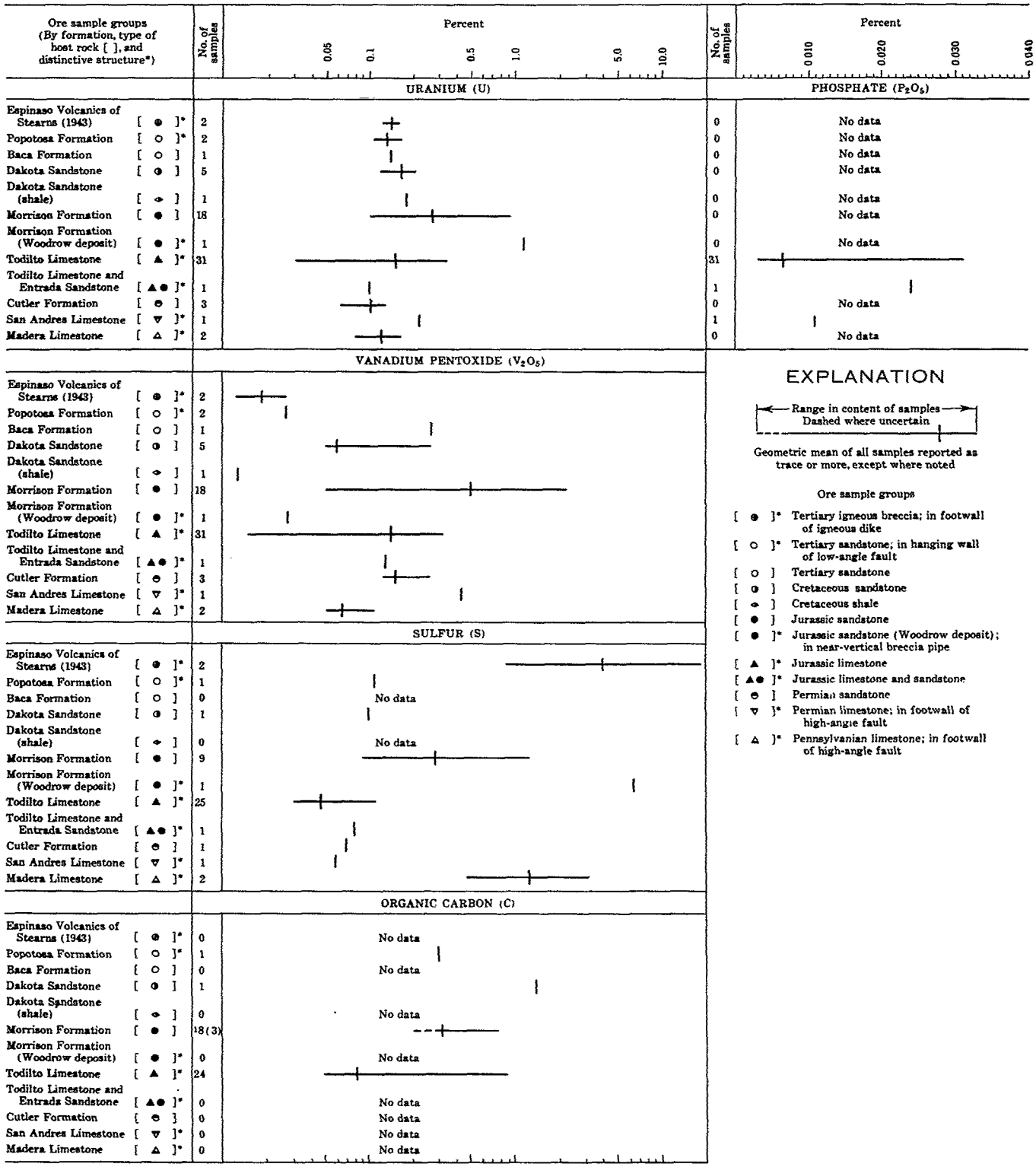
[▽]* Permian limestone; in footwall of high-angle fault

[△]* Pennsylvanian limestone; in footwall of high-angle fault

[10] Includes 2 samples reported as trace and assumed to be 0.001.

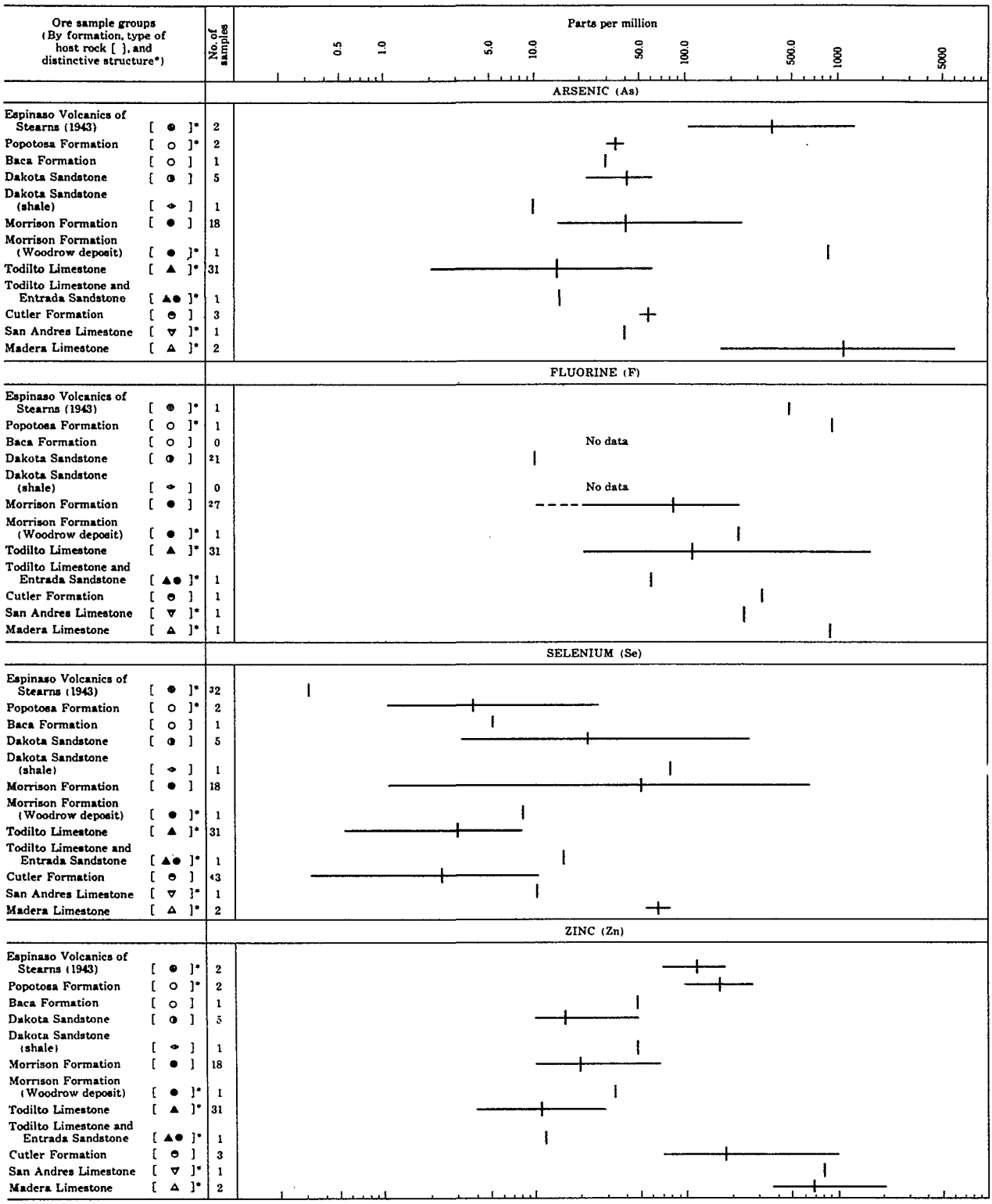
TABLE 9.—*Ranges of concentration and the geometric means of uranium, vanadium pentoxide, sulfur, phosphate, organic carbon, arsenic, fluorine, selenium, and zinc in 12 sample groups of the uranium ores, northwestern New Mexico*

[Analyses are chemical except for some samples of V_2O_5. Where no chemical analyses are available or show an assay of <0.10 percent V_2O_5, spectrographic analyses are used by conversion of V to V_2O_5.]



[1]Number in parentheses is samples below limit of detection, each reported as <0.3 and assumed to be 0.2 ppm.

LE 9.—*Ranges of concentration and the geometric means of uranium, vanadium pentoxide, sulfur, phosphate, organic rbon, arsenic, fluorine, selenium, and zinc in 12 sample groups of the uranium ores, northwestern New Mexico*—Continued



[2] One sample reported as <20, assumed to be 10 ppm.
[3] Both samples reported as <0.5, assumed to be 0.3 ppm.
[4] One sample reported as <0.5, assumed to be 0.3 ppm.

TABLE 10.—*Geometric means of 16 selected elements in the ore sample groups of classes 1 and 2*

[0, looked for but not found; <, less than amount shown; leaders (..), not looked for; ~, approximate amount shown. Analyses are in percent, except as otherwise indicated]

Ore sample groups (by host rock)	Ag	Al	Co	Cr	Cu	Fe	Mo	Ni	Pb	U	V_2O_5	S	As	F	Se	Zn
													Parts per million			
Groups of class 1																
Baca Formation	0.00003	3	0.0003	0.0015	0.003	1.5	0.0007	0.0015	0.003	0.14	0.27	.....	30	.....	5	50
Dakota Sandstone	0	2.6	.0005	.001	.004	.7	.0015	.001	<.0007	.16	.06	0.10	40	~10	21	16
Dakota Sandstone (shale)	0	7	.0007	.003	.003	.7	.0015	.0015	.0015	.18	.01	.....	10	.....	75	50
Morrison Formation	0	4.8	.0008	.002	.004	1.4	.005	.0015	.006	.26	.50	.3	40	83	48	20
Todilto Limestone	<.00005	1.6	.0004	.001	.002	.3	<.0011	.0007	.005	.14	.14	.04	14	108	2.9	11
Todilto Limestone and Entrada Sandstone	0	3	.0015	.003	.003	.7	.0009	.0007	.003	.10	.13	.08	15	60	15	12
Cutler Formation	~.00003	~9	.002	.004	.09	2.4	<.0014	.002	.025	.10	.15	.07	55	320	2.3	183
Groups of class 2																
Espinaso Volcanics of Stearns (1943) [1]	0.0003	4.6	0.02	0.015	1.5	4.6	0.005	0.09	0.0015	0.14	0.02	4.0	360	480	<.5	118
Popotosa Formation	<.000015	15	.005	.003	.05	2.1	.003	.005	.015	.13	.03	.11	35	920	3.7	167
Morrison Formation (Woodrow) deposit [2]	.0003	3	.015	.0015	.015	7	.003	.007	.03	1.16	.03	6.6	890	220	8	35
San Andres Limestone	0	1.5	.0015	.003	.003	.7	.0015	.007	.007	.22	.43	.06	41	240	10	830
Madera Limestone [3]	~.0004	3	.0015	.0046	.014	3.2	.007	.003	.05	.12	.06	1.2	1.033	890	61	703

[1] This sample group also contains 0.03 Ce, 0.015 La, ~0.01 Nd, and 0.12 Sr; 1 sample contains 0.003 Ge.
[2] This sample group also contains a trace of Tl.
[3] One sample in this sample group also contains 0.015 Sb and 0.015 Tl.

MORRISON FORMATION

Most data were obtained for the ore sample group of the Morrison Formation, the most important ore group in the area, from the standpoint of ore production and mine reserves. With the exception of some redistributed deposits in the Ambrosia Lake district and possibly the Gallup district, this ore group shows no direct relation to tectonic structures and, with the exception of the ores in the Salt Wash Member, no stratigraphic or geographic differences.

In general, the ore group in the Morrison shows a somewhat greater range in content of many elements than most other groups of class 1. This is principally the result of the greater number of samples, as indicated by the similar geometric means for the respective elements among the several sample groups (tables 7–9). An exception is vanadium, which has a relatively wide range and an average content that is much greater than that of any of the other groups. (See vanadium pentoxide, table 9.) These differences are reflected mostly by sample 254040 (table 5), which was taken from the northwestern part of the area where ores in the Salt Wash Member have an average U : V ratio of 1 : 7 (See table 2, Shiprock district.) Because the Salt Wash has a rather limited distribution in northwestern New Mexico, the ores that have a high vanadium content are restricted geographically as well as stratigraphically.

MORRISON FORMATION (WOODROW DEPOSIT)

The Woodrow deposit in the Morrison Formation differs from the groups in class 1 in its high content of 10 elements, the presence of coarse-grained coffinite in the ore, and the close association of the deposit with a faulted pipelike structural feature. These differences justify assignment of the Woodrow deposit to class 2.

The contents of each of the following nine elements in the Woodrow deposit are greater than the highest respective contents of the sample groups in class 1 by the following multiples: silver, >6×; cobalt, 7½×; copper, 3½×; iron, 3×; nickel, 3½×; lead, 5×; uranium, 4½×; sulfur, 22×; and arsenic, 16×. The contents of lead and copper in the Woodrow are about the same or less than in the group in the Cutler Formation, which contains an appreciably higher content of these and some other elements than the groups in class 1. This matter is discussed below under Cutler Formation. The Woodrow also contains a trace of thallium, which is rarely detected in deposits of the peneconcordant type, and it also has a relatively high sulfide mineral content, which is expressed in the ore principally as pyrite and marcasite; this content is indicated by the high amounts of iron and sulfur (table 10). Conversely, the Woodrow is low in vanadium.

The mineralogy of the Woodrow deposit is similar to that of the group in the Morrison Formation, with two exceptions: one is its relatively high sulfide mineral content, and the other is the presence of coarse-grained coffinite (Hilpert and Moench, 1960, p. 446) which occurs only in a fine-grained or earthy form in other deposits in the Morrison Formation as well as in all other peneconcordant deposits. Thus, the significant differences between the Woodrow deposit and groups of class 1 are the high grade of the deposit, the presence of coarse-grained coffinite in the ore, and the association of the deposit with a faulted pipelike structural feature.

Santa Fe Group (Miocene to Pleistocene?).—Several uranium deposits are known in rocks of the Santa Fe Group, but they generally are small and superficial. The resource outlook, however, is considered to range from poor at the outcrop to good in the subsurface, similar to the Galisteo and Popotosa Formations. The Santa Fe Group is widely exposed, but in most places only the upper few hundred feet of the sequence is represented; elsewhere the beds are covered by alluvium and surficial debris. Little, if any, exploration has been done for deposits in the unexposed beds. The great extent and thickness of these beds, and the favorableness of many of them for containing uranium deposits, offer a good potential for deposits that may range in size from small to large.

Older volcanic rocks of Jemez Mountains, Espinaso Volcanics of Stearns (1943), Cieneguilla Limburgite of Stearns (1953), and intrusive rocks of varied composition and form.—One medium-sized vein deposit occurs in the Espinaso Volcanics of Stearns (1943) on the eastern side of the Los Cerrillos district; a few other scattered small deposits, which are mostly surficial accumulations, occur in various types of intrusive and extrusive igneous rocks, mainly along the Rio Grande trough. The uranium resources in these rocks are small and the outlook is poor for finding more than a few small, or possibly medium-sized, deposits in them. The best potential is in the Los Cerrillos and Ortiz mining districts, where some uraniferous vein deposits might be found in association with the base-metal deposits.

AREAS RECOMMENDED FOR EXPLORATION

The principal uranium resources in northwestern New Mexico are in peneconcordant deposits, mostly in sandstone, partly in limestone, and to some extent in carbonaceous shale and coal. Most of these resources are along the margins of sedimentary basins, the most important of these areas being the southern and western parts of the San Juan Basin.

Of greatest importance is the southern part of the basin. On the basis of the frequency of distribution of the known deposits and their geologic relations, the deposits in this area are restricted to a zone or belt north of the outcrop of the Jurassic rocks which is at least 20 miles wide and which has been referred to as the southern San Juan Basin mineral belt (Hilpert and Moench, 1960). The northern limit of the belt is adjusted here to include the known areas of most intensive structural deformation during Late Jurassic time. This deformation is recognized as the prime control on the uranium deposits in the Morrison Formation and Todilto Limestone. As drawn, the northern limit of the belt extends from near the northern pinchout of the Jackpile sandstone northwestward, parallel to the reconstructed boundary of the Jurassic basin of deposition, to the outcrop of the Morrison Formation on the western side of the San Juan Basin (fig. 20). Included in the belt are the Jackpile trough in the Laguna district (roughly marked by the Jackpile sandstone) and the main ore-bearing sandstone mass in the Ambrosia Lake district (areas C and D, respectively, fig. 20). Other structurally deformed areas probably occur in the western part of the belt and along its north margin. Certainly such areas will not be expected to end abruptly where the north margin is indicated. The boundary is drawn to show approximately where the deformation became less intensive northward.

Included in the belt is the part of the limestone unit of the Todilto Limestone that is 15 feet or more thick. This part includes almost all the mine reserves, has yielded almost all the ore, and probably contains most of the uranium resources in the Todilto. Where the limestone unit of the Todilto was thickest, it probably received the most intensive deformation and thus is considered most favorable for deposits. The Todilto generally lies about 400–500 feet below the base of the Morrison Formation. Because of this general depth and the smaller deposits in it, the Todilto is not of immediate economic interest except where it is not deeply buried.

The mineral belt also contains the most favorable ground for uranium deposits in the Dakota Sandstone, although the Jurassic deformation probably had little, if any, influence on them. The best ground is in the western part of the belt, where channel-type sandstone lenses are largest and thickest. This area is near the margin of the Dakota basin of deposition. Depths to the base of the Dakota will generally be about 500 feet nearer the surface than the base of the Morrison. Although the size of the deposits in the Dakota is about the same as the size of the ones in the Todilto, the deposits in the Dakota are more amenable to exploration and development, which can be coordinated with exploration for the deeper but generally larger deposits in the Morrison Formation.

In the western part of the San Juan Basin substantial resources may also be found in the Shiprock district in the Salt Wash Member of the Morrison Formation and in the Chuska district in the Recapture Member of the Morrison (fig. 20, areas A and B, respectively). Each of these areas defines the thicker part of the respective members where they apparently occupy eastward-trending structural depressions. Deposits in these rocks are expected to range from small to medium in size, similar to the ones at the

REFERENCE # 12

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

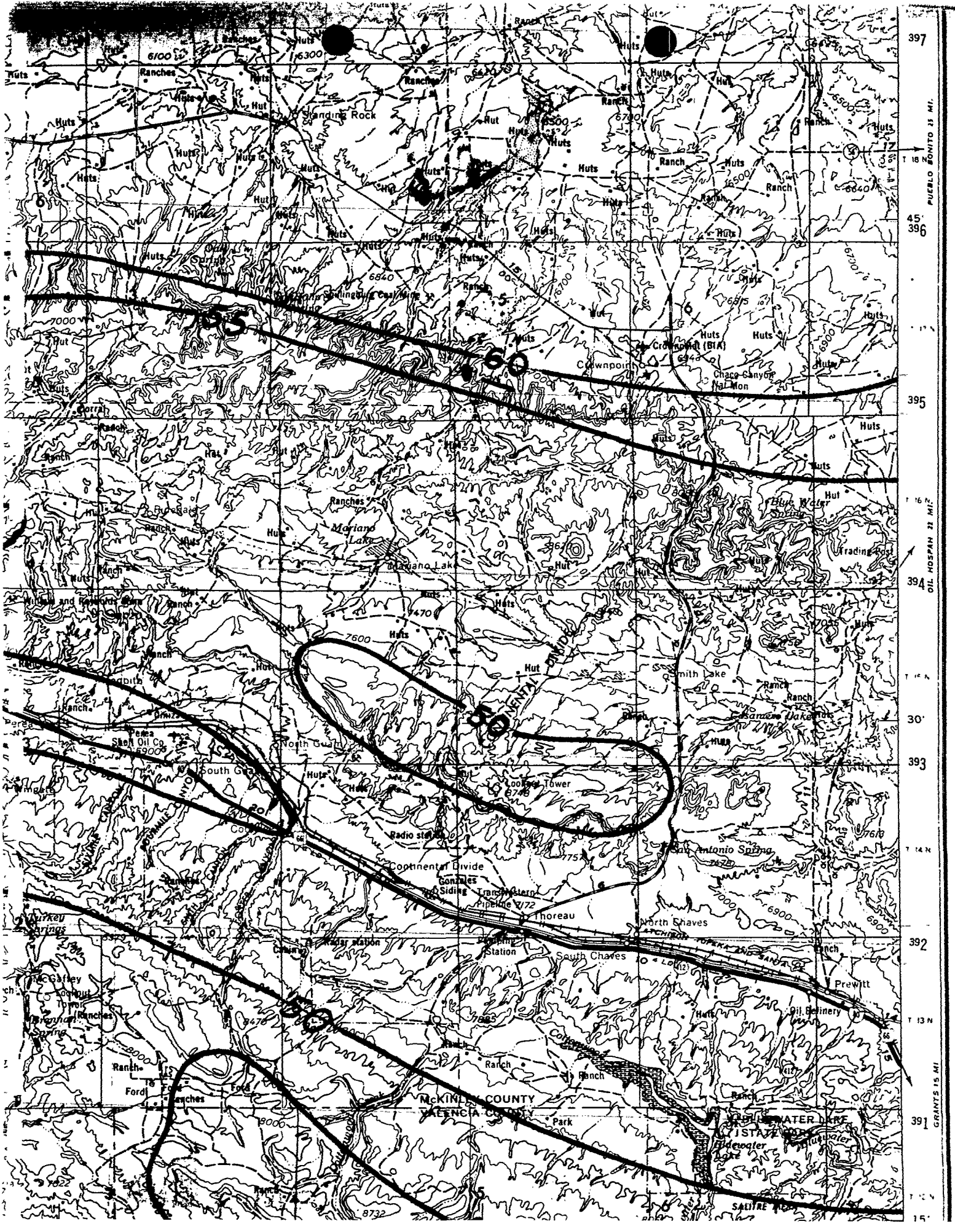
MAY,'90 P. MOLLOY

PRELIMINARY AVERAGE ANNUAL LAKE EVAPORATION FOR THE NAVAJO RESERVATION IN INCHES OF WATER

ROBERT BECKER, 1985.

19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

TOWNSHIP OR RANGE LINE



Standing Rock
Crownpoint
Crownpoint (BIA)
Chaco Canyon Nat Mon
Mariano Lake
Blue Water Spring
Trading Post
Smith Lake
Casamero Lake
North Guam
South Guam
Lookout Tower
Radio station
Continental Divide
Gonzales Siding
Transwestern Pipeline
Thoreau
North Chaves
South Chaves
Pumping Station
Radar station
Prewitt
Oil Refinery
San Antonio Spring
McKINLEY COUNTY
VALENCIA COUNTY
Park
Bluewater Lake
Bluewater
Turkey Springs
McGaffey
Lookout Tower
Brennan Spring
Perea
Shell Oil Co
Wingate
Ranches
Huts
Hut
Ranch
Corral
Cabin
Ford
Cottonwood
Salitre Mesa
PUEBLO BONITO 25 MI.
OIL HOSPAH 22 MI.
GRANTS 15 MI.
T 18 N
T 16 N
T 14 N
T 13 N
397
396
395
394
393
392
391
45'
30'
15'

REFERENCE # 13

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY, '90 P. MOLLOY

code of federal regulations

Protection of Environment

40

PARTS 190 to 399

Revised as of July 1, 1987

CONTAINING
A CODIFICATION OF DOCUMENTS
OF GENERAL APPLICABILITY
AND FUTURE EFFECT

AS OF JULY 1, 1987

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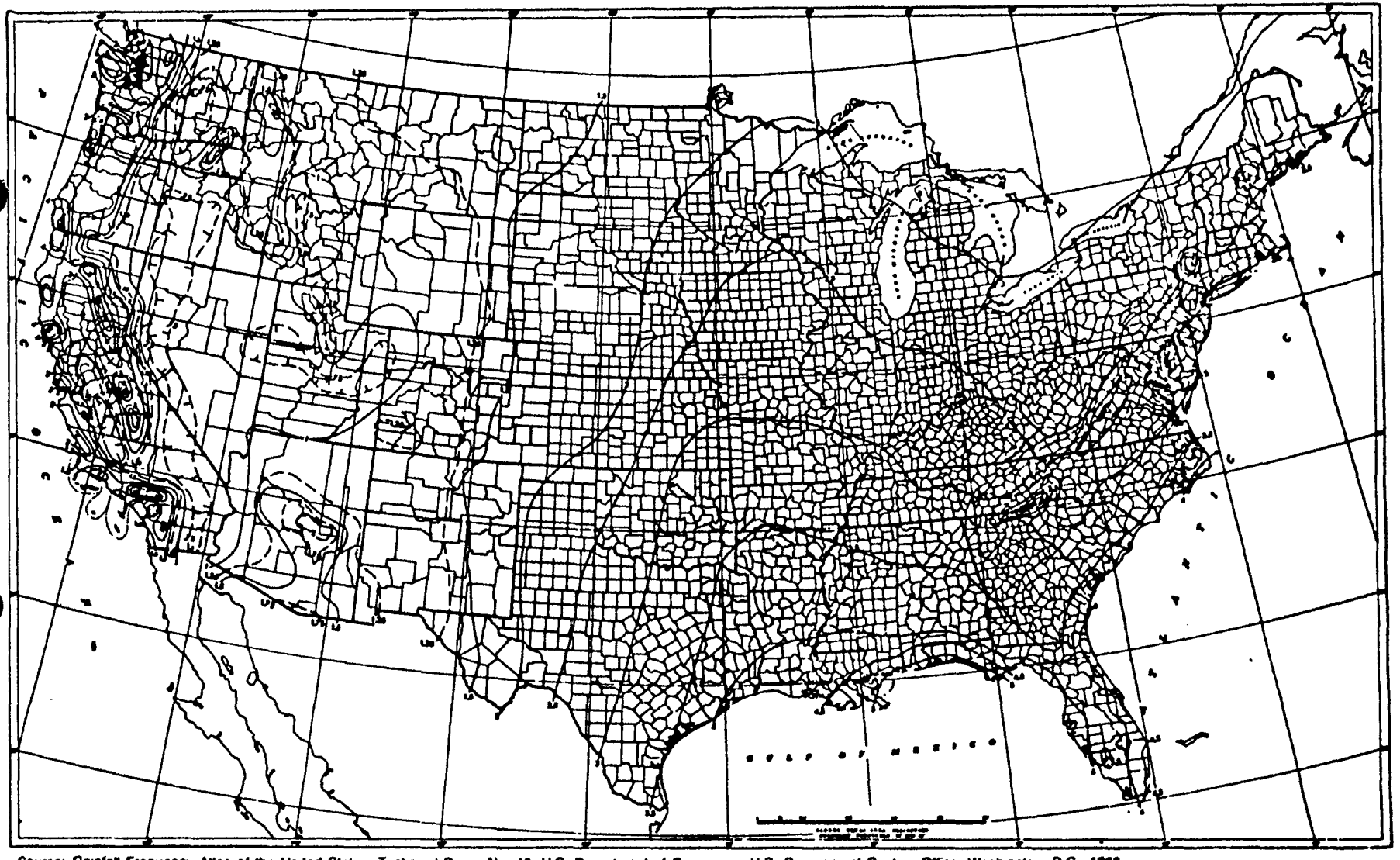
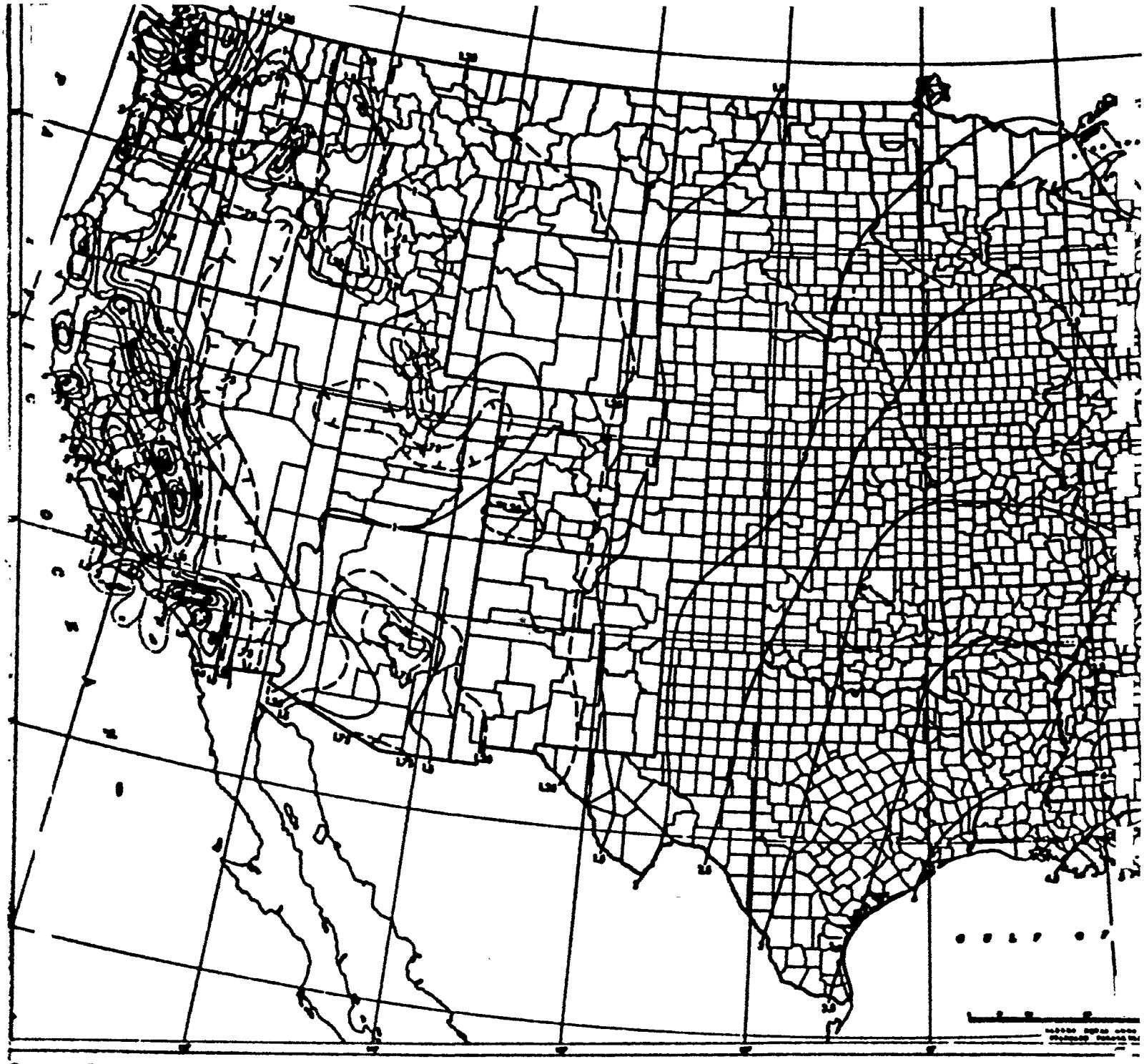
the Federal Register



Source: Rainfall Frequency Atlas of the United States, Technical Paper No. 40, U.S. Department of Commerce, U.S. Government Printing Office, Washington, D.C., 1963

FIGURE 8
1-YEAR 24-HOUR RAINFALL
(INCHES)



Source: Rainfall Frequency Atlas of the United States, Technical Paper No. 40, U.S. Department of Commerce, U.S. Government I

1.26 IN.

FIGURE 8
1-YEAR 24-HOUR RAINFALL
(INCHES)

REFERENCE # 14

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

FIRST NOTE

PAGE#1

- 9TH FRAME - DRUM #27 (ELDRIN)
□ KLEENGARD - KIMBERLY CLARK
* - MORE TEAR RESIST. THAN TYVEK

*** ◇ WHOLE BODY COUNTS ! ***

APRIL 11, 1990: B. VANDEVER MIKE (HAYSTACK BUTTE AREA)
◇ @ NSO
- LUDLUM #19 - 7 μR·hr⁻¹
- ESP-II & RATEMETER ≃ 7 (10³) cpm
◇ PREWITT SITE
- 2 FRAMES OF RECLAMATION WORK
◇ TURN OFF TO HAYSTACK BUTTE
○ BACKGROUND (LUDLUM #19)
- @ SHINE ~ 5 μR·hr⁻¹
- @ FACE ~ SAME
○ B'GRND (ESP-II
- @ SHINE ~ 6.5 (10³) cpm: FACE SAME
◇ od. RESET @ 17218.4 mE.
◇ 3RD FR. - REFERENT FRAME FOR B'GRND CHECK (NOTE EXTENSIVE SURFACE WORKS, RIGHT CNTR MIDDLE GROUND)
◇ 17220 (1.6)
○ 2 FRAMES OF RES. W OF HAYSTACK BUTTE
- 6TH FR. NOTE HAYSTACK B. IN MIDDLE GROUND AS REFERENT ALSO WINDMILL

1 ◇ 17220.9 (2
2 - 6TH FR.
3 HAYSTAC
4 ◇ 17222.4 (
5 ~1 RES. &
6 ◇ 17223.7 (
7 - BROWN VA
8 - 1 RES. (@
9 ◇ 3 FRAME
10 - 7TH FR. -
11 - 8TH FR -
12 RES
13 - 9TH FR -
14 DZ+L
15 - 10TH FR -
16 ◇ 1 FRAME
17 (@ B. VAN
18 - B'GRND
19 ○ LUDLUM
20 ○ ESP II
21 ○ SHINE
22 ○ SHINE
23
24 ◇ 12TH FR. -
25 ◇ 13TH FR. -
26 ○ LUDLUM
27 SHINE
28 ◇ B. VANDEV
29 - STOPES A
30 400 yds
31 ** - BURIED

.1 #27 (ELDRIN)
BERLY CLARK
ST. THAN

NTS! ***

VER MINE
REA)

hr⁻¹
R ≈ 7(10³) cpm

CLAMATION

ACK BUTTE
LUM #19)
r. hr⁻¹

(10³) cpm:

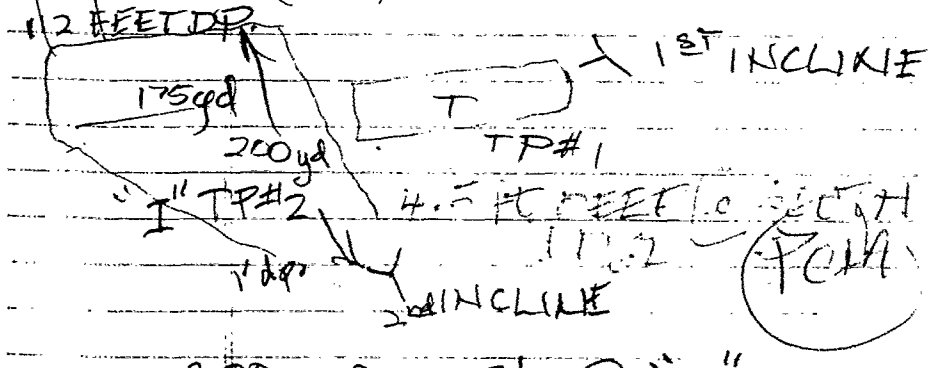
218.4 mi.
RENT FRAME
CK (NOTE EXTEN-
RKS, RIGHT CNTR

S. W OF HAYSTACK

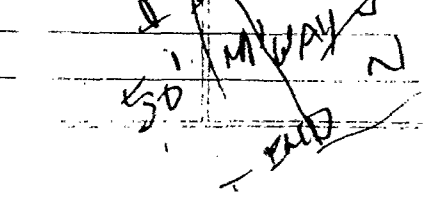
AYSTACK B. IN
REFERENT

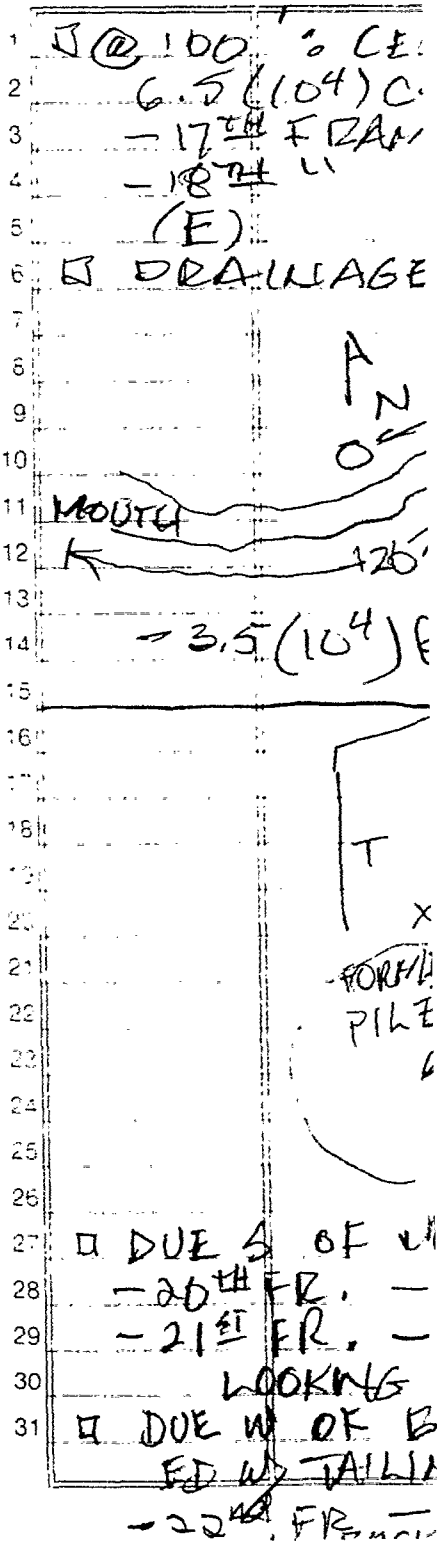
◇ 17220.9 (2.2 od.)
- 6TH FR. - RES. (2) W OF HAYSTACK B.
◇ 17222.4 (3.7 od.)
- 1 RES. & CHURCH - NO PICTURE
◇ 17223.7 (5.0 od.)
- BROWN VANDEVER RES.
- 1 RES. @ THIS LOCATION
◇ 3 FRAMES
- 7TH FR. - TRENCH CUT
- 8TH FR - GOPHERING N OF RES
- 9TH FR - REFERENT TSOH-DZM
- 10TH FR - MARTINEZ RES'S.
◇ 1 FRAME, REFERENT, B'GRND @ B. VANDEVER'S SONS RES.
- B'GRND (11TH FR.)
- o LUDLUM #19 - 24 μR·hr⁻¹ (FACE)
- o ESP II - 2.15(10⁴) cpm (FACE)
- o SHINE - SAME
- o SHINE - 2.25(10⁴) cpm
- NOTE DRAINAGE INTO
◇ 12TH FR. - INCLINED ADIT
◇ 13TH FR. - TRENCH & RXR BED
o LUDLUM #19 - 21 μR·hr⁻¹ @ SHINE
◇ B. VANDEVER
- "STOPES ARE 400 yds (ESE), 400 yds (N)"
** - "BORREGO PASS MINE; 300' OP." *

◇ TOP OF T.P. NE OF INCLINE
80 μR·hr⁻¹
◇ HOT ROCK — .1 mR·hr⁻¹
– 14TH FR.
◇ 350 μR·hr⁻¹ @ LOADING "BAY"
EDGE; 400 μR·hr⁻¹ @ CTR (SHINE)
650 μR·hr⁻¹ @ FACE), UNVALIDATE
OBSERVED
◇ 2ND INCLINE – FACE 160 μR·hr⁻¹
◇ TAILINGS STREAM 200 yds x
175 yds APPROX. 1 foot dp. @
180 μR·hr⁻¹ @ E EDGE OF
T.P. (#2) "I"



◇ 380 μR·hr⁻¹ @ "II"
☆ 15TH FR. → TP#2
☆ 16TH FR. – DRAINAGE (E)
□ IN DRAINAGE (E) AND S OF TP's
– MOUTH – 5 (10⁴) cpm
– MIDWAY – 6.5 (10⁴)
– END → 3.25 (10⁴)





E OF INCLINE

. 1 mR·hr⁻¹

OADING "BAY"
r⁻¹ @ CTE (SHINE)
ACE), VANADATE

ACE 160 μR·hr⁻¹
200 yds x
1 foot dp. :
EDGE OF

1ST INCLINE

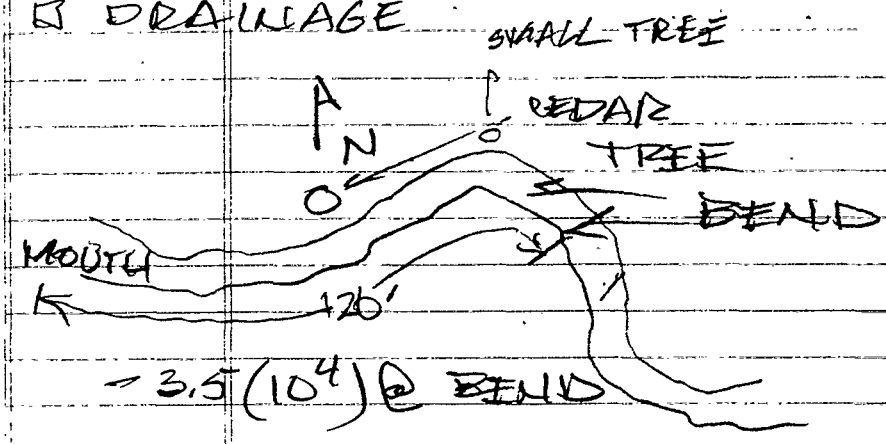
#1

@ "II"

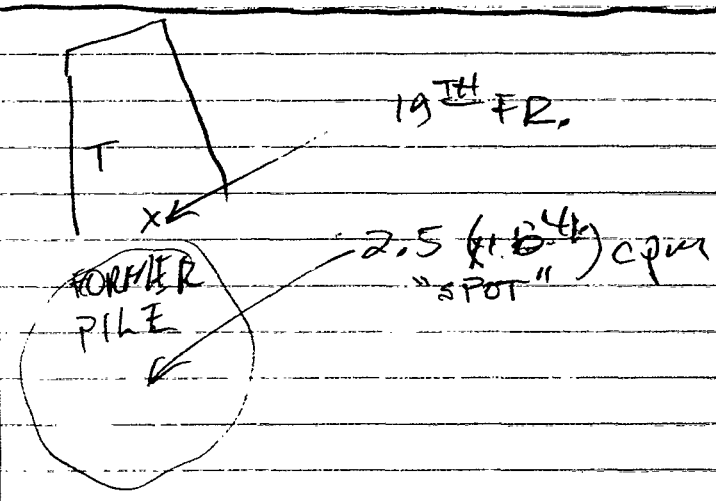
AGE (E)
S OF TP's
m

☐ @ 100' : CEDAR TREE, IN DR.
6.5 (10⁴) CPM
– 17TH FRAME (COLOC. OF 6.5 (10⁴) cpm
– 18TH " – DOWN DRAINAGE
(E)

☐ DRAINAGE



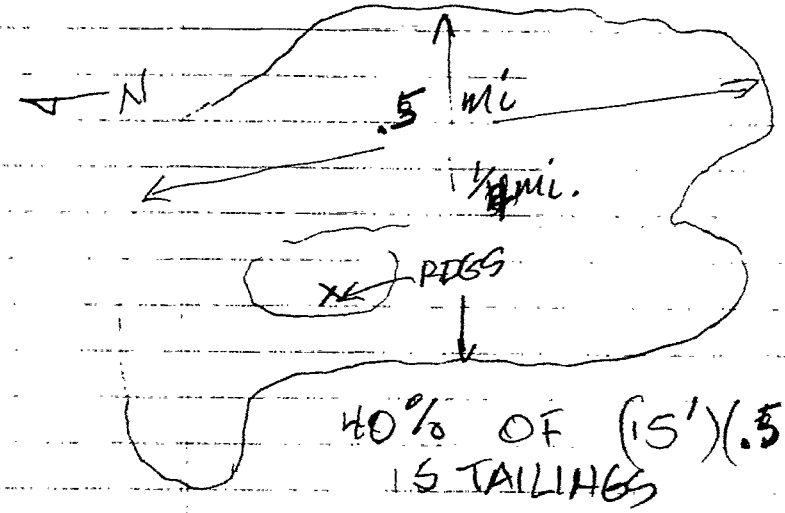
– 3.5 (10⁴) @ BEND



☐ DUE S OF MARTINEZ RES.
– 20TH FR. – STRAT. SECTION / HYSTK B.
– 21ST FR. – B. VANDERVER OUTFIT,
LOOKING WSW

☐ DUE W OF B. VANDEVER, ROAD GRAVEL
ED W/ TAILINGS (ESP-II – 10⁵ CPM)
– 22ND FR – LOOKING E, NOTE: MT. TAYLOR
IN BACKGROUND AS REF.

- ESP II - 5.2 (10^4) CFM
- LUDLUM #19 — 100 μR·hr⁻¹
★ - NOTE: BOTH RDGS @ SHINE
□ @ .8 mi. W OF B. VANDEVER RES.
- "NANA-A-BAH VANDEVER MINE"
* FRAMES 23 AND 24
□ @ EXTENSIVE SURFACE WORKS W. OF B.V. RESIDENCE
- FRAMES 25 THRU 28 - SEMI-PANORAMA



□ @ OVERLOOK
- 29TH FR - LOOKING N, RES. IN CTR MIDDLEGROUND
- 30TH FR - LKG NW, WESTERN EXTENT OF SURFACE WORKS
- 31ST FR - LKG NE, EASTERN EXTENT OF SURFACE WORKS; NOTE TAILINGS FAR CENTER M'GRND
□ @ TIMBERED INCLINE
- 33RD FR.
□ 32nd FR. - LKG SURFACE WORKS

CONT'D @ TH
- ESP-II
- LUD #19
★ B. VANDEVE
- "TH B. SH
- "DRILLING
- "RXR LT
- "B.V. - ¼ ¼ SEC"

VENT SHAFTS

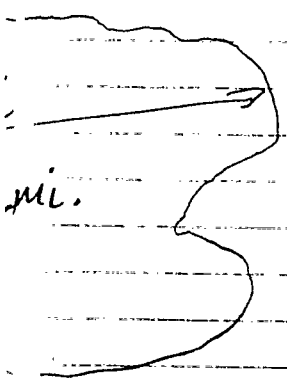
NE STOPE

ST

@ DUE N
- 33RD FR. -
- AND MR.
□ @ TURN OFF
- 34TH FR -
MINE (NO
B'GRND

) cpm
)0 μR·hr⁻¹
GS @ SHINE
3. VANDEVER

NDEVER MINE?
ND 24
ACE WORKS W. OF
CE
RU 28 – SEMI –

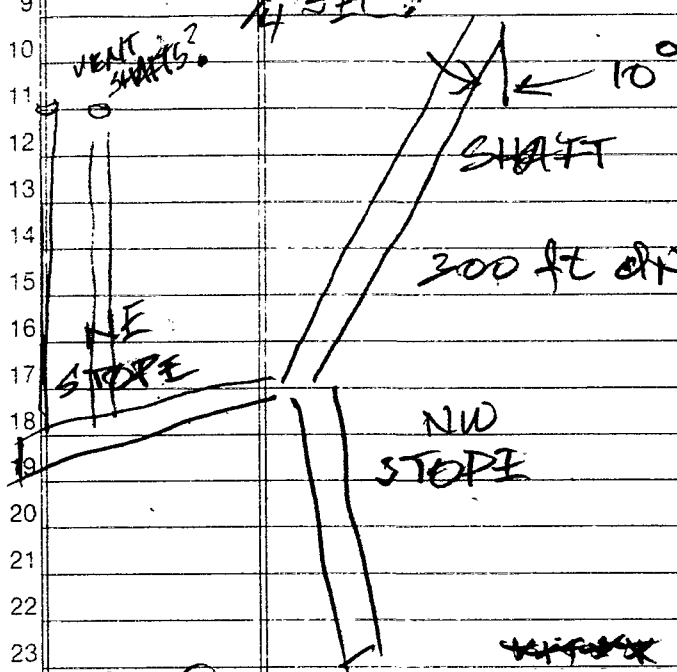


F (15')(.5mi.)(.25mi.)
LINGS

S N, RES. IN
D
W, WESTERN EX-
WORKS
E, EASTERN EX-
E WORKS: NOTE
ENTER M'GRND
INE

URFACE WORKS

CONT'D @ TIMB. SHAFT
– ESP-II – 10^4 cpm
– LUD #19 – 10 μR·hr⁻¹
★ B. VANDEVER:
– "TIMB. SHAFT ~ 300 ft DEEP"
– "DRILLING (EXPL.) NNW OF SHAFT"
– "RXR LAND W & SE OF B.V."
– "B.V. – ¼ SEC. 18, B.V. G'MOTHE ¼ SEC."



~~****~~ @ DUE N OF SURFACE WORKS
– 33rd FR. – VENT. SHAFTS: VERTICAL
~~****~~ ~~****~~
– AND MR. BROWN VANDEVER
□ @ TURN OFF TO B.V.
– 34th FR – DRAINAGE E OF B.V. MINE (NOTE: MT. TAYLOR IN B'GRND AS REFERENT)

- ☐ @ DUE S OF H'STK B.
  - 35TH FR. - ARTESIAN WELL USED FOR STOCK WATER AND ?
- ☐ @ DUE E OF H'STK B.
  - FRAMES 36 THRU 39 - HAYSTACK COMMUNITY/ RES'S.
  - FRAME 40 SAA
- ☐ @ WELL L6T-552
  - D.P. VAT & TANK - 4TH FR
  - WELL NOT FUNCTIONING
- ☐ BACK TO THE ES. GRINDER

• • •

APRIL 12, 1990: STF. MTG.

- ☐ WABOS, WABOS, WABOS, WABOS
- ☐ LEE BIGWATER
  - "WIFE IS LAB. S'VISOR @ SAGE MEM."
- ☐ LTL SPOKE (TECH. STF GOT STUCK AGAIN)

☆ CHRIS PETRE :: WILL BRING,
- HNO_3, NALGENE 2 l, 500 ml, 8-oz. SOIL SAMPLE JARS, PH, COND. METERS
- STAY IN FARMINGTON? SEE FOR CHRIS P.

○ CIBOLA MED. $262

- ☐ CHECK OUT VEH. FROM BEVERLY) NEZ
- ☐ GET TA B4
- ☐ "BOYS" AGAIN

☆ MONTHLY REPORT - APRIL 27, 1990

NSO :: NEPA SAME

◇ BMB: "REG. IX - LEAD AGENCY"

*30 ◇ CEQ: IS MANDATED TO DO THIS

LOUISE: HOLA

REFERENCE # 15

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

RADIATION PROTECTION CATALOG

Eberline A subsidiary of Thermo Instrument Systems Inc.

P.O. Box 2108
Santa Fe, New Mexico 87504-2108
(505) 471-3232 TLX: 66-0438 EIC SFE

Eberline *A subsidiary of* **Thermo Instrument** *Systems Inc.*

Service Centers

CERTIFIED CALIBRATION REPAIR

Eberline Instruments, Certified Calibration ("non-removable" contaminated instruments also calibrated)	Call Service center for prices
Other Manufacturer's Instruments, Certified Calibration	$115.00 each
Repair Rate above Calibration plus Parts at List Price	$ 70.00/hour
Repair Rate above Calibration plus Parts at List Price for "non-removable" contaminated instruments	$ 87.50/hour

Contractual rates are available for periodic repair and/or calibration. Contact Service Centers for prices.

Technical Specification Writing and Consultation	Call Service Center for prices
Service Engineer at Customer's site	$730/day plus expenses at cost

MISCELLANEOUS

1. Turn Around Time:

   Calibration: Seven (7) working days on Eberline Instruments.
   Repair: Fifteen (15) working days on Eberline instruments unless parts have to be ordered.

2. FOB Santa Fe, New Mexico, or West Columbia, South Carolina.

3. Instruments for warranty repair, repair, or calibration must be sent to:

   Instrument Repair and Calibration
   Eberline Instrument Corporation
   P.O. Box 2108, 504 Airport Road
   Santa Fe, New Mexico 87504-2108
   Telephone: (505)471-3232
   1-800-274-4212

   Instrument Repair and Calibration
   Eberline Instrument Corporation
   312 Miami Street
   West Columbia, South Carolina 29169
   Telephone: (803)796-3604
   1-800-234-4212

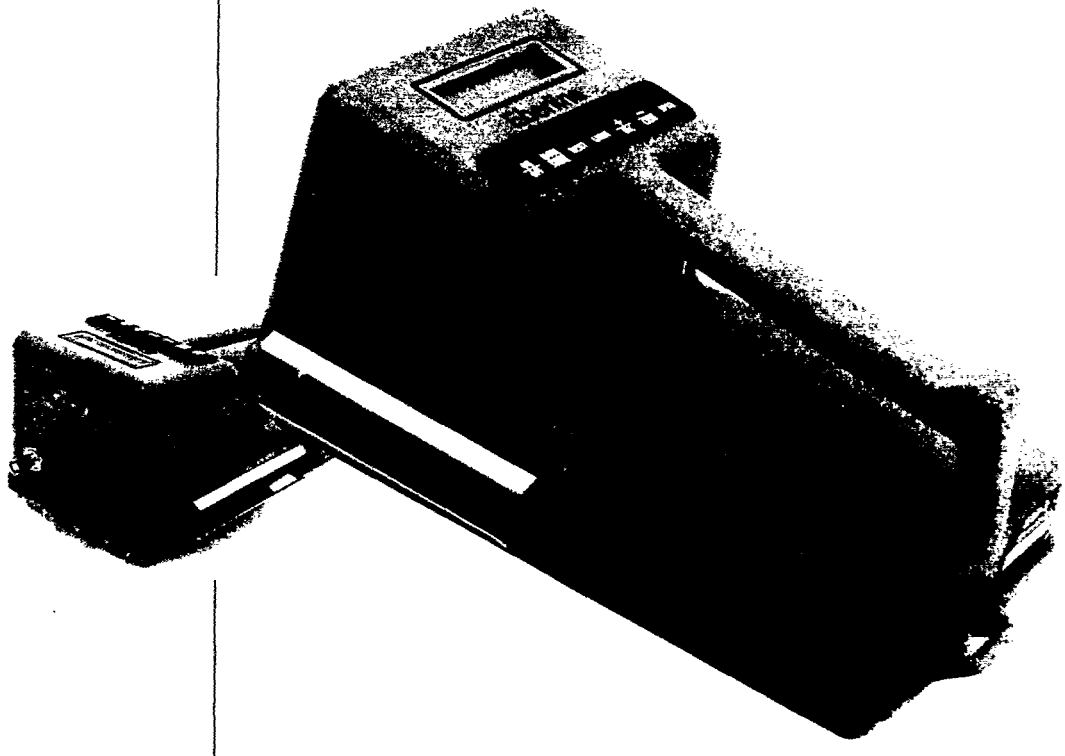
4. In addition, the following Customer Service Center is available for customers outside the United States:

   Thermo Electron, Ltd.
   Woolborough Lane
   Crawley, West Sussex
   England, RH10 2AQ

Prices at this location will vary from U.S. prices. Please contact the facility for current price and delivery information.

December 1987

Eberline Smart Portable Model ESP-2



- DATA LOGGING MICROCOMPUTER-BASED SURVEY INSTRUMENT WHICH STORES SURVEY READINGS FOR LATER OUTPUT TO A PRINTER OR PERSONAL COMPUTER
- OPERATES WITH VIRTUALLY ALL EBERLINE DETECTORS TO MEASURE ALPHA, BETA, GAMMA, X-RAY AND NEUTRON RADIATION
- AUTOMATICALLY SETS PROPER HIGH VOLTAGE, CALIBRATION CONSTANT AND DEAD TIME WHEN THE USER SPECIFIES THE DETECTOR CONNECTED TO IT
- OFFERS EXTENDED RANGE WITH AUTOMATIC DEAD TIME CORRECTION
- OPTIONAL PULSE HEIGHT ANALYSIS (PHA) CAPABILITY AVAILABLE FOR MULTIPLE ISOTOPE DISCRIMINATION
- FUNCTIONS AS A RATEMETER OR SCALER

Model ESP-2, Eberline Smart Portable

GENERAL DESCRIPTION

The Eberline Smart Portable, Model ESP-2, offers a significant advancement over currently available survey instruments. It incorporates a microcomputer with storage capability for approximately 500 separately identifiable data points. Data can be transferred to a personal computer, or to a printer to produce hard copy, via an RS-232C serial interface port. For the many users who make large numbers of routine surveys, the ESP-2 will provide significant savings of manpower as well as accuracy of data transfer.

Any data transferred to a personal computer will include number, detector, user identification, operating mode, instrument calibration settings and instrument operating status. Thus, a hard copy record is available for regulatory or legal records of instrument operating conditions during the survey. This should be especially useful for radiation safety offices, health physics departments, nuclear medicine departments, research laboratories, or any application where hard copy records are needed.

The ESP-2 is designed for use with GM, scintillation and proportional detectors with which it is capable of measuring alpha, beta, gamma, x-ray and neutron radiation. It can function as a ratemeter or scaler and displays appropriate radiation units along with the data. Ratemeter readings are displayed in both digital and analog (bar graph) format to overcome trend-indicating problems of other digital instruments. Microcomputer-based, the ESP-2 corrects for coincidence loss so that the upper limit of the range of each detector is increased by a factor of ten or more. Single-channel pulse height analysis (PHA) capability is also available (optional).

Inventory savings can be significant by using the ESP-2. This instrument will perform the functions of many other radiation survey instruments when coupled with detector probes available as accessories. One detector probe can be used to measure gamma exposure, another to measure beta contamination and another to measure neutron dose equivalent. With appropriate detectors, the ESP-2 can replace virtually all of Eberline's portable ratemeters and scalers.

Ease of operation is another reason for using the ESP-2. Parameters can be pre-set for three different detectors and by menu selection the ESP-2 will automatically adjust to the high voltage and calibration parameters as pre-selected for the detectors chosen. The high voltage adjustment is placed under computer control; thus, the high voltage can actually be changed via the keypad. Once the instrument has been calibrated to three different detector probes, keypad access can be denied to any user who does not know the password. Thus, the instrument operator can use three different detectors without any fear that he may accidentally change an important parameter.

SPECIFICATIONS

INTERNAL CONTROLS

Internal adjustment controls, located behind a splash-proof door on the right side of the ESP-2, include the following:

1) discriminator (sensitivity variable from 0.75 to 15 mV)
2) display viewing angle
3) detector pulse rate to speaker (scale ratios of 1:1, 1:64, 1:256)

EXTERNAL CONTROLS

All external controls are on a single row of seven momentary push-button switches. The switches are 3/8-inch square buttons on ½-inch centers. Functions controlled are: "ON/OFF," "MODE/STORE," "RESET," "LIGHT," "+," "-" and "SPKR."

OPERATING MODES

Ratemeter Mode

In the ratemeter mode, the microcomputer calculates counts per second, divides by the calibration factor and displays the digital value along with the appropriate units selected. Count rate is also displayed on a bar graph (analog), the length of which is proportional to the detector count rate. If the bar graph goes off-scale, the operator can adjust the scale with one push of the "RESET" button.

When the alarm level is exceeded, an alarm is sounded (2000 Hz tone) on the speaker. This is sounded even if the built-in speaker is turned off. Pressing the SPKR button acknowledges the alarm and turns it off.

Another feature available in the ratemeter mode of operation is the "peak trap" function. When operating in this mode, pressing the "STORE" key causes the maximum reading to be stored in memory. If peak mode has not been selected, pressing "STORE" simply causes the current reading to be stored in memory.

Scaler Mode

In the scaler mode, the detector signal is integrated for the selected count time (one second to four hours). Time remaining is displayed on the top line. Integrated value and units of readout are displayed on the bottom line. For example, if the HP-270 probe is used, integrated exposure in mR can be displayed. Similarly, dis/min can be displayed for the HP-210T or HP-260 probe.

When integrated counts exceed selected alarm setting, the alarm sounds. This feature can be used to tell a work party when to leave a radiation area.

An automatic store mode ("autorecycle function") is available in conjunction with the scaler mode. At the completion of the count cycle, the results are logged to memory and the cycle re-started. This feature can be used with a radon gas detector to function as a continuous radon gas monitor. Many other similar applications are possible.

Another function is provided under scaler mode which allows the user to program the scaler to count until a pre-set number of events have occurred (and thus a fixed statistical accuracy attained). This mode can be used with either the manual or automatic store modes.

Inquiry/Calibration Mode

Five different access levels are available with the ESP-2 and can be used to prevent unauthorized users from changing parameters which affect calibration and operation. The user can be limited to storing data points only, to selecting detectors, to setting the clock, or being able to change baud rate and calibration constants. All access levels where parameters can be changed are capable of being under password protection via the keypad.

Operating parameters that may be selected in the inquiry/calibration mode include units, calibration factor, detector dead time, alarm setting, operating mode, detector select and detector high voltage.

When the ESP-2 is being calibrated, any combination of the following readout units may be selected.

Prefix	**Base Unit**	**Time Unit**
none	R	s
u	rem	min
m	Sv	h
k	Gy	
auto	Cnt	
	dis	Example: mR/h
	rad	

By selecting the auto prefix in the menu, the detector readings are displayed in floating point (non-scientific notation) format with the prefix automatically adjusting to keep the reading within the three digit range. Depending on the calibration, this could allow as many as twelve decades of readout without going to scientific notation.

DATA LOGGING FEATURES

Data can be logged to memory in the ESP-2. The storage capacity, 8k bytes of random access memory (RAM), is approximately 500 points. Each point can be defined with a set of parameters to make it a unique data entry.

A routine ovided to allow the user to enter parameters which will be tied to all subsequent data. A nine digit numeric code can be entered to identify the user, such as a social security number. A six digit numeric code can be entered to identify the instrument. A thirteen digit alphanumeric code is used to identify the detector being utilized. An example of this could be: HP260 s/n 943.

The data logging mode requires the user to press the "STORE" key in order to log a data point to memory. This can be done in either the ratemeter or the scaler mode. The value stored is tied to the current date/time, through the use of an on-board real-time clock, as well as the current location code, which can be changed at any time by the user changing one or more digits of a six digit identifier. If the user does not enter a new identifier, the ESP-2 will automatically increment the location code.

Associated with the automatic store function under the scaler mode is the ability to output each data point to the peripheral in addition to storing it in memory after the cycle is completed (in strip chart fashion).

An RS-232C port is configured for use on the ESP-2. This port is flexible enough to meet a variety of needs. All transmissions are in ASCII notation eliminating the need for decoding software in the peripheral device. Standard baud rates from 150 to 9600 can be set through the keyboard.

A typical printout might look something like the following:

```
JUN 15, 86 1230
INSTRUMENT #                          000000
USER I.D. #                        000000000
DET: #1
MODE: RATEMETER
CALIB. CONSTANT                     1.00E + 00
DEAD TIME (SEC)                     9.98E-07
HIGH VOLTAGE                        5.00E + 02

                        LOC.      cnt/min    STAT
06/15/86  1230        000000  3.96E + 03
06/15/86  1230        000001  3.93E + 03
```

BATTERY

Six standard alkaline "C" cell batteries provide approximately 300 hours continuous use (excluding display lighting). The ESP-2 senses low battery condition at 0.95 V/cell and signals to the operator by blinking the first character on the display. After low battery is first detected, at least four hours of use remains. An internal capacitor is used to supply power to the computer and prevent loss of calibration parameters for about 20 minutes while the batteries are being changed.

Non-volatile memory data is retained even after the ESP-2 is turned off. Battery drain with power off is negligible.

As a protective feature, the battery compartment is separated from other internal components.

OTHER SPECIFICATIONS

Dimensions: 5.0 inches high × 5.0 inches wide × 10.25 inches long (12.7 cm × 12.7 cm × 26.0 cm)
Temperature Range: -4°F to +122°F (-20°C to +50°C)

Weight: 4.1 pounds (1.86 kg)
Connectors: MHV for detector input, 9-pin "D" shell female connector for RS-232C communication

DETECTOR PROBES RECOMMENDED FOR USE WITH ESP-2

Model No.	Type Measurement	Useful Range with ESP-2	5 Percent*
HP-270	Exposure or Exposure Rate	Bkg to 3000 mR/h	1 to 3000 mR/h
HP-290	Exposure or Exposure Rate	0.0005 to 80 R/h	0.01 to 80 R/h
HP-210L HP-260	Beta-Gamma Contamination	Bkg to 100,000 counts/s	14 to 100,000 counts/s
AC-3	Alpha Contamination	Bkg to 50,000 counts/s	14 to 50,000 counts/s
NRD	Neutron Dose Equivalent or Dose Equivalent Rate	0.001 to 60 rem/h	0.02 to 60 rem/h
LEG-1	Low Energy Gamma or x-ray	Bkg to 50,000 counts/s	14 to 50,000 counts/s
SPA-3	High Sensitivity Gamma	Bkg to 50,000 counts/s	14 to 50,000 counts/s
SPA-6	Medium Sensitivity Gamma	Bkg to 50,000 counts/s	14 to 50,000 counts/s

*Ratemeter mode provides 5 percent, or better, standard deviation readout capability over the indicated range.

ACCESSORIES

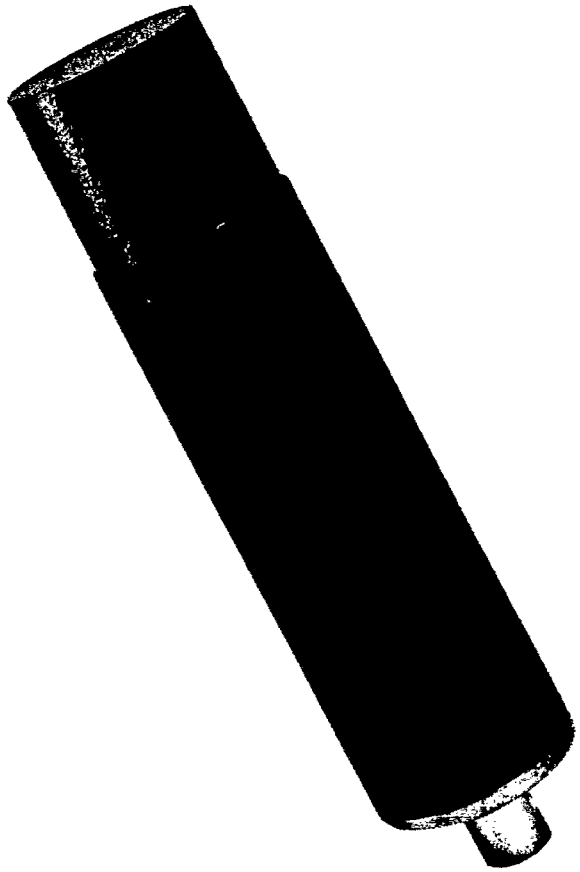
Audio Headset: Part No. ADHS4

Any of the following Eberline detectors can be used with the ESP-2:

Detector Probe	Cable	Check Sources	Probe Holder/Bracket
AC-3	CA-12-60	CS-1, CS-10, CS-12, CS-15	
HP-190A	CA-16-60	CS-7A	ZP10434029
HP-210AL	CA-16-60	CS-13	
HP-210L	CA-16-60	CS-13	
HP-210T	CA-16-60	CS-13	
HP-220A	CA-16-60		
HP-260	CA-16-60	CS-13	ZP10434029
HP-270	CA-16-60	CS-7A	ZP10434029
HP-280	CA-15-36		
HP-290	CA-16-60		ZP10434029
LEG-1	CA-12-60		
NRD	CA-15-60		ZP11292020
PG-2	CA-12-60		
SPA-3	CA-12-60	CS-7B	ZP10465017
SPA-6	CA-15-36	CS-7B	ZP10465017
SPA-8	CA-15-36	CS-7B	
SPA-9	CA-15-36	CS-7B	ZP10465017

Scintillation Probe

Model SPA-3



- HIGH GAMMA SENSITIVITY
- 2-INCH × 2-INCH NaI (Tl) CRYSTAL
- RUGGED CONSTRUCTION

Eberline *A subsidiary of* ***Thermo Instrument*** *Systems Inc.*

Model SPA-3, Scintillation Probe

GENERAL DESCRIPTION

The Model SPA-3 scintillation probe is a rugged, waterproof gamma detector designed for high sensitivity of pulse-height applications.

The SPA-3 contains a 2-inch-diameter, 2-inch-long NaI(Tl) crystal, a 2-inch, 10-stage photomultiplier tube, tube socket with a dynode resistor string, and a magnetic shield.

SPECIFICATIONS

Crystal: NaI(Tl), 2-inch-diameter × 2 inches long (5.1 cm × 5.1 cm).

Photomultiplier Tube: ≅2-inch-diameter, 10-dynode, end-window with S-11 photocathode.

Operating Voltage: Variable dependent upon application.

Maximum Voltage: +1600 V

Sensitivity: ≅1200k cpm per mR/h with ^{137}Cs

Current Drain: ≅120 MΩ resistance string yields 10 μA at 1200 V.

Wall Material: Aluminum

Wall Thickness: 1/8-inch (0.32 cm), 1/16-inch (0.16 cm) at crystal

Connector: Mates with Eberline CP-1

Finish: Enameled body with chrome-plated connector

Size: 2 5/8-inch-diameter × 11 1/8 inches long (6.7 cm × 28.3 cm)

Weight: 3.25 pounds (1.5 kg)

AVAILABLE ACCESSORIES

Instruments	Cables
ASP-1	CA-12-60
ESP-1	CA-12-60
ESP-2	CA-12-60
ESP-2/PHA	CA-12-60
MS-2	CA-12-60
RM-20	CA-12-60
RM-21	CA-12-60
RM-23	CA-12-60
SAM-2	CA-12-60
SRM-100	CA-12-60
SRM-200	CA-12-60
SRM-200PHA	CA-12-60

Eberline
A subsidiary of Thermo Instrument Systems Inc.

P.O. Box 2108
Santa Fe, New Mexico 87504-2108
(505) 471-3232 TLX: 66-0438 EIC SFE
Telecopy: (505) 473-9221

Model SPA-3, Scintillation Probe

GENERAL DESCRIPTION

The Model SPA-3 scintillation probe is a rugged, waterproof gamma detector designed for high sensitivity of pulse-height applications.

The SPA-3 contains a 2-inch-diameter, 2-inch-long NaI(Tl) crystal, a 2-inch, 10-stage photomultiplier tube, tube socket with a dynode resistor string, and a magnetic shield.

SPECIFICATIONS

Crystal: NaI(Tl), 2-inch-diameter × 2 inches long (5.1 cm × 5.1 cm)

Photomultiplier Tube: ≅2-inch-diameter, 10-dynode, end-window with S-11 photocathode.

Operating Voltage: Variable dependent upon application.

Maximum Voltage: +1600 V

Sensitivity: ≅1200k cpm per mR/h with ^{137}Cs

Current Drain: ≅120 MΩ resistance string yields 10 μA at 1200 V.

Wall Material: Aluminum

Wall Thickness: ⅛-inch (0.32 cm), 1/16-inch (0.16 cm) at crystal

Connector: Mates with Eberline CP-1

Finish: Enameled body with chrome-plated connector

Size: 2⅝-inch-diameter × 11⅛ inches long (6.7 cm × 28.3 cm)

Weight: 3.25 pounds (1.5 kg)

AVAILABLE ACCESSORIES

Instruments	Cables
ASP-1	CA-12-60
ESP-1	CA-12-60
ESP-2	CA-12-60
ESP-2/PHA	CA-12-60
MS-2	CA-12-60
RM-20	CA-12-60
RM-21	CA-12-60
RM-23	CA-12-60
SAM-2	CA-12-60
SRM-100	CA-12-60
SRM-200	CA-12-60
SRM-200PHA	CA-12-60

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Telecopy: (505) 473-9221

REFERENCE # 16

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

CONTACT REPORT

Meeting: ( ) **Telephone:** (X) **Other:** ( )

CONTACT LOCATION: NAVAJO SUPERFUND OFFICE

ADDRESS: P. O. BOX 2946, WINDOW ROCK, AZ 86515

PERSON CONTACTED AND TITLE : MIKE HOLONA, RANGER, NAVAJO FISH AND WILDLIFE

PHONE: (602) 871 - 1452

FROM (Contacting Party) : PATRICK MOLLOY, HEALTH PHYSICIST, NAVAJO SUPERFUND OFFICE

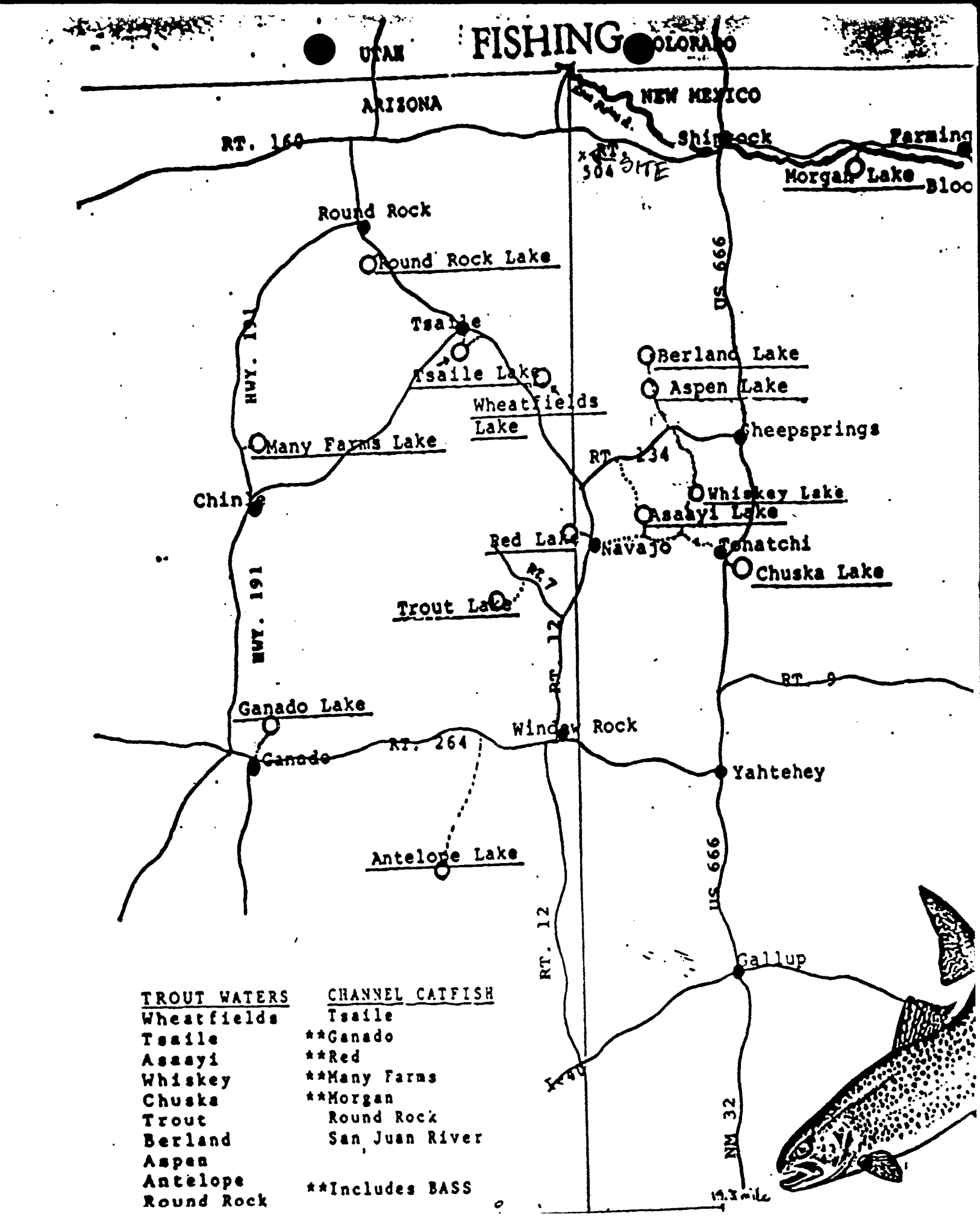
DATE : MAY 10,1990

SUBJECT: FISHERIES, HUNT UNITS AND RECREATIONAL AREAS IN HAYSTACK MOUNTAIN AREA

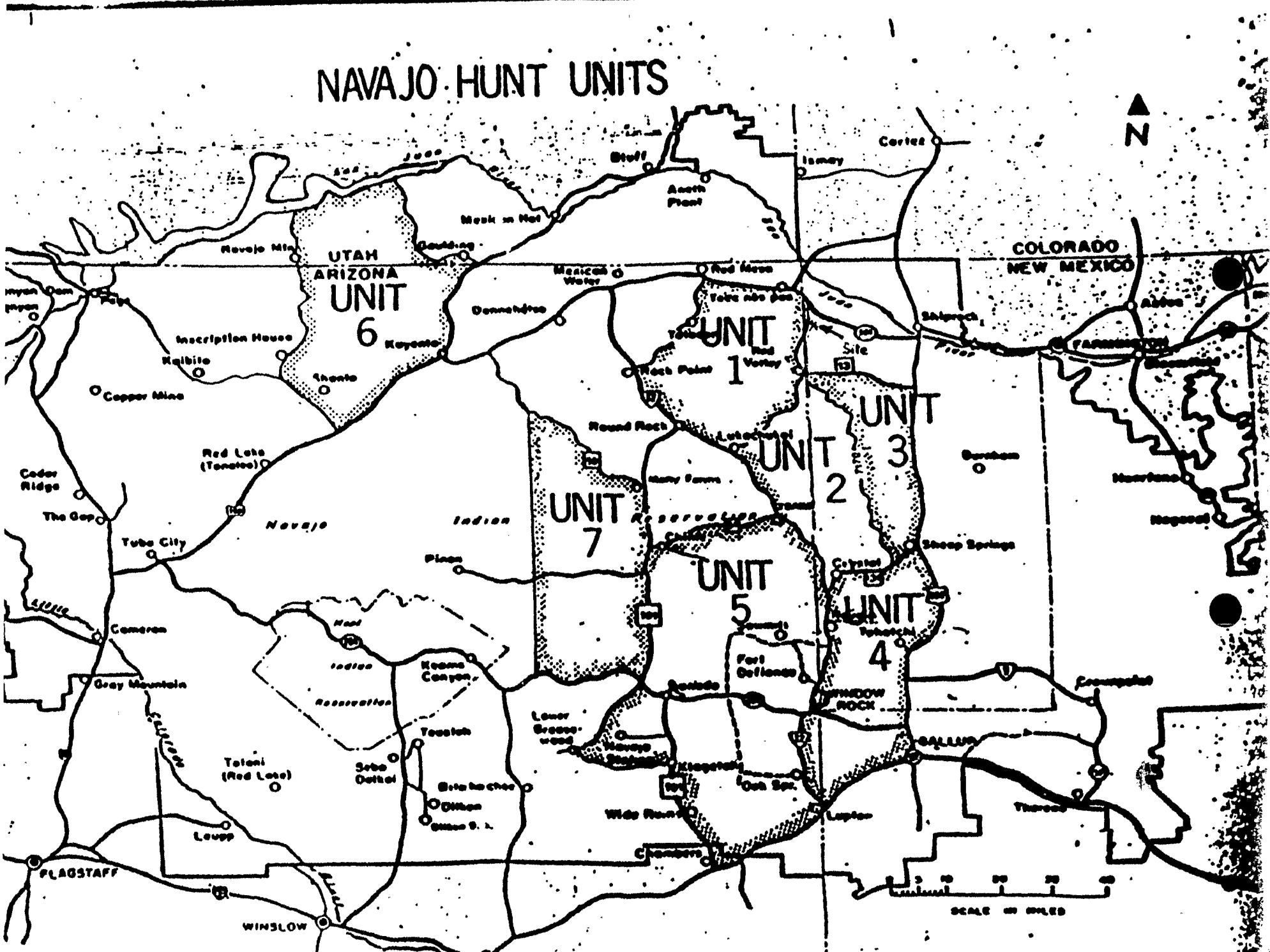
CONTACT SUMMARY REPORT:

(1) THERE ARE NO FISHERIES IN THE HAYSTACK MOUNTAIN AREA

(2) THERE ARE NO NAVAJO HUNT UNITS OR OTHER DESIGNATED RECREATIONAL AREAS IN THE HAYSTACK MOUNTAIN AREA


FISHING
UTAH
COLORADO
NEW MEXICO
ARIZONA
RT. 160
Shiprock
Farming
RT 504
SITE
Morgan Lake
Bloo
Round Rock
Round Rock Lake
US 666
HWY. 191
Tsaile
Tsaile Lake
Wheatfields Lake
Many Farms Lake
Berland Lake
Aspen Lake
Sheepsprings
RT 134
Whiskey Lake
Asaayi Lake
Chinle
Red Lake
Navajo
Tonatchi
Chuska Lake
Trout Lake
RT 12
RT 9
Ganado Lake
Window Rock
Ganado
RT. 264
Yahtehey
Antelope Lake
US 666
RT. 12
Gallup
NM 32
TROUT WATERS
Wheatfields
Tsaile
Asaayi
Whiskey
Chuska
Trout
Berland
Aspen
Antelope
Round Rock
CHANNEL CATFISH
Tsaile
**Ganado
**Red
**Many Farms
**Morgan
Round Rock
San Juan River
**Includes BASS

NAVAJO HUNT UNITS



REFERENCE # 17

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

3682

Brown Vanderwier
Mine

CONTACT REPORT

Meeting: ( ) Telephone: (X) Other: ( )

Contact Location: Navajo Nation Minerals Department

Address: P.O. Box 308, Window Rock, Arizoona 86515

Person, Title, Contacted: Rich Koch, Geologist

From: Pat Molloy PCM

Date: April 18, 1989

Subject: Leases - Navajo Lands Uranium Mines

Contact Summary Report:

Pre 1960's Uranium Mines -- no records now with tribe. All leases for mines worked before 1960 are presume to be expired.

Minerals department not existence until late 60's. No documents or records on these mines indicating lease holders are in existence with this department.

REFERENCE # 18

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

CHRIS PETRE
ICF/KAISER IND.
1509 MAIN ST.
SUITE 900
DALLAS, TX 75201

(214) 744-1641
AND CALL D. VAUGHN-WRIGHT FOR HELP REQUEST

*** PAGE#1 ***

MAY 11, 1990; HAYSTACK
- B'GRND CK. @ TURNOFF TO HAYSTACK B.
  - L#19 @ SHINE - 6 μR.hr⁻¹
  - ESP-II @ - 6.3 (10³) cpm
  - BROKEN CLOUDS, WINDY
- START 21839.0
  - 21841.1: SW OF PT. OF HAYSTACK B.: 4* RES. NOT ON IHS HOOKUP
  (NOTATION: R* - NOT ON IHS HOOKUP)
  - 21841.8: 1* - DUE W OF HAYSTACK B.
- @ NE OF HAYSTACK B. ¼ MI.
  - L#19 - 7 μR.hr⁻¹
  - ESP II - 6.8 (10³) cpm
- @ 21846.2: 3* RES.
- @ 21848.0; 16T-521 STOCKWATER
  - USED INFREQUENTLY
- @ 21849.5: 1 FRAME
  - DUE E OF B.V. OUTFIT
  - E TRENDING DRAINAGE
  - NOTE RES
  MIDDLE C
- @ TURNOF
  - OLD HAL
    - L#19 -
    - ESP II -
    - EVIDEN
    = OLD RADIOS
    E.
- @ DUE S
  2 FRAME
  - FRAME
  OF N. U
  - FRAME
  DR. S
  - L#19 -
  - ESP-II -
  - @ FACE
  2.6 (1
- NOTE SHE
  GROUND
  TING TH
  MUTH
- HAYSTACK
  DISTRIBUTI
  TO IHS U
  SYSTEM "A
- APPROXIM
  RES (DENC
  UP
- ESTIMATI

- NOTE RES. ON HORIZON
MIDDLEGROUND: B.V. OUTFIT
- @ TURNOFF TO B.V. OUTFIT
  - OLD HAULAGE ROAD
    - L#19 - RANGE: 12-20 μR·hr⁻¹
    - ESP II - " : 10^4 - $1.4(10^4)$ cpm
    - EVIDENCE OF NEW ROAD = OLD HAULAGE ROAD, RADIO STUFF MIGRATING E.
- @ DUE S OF N. VANDEVER: 2 FRAMES
  - FRAME #2 - DRAINAGE SSW OF N. VANDEVER WORKS
  - FRAME #3 - ACROSS ROAD, DR. S OF N. VANDEVER
  - L#19 - RANGE: 11-22 μR·hr
  - ESP-II - " : 1.1 - $2.5(10^4)$ cpm
  - @ FACE OF MIN. ROCK $2.6(10^5)$ cpm
- NOTE SHEEP IN CTR MIDDLEGROUND FR#2. SHEEP GETTING THEIR RED HOT BISMUTH
- HAYSTACK COMMUNITY POPULA- DISTRIBUTION CORRESPONDS TO IHS WATER DISTRIBUTION SYSTEM "AS BUILT"
- APPROXIMATELY 15% OF RESIDENCES NOT HOOKED UP
- ESTIMATE POPULATION OF

4-MILE RADIUS-OF-INFLUENCE (RELATIVE TO B. VANDEVER MINE) AT 500, 75 OF WHICH ARE NOT HOOKED UP TO IHS WATER SYS.

REFERENCE # 19

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

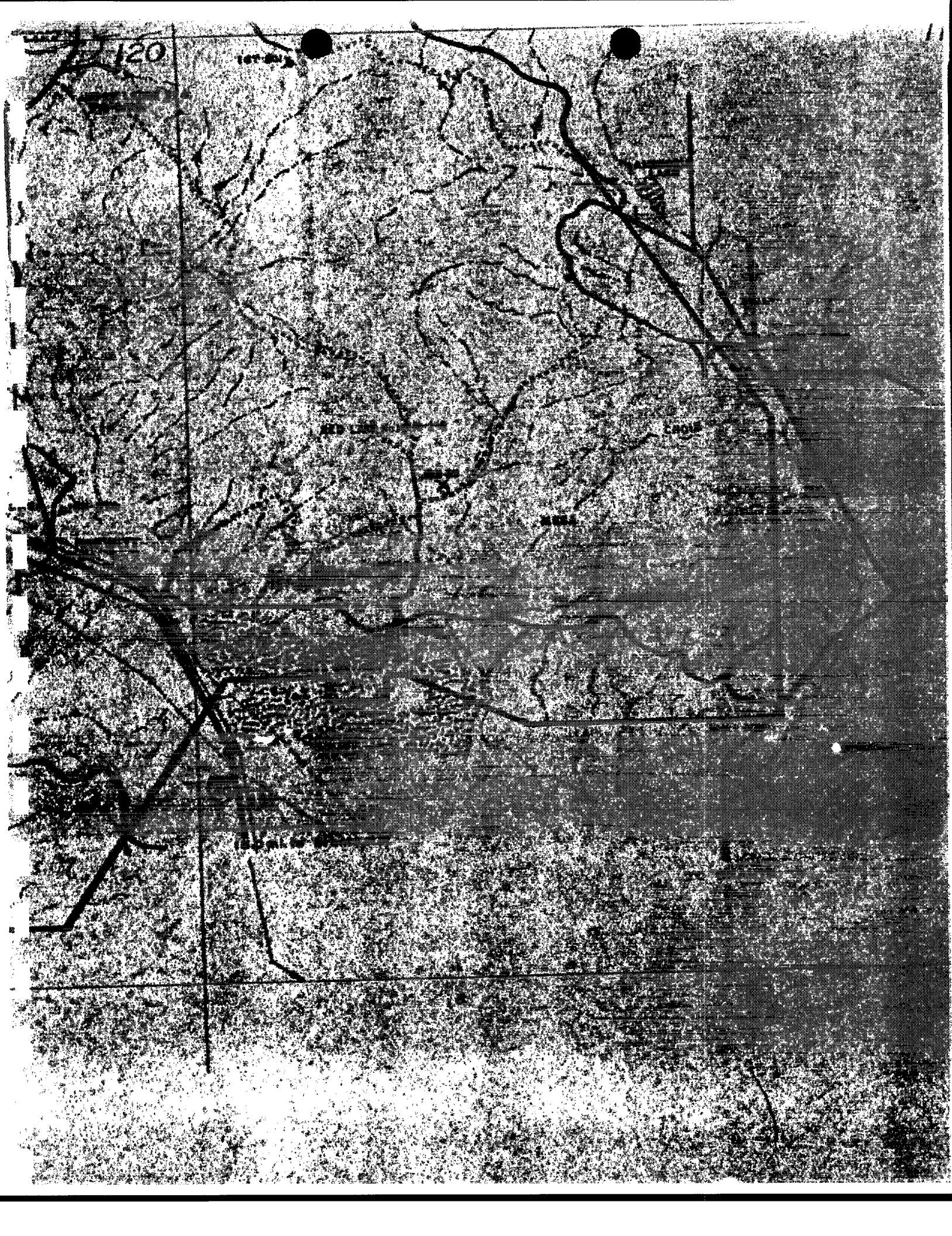
MAY,'90 P. MOLLOY

coordinates for centroid easting = 777975 meters northing = 3915441 mete

search distance from centroid 6500 meters east 6500 meters west
6500 meters north 6500 meters south

window coordinates > minimum east minimum north maximum east maximum north
771475 3908941 784475 3921941

WELLNO	EAST	NORTH	DRILLED	DEPTH	SWL	AQUIFER	OPERATOR
00-3289	780150	3909728	/ /	351.0	64.0	231CHNL	BERRYHILL
00-3332	780150	3909728	1/ 1/57	725.0	243.7	313SADG	BERRYHILL
00-3341	773644	3910762	11/ 5/57	200.0	60.4	231CHNL	GIBBS
16B-38	779911	3919037	5/12/36	357.0	331.0	221SMVR	TRIBE O&M
16T-521	778415	3916740	11/13/63	414.0	365.0	221ENRD	TRIBE O&M
16T-522	782794	3915615	0/ 0/ 0	270.0	0.0		TRIBE O&M
16T-551	779489	3915538	9/17/69	1083.0	417.0	231SNSL	TRIBE O&M
16T-552	774942	3916262	10/ 9/69	1268.0	362.0	231CHNL	TRIBE O&M
16T-586	778600	3917300	6/18/76	2400.0	47.0		TRIBE O&M



TRIBAL WELL RECORD
LOCATION FILE

ENTERED OCT 13 1986 MR

TRIBAL WELL NO [1][6][T][-][5][2][1][ ][ ][ ][ ] PWSID [ ][ ][ ][ ][ ][ ][ ][ ][ ]

WELL NAME/OTHER NO [ ]

WELL TYPE (MARK ONE ONLY)

- (✓) WW WATER WELL
- ( ) WA ARTESIAN WELL
- ( ) WS SPRING
- ( ) OW OBSERVATION WELL
- ( ) GS GAS WELL
- ( ) OP OIL PRODUCTION
- ( ) MW MINERAL WELL

WELL STATUS (MARK ONE ONLY)

- (✓) ACT ACTIVE
- ( ) INA INACTIVE
- ( ) ABA ABANDONED

WELL USE (MARK ONE ONLY)

- ( ) DOM DOMESTIC
- ( ) AGR AGRICULT.
- (✓) LIVESTOCK
- ( ) IND INDUSTRIAL
- MINING
- ( ) REC RECREATION
- ( ) MUN MUNICIPAL
- ( ) OTH OTHER

QUAD NO [1][1][9] MILES WEST [1][0].[5][0] MILES SOUTH [1][0].[0][0]

NE SE SW (NW) / NE SE SW (NW) / NE (SE) SW NW [1][8] SECT. [T][1][3].[0][N] TOWNSHIP [R][1][0].[0][W] RANGE
10 acre 40 acre 160 acre

APPROXIMATE LOCATION [6] [M][I][L][E][S] [E][A][S][T] [O][F] [P][R][E][W][I][T][T] [ ]

[ ][ ][ ][ ][ ][ ][ ][ ][ ] LATITUDE [3][5][2][1][2][6] LONGITUDE [1][0][7][5][6][1][0]

UTM COORDINATES: X(east) [ ][ ][ ][ ][ ][ ] Y(north) [ ][ ][ ][ ][ ][ ][ ] ZONE [ ][ ]

OPERATOR [T][R][1][B][E] [O][I][L] [ ] USGS WATERSHED CODE [ ][ ][ ][ ][ ][ ][ ][ ][ ][ ]

STATE: ( ) AZ ARIZONA (✓) NM NEW MEXICO ( ) UT UTAH ( ) CO COLORADO

COUNTY:
( ) AP APACHE (✓) MK MCKINLEY ( ) SJ SAN JUAN ( ) MT MONTEZUMA
( ) NA NAVAJO ( ) VL VALENCIA ( ) KA KANE ( ) LP LA PLATA
( ) CO COCNINO ( ) BL BERNALLILLO
( ) SD SANDOVAL
( ) SO SOCORRO GRAZING DISTRICT [1][6]
( ) RA RIO ARRIBA
( ) SA SAN JUAN

CHAPTER NAME BACA CHAPTER CODE [B][A][C][A]

LOCATION DATA SOURCE: [T][R][1][E][E], [B].[S][T][O][M][E] [R][T]-[6] [ ][ ][ ][ ][ ]

LOCATION FILE COMPLETED BY: Masood U. Zaman DATE 10/9/1986

FIELD CHECKED BY: [ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ] DATE __/__/__

rev:840425 form:well record loc

TRIBAL WELL RECORD
HYDROLOGY FILE

ENTERED OCT 13 1986 hr.

WELL NO [1]6]T-]5]2]1]]]]] USGS AQUIFER CODE [2]2]1]]E]N]R]D]

THICKNESS [ ]]]FT NOMINAL YIELD [ ]]]]GPM YIELD MEASURED __/__/__

( )BAILER ( )PUMP TEST @ [ ]]]3]GPM FOR[ ]]3].]0]HOURS DATE 11/13/1963

DRAWDOWN [ ]]]4]9]FT OBSERVATION WELL DATA AVAILABLE ( )YES (✓)NO

HORIZ CONDUCTIVITY[ ]]].]]]FT/DAY SPECIFIC CAPACITY[ ].]]]GPM/FT

VERT. CONDUCTIVITY[ ]]].]]] FT/DAY STORAGE COEF [.]]]]]]

COEF OF TRANSMISSIVITY [ ]]]]]] FT2/DAY

INDICATE ADDITIONAL PUMPING TEST DATA AVAILABLE AS HARD COPY:
( )Y ( )N MULTIPLE RATE DRAWDOWN PUMPING TEST
( )Y ( )N SINGLE RATE DRAWDOWN PUMPING TEST
( )Y ( )N MULTIPLE RATE DRAWDOWN/RECOVERY TEST
( )Y ( )N RECOVERY TEST

LOGS AVAILABLE: (✓)DL DRILLER'S LOG ( )EL ELECTRIC LOG

HYDROLOGY DATA SOURCE: [T]R]I]B]E]]]]]]]]]]]]]]]]]

HYDROLOGY FILE COMPLETED BY: M.Z. DATE 10/9/1986

SWL
ENTERED OCT 17 1986

STATIC WATER LEVEL FILE

DEPTH TO SWL 365 FT DATE 11/13/1963 DEPTH TO SWL_____FT DATE__/__/__

DEPTH TO SWL_____FT DATE__/__/__ DEPTH TO SWL_____FT DATE__/__/__

DEPTH TO SWL_____FT DATE__/__/__ DEPTH TO SWL_____FT DATE__/__/__

DEPTH TO SWL_____FT DATE__/__/__ DEPTH TO SWL_____FT DATE__/__/__

DEPTH TO SWL_____FT DATE__/__/__ DEPTH TO SWL_____FT DATE__/__/__

DEPTH TO SWL_____FT DATE__/__/__ DEPTH TO SWL_____FT DATE__/__/__

DEPTH TO SWL_____FT DATE__/__/__ DEPTH TO SWL_____FT DATE__/__/__

DEPTH TO SWL_____FT DATE__/__/__ DEPTH TO SWL_____FT DATE__/__/__

DEPTH TO SWL_____FT DATE__/__/__ DEPTH TO SWL_____FT DATE__/__/__

DEPTH TO SWL_____FT DATE__/__/__ DEPTH TO SWL_____FT DATE__/__/__

rev:840427 form: well record hyd

TRIBAL WELL RECORD
STRUCTURE FILE

ENTERED OCT 13 1986 HR

WELL NO [1][6][T]-[5][2][1][ ][ ][ ][ ] STARTED 10/15/1963 COMPLETED 11/13/1963

ELEVATION [ ][7][0][5][0] FT DEPTH [ ][ ][4][1][4] FT DEPTH MEASURED 11/13/1963

DEPTH IS (✓)MEASURED ( )ESTIMATED ( )REPORTED WELL DIA. [ ][8].[0][0] IN

1 CASING DIA [ ][6].[6][2] FROM[ ][ ][0][0] FT TO[ ][ ][4][1][4] FT MATL[S][T][L]

2 CASING DIA [ ][ ].[ ][ ] FROM[ ][ ][ ][ ][ ] FT TO[ ][ ][ ][ ][ ] FT MATL[ ][ ][ ]

3 CASING DIA [ ][ ].[ ][ ] FROM[ ][ ][ ][ ][ ] FT TO[ ][ ][ ][ ][ ] FT MATL[ ][ ][ ]

4 CASING DIA [ ][ ].[ ][ ] FROM[ ][ ][ ][ ][ ] FT TO[ ][ ][ ][ ][ ] FT MATL[ ][ ][ ]

casing matl codes brs=brass cop=copper evd=everdur irn=iron mon=monel
pls=plastic stl=steel sst=stainless steel

1 CASING PERFORATED FROM [ ][ ][3][8][0] FT TO[ ][ ][4][1][4] FT OPENING TYPE [P]

2 CASING PERFORATED FROM [ ][ ][ ][ ][ ] FT TO[ ][ ][ ][ ][ ] FT OPENING TYPE [ ]

3 CASING PERFORATED FROM [ ][ ][ ][ ][ ] FT TO[ ][ ][ ][ ][ ] FT OPENING TYPE [ ]

4 CASING PERFORATED FROM [ ][ ][ ][ ][ ] FT TO[ ][ ][ ][ ][ ] FT OPENING TYPE [ ]

5 CASING PERFORATED FROM [ ][ ][ ][ ][ ] FT TO[ ][ ][ ][ ][ ] FT OPENING TYPE [ ]

opening codes: f=fractured rock, l=louvered or shutter-type screen,
m=mesh screen, p=perforated,porous,slotted casing, r=wire-wound screen
s=screen,type unknown, t=sand point, w=walled or shored, x=open hole
z=other

DATE WELL TURNED OVER TO TRIBE: __/__/__

FUNDED BY: [T][R][I][B][E][ ][ ] CONTRACTOR: [T][R][I][B][E][ ][ ][ ][ ][ ][ ][ ][ ]

SITE IMPROVEMENTS
(✓)WM WINDMILL
(✓)WP WATERING POINT
(✓)TA TANK
( )WL WATER LINE
( )TR TROUGH
( )CS CISTERN
( )HP HAND PUMP
( )NO NONE

TYPE OF LIFT
( )AL AIRLIFT
(✓)PS PISTON
( )TU TURBINE
( )MT MULTIPLE TURBINE
( )CN CENTRIFUGAL
( )MC MULTIPLE CENTRIFUGAL
( )BU BUCKET
( )SU SUBMERSIBLE

ENERGY SOURCE
( )EM ELECTRIC MOTOR
( )DE DIESEL ENGINE
( )HA HAND
( )GS GAS ENGINE
( )LP LP GAS ENGINE
( )NG NATURAL GAS ENGINE
(✓)WM WINDMILL
( )SO SOLAR

PUMP HP [ ][ ][ ][ ] ON SITE STORAGE CAPACITY [ ][2][7][9][0][0] GAL

STRUCTURE DATA SOURCE: [T][R][I][B][E][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ]

STRUCTURE FILE COMPLETED BY: M.Z. DATE 10/9/1986

rev:840426 form: well record str

TRIBAL WELL RECORD
COMMENTS FILE

TRIBAL WELL NO [1][6][7]-[5][2][1][ ][ ][ ][ ]

PERTINENT
COMMENTS: water quality information on file.

— Additional 1000 gallons elevated tank for water hauling.

ENTERED OCT 13 1988 JM

rev:840430 form: well record com

Water Well Development
Navajo Tribe
Window Rock, Arizona

Project #6537
WELL NO 16T-521

Quad. No 119 Miles west 10.5 Miles south 10.0

6 miles East of Prewitt, New Mexico
Location

Began well October 15, 1963 Finished well November 13, 1963

Diameter of well 8" Depth of well 414'

Static water level 365' Drawdown 49' Recovery

Quantity of water on test run: bailer: pump: 3 G. P. M. Tested for 3 hours

Kind of casing: 6-5/8" Sizes and length 380' - 414' Perforated

Screen kind Length Mesh

Contractor THE NAVAJO TRIBE Address Window Rock, Arizona
Drillers: G. Williams, Self

LOG

DEPTH From	To	Formation	Acquifer	Remarks
0	40	Alluvium Fill	ALLUVIUM	
40	120	Sandstone	SOMMERVILLE	
120	205	Gray Lime - Hard		
205	230	White Lime		TODILTO
230	260	Gray Lime Hard		
260	280	Sandstone Hard		
280	380	Sandstone Hard	ENTRADA	
380	410	White sand soft	Water	
410	414	White lime hard		

PATRICK ANTONIO, STAFF HYDROGEOLOGIST
TO P. MOLLY, MAR 23, 1990

Remarks:

S.P. 750 Temp: 78°

Tota Salts	Calcium Ca.	Magnesium Mg.	Sodium Na.	Chlorides Cl.	Sulfates SO 4	Carbonates HCO 3	P.H.	CO 3

Excellent	Good	Fair	Poor	Doubtful	Not suitable for domestic, livestock use
	XXX				

NTRD - 61

WELL RECORD

Water Well Development
Navajo Tribe
Window Rock, Arizona

Project #6537
WELL NO. 16T-521

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6 miles East of Prewitt, New Mexico
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0	40	Alluvium Fill		
40	120	Sandstone		
120	205	Gray Lime - Hard		
205	230	White Lime		
230	260	Gray Lime Hard		
260	280	Sandstone Hard		
280	380	Sandstone Hard		
380	410	White sand soft	Water	
410	414	White lime hard		

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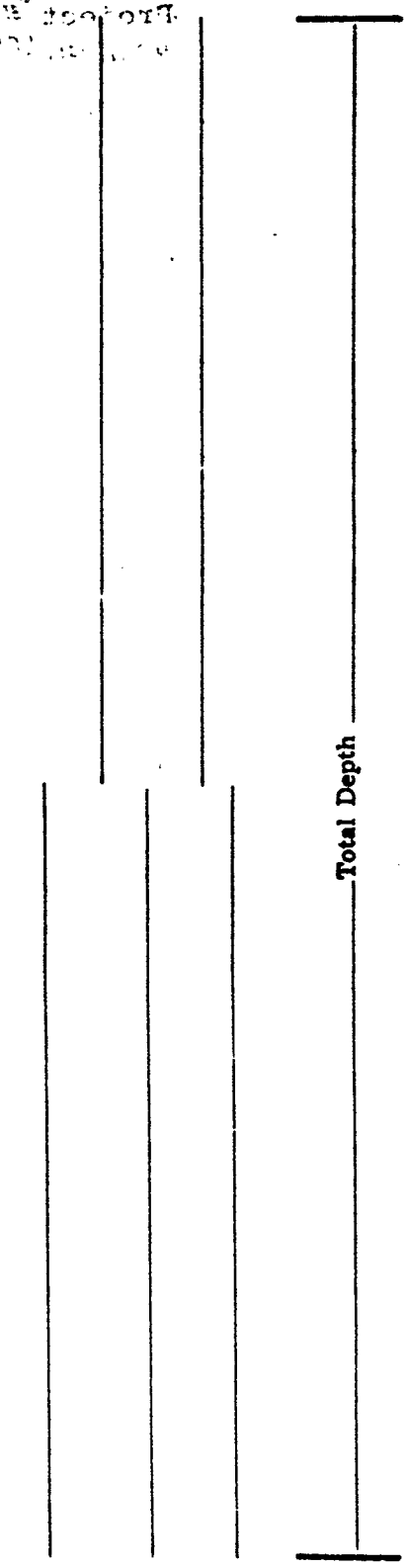
Teta Salts	Calcium Ca.	Magnesium Mg.	Sodium Na.	Chlorides CL	Sulfates SO_4	Carbonates HCO_3	P.H.	CO 3

Excellent	Good	Fair	Poor	Doubtful	Not suitable for domestic, livestock use
	XXX				

NIRD - 61



Cylinder size: _____

Tubing, cylinder and suction

pipe length in feet: 2" x

Kind of pump rod: _____

Size of box and pin: 3/4" x 7/8"

Liner, if any: _____

Windmill: (make) Aermotor

Size: 16'

Storage: (kind) Galv. & steel

Capacity: 1,000 gal. & 26,000 gal.

Troughs: (kind) No. 2 galv. - 12"x 12"x 12' -

Comments: _____

WATER RESOURCES DIVISION

WELL SCHEDULE

Date [illegible]

Record by [illegible] Office No.

Source of data [illegible]

1. Location: State New Mexico County [illegible]

Map [illegible] of Prewitt

¼ ¼ sec. 18 T 11 R 10

2. Owner: Tribe Address Window Rock

Tenant Address

Driller Bill Self - Tribe Address

3. Topography Gentle slope

4. Elevation 7050 E ft. above/below SL

5. Type: Dug, drilled, driven, bored, jetted [illegible] 19[illegible]

6. Depth: Rept. 414 ft. Meas. ft.

7. Casing: Diam. [illegible] in., to in., Type [illegible]

Depth 414 ft., Finish [illegible] Perf. 380-414

8. Chief Aquifer Entrada From ft. to ft.

Others

9. Water level 365 ft. rept/meas. 11-13 1963 above/below LS

which is ft. above/below surface

10. Pump: Type Capacity G. M.

Power: Kind Horsepower

11. Yield: Flow G. M., Pump G. M., Meas., Rept. Est.

Drawdown 49 ft. after 3 hours pumping 3 G. M.

12. Use: Dom., Stock, PS., RR., Ind., Irr., Obs.

Adequacy, permanence

13. Quality S.E. 750 Temp 78 °F.

Taste, odor, color Sample [illegible]-63

Unfit for

14. Remarks: (Log, Analyses, etc.) Drillers log on well record

Contacts on back

(OVER)

U. S. GOVERNMENT PRINTING OFFICE 16—[illegible] GPO 835013

USGS-WRD Form GN

16T-521

ANALYTICAL STATEMENT

Ariz. 6.16

COUNTY Mckinley

LAB NO. 53507

119

Location 10.5W x 10.0S 6 miles NE of Prewitt, N.M.

Source (type of well) Drilled

Owner Navajo Tribe Window Rock, Ariz.

Date drld Nov. '63 Cased to 414 ft

Depth 414' Diam 6 5/8"

WBF Entrada

Water level 365 ft below surf.

Sampled after pumping hrs

Yield 2 - 3 GPM (meas. or est)

Pt of coll Well

Appearance Reddish

Temp (°F) Use Dom., Stock

Collector Fred Zscach

Chemist EFW

Date completed Feb. 14, 1964

Checked by JON

Date of collection Nov. 15, 196[illegible]

Ignition Loss Color

Dissolved Solids:

Residue at 180°C

Calculated (Sum) 581

Tons per Acre Foot 0.79

Hardness as $CaCO_3$ 54

Non-carbonate Hardness 0

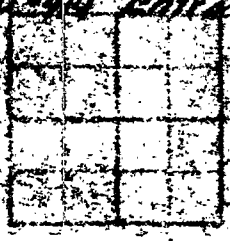
% Na 89 SAR 12 pH 7.9

Specific Conductance (micromhos at 25°C) 912

	epm	ppm
SiO_2		10
Fe		
Ca	0.95	19
Mg	0.13	1.6
Na		
K		
Na+K	8.86	204
HCO_3	6.82	416
CO_3	0.00	0
SO_4	2.58	124
Cl	0.42	15
F	0.11	2.0
NO_3	0.01	0.7
	9.94	

Mar. 3, 1964 Provisional record subject to revision.

Contacts



From Brittis Log		[illegible]	
0-40	Alluvium	0-20(?)	Alluvium
40-120	Summerville	20(?)-120	Summerville
120-260	Todilto ls.	120-180	Missing
260-[illegible]	Entrada	180-250	Todilto ls.
		250-[illegible]	[illegible]
		[illegible]	[illegible]

16T-521

THE NAVAJO TRIBE
Ground Water Development

11 June 1968
Date

MEMORANDUM

TO: Mr. Louis Tracy Acting Controller, Administration Division

THRU: Mr. Cato M. Sells, Superintendent, Ground Water Development CMS

FROM: Mr. Donald Dodge, Administrative Assistant, Ground Water Development

SUBJECT: Notice of Completion of Project Number 6537

We have inspected the work done under this project and find that it has been satisfactorily completed in accordance with plans and specifications of Ground Water Development Department.

Well No. 16T-521

Type of Project: Drilling, Windmill, and Tank Erection.

Appropriation: Base Account 6502A.50

Project No. 6537

Rod A. Hatathli
Director, Division of Resources

Approval Date

No further expenditures may be charged to the project.

DONALD DODGE, Administrative Assistant
Ground Water Development

DD:mlt

cc: Mr. Hatathli
Mr. Sells
Resources Committee
Well Folder
Chrono

REQUEST FOR PERMANENT WATER DEVELOPMENT

☒ Livestock ☒ Domestic Date: June 10, 1962

District: 16

☒ Drilled Well ☐ Spring

☐ Dug Well ☐ Charco ☐ Reservoir

Priority of Development Crown Point (Field) N. Mex. (Agency)

Land Status of Proposed Site: ☐ Tribal ☒ Allotted

Location Coordinates: T 13 N.R. 10 W

Allotted 024362 Sec. 22 S.W. ¼

Approximate distance to nearest permanent water _____ miles.

Identification No. of nearest permanent water development ___ direction ___

Remarks: The people are in need of water. in hay area. They have to water there sheep 5½ miles away every two days. and when there wind there no water, and enough for all of us to use. and that's hard for us.

☒ Livestock Water Development ☒ Domestic Water Development

K. E. Fargo
District Councilman

Wilson C. Keeto
Chairman, District Grazing Committee

Field Land Operations Officer

Tribal Water Development

APPROVED: Howard W. Gorman
Chairman, Tribal Resources Committee

Grace Desiderio
Con # 86395

(See reverse side for Policy and Instructions)

REQUEST FOR PERMANENT WATER DEVELOPMENT

Date: 6-16-63 District: #16

Livestock [X] Domestic [X] Dug Well [ ] Charco [ ]

Drilled Well [X] Spring [ ] Reservoir [ ]

Priority of Development _____ _____
Field Agency

Land Status of Proposed Site: _____ Tribal X Allotted

Location Coordinates: SECTION 18. NORTHEAST

Approximate distance to nearest permanent water Three miles.

Identification No. of nearest permanent water development _____

direction _____ Remarks: There are 14 family need water in This area

[X] Livestock Water Development [X] Domestic Water Development

Fred James
Chapter President

Clarence N. Warner
Chairman, District Grazing Committee

Tom Pickel
District Councilman

acting Tom Pickel
Field Representative, Subagency Resources Committee Member

Vern V. Kirsch
Field Land Operations Officer

Eddie M. Cohen
Agency Land Operations Officer

_____
Chairman, Tribal Resources Committee

_____
Navajo Tribal Ground Water Development

Quad-119 - 12.5W, 10.0S
4 miles - SE of Prewitt

Baca Chapter

Prewitt, New Mexico

February 11, 1963

The community people from Red Lake, Haystack, Bluewater and Baca Chapter House had a big meeting on February 2, 1963. The important meeting was about water development.

In the meeting the unanimous votes was to ask for three wells to be drilled in Haystack area.

The first person who made the agreement to have a well drilled on her five acres allotment was Helen Vandevere, C# 49539, on section 14 ~~east~~ West side of Haystack, S.W., T13 N.R., R11 west. She solomnly swore to lease her allotment for 99 years for water. AL. 059420

~~A sister to Helen Vandevere, Na Bah or Rose Vandevere also made an agreement and solomnly swore to have her five acres allotment, no.~~ 2751 (05942) ~~to be drilled for water and will lease it for 99 yrs.~~

PROBATED, Oct 6, 1944
Heirs were determined

Signed:

Helen Vandevere, C# 49539

Mother to Helen Vandever

Rose Vandevere (~~Na Bah~~)
11th Na bah or C# 6838

Deceased May 26, 1944

by [illegible]

cc:

Cato Sells, Head
Water Development
Window Rock, Arizona

Jack Martin
Water Development
Crownpoint, New Mexico

Helen Vandevere
Haystack
Prewitt, New Mexico

11Th NA Bank or
Rose Vandevere est
Haystack 6838
Prewitt, New Mexico
} Deceased May 26, 1944

Jimmie B. Largo
Councilman of Dist. 16
Thoreau, New Mexico

During the same meeting at Baca Chapter House, on February 2, 1963, Mrs. Mary Martinez Desidero, C# 6921, made an agreement and solomnly swore to have her five acres allotment to be drilled for water. She leased her allotment Section 18, northeast for 99 yrs.

Signed:

Mrs. Mary Martinez Desidero, C# 692

Mary Martinez Desidero

cc:

Cato Sells, Head
Water Development
Window Rock, Arizona

Jack Martin
Water Development
Crownpoint, New Mexico

Mary Martinez Desidero
Haystack
Prewitt, New Mexico

Jimmie B. Largo
Councilman of Dist. 16
Thoreau, New Mexico

by councilman J B Largo

During the same meeting at Baca Chapter House, on February 2, 1963, Grace Desidero made an agreement and solomnly swore to have her five acres allotment to be drilled for water. Mrs. Grace Desidero, C# 86395, leased her allotment, T. 13 N.R. 10 W. Section 22, Southwest ¼, and leased for 99 years.

Signed:

Grace Desidero, C# 86395

Grace Desidero

cci

Cato Sells, Head
Water Development
Window Rock, Arizona

Jack Martin
Water Development
Crownpoint, New Mexico

Grace Desidero
Haystack
Prewitt, New Mexico

Jimmie B. Largo
Councilman of Dist. 16
Thoreau, New Mexico

by councilman J B Largo

ENTERED NOV 26 1986

TRIBAL WE
LOCATIO

TRIBAL WELL NO [167-522] PWSID [ ]

WELL NAME/OTHER NO [ ]

WELL TYPE (MARK ONE ONLY)	WELL STATUS (MARK ONE ONLY)	WELL USE (MARK ONE ONLY)
(X) WW WATER WELL	( ) ACT ACTIVE	( ) DOM DOMESTIC
( ) WA ARTESIAN WELL	( ) INA INACTIVE	( ) AGR AGRICULT.
( ) WS SPRING	(X) ABA ABANDONED	(X) LIV LIVESTOCK
( ) OW OBSERVATION WELL	( ) UNK UNKNOWN	( ) IND INDUSTRIAL MINING
( ) GS GAS WELL		( ) REC RECREATION
( ) OP OIL PRODUCTION		( ) MUN MUNICIPAL
( ) MW MINERAL WELL		( ) OTH OTHER
		( ) UNK

QUAD NO [ ] MILES WEST [ ].[ ] MILES SOUTH [ ].[ ]

NE SE SW NW/NE SE SW NW/NE SE SW NW [22] [T] [13].[0W] [R] [10].[0W]
10 acre 40 acre 160 acre SECT. TOWNSHIP RANGE

APPROXIMATE LOCATION [ ]

[ ] LATITUDE [ ] LONGITUDE [ ]

UTM COORDINATES: X(east) [782794] Y(north) [3915615] ZONE [12]

OPERATOR [TRIBE OSM] USGS WATERSHED CODE [ ]

STATE: ( ) AZ ARIZONA (X) NM NEW MEXICO ( ) UT UTAH ( ) CO COLORADO

COUNTY: ( ) AP APACHE (X) MK MCKINLEY ( ) SJ SAN JUAN ( ) MT MONTEZUMA
( ) NA NAVAJO ( ) VL VALENCIA ( ) KA KANE ( ) LP LA PLATA
( ) CO COCNINO ( ) BL BERNALLILLO
( ) SD SANDOVAL
( ) SO SOCORRO GRAZING DISTRICT [16]
( ) RA RIO ARRIBA
( ) SA SAN JUAN

CHAPTER NAME _____ CHAPTER CODE [BACA]

LOCATION DATA SOURCE: [X] [ ]

LOCATION FILE COMPLETED BY: _____ DATE __/__/__

FIELD CHECKED BY: [ ] DATE __/__/__

rev:840425 form:well record loc

WINDMILL MAINTENANCE

16T-551

ATE REPAIRED	WORK DONE AND MATERIALS USED
10/22/69	Used sucker rods, 2½" pipes for corner post, 2" pipe for grit and cross braces out of sucker rods.
11/20/69	Installed 14' aermotor, 2" x 21' pipe, 2-2" close nipples, 2" tee, 2" elbow and 2" short nipple.
1/13/70	Repainted windmill tower.
2/5/70	Installed 4,000 gal storage tank, 1¼" x 2' pipe, 1¼" stop & waste valve, 5-1¼" elbow.
3/17/70	Welded leak on storage tank.
7/17/73	Repaired the 100 DC pump jack motor. Replace 1¼" stop and waste valve.
09-27-74	Changed oil
3/19/75 Rmt	Replaced stop and waste.
10-22-75	Welded leaky 4,000 gal. tank (Daystack)
16T-551	This well was turned over to the Public Health Service to be use it for 86-121 project, 27,900 gallon storage tank is still existing on this wel
7-30-81	METER READING
8-11-81	METER READING
8-14-81	" "
10-2-81	Routine Inspection
10-9-81	" "
10-13-81	~~TEST~~ TANK 11½ & METER READING
10-19-81	ROUTINE INSPECTION
10-26-81	INSPECTION
9-4-81	Meter Reading
9-8-81	Tank 10'
9-14-81	Routine Chick
9-18-81	Meter Reading
10-2-81	Routine Inspection.
10-9-81	Routine Inspection.
10-13-81	Tank 11½/ Meter Reading
10-19-81	Routine Inspection.
10-26-81	Inspection
07-30-81	Meter Reading
08-11-81	Meter Reading
08-14-81	Meter Reading

986 C
JECT

TRIBAL WELL RECORD
LOCATION FILE

ENTERED OCT 8 1986 MR

TRIBAL WELL NO [1]6]T]-]5]5]1]#]]]] PWSID [N]M]0]0]0]2]5]4]

WELL NAME/OTHER NO [W]A]Y]S]T]A]C]K]]C]O]M]M].]S]Y]S]T]E]M]]W]E]L]L]]

WELL TYPE (MARK ONE ONLY)

- (X) WW WATER WELL
- ( ) WA ARTESIAN WELL
- ( ) WS SPRING
- ( ) OW OBSERVATION WELL
- ( ) GS GAS WELL
- ( ) OP OIL PRODUCTION
- ( ) MW MINERAL WELL

WELL STATUS (MARK ONE ONLY)

- (X) ACT ACTIVE
- ( ) INA INACTIVE
- ( ) ABA ABANDONED

WELL USE (MARK ONE ONLY)

- ( ) DOM DOMESTIC
- ( ) AGR AGRICULT. LIVESTOCK
- ( ) IND INDUSTRIAL MINING
- ( ) REC RECREATION
- (X) MUN MUNICIPAL
- ( ) OTH OTHER

QUAD NO [1]1]9] MILES WEST [1]0].]6]5] MILES SOUTH [1]1].]0]0]

NE (SE) SW NW/NE SE SW (NW) NE SE SW (NW) [2]0 SECT. [T]]].]]] TOWNSHIP [R]]].]]] RANGE
10 acre 40 acre 160 acre

APPROXIMATE LOCATION [1]]M]1]L]E]]S]E]]O]F]]H]A]Y]S]T]A]C]K]]M]O]U]

[N]T]A]1]W]]]]] LATITUDE [3]5]2]0]4]5] LONGITUDE [1]0]7]5]5]2]9]

UTM COORDINATES: X(east) [ ]]]]]] Y(north) [ ]]]]]]] ZONE [ ]]

OPERATOR [T]R]1]B]E]]]]] USGS WATERSHED CODE [ ]]]]]]]]]]]

STATE: ( ) AZ ARIZONA ( ) NM NEW MEXICO ( ) UT UTAH ( ) CO COLORADO

COUNTY:
( ) AP APACHE ( ) MK MCKINLEY ( ) SJ SAN JUAN ( ) MT MONTEZUMA
( ) NA NAVAJO ( ) VL VALENCIA ( ) KA KANE ( ) LP LA PLATA
( ) CO COCNINO ( ) BL BERNALLILLO
( ) SD SANDOVAL
( ) SO SOCORRO GRAZING DISTRICT [1]6]
( ) RA RIO ARRIBA
( ) SA SAN JUAN

CHAPTER NAME BACA CHAPTER CODE [B]A]C]A]

LOCATION DATA SOURCE: [T]R]1]B]E],]B].]S]T]O]M]E]]R]T]-]6]]]]]]

LOCATION FILE COMPLETED BY: Masood U. Zaman DATE 10/8/1986

FIELD CHECKED BY: [ ]]]]]]]]]]]]]] DATE __/__/__

rev:840425 form:well record loc

TRIBAL WELL HYDROLOGY

ENTERED OCT 8 1986 SLR

WELL NO [1][6][7]-[5][5][1][ ][ ][ ][ ] USGS AQUIFER CODE [2][3][1][ ][5][N][S][C][ ] CHNL

THICKNESS [ ][ ][ ] FT NOMINAL YIELD [ ][ ][ ][ ] GPM YIELD MEASURED __/__/__

(X) BAILER (✓) PUMP TEST @ [ ][ ][5][0] GPM FOR [ ][1][6].[0] HOURS DATE 10/7/1976

DRAWDOWN [ ][ ][ ][1][6][7] FT OBSERVATION WELL DATA AVAILABLE ( )YES ( )NO

HORIZ CONDUCTIVITY [ ][ ][ ].[ ][ ][ ] FT/DAY SPECIFIC CAPACITY [0].[7][5] GPM/FT After 4 hrs. Pumping.

VERT. CONDUCTIVITY [ ][ ][ ].[ ][ ][ ] FT/DAY STORAGE COEF [.][ ][ ][ ][ ][ ][ ]

COEF OF TRANSMISSIVITY [ ][ ][ ][ ][ ][8][8]* FT2/DAY OR 660 GPD/FT.

INDICATE ADDITIONAL PUMPING TEST DATA AVAILABLE AS HARD COPY:
( )Y ( )N MULTIPLE RATE DRAWDOWN PUMPING TEST
(✓)Y ( )N SINGLE RATE DRAWDOWN PUMPING TEST
( )Y ( )N MULTIPLE RATE DRAWDOWN/RECOVERY TEST
(✓)Y ( )N RECOVERY TEST

LOGS AVAILABLE: (✓)DL DRILLER'S LOG ( )EL ELECTRIC LOG

HYDROLOGY DATA SOURCE: [T][R][I][B][E][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ]

HYDROLOGY FILE COMPLETED BY: M.Z. DATE 10/8/1986

STATIC WATER LEVEL FILE

SLR ENTERED OCT 8 1986

DEPTH TO SWL 446 FT DATE 9/17/1969	DEPTH TO SWL ____ FT DATE __/__/__
DEPTH TO SWL 417 FT DATE 10/7/1976	DEPTH TO SWL ____ FT DATE __/__/__
DEPTH TO SWL ____ FT DATE __/__/__	DEPTH TO SWL ____ FT DATE __/__/__
DEPTH TO SWL ____ FT DATE __/__/__	DEPTH TO SWL ____ FT DATE __/__/__
DEPTH TO SWL ____ FT DATE __/__/__	DEPTH TO SWL ____ FT DATE __/__/__
DEPTH TO SWL ____ FT DATE __/__/__	DEPTH TO SWL ____ FT DATE __/__/__
DEPTH TO SWL ____ FT DATE __/__/__	DEPTH TO SWL ____ FT DATE __/__/__
DEPTH TO SWL ____ FT DATE __/__/__	DEPTH TO SWL ____ FT DATE __/__/__
DEPTH TO SWL ____ FT DATE __/__/__	DEPTH TO SWL ____ FT DATE __/__/__
DEPTH TO SWL ____ FT DATE __/__/__	DEPTH TO SWL ____ FT DATE __/__/__

rev:840427 form: well record hyd

OCT 8 1986 JWR

TRIBAL WELL RE
STRUCTURE FI

WELL NO [16T-551] STARTED 9/11/1969 COMPLETED 9/17/1969

ELEVATION [6890] FT DEPTH [1083] FT DEPTH MEASURED 9/17/1969

DEPTH IS (✓)MEASURED ( )ESTIMATED ( )REPORTED WELL DIA. [9.00] IN

1 CASING DIA [7.00] FROM [+2] FT TO [1083] FT MATL [STL]

2 CASING DIA [ ].] FROM [ ] FT TO [ ] FT MATL [ ]

3 CASING DIA [ ].] FROM [ ] FT TO [ ] FT MATL [ ]

4 CASING DIA [ ].] FROM [ ] FT TO [ ] FT MATL [ ]

casing matl codes brs=brass cop=copper evd=everdur irn=iron mon=monel
pls=plastic stl=steel sst=stainless steel

1 CASING PERFORATED FROM [833] FT TO [1053] FT OPENING TYPE [P]

2 CASING PERFORATED FROM [ ] FT TO [ ] FT OPENING TYPE [ ]

3 CASING PERFORATED FROM [ ] FT TO [ ] FT OPENING TYPE [ ]

4 CASING PERFORATED FROM [ ] FT TO [ ] FT OPENING TYPE [ ]

5 CASING PERFORATED FROM [ ] FT TO [ ] FT OPENING TYPE [ ]

opening codes: f=fractured rock, l=louvered or shutter-type screen, m=mesh screen, p=perforated,porous,slotted casing, r=wire-wound screen s=screen,type unknown, t=sand point, w=walled or shored, x=open hole z=other

DATE WELL TURNED OVER TO TRIBE: __/__/__

FUNDED BY: [ ] CONTRACTOR: [ ]

SITE IMPROVEMENTS	TYPE OF LIFT	ENERGY SOURCE
( )WM WINDMILL	( )AL AIRLIFT	(✓)EM ELECTRIC MOTOR
( )WP WATERING POINT	( )PS PISTON	( )DE DIESEL ENGINE
(✓)TA TANK	( )TU TURBINE	( )HA HAND
( )WL WATER LINE	( )MT MULTIPLE TURBINE	( )GS GAS ENGINE
( )TR TROUGH	( )CN CENTRIFUGAL	( )LP LP GAS ENGINE
( )CS CISTERN	( )MC MULTIPLE CENTRIFUGAL	( )NG NATURAL GAS ENGINE
( )HP HAND PUMP	( )BU BUCKET	( )WM WINDMILL
( )NO NONE	(✓)SU SUBMERSIBLE	( )SO SOLAR

PUMP HP [ ] ON SITE STORAGE CAPACITY [ ] GAL

STRUCTURE DATA SOURCE: [TRIBE]

STRUCTURE FILE COMPLETED BY: M. Z. DATE 10/8/1986

rev:840426 form: well record str

[redacted]

TRIBAL WELL RECO
COMMENTS FILE

TRIBAL WELL NO V16T-1551

PERTINENT
COMMENTS: The Haystack Community System serves approximately 140 homes in the area (Dale Cartmel IHS Engineer's Letter & Alison Damon Jr. February 5, 1979).

⊗ A bailer test was also run @ 20 GPM for 6 hours, the Drawdown was 41 feet on September 17, 1969.

* T calculated from IHS Pump test data Time/Drawdown curve on file.

⊗⊗ Originally the well was used as a stock well and used to have a windmill, storage tank, troughs etc. Now well is being used for Haystack Community Water Supply System Since December 20, 1976 and has an electric pump, water tank and a complete control house and the water distribution system.

— Water quality information on file. Water quality is acceptable for Public water supply.

— property easement is on file

ENTERED OCT 09 1986

rev:840430 form: well record com

WELL

Water Well Development
Navajo Tribe
Window Rock, Arizona

WELL NO. 16T-551

Quad. No. 119 Miles west 10.65 Miles south 11.00

1 mile SE of Haystack Mountain
Location

Began well September 11, 1969 Finished well September 17, 1969

Diameter of well 9.00" Depth of well 1083'

Static water level 446' Drawdown 41' Recovery

Quantity of water on test run: bailer: pump: 21 G. P. M. Tested for 6 hours

Kind of casing: T & C Sizes and length 7" OD x 1085'

PERFORATION: See Attached Sheet
Screen kind Length Mesh

Contractor THE NAVAJO TRIBE Address Window Rock, Az
DRILLERs: B. Yazzie & j. Sam FAILING - 2500 Rotary

LOG

DEPTH From	To	Formation	Acquifer	Remarks
0	55	Top soil brown sand - soft		
55	79	Black Volcanic materials - hard		
79	180	Red shale - soft		
180	190	Red shale and white clay - soft		
190	255	Red shale and purple shale		
255	350	Red shale - soft		
350	376	Red shale and purple sandstone - soft		
376	465	Red shale - soft		
465	470	Red shale and purple and white sandstone - soft		
470	803	Red shale - soft		
803	807	Purple and white sandstone - soft		
807	819	Red and purple shale		
819	822	Purple sandstone		
822	911	Medium grain with to red sandstone - soft		
911	916	White clay - soft		
916	935	Brown to white sandstone - soft		
935	1083'	Red brownish sandstone - soft and hard		

Remarks:

S.P.

Teta Salts	Calcium Ca.	Magnesium Mg.	Sodium Na.	Chlorides Cl	Sulfates SO 4	Carbonates HCO 3	P.H.	CO 3

Excellent Good Fair Poor Doubtful Not suitable for domestic, livestock use

NTRD - 61

WINDMILL MAINTENANCE RECORD

..ELL No.__

DATE REPAIRED	WORK DONE AND MATERIALS USED
10/22/69	Set windmill tower and level.
10/27/69	Replaced 24-21'-0" x 2½ tubing (pipe), 25-21'-0" x 3/4" (pipe) sucker rods, 4-21½" x 1 7/8" leather cups and 2½" cylinder.
12/22/69	Replaced 19-3/4" x 21'-0" sucker rods. 18-2½" x 21'-0" tubing and 2¼" x 36" cylinder.
1/12/70	Set up 12' aermotor head and connected pump rod.
2/17/70	Releathered plunger and foot valve.
2/25/70	Installed 4,000 gal storage tank, 1¼" x 2' pipe, 1¼" stop & waste valve, 5-1¼" ell.
3/17/70	Checked windmill, ok.
2-15-72	6 gal. alumuim and 2 gal. alumuim brust.
09-27-74	CHANGED OIL
3/19/75	Checked.

16T-552

Well is equipped with 12' Aermotor, two (2) steel trough, 27,900 gal. storage tank. A new concrete floor needs to be pour for windmill base. It laso needs a tank cover for 27,900 gallon storage tank. The well is being use for domestic use.

two steel trough, 6 5/8" casing, 2" tubings, this well has 33,849' of waterline with 7 drinkers. The tank was full when inspected.

WELL RECORD

Water W...
Navajo T...
Window ...

WEL...

Quad. No. 119 Miles west 12.65 Miles south 9.95

Location 1 ~~mile~~ West ~~of Haystack~~ Mountain; NE, SW, Sec. 14, T13N, R11W N.M.P.M.

Began well September 26, 1969 Finished well October 9, 1969

Diameter of well 9" Depth of well 1268'

Static water level 362' Drawdown None Recovery

Quantity of water on test run: bailer: pump: 18 G. P. M. Tested for 6 hours

Kind of casing: T & C Sizes and length 7" x 1270'

Perforation: See Casing Tally

Screen kind Length Mesh

Contractor THE NAVAJO TRIBE Address Window Rock, Arizona

Driller: Bob Yazzie, Jim Sam

LOG

DEPTH From	To	Formation	Acquifer	Remarks
0	22	Top soil brown to red - soft		
22	30	White sandstone - soft		
30	42	Red sandstone - soft		
42	50	White to red sand & lime streak - Hard		
50	206	Red & blue shale & lime spot - soft		
206	280	Red shale - Soft		
280	715	Red & purple shale - soft		
715	760	Red shale - hard		
760	765	Brown & blue lime stone - very hard		
765	888	Red shale - soft		
888	932	Red shale & lime streak - hard		
932	1000	Fine grained white sandstone, blue & purple shale - soft		
1000	1013	White clay and fine grained white sandstone - soft		
1013	1050	Grey to white sandstone & silt stone - soft		
1050	1080	Blue shale, silty sandstone & grey limestone - hard		
1080	1098	Purple red shale & white sandstone - hard		
1098	1119	Fine grained white sandstone & blue to white clay		
1119	1260	Grey lime stone & fine reddish sandstone - hard		

Remarks:

S.P.

Tota Salts	Calcium Ca.	Magnesium Mg.	Sodium Na.	Chlorides CL	Sulfates SO 4	Carbonates HCO 3	P.H.	CO 3

Excellent Good Fair Poor Doubtful Not suitable for domestic, livestock use

NTRD - 61

WELL

Well No. 16T-552

Quad. No. 119 Miles west 12.65 Miles south 9.95

Location: 1 mile West of Haystack Mountain; NE, SW, Sec. 14, T13N, R11W, N.M.P.M.

LOG

DEPTH		FORMATION	REMARKS
FROM	TO		
1260	1268'	Purple shale - soft	

REMARKS: Lost circulation 940' to 944'

16T-552

T 11 W, R 13 N, Section 14, SW¼ of NW¼ N M P M Sept. 22, 1969

A well drilled at this location would start at approximately 6900 feet elevation, and be situated about a mile west of Haystack Mountain. This well will be identical to the well just completed in T 13 N, R 10 W, Section 20, SW¼, 16T-551, with the following exceptions: The new well will not encounter a surface basalt flow and, the new well may begin slightly higher in the section with some Wingate sandstone present.

The quality and quantity of the water will be the same as found in 16T-551.

The anticipated geologic section is as follows:

Formation	Depth (ft.)	Description
Wingate Sandstone	0 - 50	Sandstone, brown to reddish
Chinle Formation Upper Member	50 - 240	Siltstone, limy; pale bluish-gray or olive gray to dark greenish-gray
	240 - 390	Siltstone; reddish brown
Correo Sandstone Member	390 - 465	Sandstone; pale-grayish-red with some gray to pale-brown pebble conglomerate
Middle Member	465 - 865	Siltstone; reddish-brown
Sonsela Sandstone	865 - 1165	Sandstone, conglomerate; white, pale-yellowish-brown, yellow, and brown

W. L. Werrell
Hydrologist

RECEIVED
SEP 23 1969
WATER DEVELOPMENT

TRIBAL WELL RECORD
LOCATION FILE

ENTERED OCT 8 1986

TRIBAL WELL NO [1]6]T]-]5]5]2]]]]]] PWSID [ ]]]]]]]]]]

WELL NAME/OTHER NO [ ]

WELL TYPE (MARK ONE ONLY)	WELL STATUS (MARK ONE ONLY)	WELL USE (MARK ONE ONLY)
(✓)WW WATER WELL	(✓)ACT ACTIVE	( )DOM DOMESTIC
( )WA ARTESIAN WELL	( )INA INACTIVE	( )AGR AGRICULT.
( )WS SPRING	( )ABA ABANDONED	(✓) LIVESTOCK
( )OW OBSERVATION WELL		( )IND INDUSTRIAL MINING
( )GS GAS WELL		( )REC RECREATION
( )OP OIL PRODUCTION		( )MUN MUNICIPAL
( )MW MINERAL WELL		( )OTH OTHER

QUAD NO [1]1]9] MILES WEST [1]2].]6]5] MILES SOUTH [ ]9].]9]5]

NE SE SW NW/(NE) SE SW NW/NE SE (SW) NW [1]4] [T]1]3].]0]N] [R]1]1].]0]W]
10 acre 40 acre 160 acre SECT. TOWNSHIP RANGE

APPROXIMATE LOCATION [1]]M]1]L]E]]W]E]S]T]]O]F]]H]A]Y]S]T]A]C]K]]]

[M]O]U]N]T]A]1]N]]] LATITUDE [3]5]2]1]1]3] LONGITUDE [1]0]7]5]8]2]8]

UTM COORDINATES: X(east) [ ]]]]]]] Y(north) [ ]]]]]]]] ZONE [ ]]

OPERATOR [T]R]1]B]E]]]]]] USGS WATERSHED CODE [ ]]]]]]]]]]]]

STATE: ( )AZ ARIZONA (✓)NM NEW MEXICO ( )UT UTAH ( )CO COLORADO

COUNTY: ( )AP APACHE (✓)MK MCKINLEY ( )SJ SAN JUAN ( )MT MONTEZUMA
( )NA NAVAJO ( )VL VALENCIA ( )KA KANE ( )LP LA PLATA
( )CO COCNINO ( )BL BERNALLILLO
( )SD SANDOVAL
( )SO SOCORRO GRAZING DISTRICT [1]6]
( )RA RIO ARRIBA
( )SA SAN JUAN

CHAPTER NAME BACA CHAPTER CODE [B]A]C]A]

LOCATION DATA SOURCE: [T]R]1]B]E],]E]·]S]T]O]N]E]]R]T]-]6]]]]]]]]

LOCATION FILE COMPLETED BY: Masud U. Zaman DATE 10/8/1986

FIELD CHECKED BY: [ ]]]]]]]]]]]]]]]] DATE __/__/__

rev:840425 form:well record loc

L R E C D

G Y F I L E

ENTERED OCT 8 1

WELL NO [ ]]]]] USGS AQUI R CODE [2]3]1]]C]H]N]L]

THICKNESS INAL YIELD [ ]]]]GP YIELD MEASURED __/__/__

(✓)BAILER [ ]]1]8]GPM FOR[ ]]].]0]HOURS DATE 10/9/19

DRAWDOWN [OBSERVATION WELL DA AVAILABLE ( )YES (✓)NO

HORIZ CONI].]]]]FT/DAY SPECIF CAPACITY[ ].]]]GPM/FT

VERT. CONI].]]]] FT/DAY STORAGE COEF [.]]]]]]]

COEF OF TR]]]]]]] FT2/DAY

INDICATE A ING TEST DATA AVAILABL AS HARD COPY:
( )Y ( )N DRAWDOWN PUMPING TEST
( )Y ( )N AWDOWN PUMPING TEST
( )Y ( )N DRAWDOWN/RECOVERY TEST
( )Y ( )N

LOGS AVAIL. ILLER'S LOG ( )EL EL TRIC LOG

HYDROLOGY [T]R]1]8]E]]

HYDROLOGY BY: M.B. DATE 10/8/19

C W A T E R L E V E L F I L E

ENTERED OC

DEPTH TO S ATE 10/9/1989 DEPTH TO SWL FT DATE__/__/__

DEPTH TO S ATE__/__/__ DEPTH TO SWL FT DATE__/__/__

DEPTH TO S ATE__/__/__ DEPTH TO SWL FT DATE__/__/__

DEPTH TO SW ATE__/__/__ DEPTH TO SWL FT DATE__/__/__

DEPTH TO S ATE__/__/__ DEPTH TO SWL FT DATE__/__/__

DEPTH TO S ATE__/__/__ DEPTH TO SWL FT DATE__/__/__

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DEPTH TO S ATE__/__/__ DEPTH TO SWL FT DATE__/__/__

DEPTH TO S ATE__/__/__ DEPTH TO SWL FT DATE__/__/__

DEPTH TO S ATE__/__/__ DEPTH TO SWL FT DATE__/__/__

DEPTH TO S ATE__/__/__ DEPTH TO SWL FT DATE__/__/__

rev:840427 form: well record hyd

TRIBAL WELL REC
STRUCTURE FI

RECEIVED OCT 8 1986

WELL NO [1][6][7]-[5][5][2][ ][ ][ ][ ] STARTED 9/26/1967 COMPLETED 10/9/1967

ELEVATION [ ][6][8][5][5] FT DEPTH [ ][1][2][6][8] FT DEPTH MEASURED 10/9/1967

DEPTH IS (✓)MEASURED ( )ESTIMATED ( )REPORTED WELL DIA. [ ][9].[0][0] IN

1 CASING DIA [ ][7].[0][0] FROM[ ][ ][+][2]FT TO[ ][1][2][6][8]FT MATL[S][T][L]

2 CASING DIA [ ][ ].[ ][ ] FROM[ ][ ][ ][ ]FT TO[ ][ ][ ][ ][ ]FT MATL[ ][ ][ ]

3 CASING DIA [ ][ ].[ ][ ] FROM[ ][ ][ ][ ]FT TO[ ][ ][ ][ ][ ]FT MATL[ ][ ][ ]

4 CASING DIA [ ][ ].[ ][ ] FROM[ ][ ][ ][ ]FT TO[ ][ ][ ][ ][ ]FT MATL[ ][ ][ ]

casing matl codes brs=brass cop=copper evd=everdur irn=iron mon=monel
pls=plastic stl=steel sst=stainless steel

1 CASING PERFORATED FROM [ ][9][7][5]FT TO[ ][1][1][3][7]FT OPENING TYPE [P]

2 CASING PERFORATED FROM [ ][1][1][7][0]FT TO[ ][1][2][0][3]FT OPENING TYPE [P]

3 CASING PERFORATED FROM [ ][1][2][3][6]FT TO[ ][1][2][7][0]FT OPENING TYPE [P]

4 CASING PERFORATED FROM [ ][ ][ ][ ][ ]FT TO[ ][ ][ ][ ][ ]FT OPENING TYPE [ ]

5 CASING PERFORATED FROM [ ][ ][ ][ ][ ]FT TO[ ][ ][ ][ ][ ]FT OPENING TYPE [ ]

opening codes: f=fractured rock, l=louvered or shutter-type screen,
m=mesh screen, p=perforated,porous,slotted casing, r=wire-wound screen
s=screen,type unknown, t=sand point, w=walled or shored, x=open hole
z=other

DATE WELL TURNED OVER TO TRIBE: __/__/__

FUNDED BY: [T][R][1][B][E][ ][ ] CONTRACTOR: [T][R][1][B][E][ ][ ][ ][ ][ ][ ][ ][ ]

SITE IMPROVEMENTS	TYPE OF LIFT	ENERGY SOURCE
(✓)WM WINDMILL	( )AL AIRLIFT	( )EM ELECTRIC MOTOR
(✓)WP WATERING POINT	(✓)PS PISTON	( )DE DIESEL ENGINE
(✓)TA TANK	( )TU TURBINE	( )HA HAND
(✓)WL WATER LINE	( )MT MULTIPLE TURBINE	( )GS GAS ENGINE
(✓)TR TROUGH (2)	( )CN CENTRIFUGAL	( )LP LP GAS ENGINE
( )CS CISTERN	( )MC MULTIPLE CENTRIFUGAL	( )NG NATURAL GAS ENGINE
( )HP HAND PUMP	( )BU BUCKET	(✓)WM WINDMILL
( )NO NONE	( )SU SUBMERSIBLE	( )SO SOLAR

PUMP HP [ ][ ][ ][ ] ON SITE STORAGE CAPACITY [ ][2][7][9][0][0] GAL

STRUCTURE DATA SOURCE: [ ]

STRUCTURE FILE COMPLETED BY: M. Z. DATE 10/8/1986

rev:840426 form: well record str

TRIBAL WELL RECO
COMMENTS FILE

TRIBAL WELL NO [1][6][T]-[5][5][2][ ][ ][ ][ ]

PERTINENT
COMMENTS: (X) 33,849 feet of water line.

water quality information on file.

property easement on file ENTERED OCT 09 1986

rev:840430 form: well record com

OPTIONAL FO
JULY 1973 ED
GSA FPMR (41

UNITED S

Men

16T-552

TO : Ejars
Hydrol
Water and Sanitation, Navajo Tribe

DATE: August 16, 19

FROM : Field Engineer
Crownpoint Service Unit

SUBJECT: Windmill 16T-552

As per our visit to the Haystack project area, July 13, 1976 and our discussion of the same date concerning the possible use of the subject windmill, please supply this office with any information you have on this well such as total depth, screened depth, static water level, test pumping data and drillers leg.

Preliminary results of the chemical analysis for the subject well follow:

Boron	1.02 mg/l
Fe	0.28 "
Ca	2.00 "
Mg	Trace
Na	190.82 mg/l
K	2.74 mg/l
P	0.0218 mg/l
HCO_3	165.92 mg/l
CO_3	76.80 mg/l
Cl	26.59 mg/l
T	0.89 mg/l
Total F	0.4998 mg/l
EC	850 micromhos/cm
pH	9.1

Based upon this data and the analyses remaining, it appears that test pumping of this well may be feasible.

Your prompt attention to this matter will be appreciated.

s/ Robert Mayers
Robert Mayers,
Field Engineer

RM/ejb

cc: File/chron

5010-110

Buy U.S. Savings Bonds Regularly on the Payroll Savings Plan

ABANDONED
Per U.S.G.S Record. ?

TRIB[illegible] CORD
LO[illegible] E

ENTERED OCT 6 1986 [illegible]

TRIBAL WELL NO [1]6[T]-[5]8[6]]]]]] PWSID [N]M[0]0[0]0[2]5[4]

WELL NAME/OTHER NO [H]A[Y]S[T]A[C]K]]R[U]R[A]L]]W[A]T[E]R]]S[U]P[L]Y] WELL.

WELL TYPE (MARK ONE ONLY)	WELL STATUS (MARK ONE ONLY)	WELL USE (MARK ONE ONLY)
(✓)WW WATER WELL	( )ACT ACTIVE	(✓)DOM DOMESTIC
( )WA ARTESIAN WELL	( )INA INACTIVE	(✓)AGR AGRICULT. LIVESTOCK
( )WS SPRING	( )ABA ABANDONED	( )IND INDUSTRIAL MINING
( )OW OBSERVATION WELL		( )REC RECREATION
( )GS GAS WELL		( )MUN MUNICIPAL
( )OP OIL PRODUCTION		( )OTH OTHER
( )MW MINERAL WELL		

QUAD NO [1]1[9] MILES WEST [1]0[.]4[5] MILES SOUTH [ ]9[.]8[0]

(NE) SE SW NW/NE SE SW (NW)/(NE) SE SW NW [1]8] [T]1[3].]0[N] [R]1[0].]0[W]
10 acre 40 acre 160 acre SECT. TOWNSHIP RANGE

APPROXIMATE LOCATION [N]E[A]R]]H[A]Y[S]T[A]C[K]]M[O]U[N]T[A]I[N]]]]

[ ]]]]]]]]]] LATITUDE [3]5[2]1[4]3] LONGITUDE [1]0[7]5[6]0[2]

UTM COORDINATES: X(east) [ ]]]]]] Y(north) [ ]]]]]]] ZONE [ ]]

? OPERATOR [T]R[1]8[E]]0[1]M]] USGS WATERSHED CODE [ ]]]]]]]]]]]

STATE: ( )AZ ARIZONA (✓)NM NEW MEXICO ( )UT UTAH ( )CO COLORADO

COUNTY: ( )AP APACHE (✓)MK MCKINLEY ( )SJ SAN JUAN ( )MT MONTEZUMA
( )NA NAVAJO ( )VL VALENCIA ( )KA KANE ( )LP LA PLATA
( )CO COCNINO ( )BL BERNALLILLO
( )SD SANDOVAL
( )SO SOCORRO GRAZING DISTRICT [1]6]
( )RA RIO ARRIBA
( )SA SAN JUAN

CHAPTER NAME BACA CHAPTER CODE [B]A[C]A]

LOCATION DATA SOURCE: [T]R[1]8[E],]1]H[S],]B]·]S]T[O]N[E]]R[T]-[6]]]

LOCATION FILE COMPLETED BY: Masud U. Zaman DATE 10/3/1986

FIELD CHECKED BY: [ ]]]]]]]]]]]]]]]] DATE __/__/__

rev:840425 form:well record loc

T

TRIBAL

HYDRO

ERED OCT 6 1986 MR

See Remarks

WELL NO [1]6[T]-[3]0[6] [ ] [ ] [ ] [ ] USGS AQUIFER CODE [ ] [ ] [ ] [ ] [ ] [ ] [ ]

THICKNESS [ ] [ ] [ ] FT NOMINAL YIELD [ ] [ ] [ ] [ ] GPM YIELD MEASURED __/__/__

( )BAILER ( )PUMP TEST @ [ ] [ ] [9]0] GPM FOR [ ]2]4].]0] HOURS DATE __/__/__

DRAWDOWN [ ] [ ] [ ] [9]9] FT OBSERVATION WELL DATA AVAILABLE ( )YES (✓)NO

HORIZ CONDUCTIVITY [ ] [ ] [ ].] [ ] [ ] FT/DAY SPECIFIC CAPACITY [ ].] [ ] [ ] GPM/FT

VERT. CONDUCTIVITY [ ] [ ] [ ].] [ ] [ ] FT/DAY STORAGE COEF [.] [ ] [ ] [ ] [ ] [ ]

COEF OF TRANSMISSIVITY [ ] [ ] [ ] [ ] [ ] [ ] FT2/DAY

INDICATE ADDITIONAL PUMPING TEST DATA AVAILABLE AS HARD COPY:
( )Y ( )N MULTIPLE RATE DRAWDOWN PUMPING TEST
( )Y ( )N SINGLE RATE DRAWDOWN PUMPING TEST
( )Y ( )N MULTIPLE RATE DRAWDOWN/RECOVERY TEST
( )Y ( )N RECOVERY TEST

LOGS AVAILABLE: (✓)DL DRILLER'S LOG (✓)EL ELECTRIC LOG

HYDROLOGY DATA SOURCE: [1]MS] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]

HYDROLOGY FILE COMPLETED BY: M.Z. DATE 10/3/1986

ENTERED OCT 6 1986 MR

STATIC WATER LEVEL FILE

(X) DEPTH TO SWL 47 FT DATE 6/16/1976 DEPTH TO SWL ____ FT DATE __/__/__

(X)(X) DEPTH TO SWL 580 FT DATE __/__/__ DEPTH TO SWL ____ FT DATE __/__/__

DEPTH TO SWL ____ FT DATE __/__/__ DEPTH TO SWL ____ FT DATE __/__/__

DEPTH TO SWL ____ FT DATE __/__/__ DEPTH TO SWL ____ FT DATE __/__/__

DEPTH TO SWL ____ FT DATE __/__/__ DEPTH TO SWL ____ FT DATE __/__/__

DEPTH TO SWL ____ FT DATE __/__/__ DEPTH TO SWL ____ FT DATE __/__/__

DEPTH TO SWL ____ FT DATE __/__/__ DEPTH TO SWL ____ FT DATE __/__/__

DEPTH TO SWL ____ FT DATE __/__/__ DEPTH TO SWL ____ FT DATE __/__/__

DEPTH TO SWL ____ FT DATE __/__/__ DEPTH TO SWL ____ FT DATE __/__/__

DEPTH TO SWL ____ FT DATE __/__/__ DEPTH TO SWL ____ FT DATE __/__/__

rev:840427 form: well record hyd

ENTERED

RIBAL WELL RECORD
STRUCTURE FILE

WEL [ ] [ ] [ ] [ ] [ ] [ ] STARTED 10/30/1975 COMP

ELEVATION [ ] [ ] [ ] [ ] FT DEPTH [ ]2[4]0[0] FT DEPTH MEASURED 6/18/1976

DEPTH IS (✓)MEASURED ( )ESTIMATED ( )REPORTED WELL DIA. [1]0[.]6[2] IN

1 CASING DIA [ ]8[.]6[2] FROM[ ]]]0[0]FT TO[ ]1[5][5][5]FT MATL[S][T][L]

2 CASING DIA [ ]].]]] FROM[ ]]]]]FT TO[ ]]]]]FT MATL[ ]]]

3 CASING DIA [ ]].]]] FROM[ ]]]]]FT TO[ ]]]]]FT MATL[ ]]]

4 CASING DIA [ ]].]]] FROM[ ]]]]]FT TO[ ]]]]]FT MATL[ ]]]

casing matl codes brs=brass cop=copper evd=everdur irn=iron mon=monel
pls=plastic stl=steel sst=stainless steel

Perforation against shale formation

1 CASING PERFORATED FROM [ ]1[4]0[0]FT TO[ ]1[4]2[1]FT OPENING TYPE [P]

2 CASING PERFORATED FROM [ ]1[4]3[2]FT TO[ ]1[4]9[5]FT OPENING TYPE [P]

3 CASING PERFORATED FROM [ ]1[5]0[5]FT TO[ ]1[5][5][6]FT OPENING TYPE [P]

4 CASING PERFORATED FROM [ ]]]]]FT TO[ ]]]]]FT OPENING TYPE [ ]

5 CASING PERFORATED FROM [ ]]]]]FT TO[ ]]]]]FT OPENING TYPE [ ]

opening codes: f=fractured rock, l=louvered or shutter-type screen,
m=mesh screen, p=perforated,porous,slotted casing, r=wire-wound screen
s=screen,type unknown, t=sand point, w=walled or shored, x=open hole
z=other

DATE WELL TURNED OVER TO TRIBE: __/__/__

FUNDED BY: [1][W][S]]]]] CONTRACTOR: [T][R][1][B][E]]]]]]]]]

SITE IMPROVEMENTS	TYPE OF LIFT	ENERGY SOURCE
( )WM WINDMILL	( )AL AIRLIFT	( )EM ELECTRIC MOTOR
( )WP WATERING POINT	( )PS PISTON	( )DE DIESEL ENGINE
( )TA TANK	( )TU TURBINE	( )HA HAND
( )WL WATER LINE	( )MT MULTIPLE TURBINE	( )GS GAS ENGINE
( )TR TROUGH		( )LP LP GAS ENGINE
( )CS CISTERN	( )CN CENTRIFUGAL	( )NG NATURAL GAS ENGINE
( )HP HAND PUMP	( )MC MULTIPLE CENTRIFUGAL	( )WM WINDMILL
( )NO NONE	( )BU BUCKET	( )SO SOLAR
	( )SU SUBMERSIBLE	

PUMP HP [ ]]]] ON SITE STORAGE CAPACITY [ ]]]]]] GAL

STRUCTURE DATA SOURCE: [T][R][1][B][E]]]]]]]]]]]]]]]]

STRUCTURE FILE COMPLETED BY: M.Z. DATE 10/3/1986

rev:840426 form: well record str

L WELL RECORD
O G FILE

TRIBAL WE [6] [ ] [ ] [ ] [ ] DATE LOGGED [1][2]/[0][4]

WELL NAME [ ]

TYPE OF LOG [G][A][M][M][A] [R][A][Y], [ ][S][P], [R][E][S][I][S][T][I][V][I][T][Y] [ ] [ ] [ ]

(NE) SE SW NW/NE SE SW (NW) (NE) SE SW NW [1][8] [T][1][3].[0][N] [R][1][0].[0][W]
10 acre 40 acre 160 acre SECT. TOWNSHIP RANGE

FT-E/W [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] FT-N/S [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]

UTM COORDINATES: X(east) [ ] [ ] [ ] [ ] [ ] [ ] Y(north) [ ] [ ] [ ] [ ] [ ] [ ] [ ] ZONE [ ] [ ]

STATE: ( )AZ ARIZONA (✓)NM NEW MEXICO ( )UT UTAH ( )CO COLORADO

COUNTY: ( )AP APACHE (✓)MK MCKINLEY ( )SJ SAN JUAN ( )MT MONTEZUMA
( )NA NAVAJO ( )VL VALENCIA ( )KA KANE ( )LP LA PLATA
( )CO COCNINO ( )BL BERNALLILLO
( )SD SANDOVAL
( )SO SOCORRO DEPTH OF HOLE [ ][2][4][0][0] FT
( )RA RIO ARRIBA HOLE LOGGED 1680 FT
( )SA SAN JUAN BIT SIZE/DIA. [1][0].[6][2] IN

LOG FILE COMPLETED BY: M. Z DATE 10/6/1986

****

TRIBAL WELL NO [1][6][T]-[5][8][6] [ ] [ ] [ ] [ ], DATE LOGGED [1][2]/[0][4]/[7][5]

WELL NAME/OTHER NO [ ]

TYPE OF LOG [C][A][L][I][P][E][R] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]

(NE) SE SW (NW)/(NE) SE SW NW/NE SE SW NW [1][8] [T][1][3].[0][W] [R][1][0].[0][W]
10 acre 40 acre 160 acre SECT. TOWNSHIP RANGE

FT-E/W [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] FT-N/S [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]

UTM COORDINATES: X(east) [ ] [ ] [ ] [ ] [ ] [ ] Y(north) [ ] [ ] [ ] [ ] [ ] [ ] [ ] ZONE [ ] [ ]

STATE: ( )AZ ARIZONA (✓)NM NEW MEXICO ( )UT UTAH ( )CO COLORADO

COUNTY: ( )AP APACHE (✓)MK MCKINLEY ( )SJ SAN JUAN ( )MT MONTEZUMA
( )NA NAVAJO ( )VL VALENCIA ( )KA KANE ( )LP LA PLATA
( )CO COCNINO ( )BL BERNALLILLO
( )SD SANDOVAL
( )SO SOCORRO DEPTH OF HOLE [ ][2][4][0][0] FT
( )RA RIO ARRIBA HOLE LOGGED 1680 FT
( )SA SAN JUAN BIT SIZE/DIA. [1][0].[6][2] IN

LOG FILE COMPLETED BY: M. Z. DATE 10/6/1986

rev:840820 form:well record log

TRIBAL WE
COMMENT

TRIBAL WELL NO [1][6][T]-[5][8][6]

PERTINENT
COMMENTS: * Originally well drilled to 733 feet depth, logged and bailed. Specific Conductance 200 mmhos on 10-30-1975 Well deepened to 2,400 feet through Repeinti Psa, Pg and tested Specific Conductance 20420 on 6-18-1976. Perforated opposite Rcps and retested, Sp. Cnd. 33810 mmhos on 12-22-76, Abandoned.

(X) Static water level 47 feet when well tapped Pg, Psa at 2400 feet depth.

(X)(X) S.W.L 580 feet when well perforated against Chinle Formation.

1. U.S.G.S Well Feasibility Report written for IHS is on file.
2. As built drawing upto 1686 feet with well completion to 1550 feet depth on file. ENTERED OCT 7 1986 FWR

rev:840430 form: well record com

WELL RECORD

opment

izona 16T-586

Quad. No. 19 (S.W.) ¼ Miles west 10.45 Miles south 9.80

NW¼, NE¼, Section 18.T13 N R 10W, Haystack, New Mexico
Location

Began well _____ Finished well January 05, 1976

Diameter of well 10-5/8 inch Depth of well 1555 feet ?

Static water level 580 feet Drawdown none Recovery none

Quantity of water on test run: bailer: pump: 8.5 G. P. M. Tested for 12 hours

Kind of casing: T/C Sizes and length 8-5/8 inch O.D. X 1555 feet
1400 feet - 1421.57 feet

Screen kind Machine slotted Length 1431.57 feet - 1495 feet Mesh
1505 feet - 1555 feet

Contractor The Navajo Tribe Address Water and Sanitation Division
Post Office Box 678
Drillers: Jerry Barney
Steven Yazzie Fort Defiance, Arizona

DEPTH LOG

From	To	Formation	Acquifer	Remarks
0'	70'	Surface Soil - Fine sand		Soft
70'	110'	Red and White sandstone with yellow gravels		Soft
110'	120'	Red and white sandstone		Soft
120'	140'	Red, white and gray sandstone		Soft
140'	150'	Red sandstone		Soft
150'	250'	Pink to white sandstone		Soft
250'	260'	Gray and light red sandstone		Soft
260'	280'	Lime stone		Hard
280'	290'	White and red sandstone		Soft
290'	455'	Orange sandstone		Soft
455'	480'	Orange and white sandstone		Soft
480'	550'	Orange sandstone		Soft
550'	560'	Orange shale		Soft
560'	938'	Orange white and brown shale with sandstonee		Soft
938'	1214'	Red and blue sandstone		Hard
1214'	1375'	Clay		Hard
1375'	1420'	Red, brown and purple shale with white sandstone		Hard

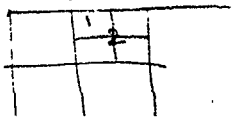
Remarks: Surface casing: 12½ inch to 200 feet

S.P.

Teta Salts	Calcium Ca.	Magnesium Mg.	Sodium Na.	Chlorides Cl.	Sulfates SO 4	Carbonates HCO 3	P.H.	CO 3

Excellent Good Fair Poor Doubtful Not suitable for domestic, livestock use

* The hole was drilled up to 1718 feet.. The hole caved in up to 1686 cement plug was set from 1686 to 1555.



NTRD - 61

WELL RECORD

Ground Water Development
The Navajo Tribe
Window Rock, Arizona

WELL NO. 16T-586

Quad. No. 19 (SW¼) Miles west 10.45 Miles south 9.80

Location: NW¼, NE¼, Section 18.T13 N R 10W, Haystack, New Mexico

LOG

DEPTH		FORMATION	REMARKS
From	To		
1420'	1489'	Red shale with white and gray sandstone	Hard
1489'	1555'	Red shale	Soft
1555'	1718'	Purple, light blue and red shale	Hard

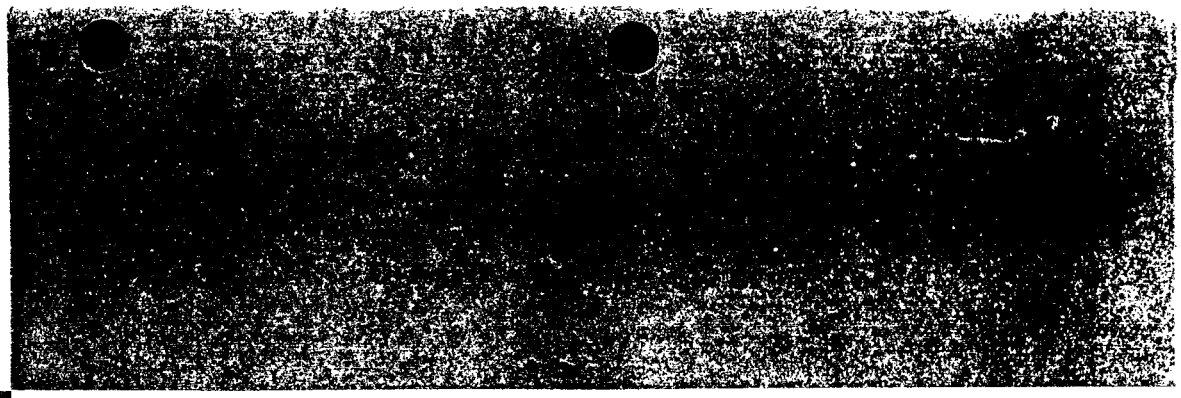
REMARKS:

REFERENCE # 20

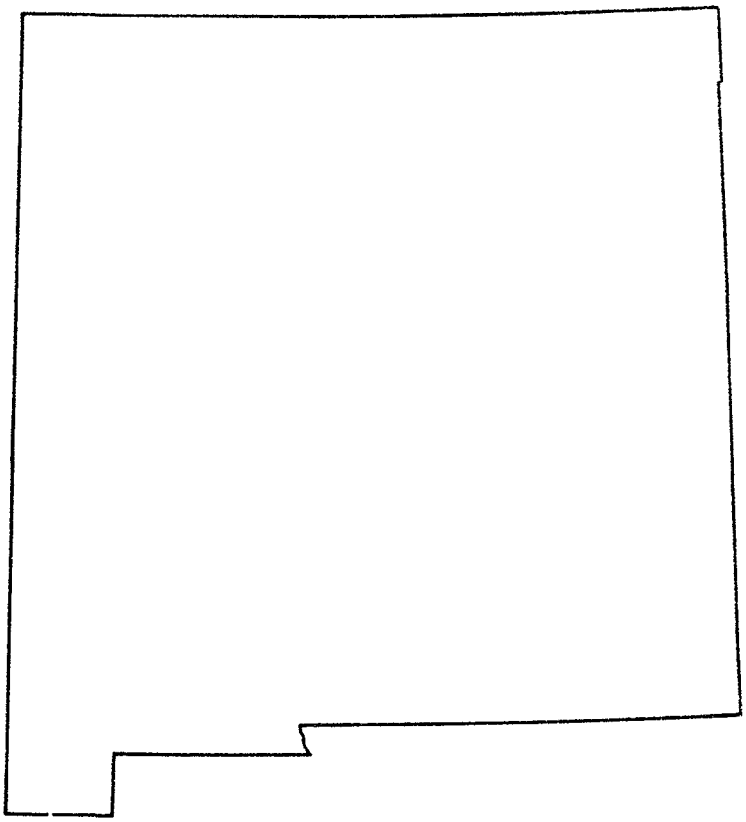
NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY



Water Resources Data New Mexico Water Year 1988



U.S. GEOLOGICAL SURVEY WATER -DATA REPORT NM-88-1

Prepared in cooperation with the State of New Mexico and with other agencies

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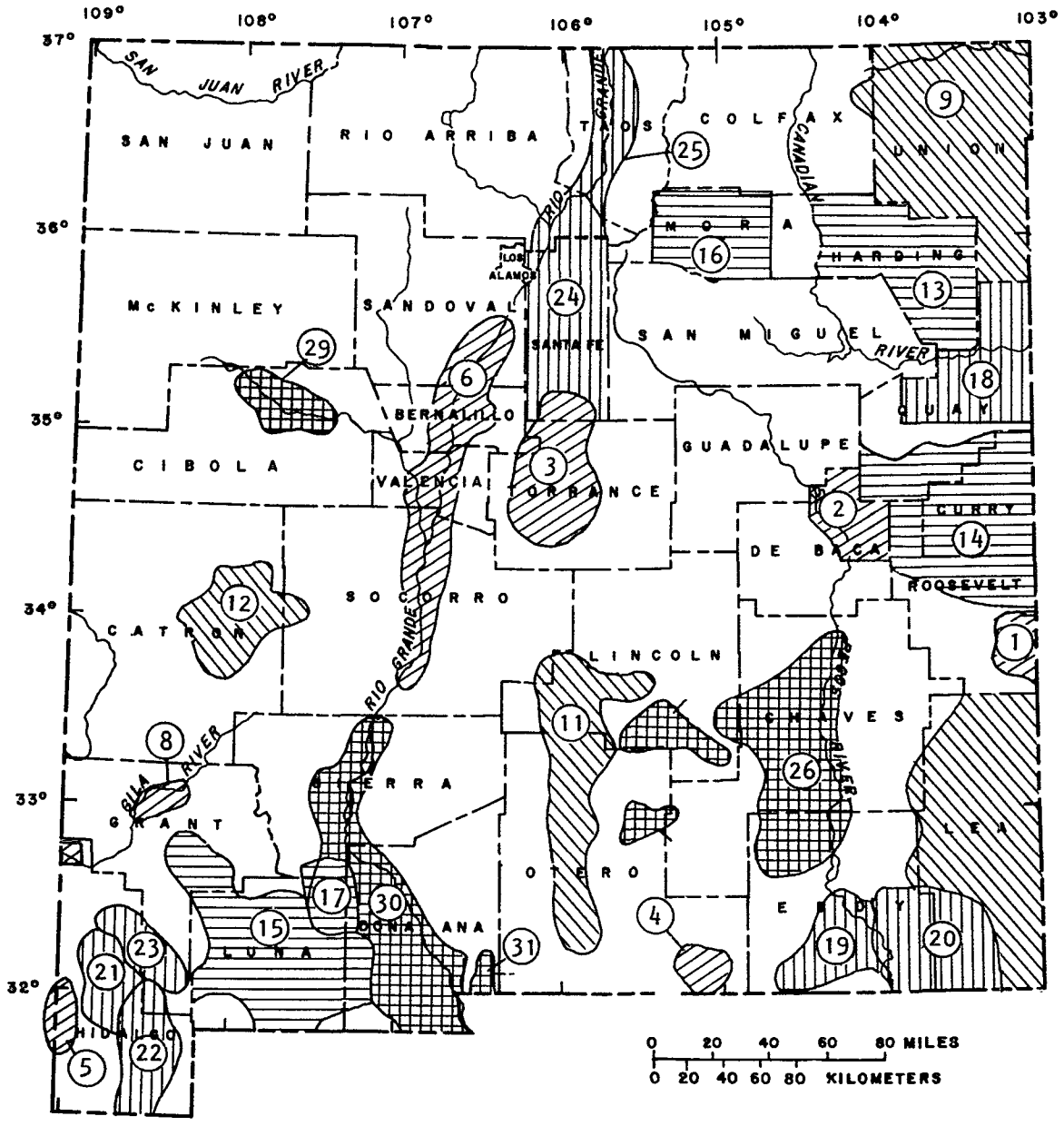

1985/1990 | 1986/1991 | 1987/1992 | 1988/1993 | 1989/1994

1. CAUSEY-LINGO
2. FT. SUMNER
3. ESTANCIA
4. SALT BASIN
5. SAN SIMON
6. MIDDLE RIO GRANDE
7. VIRDEN
8. GILA RIVER
9. N. HIGH PLAINS
10. TATUM-LOVINGTON-HOBBS
11. TULAROSA BASIN
12. SAN AGUSTIN PLAINS
13. HARDING COUNTY
14. CURRY COUNTY-HOUSE-PORTALES
15. MIMBRES BASIN
16. MORA AREA
17. NUTT-HOCKETT
18. LOWER CANADIAN
19. CARLSBAD
20. CAPITAN REEF
21. ANIMAS
22. PLAYAS
23. LORDSBURG
24. SANTA FE COUNTY
25. UPPER RIO GRANDE
26. ROSWELL BASIN
27. RIO HONDO
28. RIO PEÑASCO
29. GRANTS-BLUEWATER
30. LOWER RIO GRANDE
31. HUECO

Figure 1.--Areas of 5-year ground-water-level monitoring and years measured or scheduled for measurement.

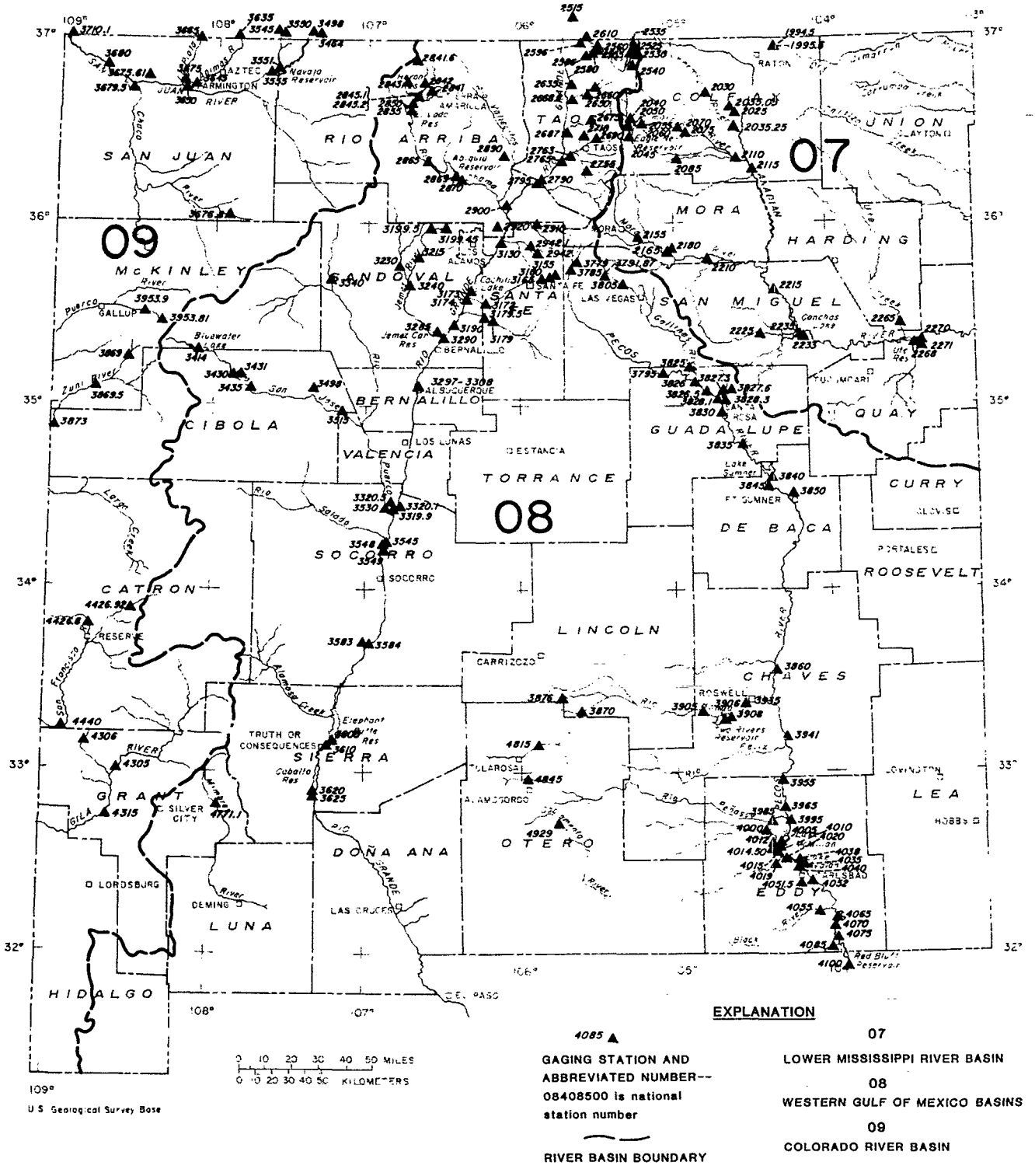

Figure 5.--Location of surface-water gaging stations.

08343000 RIO SAN JOSE AT GRANTS, NM

LOCATION.--Lat 35°09'16", long 107°52'11", in SW¼NW¼ sec.26, T.11 N., R.10 W., Cibola County, Hydrologic Unit 13020207, on right bank at bridge on El Morro St., 0.2 mi south of Santa Fe Ave. in Grants, and at mile 67.8

DRAINAGE AREA.--1,020 mi², approximately.

PERIOD OF RECORD.--October 1912 to February 1914, June 1914, October 1914 to February 1915, May 1915 to June 1921, September 1921 to June 1923, October 1923 to May 1926, September to December 1926, May 1949 to September 1966, June 1968 to current year. Monthly discharge only for some periods published in WSP 1312. Prior to October 1967, published as "Bluewater Creek at Grants".

REVISED RECORDS.--WSP 1512: 1913-14. WSP 1712: Drainage area.

GAGE.--Water-stage recorder. Datum of gage is 6,468.34 ft above National Geodetic Vertical Datum of 1929 (levels by U. S. Army Corps of Engineers). See WSP 1732 or 1923 for history of changes prior to Jan. 1, 1926.

REMARKS.--Estimated daily discharges: May 30 to July 13. Records good except for estimated daily discharge, which are poor. Flow slightly regulated by Bluewater Lake (station 08341400) 24 mi upstream. Diversions and groundwater withdrawals for irrigation of about 4,500 acres upstream from station. Several observations of water temperature were made during the year.

AVERAGE DISCHARGE.--47 years (water years 1913, 1915-20, 1922, 1924-25, 1950-66, 1968-88), 2.97 ft³/s, 2,150 acre-ft/yr.

EXTREMES FOR PERIOD OF RECORD (1950-66 AND SINCE 1968).--Maximum discharge recorded, 1,760 ft³/s, Aug. 28, 1952, gage height, 5.35 ft, from rating curve extended above 300 ft³/s on basis of velocity-area studies; no flow for long periods.

EXTREMES OUTSIDE PERIOD OF RECORD.--Maximum flood observed occurred Sept. 6 or 7, 1909, when Bluewater Dam washed out. A flood in July 1919 probably exceeded the one in 1952.

EXTREMES FOR CURRENT YEAR.--Peak discharges greater than base discharge of 200 ft³/s and maximum (*):

Date	Time	Discharge (ft³/s)	Gage height (ft)	Date	Time	Discharge (ft³/s)	Gage height (ft)
Sept. 12	0630	*2.0	*1.54				

No flow most of time.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1987 TO SEPTEMBER 1988
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
4	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
7	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
8	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
9	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
10	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
11	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.01
12	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.34
13	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
14	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
15	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
16	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.06	.00
17	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
18	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
19	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
20	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
21	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
22	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
23	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
24	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
25	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
26	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
27	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.07	.00
28	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.24	.00
29	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
30	.00	.00	.00	.00	---	.00	.00	.00	.00	.00	.00	.00
31	.00	---	.00	.00	---	.00	---	.00	---	.00	.00	---
TOTAL	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.37	.35
MEAN	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.01	.01
MAX	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.24	.34
MIN	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
AC-FT	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.7	.7

CAL YR 1987	TOTAL	14.75	MEAN	.04	MAX	8.4	MIN	.00	AC-FT	29
WTR YR 1988	TOTAL	.72	MEAN	.00	MAX	.34	MIN	.00	AC-FT	1.4

REFERENCE # 22

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

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1989-1990

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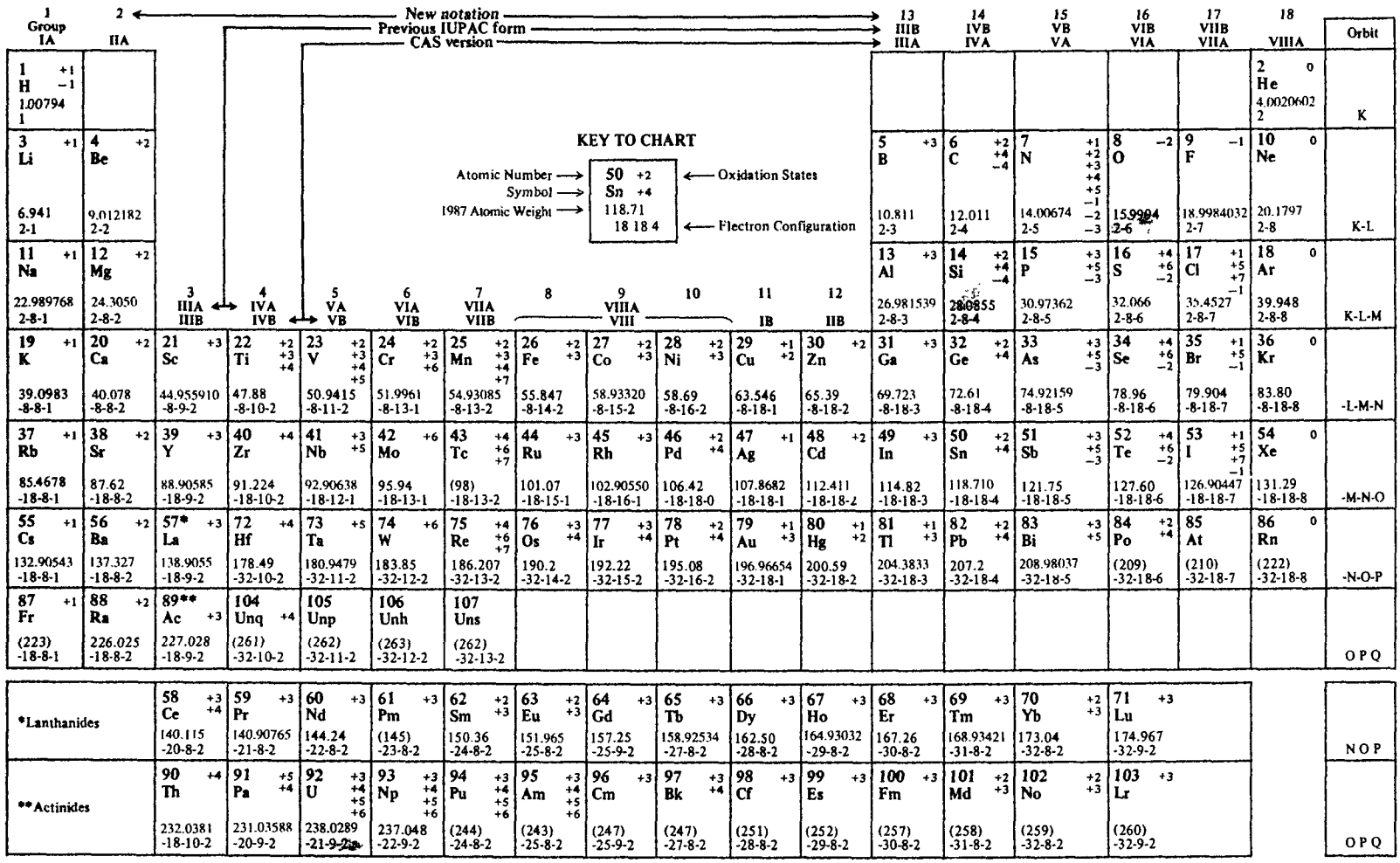


Numbers in parentheses are mass numbers of most stable isotope of that element

From *Chemical and Engineering News*, 63(5), 27, 1985. This format numbers the groups 1 to 18.

Density
.0155
150
146
141
.0137
.0132
0128
123
119
114
.0110
.0106
^101
097
092
.088
.0083
.0079
^074
070
066
..061
.0057
.0052
048
044
039
.0035
.0030
.0026
022
017
013
.0009
.0004
0000

DENSITY OF VARIOUS SOLIDS

pproximate density of various solids at ordinary atmospheric temperature.
case of substances with voids such as paper or leather the bulk density is indicated rather than the density of the solid portion.

(Selected principally from the Smithsonian Tables.)

Substance	Grams per cu cm	Pounds per cu ft
nce		
	2.5–2.7	156–168
r, carbon-		
	2.69–2.78	168–173
	2.26–2.32	141–145
	2.62–2.65	163–165
	1.06–1.11	66–69
	2.9–3.2	180–200
boles	2.74–2.76	171–172
ite	2.0–2.8	125–175
s		
s slate	1.8	112
	1.1–1.5	69–94
	2.4–3.1	150–190
	0.96–0.97	60–61
x	2.69–2.7	168–169
	2.7–3.1	170–190
	1.7–2.0	106–125
	1.4–2.2	87–137
	0.86–0.87	53–54
e	4.1–4.5	255–280
	2.6–2.8	162–175
or	0.99	62
bouc	0.92–0.99	57–62
ard	0.69	43
d	1.4	87
, set	2.7–3.0	170.190
	1.9–2.8	118–175
al, oak	0.57	35
	0.28–0.44	18–28
r	8.12	507
	1.8–2.6	112–162
thracite	1.4–1.8	87–112
ous	1.2–1.5	75–94
butter	0.89–0.91	56–57
	1.0–1.7	62–105
	1.04–1.14	65–71
	0.22–0.26	14–16
oleum	0.54	34
um	3.9–4.0	245–250
d	3.01–3.52	188–220
e	2.84	177
	1.15	72
	4.0	250
	3.25–3.50	203–218
r	2.55–2.75	159–172
	2.63	164
	3.18	198
	7.3–7.6	460–470
e	1.2	75
	3.15–4.3	197–268
bon	1.88	117
	1.27	79

Substance	Grams per cu cm	Pound per cu ft
Glass, common	2.4–2.8	150–175
flint	2.9–5.9	180–370
Glue	1.27	79
Granite	2.64–2.76	165–172
Graphite*	2.30–2.72	144–170
Gum arabic	1.3–1.4	81–87
Gypsum	2.31–2.33	144–145
Hematite	4.9–5.3	306–330
Hornblende	3.0	187
Ice	0.917	57.2
Ivory	1.83–1.92	114–120
Leather, dry	0.86	54
Lime, slaked	1.3–1.4	81–87
Limestone	2.68–2.76	167–171
Linoleum	1.18	74
Magnetite	4.9–5.2	306–324
Malachite	3.7–4.1	231–256
Marble	2.6–2.84	160–177
Meerschaum	0.99–1.28	62–80
Mica	2.6–3.2	165–200
Muscovite	2.76–3.00	172–187
Ochre	3.5	218
Opal	2.2	137
Paper	0.7–1.15	44–72
Paraffin	0.87–0.91	54–57
Peat blocks	0.84	52
Pitch	1.07	67
Porcelain	2.3–2.5	143–156
Porphyry	2.6–2.9	162–181
Pressed wood		
pulp board	0.19	12
Pyrite	4.95–5.1	309–318
Quartz	2.65	165
Resin	1.07	67
Rock salt	2.18	136
Rubber, hard	1.19	74
Rubber, soft		
commercial	1.1	69
pure gum	0.91–0.93	57–58
Sandstone	2.14–2.36	134–147
Serpentine	2.50–2.65	156–165
Silica, fused trans-		
parent	2.21	138
translucent	2.07	129
Slag	2.0–3.9	125–240
Slate	2.6–3.3	162–205
Soapstone	2.6–2.8	162–175
Spermacéti	0.95	59
Starch	1.53	95
Sugar	1.59	99
Talc	2.7–2.8	168–174

Substance	Grams per cu cm	Pounds per cu ft
Tallow, beef	0.94	59
mutton	0.94	59
Tar	1.02	66
Topaz	3.5–3.6	219–223
Tourmaline	3.0–3.2	190–200
Wax, sealing	1.8	112
Wood (seasoned)		
alder	0.42–0.68	26–42
apple	0.66–0.84	41–52
ash	0.65–0.85	40–53
balsa	0.11–0.14	7–9
bamboo	0.31–0.40	19–25
basswood	0.32–0.59	20–37
beech	0.70–0.90	43–56
birch	0.51–0.77	32–48
blue gum	1.00	62
box	0.95–1.16	59–72
butternut	0.38	24
cedar	0.49–0.57	30–35
cherry	0.70–0.90	43–56
dogwood	0.76	47
ebony	1.11–1.33	69–83
elm	0.54–0.60	34–37
hickory	0.60–0.93	37–58
holly	0.76	47
juniper	0.56	35
larch	0.50–0.56	31–35
lignum vitae	1.17–1.33	73–83
locust	0.67–0.71	42–44
logwood	0.91	57
mahogany		
Honduras	0.66	41
Spanish	0.85	53
maple	0.62–0.75	39–47
oak	0.60–0.90	37–56
pear	0.61–0.73	38–45
pine, pitch	0.83–0.85	52–53
white	0.35–0.50	22–31
yellow	0.37–0.60	23–37
plum	0.66–0.78	41–49
poplar	0.35–0.5	22–31
satinwood	0.95	59
spruce	0.48–0.70	30–44
sycamore	0.40–0.60	24–37
teak, Indian	0.66–0.88	41–55
African	0.98	61
walnut	0.64–0.70	40–43
water gum	1.00	62
willow	0.40–0.60	24–37

e values reported as low as 1.6.

TABLE OF THE ISOTOPES (Continued)

	Gamma-ray energy (MeV)	Gamma-ray intensity
	0.89922 ± 0.00007	98%
	0.91175 ± 0.00007	14%
	0.91231 ± 0.00008	11.1%
	0.91834 ± 0.00008	10.8%
	0.98409 ± 0.00005	58%
	1.11140 ± 0.00006	1.4%
	1.20392 ± 0.00008	2.1%
	1.21181 ± 0.00006	3.1%
	1.27481 ± 0.00007	2.2%
	1.70355 ± 0.00009	2.0%
	1.75534 ± 0.00006	1.2%
	1.89640 ± 0.00009	1.3%
	1.6808 ± 0.0002	0.4%
	1.8374 ± 0.0001	0.2%
	Pb k x-ray	35%
	0.54986 ± 0.00003	0.3%
	1.57060 ± 0.00003	0.43%
	1.57974 ± 0.00003	0.54%
	0.70347 ± 0.00003	31%
	0.98764 ± 0.00003	1.6%
	1.04375 ± 0.00003	0.75%
	1.19004 ± 0.00004	0.23%
	1.51435 ± 0.00004	0.23%
	1.76435 ± 0.00004	32.5%
	1.96171 ± 0.00003	0.61%
	2.0345 ± 0.00004	0.25%
	Pb k x-ray	54%
	0.8403 ± 0.00002	15.8%
	1.4353 ± 0.00002	23.4%
	0.39803 ± 0.00002	10.7%
	0.7700 ± 0.00003	15.3%
	0.7619 ± 0.00003	40.7%
	0.53748 ± 0.00003	30.4%
	1.0053 ± 0.0003	5.8%
	1.0228 ± 0.00003	4.5%
	0.65721 ± 0.00003	1.9%
	0.0313 ± 0.0005	98.9%
	0.0100 ± 0.00003	66.2%
	0.89503 ± 0.0003	15.7%
	1.0356 ± 0.0003	7.6%
	1.09825 ± 0.00003	13.5%
	1.40510 ± 0.0004	1.4%
	1.0025 ± 0.0003	5.0%
	0.71878 ± 0.00003	31.8%

Z	% Natural abundance	Atomic mass	Half-life	Decay mode	Decay energy (MeV)	Particle energy (MeV)	Particle intensity	Thermal neutron cross section	Spin (h/2π)	μ Nucl. mag. moment	Gamma-ray energy (MeV)	Gamma-ray intensity
83											1.87898 ± 0.00005	2.0%
83		206.978446	32.2 ± 0.1 y.	E.C.	2.398				9/2-	4.10	Pb k x-ray	36%
83											0.56915 ± 0.00002	97.8%
83											1.06310 ± 0.00002	74.9%
83											1.76971 ± 0.00004	6.9%
83		207.979717	3.68 x 10^5y.	E.C.	2.878				5+		Pb k x-ray	32%
83											2.61435 ± 0.0001	99.89
83	100%	208.980374						(10 mb + 24 mb)	9/2-	+4.110	6	
83			3.0 x 10^6 y.	α		4.420(3)	0.29%		9-		Tl k x-ray	6.6%
83						4.569(3)	3.9%				0.2661 ± 0.0002	50%
83						4.584(3)	1.4%				0.3052 ± 0.0002	28%
83						4.908(4)	39%				0.6502 ± 0.0002	3.6%
83						4.946(3)	55%					
83		209.984095	5.01 ± 0.01 d.	β-	1.16	1.16	99%		1-	-0.044	0.2661 ± 0.0002	4 × 10
83											0.352 ± 0.0002	6 × 10
83		210.987255	2.14 ± 0.02 m.	α(99.7%)		6.279	16%		9/2-		Tl k x-ray	1.3%
83				β-(0.3%)	0.584	6.623	84%				0.3501 ± 0.0002	12.8%
83			9 ± 1 m.	β-					(15-)			
83			25 ± 1 m.	α(93%)		6.300	40%		(9-)		0.120 ± 0.001	
83				β-(7%)		6.340	53%				0.233 ± 0.001	
83											0.275 ± 0.001	
83											0.404 ± 0.001	
83											0.727 ± 0.001	
83		211.991255	1.009 ± 0.001 h.	β-(64%)	2.248				(1-)		Tl k x-ray	0.13%
83				α(36%)		6.051	25%				Po k x-ray	0.1%
83						6.090	9.6%				0.2881 ± 0.0001	0.34%
83											0.4528 ± 0.0001	0.36%
83											0.72725 ± 0.00005	6.6%
83											0.78551 ± 0.00005	1.1%
83											0.87342 ± 0.00006	0.37%
83											0.89342 ± 0.00006	0.37%
83											0.9522 ± 0.0001	0.18%
83											1.0787 ± 0.0001	0.53%
83											1.51275 ± 0.00006	0.31%
83											1.62066 ± 0.00006	1.5%
83											1.8059 ± 0.0001	0.1%
83		212.994359	45.6 ± 0.1 m.	β-(98%)	1.422	1.02	31%		9/2-		Po k x-ray	1.3%
83				α(2%)		1.42	66%				0.3288 ± 0.0001	0.2%
83						5.549	0.16%				0.44034 ± 0.00002	16%
83						5.869	2.0%				0.80727 ± 0.00004	0.26%
83											1.10006 ± 0.00005	0.28%
83		213.998691	19.9 ± 0.4 m.	β-	3.27						0.60931 ± 0.00001	46.1%
83											0.66544 ± 0.00002	1.6%
83											0.76835 ± 0.00001	4.9%
83											0.80615 ± 0.00002	1.2%
83											0.93404 ± 0.00002	3.2%
83											1.12027 ± 0.00002	15%
83											1.15518 ± 0.00002	1.7%
83											1.23810 ± 0.00002	5.96%
83											1.28095 ± 0.00002	1.5%
83											1.37766 ± 0.00002	4.0%
83											1.40148 ± 0.00004	1.4%
83											1.40797 ± 0.00004	2.5%
83											1.50922 ± 0.00003	2.2%

TABLE OF THE ISOTOPES (Continued)

Isotope	A	Z	% Natural abundance	Atomic mass	Half-life	Decay mode	Decay energy (MeV)	Particle energy (MeV)	Particle intensity	Thermal neutron cross section	Spin (h/2π)	μ Nucl. mag. moment	Gamma-ray energy (MeV)	G…
	214	83											1.66126 ± 0.00002	1…
	214	83											1.72958 ± 0.00002	3…
	214	83											1.76449 ± 0.00002	15…
	214	83											1.84741 ± 0.00003	2…
	214	83											2.20409 ± 0.00011	4…
	214	83											2.44768 ± 0.00004	1…
	214	83											(0.19 - 3.27)many	
$_{83}Bi^{215}$	215	83		215.001930	7.4 ± 0.6 m	β-	2.250							
Po		84									0+			
$_{84}Po^{194}$	194	84		193.988180	0.7 s.	α		6.85						
$_{84}Po^{195m}$	195	84			2.0 s.	α		6.70						
$_{84}Po^{195}$	195	84		194.988010	≈ 4.5 s	α		6.61						
$_{84}Po^{196}$	196	84		195.985540	≈ 5.5 s.	α(95%)		6.520			0+			
	196	84				β+, EC (5%)								
$_{84}Po^{197m}$	197	84			26 s.	α(84%)		6.385			13/2+			
	197	84				β+, EC (16%)								
$_{84}Po^{197}$	197	84		196.985600	56 s.	α(44%)		6.282			(3/2-)			
	197	84				β+, EC (56%)								
$_{84}Po^{198}$	198	84		197.983360	1.76 m.	α(70%)		6.182			0+			
	198	84				β+, EC (30%)								
$_{84}Po^{199m}$	199	84			4.2 m.	β+, EC (51%)					13/2+		ann.rad.	
	199	84				α(39%)		6.059					0.2745	7.4…
	199	84											0.4998 ± 0.0005	25…
	199	84											1.0020 ± 0.0005	60…
	199	84									(3/2-)		Bi k x-ray	38…
$_{84}Po^{199}$	199	84		198.983610	5.2 m.	β+, EC (88%)	5.67							
	199	84				α(12%)		5.952					0.1877 ± 0.0005	7.5…
	199	84											0.2291 ± 0.0005	4.8…
	199	84											0.2335 ± 0.0005	5.5…
	199	84											0.2460 ± 0.0006	4.2…
	199	84											0.2607 ± 0.0005	4.0…
	199	84											0.3616 ± 0.0005	22…
	199	84											0.3978 ± 0.0004	4…
	199	84											0.4749 ± 0.0005	7…
	199	84											0.5068 ± 0.0005	3.7…
	199	84											0.9984 ± 0.0005	15…
	199	84											1.0214 ± 0.0006	24…
	199	84											1.0344 ± 0.0005	47…
	199	84											0.14748 ± 0.00001	4.4…
	199	84									0+		0.32792 ± 0.00009	2.6…
$_{84}Po^{200}$	200	84		199.981700	11.5 ± 0.1 m.	β+, EC (85%)	3.370						0.43007 ± 0.00012	4.8…
	200	84				α(15%)		5.863					0.4343 ± 0.00001	9.3…
	200	84											0.6176 ± 0.0001	19.7…
	200	84											0.6709 ± 0.0001	34…
	200	84											0.6956 ± 0.0002	5.5…
	200	84											0.7966 ± 0.0001	7.9…
	200	84											0.8499 ± 0.0001	4.9…
	200	84											0.8758 ± 0.0001	1.8…
	200	84											0.8958 ± 0.0002	1.5…
	200	84											0.9146 ± 0.0002	1.2…
	200	84											0.9455 ± 0.0001	1..1…
	200	84											1.0845 ± 0.0002	3.8…
	200	84											1.1729 ± 0.0002	1.1…
	200	84											1.2856 ± 0.0001	1.2…
	200	84											1.3876 ± 0.0002	1.0…
	200	84											1.8019 ± 0.0002	1.3…
	200	84											Bi k x-ray	19…
$_{84}Po^{201m}$	201	84			8.9 ± 0.2 m.	β+, EC (57%)					13/2+			
	201	84				I.T.(40%)	0.418						Po k x-ray	44…
	201	84				α(3%)		5.786					0.2726 ± 0.0004	2.8…
	201	84											0.4123 ± 0.0005	15.1…
	201	84											0.4179 ± 0.0003	33…
	201	84											0.9670 ± 0.0005	34…
	201	84											Bi k x-ray	38…
$_{84}Po^{201}$	201	84		200.982190	15.3 ± 0.2 m.	β+, EC (98%)	4.90				3/2-			
	201	84				α(2%)		5.683(3)					0.2056 ± 0.0003	8.0…
	201	84											0.2229 ± 0.0004	5.5…
	201	84											0.2250 ± 0.0004	12…
	201	84											0.2390 ± 0.0005	8.1…
	201	84											0.4285 ± 0.0004	8.9…

TABLE OF THE ISOTOPES (Continued)

A	Z	% Natural abundance	Atomic mass	Half-life	Decay mode	Decay energy (MeV)	Particle energy (MeV)	Particle intensity	Thermal neutron cross section	Spin (h/2π)	μ Nucl. mag. moment	Gamma-ray energy (MeV)	Gamma-ray intensity
221	86				β-(78%)	1.150	5.788(3)	2.2%				0.07384 ± 0.00004	0.53%
							6.037(3)	18%				0.08323	8.2%
221	86											0.0610	13.6%
221	86											0.09727	4.9%
221	86											0.09982	2.8%
221	86											0.10060	1.6%
221	86											0.10836 ± 0.00003	2.2%
211	86											0.11156 ± 0.00003	2.1%
211	86											0.15008 ± 0.00003	4.4%
211	86											0.18639 ± 0.00004	20.4%
211	86											0.21686 ± 0.00004	2.3%
211	86											0.254 ± 0.0003	2%
211	86											0.26468 ± 0.00004	1.1%
211	86											0.27927 ± 0.00003	1.8%
222	86		222.017570	3.82 d‡	α ‡	5.590	4.987(1)	0.08%	0.7 b.	0+		0.510 ± 0.002	0.07%
222	86						5.4897(3)	99.9%					
223	86			43 m.	β-								
224	86			1.78 ± 0.005h.	β-					0+		0.1085 ± 0.0005	3.3 +
224	86											0.1132 ± 0.0003	3.3
224	86											0.2026 ± 0.0003	4.4
224	86											0.2562 ± 0.0003	3.0
224	86											0.2601 ± 0.0001	23
224	86											0.2655 ± 0.0001	21
224	86											0.3719 ± 0.0003	3.5
224	86											0.398 ± 0.001	5.6
224	86											0.402 ± 0.001	5.7
225	86			4.5 m.	β-								
226	86			6.0 m.	β-								
	87												
201	87		201.004110	48 ms.	α	7.54	7.388(15)						
202	87		202.003300	0.34 s.	α	7.590	7.250(20)						
203	87		203.001000	0.55 s.	α	7.280	7.132(5)						
204	87		204.000670	2.1 s.	α	7.170	6.967(5)	30 +					
204	87						7.027(5)	70					
205	87		204.998610	3.96 s.	α	7.050	6.914(5)						
206	87		205.99846s	16.0 ± 0.1 s.	α	7.416	6.789(5)						
207	87		206.996800	14.8 ± 0.1 s.	α	6.900	6.766(5)			9/2-			
208	87		207.997080	59 s.	α(77%)	6.770	6.636(5)			7			
208	87				E.C.(23%)	6.960							
209	87		208.995878	50.0 ± 0.3 s.	α(89%)	5.130	6.646(3)			9/2-			
209	87				E.C.(11%)	6.778							
210	87		209.996340	3.2 m.	α	6.670	6.543(5)			6+		0.2030 ± 0.0008	35 +
210	87											0.2562 ± 0.0001	11
210	87											0.4252 ± 0.0001	10
210	87											0.461 ± 0.001	11
210	87											0.6438 ± 0.0008	100
210	87											0.733 ± 0.001	10
210	87											0.8175 ± 0.0008	60
210	87											0.9008 ± 0.0007	30
211	87		210.995490	3.1 m.	α	6.660	6.534(5)			9/2-		0.220 ± 0.0008	9 +
211	87				E.C.	4.570						0.2799 ± 0.001	34
211	87											0.4389 ± 0.001	20
211	87											0.5389 ± 0.001	100
211	87											0.9169 ± 0.001	55
211	87											0.9819 ± 0.0008	20
212	87		211.996130	20.0 ± 0.6 m.	E.C.(57%)	5.070	6.076(3)	0.17%		(5+)		Rn x-ray	14%
212	87				α(43%)	6.529	6.127(3)	0.43%				0.0789	2.4%
212	87						6.173(4)	0.5%				0.08107	14%
212	87						6.183(3)	0.6%				0.08152	4%
212	87						6.261(1)	16%				0.08378	24%
212	87						6.335(1)	4%				0.09468	8%
212	87						6.343(1)	1.3%				0.1383 ± 0.0001	7.7%
212	87						6.383(1)	10%				0.3091 ± 0.0002	1.0%
212	87						6.406(1)	9.5%				0.3115 ± 0.0002	1.3%
212	87											0.5320 ± 0.0005	2.8%
212	87											0.8019 ± 0.0015	3.5%
212	87											1.0473 ± 0.0014	7.2%
212	87											1.1784 ± 0.0020	1.3%
212	87											1.1856 ± 0.0014	14%
212	87											1.2748 ± 0.0020	46%
213	87		212.996165	34.6 ± 0.3 s.	α	6.905	6.775(2)			9/2-			

Gamma-ray energy (MeV)	Gamma-ray intensity
05460 ± 0.00005	1.7%
06567 ± 0.00007	1.7%
1.15893 ± 0.00006	0.85%
.5432 ± 0.0001	0.8%
9258 ± 0.0003	0.3%
.1142 ± 0.0002	0.33%
2.6428 ± 0.0002	0.32%
(0.18 - 3.2)many	
At k x-ray	2.3%
.19625 ± 0.00007	0.32%
.23324 ± 0.00006	0.5%
0.45824 ± 0.00006	1.6%
.57104 ± 0.00006	0.8%
0.64868 ± 0.00006	0.82%
0.76148 ± 0.00006	0.52%
.95773 ± 0.00007	0.3%
(0.14 - 1.7)weak	
At k x-ray	30%
.16877 ± 0.00006	6.8%
25022 ± 0.00006	6.1%
0.37049 ± 0.00008	1.4%
.41632 ± 0.00006	3.5%
44209 ± 0.00006	23%
0.67412 ± 0.00007	46%
67839 ± 0.00006	29%
0.85377 ± 0.00006	4.7%
0.86600 ± 0.00007	8.0%
93481 ± 0.00006	3.7%
0.94666 ± 0.00006	3.7%
0.94744 ± 0.00007	5.1%
12668 ± 0.00006	22.5%
1.36298 ± 0.00005	33.1%
1.53985 ± 0.00008	4.8%
9926 ± 0.0001	0.5%
(.11 - 2.7)weak	
Po k x-ray	0.9%
13057 ± 0.00006	0.13%
27113 ± 0.00005	9.9%
0.40170 ± 0.00006	6.6%
(.1 - 1.05)weak	
Fr L x-ray	1.6%

TABLE OF THE ISOTOPES (Continued)

Isotope	A	Z	% Natural abundance	Atomic mass	Half-life	Decay mode	Decay energy (MeV)	Particle energy (MeV)	Particle intensity	Thermal neutron cross section	Spin (h/2π)	μ Nucl. mag. moment	Gamma-ray energy (MeV)	Gamma-ray intensity
$_{91}Pa^{238}$	238	91		238.055040	2.3 m.	β-	3.960	1.2			(3-)		0.10350 ± 0.00004	12 +
	238	91						1.7					0.1785 ± 0.0005	11
	238	91											0.2179 ± 0.0005	14
	238	91											0.3698 ± 0.0005	12
	238	91											0.2930 ± 0.001	12
	238	91											0.3964 ± 0.0004	18
	238	91											0.4369 ± 0.0004	16
	238	91											0.4484 ± 0.0004	76
	238	91											0.4961 ± 0.0005	19
	238	91											0.4889 ± 0.0004	20
	238	91											0.5019 ± 0.0005	26
	238	91											0.5471 ± 0.0004	40
	238	91											0.6057 ± 0.0005	10
	238	91											0.6236 ± 0.001	19
	238	91											0.6350 ± 0.0004	88
	238	91											0.6800 ± 0.0004	73
	238	91											0.6870 ± 0.0004	54
	238	91											0.8058 ± 0.0004	44
	238	91											0.8491 ± 0.0005	14
	238	91											0.8637 ± 0.0005	54
	238	91											0.8857 ± 0.0004	45
	238	91											0.9049 ± 0.0005	23
	238	91											0.9111 ± 0.0004	19
	238	91											0.9526 ± 0.0005	21
	238	91											0.9571 ± 0.0005	18
	238	91											1.01446 ± 0.0004	100
	238	91											1.0602 ± 0.0005	45
	238	91											1.0834 ± 0.0003	50
	238	91											1.8892 ± 0.0004	17
	238	91											(0.04 - 2.5)many	
U		92		238.0289						7.57 b. σf 4.20 b.				
$_{92}U^{226}$	226	92		226.029170	0.50 ± 0.2 s.	α	7.560	7.430			0+			
$_{92}U^{227}$	227	92		227.030990	1.1 ± 0.3 m	α	7.200	6.870						
$_{92}U^{228}$	228	92		228.031356	9.1 ± 0.2 m.	α	6.803	6.404(6)	0.6+		0+		0.095	1.6%
	228	92						6.440(5)	0.7				0.152	0.2%
	228	92						6.589(5)	29				0.187	0.3%
	228	92						6.681(6)	70				0.246	0.4%
$_{92}U^{229}$	229	92		229.033474	58 ± 3 m.	E.C.(80%)	1.305	6.223	3 +		(3.2+)			
	229	92				α(20%)	6.473	6.297(3)	11					
	229	92						6.332(3)	20					
	229	92						6.360(3)	64					
$_{92}U^{230}$	230	92		230.033921	20.8 d.	α	5.992	5.5886(3)	0.01%		0+		Th L x-ray	6.0%
	230	92						5.6624(3)	0.26%				0.07218 ± 0.00003	0.60%
	230	92						5.6663(3)	0.38%				0.15421 ± 0.00003	0.12%
	230	92						5.8178(3)	32%				0.23034 ± 0.00004	0.12%
	230	92						5.8887(3)	67%					
$_{92}U^{231}$	231	92		231.036270	4.2 ± 0.1 d.	E.C>					(5.2-)		Pa L x-ray	41%
	231	92											Pa k x-ray	27%
	231	92											0.02564 ± 0.00001	13%
	231	92											0.08420 ± 0.00001	6.0%
	231	92											0.21793 ± 0.00002	0.8%
	231	92											0.23598 ± 0.00002	0.2%
	231	92											0.31100 ± 0.00003	0.06%
$_{92}U^{232}$	231	92		232.037130	68.9 ± 0.1 y	α	5.414	4.9979(1)	0.003%	73 b.	0+			
	232	92						5.1367(1)	0.3%					
	232	92						5.2635(1)	31%					
	232	92						5.3203(1)	69%					
$_{92}U^{233}$	233	92		233.039628	1.59 x 10^5 y.	α	4.909	4.5097(8)	0.01%	466 b	5/2+	+0.55	Th L x-ray	3.3%
	233	92						4.5130(8)	0.02%	σf 529 b.			0.04244 ± 0.00001	0.06%
	233	92						4.6323(8)	0.01%				0.09714 ± 0.00002	0.02%
	233	92						4.6642(8)	0.04%					
	233	92						4.6809(8)	0.01%					
	233	92						4.7014(8)	0.06%					
	233	92						4.7292(8)	1.6%					
	233	92						4.7541(8)	0.16%					
	233	92						4.758(10)	0.02%					
	233	92						4.7830(8)	13.2%					
	233	92						4.7960(8)	0.3%					
	233	92						4.804(8)	0.05%					

TABLE OF THE ISOTOPES (Continued)

Isotope	A	Z	% Natural abundance	Atomic mass	Half-life	Decay mode	Decay energy (MeV)	Particle energy (MeV)	Particle intensity	Thermal neutron cross section	Spin (h/2π)	μ Nucl. mag. moment	Gamma-ray energy (MeV)	Gamma-ray intensity
	233	92						4.8247(8)	84.4%					
	234	92		234.040946	2.45 x 10^5y.	α	4.856	4.604(1)	0.24%	100 b.	0+		0.05323 ± 0.00003	0.12%
	234	92						4.7231(1)	27.5%				0.12091 ± 0.00002	0.04%
	234	92						4.776(1)	72.5%					
	235	92			26 ± 2 m.	I.T.	0.0007				1/2+			
	235	92	0.720%	235.043924	7.04 x 10^8y.	α	4.6793	4.1525(9)	0.9%	98 b.	7/2-	-0.35	Th L x-ray	15%
	235	92						4.2157(9)	5.7%	σf 583 b.			Th k x-ray	5.5%
	235	92						4.3237(9)	4.6%				0.10917 ± 0.00001	1.5%
	235	92						4.3641(9)	11%				0.14378 ± 0.00001	10.5%
	235	92						4.370(4)	6%				0.16338 ± 0.00001	4.7%
	235	92						4.3952(9)	55%				0.18574 ± 0.00001	53%
	235	92						4.4144(9)	2.1%				0.20213 ± 0.00001	1.0%
	235	92						4.5025(9)	1.7%				0.20533 ± 0 00001	4.7%
	235	92						4.5558(9)	4.2%				0.22140 ± 0.00002	0.1%
	235	92						4.5970(9)	5.0%				(0.03 - 0.79)weak	
	236	92		236.045562	2.34 x 10^7y.	α	4.569	4.332(8)	0.26%	5.1 b.	0+		Th L x-ray	3 4%
	236	92						4.445(5)	26%				0.04937 ± 0.00001	0.08%
	236	92						4.494(3)	74%				0.11275 ± 0.00001	0.02%
	237	92		237.048724	6.75 ± 0.01 d.	β-	0.519	0.24		400 b.	1/2+		Np L x-ray	30%
	237	92						0.25					Np k x-ray	26%
	237	92											0.02634 ± 0.00001	2.3%
	237	92											0.05953 ± 0.00001	33%
	237	92											0.06482 ± 0.00001	1.2%
	237	92											0.16459 ± 0.00001	1.8%
	237	92											0.20801 ± 0.00001	22%
	237	92											0.33236 ± 0.00001	1.2%
	237	92											0.37092 ± 0.00002	0.11%
	238	92	99.2745%	238.050784	4.46 x 10^9y.	α		4.039(5)	0.23	% 2.68 b.	0+		Th L x-ray	4.1%
	238	92						4.147(5)	23%				0.04955 ± 0.00006	0.07%
	238	92						4.196(5)	77%					
$_{92}U^{239}$	239	92		239.054289	23.54 ± 0.05m.	β-	1.264	1.2		22 b.	5/2+		0.04354 ± 0.00001	4.4%
	239	92						1.3		σf 15 b.			0.07467 ± 0.00001	52%
	239	92											0.11770 ± 0.00003	0.12%
	239	92											0.66225 ± 0.00002	0.20%
	239	92											0.74805 ± 0.00003	0.10%
	239	92											0.81927 ± 0.00003	0.15%
	239	92											0.84410 ± 0.00003	0.17%
$_{92}U^{240}$	240	92		240.056587	14.1 ± 0.2 h	β-	0.50	0.36			0+		Np L x-ray	18%
	240	92											0.04410 ± 0.00007	1.7%
$_{92}U^{242}$	242	92			16.8 m.	β-							0.05558 ± 0.0005	3.7%
	242	92											0.06760 ± 0.00005	9.2%
	242	92											0.1604 ± 0.0001	0.75%
	242	92											0.1820 ± 0.0001	0.70%
	242	92											0.32972 ± 0.00009	0.75%
	242	92											0.5729 ± 0.0001	1.8%
	242	92											0.5849 ± 0.0001	1.8%
Np		93												
$_{93}Np^{228}$	228	93			1.0 m.	S F.								
$_{93}Np^{229}$	229	93		229.036230	4.0 ± 0.2 m.	α	7.010	6.890(20)						
$_{93}Np^{230}$	230	93		230.937810	4.6 m.	E.C.(97%)	3.620							
	230	93				α(3%)		6.660(20)						
$_{93}Np^{231}$	231	93		231.038240	48.8 ± 0.2 m.	E.C.(98%)	1.84				5/2		0.2629 ± 0.0003	2.8 +
	231	93				α(2%)	6.368	6.280	2%				0.3475 ± 0.0003	3.6

Gamma-ray energy MeV)	Gamma-ray intensity
[illegible]50 ±	12 +
0 [illegible]004	
1785 ± 0.0005	11
2179 ± 0.0005	14
[illegible]608 ± 0.0005	12
[illegible] ± 0.001	12
[illegible] ± 0.0004	18
[illegible] ± 0.0004	16
[illegible]4484 ± 0.0004	76
[illegible]4961 ± 0.0005	19
[illegible] ± 0.0004	20
[illegible] ± 0.0005	26
[illegible] ± 0.0004	40
[illegible]7 ± 0.0005	10
6236 ± 0.001	19
6350 ± 0.0004	88
[illegible] ± 0.0004	73
[illegible] ± 0.0004	54
[illegible]3 ± 0.0004	44
[illegible]8491 ± 0.0005	14
.8637 ± 0.0005	54
8857 ± 0.0004	45
[illegible] ± 0.0005	23
[illegible] ± 0.0004	19
[illegible] ± 0.0005	21
9571 ± 0.0005	18
01446 ± 0.0004	100
[illegible]0602 ± 0.0005	45
[illegible] ± 0.0003	50
[illegible] ± 0.0004	17
[illegible] - 2.5)many	
[illegible]095	1.6%
[illegible]	0.2%
[illegible]	0.3%
[illegible]240	0.4%
Th [illegible]-ray	6.0%
[illegible]07218 ± 0.00003	0.60%
[illegible]15421 ± 0[illegible]003	0.12%
[illegible]34 ± 0[illegible]004	0.12%
[illegible]a L x-ray	41%
[illegible]a [illegible]-ray	27%
[illegible]54 ± 0[illegible]001	13%
[illegible]20 ± 0.00001	6.0%
[illegible]21793 ± 0[illegible]002	0.8%
[illegible]38 ± 0[illegible]002	0.2%
[illegible]1100 ± 0 00003	0.06%
Th L x-ray	3.3%
[illegible]04244 ± 0[illegible]001	0.06%
[illegible]14 ± [illegible]002	0.02%

2682

FA
Reference

REFERENCE # 23

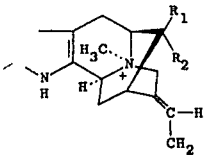
NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

genic reactions when tested in animals *cit.).*

I n of A and B from *Strychnos toxi-* ic e: A. R. Battersby *et al., J. Chem.* ci e of A: A. T. McPhail *et al., Proc.* of B: A. R. Battersby, D. A. Yeowell, M.-M. Janot *et al., Bull. Soc. Chim.* Crystal and molecular structure of A: J Chem. Soc. **1963,** 1832. Sepn of C and C: A. R. Battersby, D. A.



$_7N_2O_3]^+$, *17-hydroxy-16-(methoxycar-* anium, R_1 = CH_2OH, R_2 = COO- m ethanol + ether, mp 252°. $[\alpha]_D^{25}$

$_2O]^+$, *17-hydroxy-4-methylsarpa-* = CH_2OH. Chloride, prisms from 248-249°. $[\alpha]_D^{22}$ +15.6° (c = 1.21). uv 290, 291 nm (log ε 4.61, 3.84, 3.82,

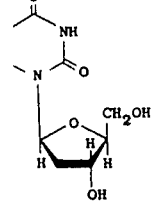
$)_3]^+$, the C-16 epimer of A, R_1 = Chloride, crystals from ethanol $[\alpha]_D^{24}$ −60.8° (c = 2.13). uv max 289 nm (log ε 4.63, 3.88, 3.87, 3.76).

S . Polymeric sodium metaphos- $(NaPO_4$ or $NaNH_4HPO_4$ to 250° and first $Na_2H_2P_2O_7$ and then the insol ined, which is stable to about 500°; at u trimetaphosphate, and above 607° hate. According to Maddrell, ult may be prepd by heating two part H_3PO_4. An improved procedure orre, *Z. Anorg. Chem.* **24,** 397 (1900). *Cryst.* **16,** 428 (1963). *Reviews: see*

dly insol in water and in aq solns kametaphosphates. Sol in mineral complexes with Fe(II), Fe(III), U(IV)

shing agents, abrasive detergents.

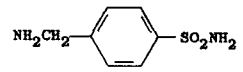
oxy-5-(methylamino)uridine; 5- uridine. $C_{10}H_{15}N_3O_5$; mol wt 5.88%, N 16.34%, O 31.10%. Prepn: *Biophys. Acta* **76,** 463 (1963). Active ections: Nemes, Hilleman, *Proc.* 115 (1965); Shen, U.S. pat. **3,322,**-.).



- water, mp 180-182°.

α-Amino-p-toluenesulfonamide; p- sulfonamide; 4-homosulfanilamide; lesudrin; Mesudin; Sulfamylon; de; Neofamid; Septicid; Emilene;

Homonal; Paramenyl. $C_7H_{10}N_2O_2S$; mol wt 186.25. C 45.14%, H 5.41%, N 15.04%, O 17.18%, S 17.22%. Prepn: Miller *et al., J. Am. Chem. Soc.* **62,** 2099 (1940); Klarer, U.S. pat. **2,288,531** (1942 to Winthrop); Bergeim, Braker, *J. Am. Chem. Soc.* **66,** 1459 (1944); Kusami *et al., J. Pharm. Soc. Japan* **64,** no. 9a, 51 (1944); Komokina *et al., J. Appl. Chem. (USSR)* **21,** 681 (1948); Angyal, Jenkin, *Aust. J. Sci. Res.* **3A,** 461 (1950).



Crystals from alc, mp 151-152°. Sol in dil alkali, acid. Hydrochloride, $C_7H_{10}N_2O_2S.HCl$, crystals from 95% alc, mp 256°. Neutral in soln. LD_{50} in rats, mice: 1.17, 0.9 g/kg i.v., Skulan, Hoppe, *Life Sci.* **5,** 2279 (1966).

Acetate, *Mafatate, Mefamide.* LD_{50} in rats, mice: 2.04, 1.58 g/kg i.v.

Propionate, *Sulfomyl,* crystals, mp 158°. Readily sol in water.

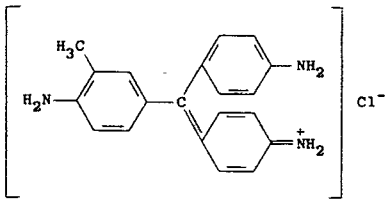
THERAP CAT: Antibacterial.

5467. Magaldrate. *Aluminum magnesium hydroxide $(AlMg(OH)_7)$ monohydrate;* magnesium aluminate hydrate; monalium hydrate; AY 5710; Riopan; Ripon. Formerly treated as $[Mg(OH)]_4[(HO)_4Al(OH)(HO)Al(OH)_4].2H_2O$. Byk Gulden company information states that based on ^{27}Al broadline nuclear resonance spectra, radiographic investigation and chemical analytical finds, the chemical formula for Riopan powder is: $Mg_{1.5+x}Al(OH)_6(SO_4)_x(H_2O)_{0.5-x}$ with $0.325 < x < 0.462$. Prepd by mixing together and allowing to react at 0° to 50° an alkali aluminate soln (contg 3-5 mols of Na_2O or K_2O per mol Al_2O_3) with a magnesium salt soln in such proportions that 1 g of Al combines with 0.9 to 3.0 g of Mg, and washing the pptd product: Hallmann, U.S. pat. **2,923,660** (1960 to Byk-Gulden Lomberg).

White, odorless, crystalline powder which contains the equivs of not < 28.0% and not > 39.0% MgO and not < 17.0% and not > 25.0% Al_2O_3.

THERAP CAT: Antacid.

5468. Magenta I. *4-[(4-Aminophenyl)(4-imino-2,5-cyclohexadien-1-ylidene)methyl]-2-methylbenzenamine monohydrochloride; C.I. Basic Violet 14;* α^4-(*p*-aminophenyl)-α^4-(4-imino-2,5-cyclohexadien-1-ylidene)-2,4-xylidine hydrochloride; 2-methyl-4,4'-[(4-imino-2,5-cyclohexadien-1-ylidene)methylene]dianiline hydrochloride; fuchsine; magenta; rosaniline hydrochloride; C.I. 42510. $C_{20}H_{20}ClN_3$; mol wt 337.85. C 71.10%, H 5.97%, Cl 10.49%, N 12.44%. Prepn: Fischer, Fischer, *Ann.* **194,** 276, 290 (1878); *Ber.* **13,** 2204 (1880); J. T. Scalan, *J. Am. Chem. Soc.* **57,** 887 (1935). Evaluation of carcinogenicity studies: *IARC Monograph* **4,** 57 (1974). *See also: Colour Index* vol. **4** (3rd ed., 1971) p 4389.



Metallic green, lustrous crystals, dec above 200°. Absorption max (ethanol): 543 nm (ε 93,000). 2.65 parts dissolve in 1000 parts water. Practically insol in ether; sol in alcohol with a carmine red color.

USE: As a dye or in manuf of other dyes.

THERAP CAT: Antifungal.

5469. Magnesium. Mg; at. wt 24.305; at. no. 12; valence 2. An alkaline earth metal. One of the most common elements in the earth's crust: 2.1% by weight. Isotopes: 24 (78.70%); 25 (10.13%); 26 (11.17%). Found naturally only in the form of its compounds in magnesite, carnallite, *dolomite* $[CaMg(CO_3)_2]$, epsomite, kieserite, and many other minerals; found in sea-water; in animal and vegetable kingdom. First obtained in metallic form by Davy in 1808 by electrolysis of a mixture of magnesia and mercuric oxide. Methods of prepn: Deville, Caron, etc, cited in *Gmelin's, Magnesium* (8th ed.) **27A,** 121 (1937). Prepd industrially by reduction of MgO-contg materials. Examples of large-scale processes: Weiss, U.S. pat. **3,264,097** (1966 to Ver. Aluminium-Werke). Review of magnesium and its compounds: Goodenough, Stenger, "Magnesium, Calcium, Strontium, Barium and Radium" in *Comprehensive Inorganic Chemistry,* vol. **1,** J. C. Bailar, Jr. *et al.,* Eds. (Pergamon Press, Oxford, 1973) pp 591-664; L. F. Lockwood *et al.,* in Kirk-Othmer *Encyclopedia of Chemical Technology* vol. **14** (Wiley-Interscience, New York, 3rd ed., 1981) pp 570-615.

Silvery-white metal; hexagonal close-packed structure. Slowly oxidizes in moist air. Available as bars, ribbons, wire and powder. mp 651°. bp 1100°. d^{20} 1.738. Sp heat (20°) 0.245 cal/g. Heat of fusion 88 cal/g. Electrical resistivity 4.46 μohm-cm. E° (aq) Mg^{2+}/Mg −2.37 V. Reacts very slowly with water at ordinary temp, less slowly at 100°. Reacts readily with dil acids with liberation of hydrogen; reacts with aq solns of ammonium salts, forming a double salt. Reduces carbon monoxide, carbon dioxide, sulfur dioxide, nitric oxide, and nitrous oxide at a red heat. Burns in air; continues to burn in a current of steam. Combines directly with nitrogen, sulfur, the halogens, phosphorus, and arsenic. Reacts with methyl alcohol at 200° giving magnesium methylate.

Human Toxicity: Particles embedded in skin can produce gaseous blebs with a protracted course. Inhalation of the dust is irritating; fumes can cause metal fume fever.

USE: As a constituent of light alloys; for manuf precision instruments, optical mirrors; in pyrotechnics; in metallurgy as deoxidizing and desulfurizing agent; instead of zinc in dry batteries; for flash bulbs and flares, alumino-thermics, ignition of thermite mixture, intense signal lights; for Grignard reagents; in the recovery of titanium.

5470. Magnesium Acetate. Cromosan. $C_4H_6MgO_4$; mol wt 142.40. C 33.73%, H 4.25%, Mg 17.08%, O 44.94%. $Mg(C_2H_3O_2)_2$.

Tetrahydrate, colorless or white, deliquesc crystals. d 1.45. mp about 80°. Very sol in water or alcohol. The aq soln is neutral or slightly acid. *Keep well closed.* LD_{50} i.v. in mice: 18 mg/kg.

5471. Magnesium Acetylsalicylate. *2-(Acetyloxy)benzoic acid magnesium salt;* magnesium aspirin; Apyron; Fyracyl; Magisal; Magnespirin; Novacetyl. $C_{18}H_{14}MgO_8$; mol wt 382.61. C 56.50%, H 3.69%, Mg 6.36%, O 33.45%. $(CH_3COOC_6H_4COO)_2Mg$.

White, nonhygroscopic, almost tasteless and odorless powder. Freely soluble in water; less sol in alcohol.

THERAP CAT: Has been used as analgesic, antipyretic.

5472. Magnesium Amide. Magnesium diamide. H_4MgN_2; mol wt 56.37. Mg 43.15%, N 49.70%, H 7.15%. $Mg(NH_2)_2$. Prepd by the action of ammonia on an ether soln of magnesium diethyl [illegible]n magnesium activated with iodine (at 400°): Terentiew, *Z. Anorg. Chem.* **162,** 351 (1927); Schlenk, Jr., *Ber.* **64,** 738 (1931). Prepd from metal and liquid ammonia at high pressure: Juza, Jacobs, *Angew. Chem., Int. Ed.* **5,** 247 (1966); *eidem, Z. Anorg. Allgem. Chem.* **370,** 245 (1969).

White powder or crystals. d_4^{25} 1.39. Catches fire in air. Dec on heating. Reacts violently with water, evolving ammonia.

USE: Polymerization catalyst.

5473. Magnesium Benzoate. $C_{14}H_{10}MgO_4$; mol wt 320.60. C 63.08%, H 3.78%, Mg 9.12%, O 24.01%. $Mg(C_7H_5O_2)_2$.

Trihydrate, white, odorless powder. mp about 200°. Sol in 20 parts water, freely in hot water, alcohol. The aq soln is neutral or slightly acid.

5474. Magnesium Bisulfate. Magnesium hydrogen sulfate; acid magnesium sulfate. $H_2MgO_8S_2$; mol wt 218.47. H 0.92%, Mg 11.13%, O 58.59%, S 29.36%. $Mg(HSO_4)_2$.

White powder. Sol in water.

5475. Magnesium Borate. "Antifungin". B_2MgO_4; mol wt 109.93. B 19.67%, Mg 22.11%, O 58.22%. $Mg(BO_2)_2$. Various magnesium borate minerals occur in nature. These include: *ascharite, camsellite, inderite, kotoite, kurnakovite, paternoite, pinnoite, szaibelyite.*

Octahydrate, white powder. Slightly sol in water.

USE: Antiseptic; fungicide.

5476. Magnesium Bromate. Br_2MgO_6; mol wt 280.13. Br 57.05%, Mg 8.68%, O 34.27%. $Mg(BrO_3)_2$.

Hexahydrate, colorless or white crystals; loses all water at about 200°; dec at higher temp. Sol in 1.5 parts water.

5477. Magnesium Bromide. Br_2Mg; mol wt 184.13. Br 86.80%, Mg 13.20%. $MgBr_2$.

Hexahydrate, colorless, very deliquesc crystals or white granules; bitter taste. mp about 165° with decompn. Sol in 0.3 part water; sol in alcohol. The aq soln is neutral. *Keep well closed.*

USE: In organic syntheses.

THERAP CAT: Sedative, anticonvulsant.

5478. Magnesium Carbonate Hydroxide. Marinco C. Usually a basic carbonate, approx $(MgCO_3)_4.Mg(OH)_2.5H_2O$; approx mol wt 485; contains 40-42% MgO. Prepn of various hydrates: Pond, Heneghan, U.S. pat. 3,169,826 (1965 to Merck & Co.). Magnesium carbonate minerals include *magnesite* and *lansfordite.*

White, odorless, bulky powder or light friable masses; at about 700° is converted into MgO. Sol in about 3300 parts CO_2-free water; more sol in water contg CO_2; sol in dil acids with effervescence; insol in alcohol. Imparts slight alkaline reaction to water.

Hydrotalcite, Altacite, Hi-Ti, Nacid, Talcid, an aluminum magnesium hydroxide carbonate hydrate of the general formula $Al_2O_3.6MgO.CO_2.12H_2O$. Prepn: Kumuru *et al.*, U.S. pat. 3,539,306 (1970 to Kyowa).

USE: Fireproofing, heat insulating; preparing effervescent magnesium citrate; clarifying liqs by filtration; in tooth and face powders, in polishing compds; manuf mineral waters, pigments, paper; filler for rubber.

THERAP CAT: Magnesium carbonate hydroxide as antacid, cathartic; hydrotalcite as antacid.

THERAP CAT (VET): Laxative.

5479. Magnesium Chlorate. Cl_2MgO_6; mol wt 191.21. Cl 37.08%, Mg 12.71%, O 50.21%. $Mg(ClO_3)_2$.

Hexahydrate, white, very deliquesc [illegible]stals or cryst powder; bitter taste; d 1.80. mp about [illegible]. Sol in 0.9 part water; slightly sol in alcohol. *Keep well closed.* LD_{50} orally in rats: 5.25 g/kg, Ulrich, *J. Pharmacol. Exp. Ther.* 35, 1 (1929).

5480. Magnesium Chloride. Magnogene. Cl_2Mg; mol wt 95.23. Cl 74.46%, Mg 25.54%. $MgCl_2$. Prepd from magnesium ammonium chloride hexahydrate in the presence of HCl: Bryce-Smith, *Inorg. Syn.* 6, 9 (1960).

Soft, highly deliquescent leaflets. mp 712° (rapid heating). d 2.41, also reported as d 2.325. Slow heating releases chlorine at 300°. Can be distilled in a stream of hydrogen. Attacks fused silica when melted. Sol in water, with the evolution of much heat, giving a clear soln. Easily forms alcoholates and etherates.

Hexahydrate, deliquescent crystals. d 1.56. At 100° loses $2H_2O$ (17.7%); at 110° begins to lose some HCl. By strong ignition is converted into oxychloride. mp, when rapidly heated, at about 118° with decompn. One gram dissolves in 0.6 ml water, 0.3 ml boiling water, 2 ml alcohol. Its aq soln is neutral. *Keep well closed.* LD_{50} orally in rats: 8.1 g/kg, H. F. Smyth *et al., Am. Ind. Hyg. Assoc. J.* 30, 470 (1969).

USE: Fireproofing wood; in disinfectants; various magnesia cements; fire extinguishers; dressing cotton fabrics; in floor-sweeping compds; carbonizing wool; manuf parchment paper or artificial leather; as addition to casein glue; as a reagent in analytical chemistry.

THERAP CAT: Cathartic.

THERAP CAT (VET): Has been used in bovine hypomagnesemia.

5481. Magnesium Citrate. *2-Hydroxy-1,2,3-propanetricarboxylic acid magnesium salt (2:3).* $C_{12}H_{10}Mg_3O_{14}$; mol wt 451.13. C 31.95%, H 2.23%, Mg 16.17%, O 49.65%. $Mg_3(C_6H_5O_7)_2$.

Tetradecahydrate, white, odorless, cryst powder or granules. Slightly sol in water, the soly is increased by citric acid or alkali citrates; sol in dil acids.

THERAP CAT: Cathartic.

5482. Magnesium Citrate, Dibasic. *2-Hydroxy-1,2,3-propanetricarboxylic acid magnesium salt (1:1);* magnesium citrate sol; acid magnesium citrate; Citresia. $C_6H_6MgO_7$; mol wt 214.42. C 33.61%, H 2.82%, Mg 11.34%, O 52.23%. Prepn of stable, hydrated compd: Davenport, Costa, U.S. pat. 2,260,004 (1941 to Pfizer).

Pentahydrate, white or slightly yellow, odorless, granules or powder. Sol in about 5 parts water, becoming less sol with age or by loss of water; insol in alcohol.

5483. Magnesium Fluoride. Afluon; Sellaite. F_2Mg; mol wt 62.32. F 60.98%, Mg 39.02%. MgF_2. Prepd from $MgCO_3$ + HF: Klemm *et al., Z. Anorg. Allgem. Chem.* 176, 13 (1928).

Colorless substance (rutile-type lattice). Slight violet fluorescence. d 3.148. Mohs' hardness: 6. mp 1248°. bp 2260°. Very sparingly sol in water 87 mg/l (18°). Slightly sol in dil acids, especially nitric acid. May be stored in glass bottles. LD orally in guinea pigs: 1.0 g/kg, *Handbook of Toxicology,* vol. 1, W. S. Spector, Ed. (Saunders, Philadelphia, 1956) pp 180-181.

USE: In the ceramics and glass industry.

5484. Magnesium Formate. $C_2H_2MgO_4$; mol wt 114.35. C 21.01%, H 1.76%, Mg 21.27%, O 55.96%. $Mg(HCOO)_2$.

Dihydrate, crystals or granules. Sol in water; insol in alcohol. Its aq soln is practically neutral.

5485. Magnesium Germanide. $GeMg_2$; mol wt 121.24. Mg 40.12%, Ge 59.88%. Mg_2Ge. Prepd by fusion of the components: Winkler, *Helv. Phys. Acta* 28, 633 (1955).

Crystals, mp 1115°.

USE: In semiconductor research.

5486. Magnesium Hexafluorosilicate. Magnesium silicofluoride; magnesium fluosilicate. F_6MgSi; mol wt 166.40. F 68.51%, Mg 14.61%, Si 16.88%. $MgSiF_6$.

Hexahydrate, white, efflorescent, odorless crystals. d 1.788. At about 120° loses SiF_4. Soluble in water; insol in alcohol. pH of 1% aq soln: 3.1. LD orally in guinea pigs: 200 mg/kg, *Handbook of Toxicology,* vol. 1, W. S. Spector, Ed. (Saunders, Philadelphia, 1956) pp 180-181.

USE: For mothproofing of textile fabrics.

5487. Magnesium Hydride. H_2Mg; mol wt 26.34. H 7.65%, Mg 92.35%. MgH_2. Prepd by thermal decompn of diethylmagnesium at 200° in high vacuum: Wiberg, Bauer, *Ber.* 85, 593 (1952); from the elements: Ellinger *et al., J. Am. Chem. Soc.* 77, 2647 (1955).

White, nonvolatile mass or tetragonal crystals. d 1.45. Dec at 280° in high vacuum. Strong reducing agent. Ignites spontaneously on contact with air, forming MgO and H_2O. On contact with water a violent evolution of hydrogen takes place. On contact with methanol, magnesium alcoholate and hydrogen are formed. Forms double hydrides with boron hydride and aluminum hydride.

5488. Magnesium Hydroxide. Magnesium hydrate; Marinco H. H_2MgO_2; mol wt 58.34. H 3.46%, Mg 41.69%, O 54.85%. $Mg(OH)_2$. Occurs in nature as the mineral *brucite.* Prepn from magnesium chloride or sulfate and NaOH: Perlard, Waldron, U.S. pat. 3,127,241 (1964 to Dow). Industrial method for producing magnesium hydroxide having variable particle sizes: Chisholm, U.S. pat. 3,232,708 (1966 to FMC).

Amorphous powder. Practically insol in water (1:80,000); sol in dil acids. Imparts slight alkaline reaction to water. pH of aq slurry: 9.5-10.5. Absorbs CO_2 in the presence of water. *Keep well closed.*

Suspension of 30% magnesium hydroxide in water: *Hydro-Magma.*

THERAP CAT: Antacid, cathartic.

THERAP CAT (VET): Laxative.

5489. Magnesium Iodide. I_2Mg; mol wt 278.11. I 91.26%, Mg 8.74%. MgI_2.

Octahydrate, white, deliquesc powder; readily discolors in air and light. Very sol in water; sol in alcohol. The aq soln is neutral or slightly alkaline. *from light.*

5490. Magnesium Lactat *magnesium salt.* $C_6H_{10}MgO_6$ 4.98%, Mg 12.01%, O 47.42%

Trihydrate, white cryst, ve dissolves in 25 ml cold water sol in alcohol. The aq soln i

THERAP CAT: Cathartic.

5491. Magnesium Mandel mol wt 326.61. C 58.84%, H $Mg[C_6H_5CH(OH)COO]_2$.

White, odorless powder. St water; sol in about 250 parts The aq soln is practically neu mandelic acid.

THERAP CAT: Urinary antis

5492. Magnesium Nitrate. 16.39%, N 18.88%, O 64.73% occurs in nature as the miner

Hexahydrate, colorless, cle mp about 95°. Sol in 0.8 pa The aq soln is neutral. *Keep*

USE: In pyrotechnics; in th

5493. Magnesium Oleate. *sium salt.* $C_{36}H_{66}MgO_4$; m 11.33%, Mg 4.14%, O 10.90% form usually contains some s

Yellowish powder or mass alcohol, ether, petr ether.

USE: As an addition to n ignition in cleaning establishi

5494. Magnesium Oxalat *salt.* C_2MgO_4; mol wt 112. 56.97%. MgC_2O_4.

Dihydrate, white powder. in dil mineral acid; insol in a

5495. Magnesium Oxide. magnesia usta; Magcal; Mag 60.32%, O 39.68%. Occurs in Commercial prepn from mag 3,320,029 (1967 to Northwes

White, very fine, odorless bulky form termed "Light" "Heavy." Takes up CO_2 an form more readily than the h tive in visible and near uv re form magnesium hydroxide. soly increased by CO_2; sol Imparts a slight alkaline rea soln 10.3. *Keep well closed.*

USE: Manuf refractory c cements and boiler scale co sein glue. Reflector in optica dard. Insulator at low temp

THERAP CAT: Antacid.

THERAP CAT (VET): Antacid

5496. Magnesium Perbor B 15.23%, Mg 17.13%, O 67

Heptahydrate, white, bulk loss of active oxygen. Spar decompn; sol in dil acids.

USE: As of sodium perbo powders.

5497. Magnesium Perchl Cl_2MgO_8; mol wt 223.23. M $Mg(ClO_4)_2$.

White, very hygroscopic, above 250°. Dissolves in wat able amount of heat. Crys *Keep tightly closed.*

USE: As a drying agent for may contain an amount of w but even the trihydrate is

...orless, cryst powder or gran-
...he soly is increased by citric acid
...acids.

...te **Dibasic.** *2-Hydroxy-1,2,3-...agnesium salt (1:1);* magnesium ...citrate; Citresia. $C_6H_6MgO_7$; ...f ? 82%, Mg 11.34%, O 52.23%. ...o ...d: Davenport, Costa, U.S. ...et

...g...y yellow, odorless, granules ...parts water, becoming less sol ...insol in alcohol.

...d ...Afluon; Sellaite. F_2Mg; mol ... ...02%. MgF_2. Prepd from ...*et al., Z. Anorg. Allgem. Chem.*

...ile-type lattice). Slight violet ...s ...ardness: 6. mp 1248°. bp ...ater 87 mg/l (18°). Slightly ...r... acid. May be stored in glass ...a pigs: 1.0 g/kg, *Handbook of ...ector*, Ed. (Saunders, Philadel-

...g ...s industry.

...te. $C_2H_2MgO_4$; mol wt 114.35. ...27%, O 55.96%. $Mg(HCOO)_2$. ...anules. Sol in water; insol in ...ly neutral.

...n ... $GeMg_2$; mol wt 121.24. ...fg...ue. Prepd by fusion of the ...*Phys. Acta* **28**, 633 (1955).

...e ...h.

...h **...osilicate.** Magnesium sili-...licate. F_6MgSi; mol wt 166.40. ...88%. $MgSiF_6$.

...or ...ent, odorless crystals. d ...Si ... Soluble in water; insol in ... LD orally in guinea pigs: ...*xicology*, **vol. 1**, W. S. Spector, ...1956) pp 180-181. ...textile fabrics.

...le H_2Mg; mol wt 26.34. H ...pd by thermal decompn of ...high vacuum: Wiberg, Bauer, ...e elements: Ellinger *et al., J. ...*

...or ...tragonal crystals. d 1.45. ...S ...ng reducing agent. Ignites ...th ...air, forming MgO and H_2O. ...ent evolution of hydrogen takes ...ethanol, magnesium alcoholate ... ...rms double hydrides with ...1 ...oxide.

...oxide. Magnesium hydrate; ...t 58.34. H 3.46%, Mg 41.69%, ...rs in nature as the mineral *bru-...c* ...oride or sulfate and NaOH: ...3 ...7,241 (1964 to Dow). In-...g ...agnesium hydroxide having ...olm, U.S. pat. **3,232,708** (1966

...i ...ly insol in water (1:80,000); ...g ...alkaline reaction to water. ...\ ...rbs CO_2 in the presence of

...ium hydroxide in water: *Hy-*

...a ...

...I_2Mg; mol wt 278.11. I

...s ...owder; readily discolors in ...e ...sol in alcohol. The aq soln is neutral or slightly alkaline. *Keep well closed and protected from light.*

5490. Magnesium Lactate. *2-Hydroxypropanoic acid magnesium salt.* $C_6H_{10}MgO_6$; mol wt 202.45. C 35.59%, H 4.98%, Mg 12.01%, O 47.42%. $(CH_3CHOHCOO)_2Mg$.

Trihydrate, white cryst, very bitter powder. One gram dissolves in 25 ml cold water, 3.5 ml boiling water; slightly sol in alcohol. The aq soln is slightly acid.

THERAP CAT: Cathartic.

5491. Magnesium Mandelate. Magdelate. $C_{16}H_{14}MgO_6$; mol wt 326.61. C 58.84%, H 4.32%, Mg 7.45%, O 29.39%. $Mg[C_6H_5CH(OH)COO]_2$.

White, odorless powder. Stable in air. Slightly sol in cold water; sol in about 250 parts boiling water; insol in alcohol. The aq soln is practically neutral. Dec by acids forming free mandelic acid.

THERAP CAT: Urinary antiseptic.

5492. Magnesium Nitrate. MgN_2O_6; mol wt 148.32. Mg 16.39%, N 18.88%, O 64.73%. $Mg(NO_3)_2$. Hydrated form occurs in nature as the mineral *nitromagnesite.*

Hexahydrate, colorless, clear, deliquesc crystals. d 1.464. mp about 95°. Sol in 0.8 part water; freely sol in alcohol. The aq soln is neutral. *Keep well closed.*

USE: In pyrotechnics; in the concentration of nitric acid.

5493. Magnesium Oleate. *9-Octadecenoic acid magnesium salt.* $C_{36}H_{66}MgO_4$; mol wt 587.21. C 73.63%, H 11.33%, Mg 4.14%, O 10.90%. $Mg(C_{18}H_{33}O_2)_2$. Commercial form usually contains some stearate and palmitate.

Yellowish powder or mass. Insol in water; partly sol in alcohol, ether, petr ether.

USE: As an addition to naphtha to prevent spontaneous ignition in cleaning establishments.

5494. Magnesium Oxalate. *Ethanedioic acid magnesium salt.* C_2MgO_4; mol wt 112.33. C 21.38%, Mg 21.65%, O 56.97%. MgC_2O_4.

Dihydrate, white powder. Sol in about 1500 parts water, in dil mineral acid; insol in alcohol.

5495. Magnesium Oxide. Magnesia; calcined magnesia; magnesia usta; Magcal; Maglite. MgO; mol wt 40.32. Mg 60.32%, O 39.68%. Occurs in nature as the mineral *periclase.* Commercial prepn from magnesite ores: Adams, U.S. pat. **3,320,029** (1967 to Northwest Magnesite).

White, very fine, odorless powder. Available in a very bulky form termed "Light" or in a dense form termed "Heavy." Takes up CO_2 and H_2O from the air, the light form more readily than the heavy. mp 2800°. Highly reflective in visible and near uv region. Combines with water to form magnesium hydroxide. Very slightly sol in pure water, soly increased by CO_2; sol in dil acids; insol in alcohol. Imparts a slight alkaline reaction to water. pH of satd aq soln 10.3. *Keep well closed.*

USE: Manuf refractory crucibles, fire bricks, magnesia cements and boiler scale compounds, "powdered" oils, casein glue. Reflector in optical instruments; white color standard. Insulator at low temp.

THERAP CAT: Antacid.

THERAP CAT (VET): Antacid, laxative, in hypomagnesemia.

5496. Magnesium Perborate. B_2MgO_6; mol wt 141.93. B 15.23%, Mg 17.13%, O 67.64%. $Mg(BO_3)_2$.

Heptahydrate, white, bulky powder; gradually dec with loss of active oxygen. Sparingly sol in water with partial decompn; sol in dil acids.

USE: As of sodium perborate; with pptd chalk in tooth powders.

5497. Magnesium Perchlorate. Anhydrone; Dehydrite. Cl_2MgO_8; mol wt 223.23. Mg 10.89%, Cl 31.77%, O 57.34%. $Mg(ClO_4)_2$.

White, very hygroscopic, granular or flaky powder; dec above 250°. Dissolves in water with evolution of a considerable amount of heat. Crystallizes from water with $6H_2O$. *Keep tightly closed.*

USE: As a drying agent for gases. The article of commerce may contain an amount of water equivalent to a dihydrate, but even the trihydrate is said to be effective for drying gases. *Caution:* Can cause irritation of skin, mucous membranes.

5498. Magnesium Permanganate. $MgMn_2O_8$; mol wt 262.19. Mg 9.27%, Mn 41.91%, O 48.82%. $Mg(MnO_4)_2$.

Bluish-black, deliquesc crystals. Freely sol in water. *Keep well closed.*

USE: As polymerization catalyst: Pengilly *et al.*, U.S. pat. **3,576,790** (1971 to Goodyear). In purification of benzene: Ingwalson *et al.*, U.S. pat. **3,478,092** (1969 to Velsicol).

5499. Magnesium Peroxide. Magnesium dioxide; Magnesium Perhydrol; Magnesium Superoxol. MgO_2; mol wt 56.31. Mg 43.17%, O 56.83%. The article of commerce contains 15-25% MgO_2, the balance being magnesium hydroxide. For medicinal use the 25% article is preferred.

White, tasteless, odorless powder. Insol in water and gradually dec by it with liberation of oxygen; sol in dil acids, forming hydrogen peroxide; when strongly heated loses all the peroxide oxygen. *Keep well closed.*

THERAP CAT: Antacid, anti-infective.

5500. Magnesium Phosphate, Dibasic. Magnesium hydrogen phosphate; secondary magnesium phosphate. $HMgO_4P$; mol wt 120.29. H 0.84%, Mg 20.21%, O 53.20%, P 25.74%. $MgHPO_4$. Trihydrate occurs in nature as the minerals *newberyite, phosphor-roesslerite.*

Trihydrate, white, cryst powder. d 2.13. Slightly sol in water; sol in dil acids.

THERAP CAT: Cathartic.

5501. Magnesium Phosphate, Monobasic. Magnesium biphosphate; acid magnesium phosphate; primary magnesium phosphate. $H_4MgO_8P_2$; mol wt 218.28. H 1.84%, Mg 11.14%, O 58.64%, P 28.38%. $Mg(H_2PO_4)_2$.

Trihydrate, white powder. Soluble in water.

USE: In fireproofing wood.

5502. Magnesium Phosphate, Tribasic. "Neutral" magnesium phosphate; tertiary magnesium phosphate; trimagnesium phosphate. $Mg_3O_8P_2$; mol wt 262.86. Mg 27.74%, O 48.70%, P 23.56%. $Mg_3(PO_4)_2$. Octahydrate occurs in nature as the mineral *bobierrite.*

Pentahydrate, white, cryst powder. Loses last mol of water at about 400°. Insol in water; sol in dil mineral acids.

THERAP CAT: Antacid.

5503. Magnesium Potassium Selenate. Potassium magnesium selenate. $K_2MgO_8Se_2$; mol wt 388.43. K 20.13%, Mg 6.26%, Se 40.66%, O 32.95%. $K_2Mg(SeO_4)_2$. Prepd from a soln of aq magnesium and potassium selenates: Tutton, cited in *Mellor's* **10**, 864 (1930).

Hexahydrate, monoclinic prisms. d_4^{20} 2.365. Freely sol in water.

5504. Magnesium Pyrophosphate. $Mg_2O_7P_2$; mol wt 222.55. Mg 21.84%, O 50.33%, P 27.83%. $Mg_2P_2O_7$.

Trihydrate, white powder; loses its water at 100°. d 2.56. Insol in water; sol in dil mineral acids.

5505. Magnesium Salicylate. *2-Hydroxybenzoic acid magnesium salt;* Analate; Lorisal; Magan; Mobidin; Triact. $C_{14}H_{10}MgO_6$; mol wt 298.54. C 56.32%, H 3.38%, Mg 8.15%, O 32.15%. $Mg[C_6H_4(OH)COO]_2$.

Tetrahydrate, white, odorless, efflorescent, cryst powder. Sol in 13 parts water; sol in alc. The aq soln is slightly acid.

THERAP CAT: Intestinal anti-infective.

5506. Magnesium Selenate. MgO_4Se; mol wt 167.27. Mg 14.53%, O 38.26%, Se 47.21%. $MgSeO_4$. Prepn: Mitscherlich, *Pogg. Ann.* **9**, 623 (1827); Berzelius, *ibid.* **32**, 11 (1834); Huff, McCrosky, *J. Am. Chem. Soc.* **51**, 1457 (1929).

Hexahydrate, monoclinic crystals. d 1.928. Stable in air. Sol in water.

5507. Magnesium Selenide. MgSe; mol wt 103.28. Mg 23.55%, Se 76.45%. Prepd by the action of hydrogen selenide on anhydr magnesium chloride at a red heat and by the action of selenium vapor carried in a current of nitrogen on powdered magnesium: Fonzes-Diacon, *Contribution a l'Etude des Séléniures Métalliques* (Montpellier, 1901); by dropping selenium into molten magnesium: Liddell, *Chem. Met. Eng.* **25**, 102, 263, 453 (1921).

Light brown powder. d 4.21. Unstable in air. Dec in water.

5508. Magnesium Selenite. MgO_3Se; mol wt 151.27. Mg 16.07%, O 31.73%, Se 52.20%. $MgSeO_3$. Hexahydrate prepd by adding sodium selenite to a soln of magnesium chloride: Nilson, cited in *Mellor's* **10,** 826 (1930); by treating a soln of magnesium chloride or sulfate with selenious acid and adding sodium carbonate to start precipitation: Boutzoureano, *Recherches sur les Sélénites* (Paris, 1889).

Orthorhombic crystals. Insol in water; sol in dil acids. Forms monoclinic prisms of the dihydrate when heated in a sealed tube to 150°. When heated to 100°, it loses 5 mols of water leaving the monohydrate.

5509. Magnesium Silicates. Several varieties of magnesium silicate are known. *See also* asbestos, talc.

Magnesium metasilicate, MgO_3Si. Occurs in nature as the minerals ***clinoenstatite, enstatite, protoenstatite.*** White monoclinic crystals, dec at 1557°. d_4^{25} 3.192. Practically insol in water; very slightly sol in HF.

Magnesium orthosilicate, Mg_2O_4Si. Occurs in nature as the mineral ***forsterite.*** White orthorhombic crystals. mp 1910°; d 3.21. Practically insol in water.

Magnesium trisilicate, $Mg_2O_8Si_3$, ***magnesium mesotrisilicate, Magnosil, Petimin, Trisomin.*** Occurs in nature as the minerals ***meerschaum, parasepiolite, sepiolite.*** Prepd from sodium silicate and magnesium sulfate: Glass, *Quart. J. Pharm. Pharmacol.* **9,** 445 (1936); Uyeda, U.S. pat. **3,272,594** (1966 to Merck & Co.). Odorless, tasteless, slightly hygroscopic powder. Usually contains some water of hydration. Practically insol in water.

Magnesium trisilicate pentahydrate, ***Sellagen.***

Serpentine (mineral), $Mg_3O_7Si_2$. Occurs in nature as the dihydrate, $(OH)_4MgSi_2O_5$; exists in two forms: ***antigorite,*** a platy variety, and ***chrysotile,*** a fibrous variety. The latter is the most common form of asbestos, *q.v.*

USE: An activated magnesium silicate, ***Florisil,*** a hard, porous, granular substance, is used in vitamin analysis, chromatography, antibiotic processing: Simons, U.S. pat. **2,393,625** (1946 to Floridin).

THERAP CAT: Trisilicate as antacid.

THERAP CAT (VET): Trisilicate as antacid; gastric sedative.

5510. Magnesium Silicide. Mg_2Si; mol wt 76.73. Mg 63.39%, Si 36.61%. Prepd by heating finely powdered Mg and Si in a proportion of 20 to 6: Gire, *Compt. Rend.* **196,** 1404 (1933), *C.A.* **27,** 2578 (1933); Winkler, *Helv. Phys. Acta* **28,** 633 (1955), *C.A.* **50,** 6908c (1956). Prepn and conversion to silanes: Emeleus, Maddock, *J. Chem. Soc.* **1946,** 1131.

Slate-blue, cubic crystals. d_4^{20} about 2.0. mp 1085°. Dec at 550° *in vacuo* yielding Mg_3Si_2. Heat of formation: 18.5 cal/mol. Dec by water, HCl.

USE: In semiconductor research. Has been used to build Mg-Si rectifiers.

5511. Magnesium Stannide. Mg_2Sn; mol wt 167.34. Mg 29.07%, Sn 70.93%. Prepn by fusion of a stoichiometric mixture of the elements: Winkler, *Helv. Phys. Acta* **28,** 633 (1955); Korenblit, Kolesnikov, *Zh. Tekh. Fiz.* **26,** 941 (1956), *C.A.* **50,** 11475b (1956).

Bluish-white, metallic substance. Calcium fluoride crystal structure. mp 778°. Magnetic susceptibility and electrical conductivity measurements: Boltaks, *Doklady Akad. Nauk SSSR* **64,** 487, 653, (1949), *C.A.* **43,** 4528f, 4533f (1949). Resistivity (25°): 42,000 microhm-cm; thermoelectric power 90 microvolts per degree for 15-100°. Energy of activation: 22,100 cal/mole. Electrical conductivity, magnetoresistance: Frederikse *et al., Phys. Rev.* **103,** 67 (1956). Soluble in water, dilute HCl.

USE: In semiconductor research.

5512. Magnesium Stearate. ***Octadecanoic acid magnesium salt.*** $C_{36}H_{70}MgO_4$; mol wt 591.27. C 73.13%, H 11.93%, Mg 4.11%, O 10.82%. $Mg(C_{18}H_{35}O_2)_2$. The commercial preparation also contains palmitate.

White powder. Insoluble in water; dec by dil acids.

USE: In baby dusting powders; as tablet lubricant.

5513. Magnesium Sulfate. MgO_4S; mol wt 120.38. Mg 20.20%, O 53.16%, S 26.63%. $MgSO_4$. Monohydrate occurs in nature as the mineral ***kieserite.***

Trihydrate, odorless crystals. Prepn: Bennett, U.S. pat. **3,297,413** (1967 to Dow).

Heptahydrate, ***bitter salts, epsom salts.*** Occurs in nature as the mineral ***epsomite.*** Efflorescent crystals or powder; bitter, saline, cooling taste. d 1.67. Soly in water (g/100 ml): at 20° = 71; at 40° = 91. Slightly sol in alcohol. Its aq soln is neutral. pH 6-7. On exposure to dry air at ordinary temp it loses about $1H_2O$; at 70-80° loses $4H_2O$; at 100° loses $5H_2O$; at 120° loses $6H_2O$, rapidly reabsorbing water when exposed to moist air; loses the last mol of water at about 250°: *Gmelin's, Magnesium* (8th ed) **27,** 210-211, 223-226 (1939). ***Dried magnesium sulfate*** is prepd by heating the heptahydrate until approx 25% of its weight is lost. Used in ***Morison's paste.*** ***Keep well closed.***

Human Toxicity: Parenteral use or use in presence of renal insufficiency may lead to magnesium intoxication.

USE: Weighting cotton and silk; increasing the bleaching action of chlorinated lime; manuf mother-of-pearl and frosted papers; fire-proofing fabrics; dyeing and printing calicos; in fertilizers; explosives, matches; mineral water; tanning leather.

THERAP CAT: Heptahydrate as anticonvulsant: cathartic. Dried magnesium sulfate in aperients.

THERAP CAT (VET): Purgative, in general anesthesia, in hypomagnesemia; externally (in strong solns) in local inflammations, infected wounds.

5514. Magnesium Sulfite. MgO_3S; mol wt 104.37. Mg 23.29%, O 45.99%, S 30.72%. $MgSO_3$. Occurs as tri- and hexahydrates.

Hexahydrate, colorless crystals or white, cryst powder, gradually oxidizes to sulfate on exposure to air; loses all its water at 200°; dec at higher temp. Sol in about 150 parts water, slightly more in boiling water.

USE: A soln of magnesium sulfite in sulfurous acid (magnesium bisulfite) is used in the manuf of paper pulp.

5515. Magnesium Thiocyanate. Magnesium sulfocyanate. $C_2MgN_2S_2$; mol wt 140.46. C 17.10%, Mg 17.31%, N 19.94%, S 45.65%. $Mg(SCN)_2$.

Tetrahydrate, colorless or white deliquesc crystals. Freely sol in water or alcohol. ***Keep well closed.***

5516. Magnesium Thiosulfate. Magnesium hyposulfite. Magnosulf; Antichoc Hipmag. MgO_3S_2; mol wt 136.43. Mg 17.82%, O 35.18%, S 47.00%. MgS_2O_3.

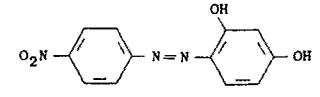
Hexahydrate, colorless or white crystals; loses $3H_2O$ at 170°. d 1.82. Sol in 2 parts water; insol in alcohol. Its aq soln is neutral.

5517. Magnesium Tungstate(VI). MgO_4W; mol wt 272.18. Mg 8.93%, O 23.51%, W 67.56%. $MgWO_4$. Prepn of doped single crystals: Van Vitert, U.S. pat. **3,003,113** (1961 to Bell).

White, cryst powder. Insol in water.

USE: In solid state maser.

5518. Magneson. ***4-[(4-Nitrophenyl)azo]-1,3-benzenediol; 4-(p-nitrophenylazo)resorcinol;*** 2,4-dihydroxy-4'-nitroazobenzene. $C_{12}H_9N_3O_4$; mol wt 259.22. C 55.60%, H 3.50%, N 16.21%, O 24.69%. *Ref:* Suitzu, Okuma, *J. Chem. Ind. (Japan)* **29,** 132 (1926); Ruigh, *J. Am. Chem.* **51,** 1456 (1929); Engel, *ibid.* **52,** 1812 (1930).



Brownish-red powder. Practically insol in water; sol in aq NaOH.

USE: For the detection of magnesium with which it yields a bright blue color in alkaline soln. Also used to determine molybdenum with which it forms a red-violet complex: Nikitina, Andrianova, *C.A.* **75,** 136789v (1971).

5519. Magnoflorine. ***5,6,6a,7-Tetrahydro-1,11-dihydroxy-2,10-dimethoxy-6,6-dimethyl-4H-dibenzo[de,g]quinolinium;*** thalictrine. $[C_{20}H_{24}NO_4]^+$; mol wt 342.50. *Magnolia grandiflora* L., *Magnoliaceae.* Isoln and str. Nakano, *Chem. Pharm. Bull.* **2,** 329 (1954). From *C. trilobus* D.C., *Menispermaceae:* Nakano, *ibid.* **4,** 69

methanol, ethanol, cold water, forming deep red solns; slightly sol in acetone; practically insol in ethyl acetate.

5538. Manaca. Manacan; camganiba; geratacaca; vegetable mercury. Dried root of *Brunfelsia hopeana* Benth. (*Franciscea uniflora* Pohl), *Solanaceae. Habit.* Brazil. *Constit.* The alkaloid manacine, esculetin, a fluorescent substance probably identical with gelsemic acid.

THERAP CAT: Antisyphilitic.

5539. Mandelic Acid. *α-Hydroxybenzeneacetic acid; dl-*mandelic acid; racemic mandelic acid; α-hydroxy-α-toluic acid; α-hydroxyphenylacetic acid; phenylhydroxyacetic acid; phenylglycolic acid; amygdalic acid; amygdalinic acid; paramandelic acid; Uromaline. $C_8H_8O_3$; mol wt 152.14. C 63.15%, H 5.30%, O 31.55%. $C_6H_5CH(OH)COOH$. Prepd by the action of warm, dil alkali upon dichloroacetophenone: *Org. Syn.* **23,** 48 (1943); by hydrolysis of mandelonitrile (prepd from benzaldehyde and hydrogen cyanide or from benzaldehyde, sodium bisulfite, and sodium cyanide): *Org. Syn.* **coll. vol. I,** 336 (1941); *ibid.* **coll. vol. III,** 538 (1955); L. F. Fieser, *Organic Experiments* (Boston, 1964) p 109. May be prepd by boiling amygdalin with HCl.

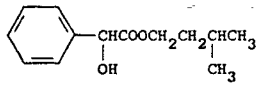
Orthorhombic plates from water, mp 119°. Darkens and dec on prolonged exposure to light. d 1.30. Can be distilled rapidly *in vacuo* at 2 mm without much decompn. Acid to litmus. K at 25° = 4.3×10^{-4}. One gram dissolves in 6.3 ml water, 1 ml alc; freely sol in ether, isopropyl alcohol.

Calcium salt, $C_{16}H_{14}CaO_6$, *calcium mandelate, Camdelate.* Contains 88.88% mandelic acid. White powder. One gram dissolves in 80 ml boiling water. Slightly sol in cold water. Insol in alc. The aq soln is slightly acid.

Sodium salt, $C_8H_7NaO_3$, *sodium mandelate.* Cryst powder; slight aromatic odor. Very sol in water; sol in alcohol; the aq soln is neutral or slightly alkaline to litmus.

THERAP CAT: Urinary antiseptic.

5540. Mandelic Acid Isoamyl Ester. *α-Hydroxybenzeneacetic acid 3-methylbutyl ester; mandelic acid isopentyl ester;* isoamyl mandelate; Atractyl; Spasmol; Mandaverm; Vermiparin; Spasmostenyl. $C_{13}H_{18}O_3$; mol wt 222.27. C 70.24%, H 8.16%, O 21.59%. Prepd by esterification of DL-mandelic acid with an excess of isoamyl alcohol in the presence of concd H_2SO_4: Rona *et al., Biochem. Z.* **181,** 50 (1927). Improved procedure: Brock *et al., Arzneimittel-Forsch.* **2,** 166 (1952).



Oily liquid. bp_{11} 172° (Rona); bp_{12} 155° (Brock). Practically insol in water. Miscible with fat solvents. Easily hydrolyzed by esterases. *The pure, undiluted liquid is a skin irritant.*

THERAP CAT: Adjunct in the treatment of gastric and intestinal spasms.

THERAP CAT (VET): Has been used as an anthelmintic.

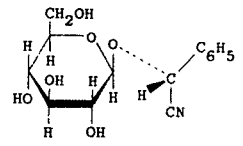
5541. Mandelonitrile. *α-Hydroxybenzeneacetonitrile;* mandelic acid nitrile; benzaldehyde cyanohydrin. C_8H_7NO; mol wt 133.14. C 72.16%, H 5.30%, N 10.52%, O 12.02%. $C_6H_5CH(OH)CN$. Isoln of *d*-form from peach flower buds: Jones, Enzie, *Science* **134,** 284 (1961). Prepn of *d*-form by hydrolysis of amygdalin: Auld, *J. Chem. Soc.* **95,** 927 (1909); Smith, *Ber.* **64,** 427 (1931). Resolution of *dl*-form: Feist, *Arch. Pharm.* **247,** 226 (1909). Synthesis of *l*-form using cotton fibers: Bredig, Gerstner, *Biochem. Z.* **250,** 414 (1932). Asymmetric synthesis: Krieble, Wieland, *J. Am. Chem. Soc.* **43,** 164 (1921); Prelog, Wilhelm, *Helv. Chim. Acta* **37,** 1634 (1954); Tsuboyama, *Bull. Chem. Soc. Japan* **35,** 1004 (1962). It has been suggested that mandelonitrile may be responsible for the alleged anticancer activity of Laetrile (*q.v.*): *see* Culliton, *Science* **182,** 1000 (1973).

dl-Form, yellow, oily liquid, mp −10°. Decomp at 170°. d 1.115-1.120. Almost insol in water; freely sol in alcohol, chloroform, ether. LD s.c. in rabbits: 6 mg/kg.

d-Form, $[\alpha]_D^{25}$ +43.75° (c = 5.006 in benzene).

USE: Preparing bitter almond water, by mixing 11 g with 500 g alc and 1489 g water; the mixture contains 0.1% HCN.

5542. Mandelonitrile Glucoside. *α-(β-D-Glucopyranosyloxy)benzeneacetonitrile.* $C_{14}H_{17}NO_6$; mol wt 295.28. C 56.94%, H 5.80%, N 4.74%, O 32.51%. Prepn of *d*-form by action of yeast on amygdalin: Fischer, *Ber.* **28,** 1508 (1895); Auld, *J. Chem. Soc.* **93,** 1276 (1908). Isoln of *d*-form from *Prunus serotina,* Ehrk, *P. macrophylla* Sieb et Zucc., *Rosaceae:* Power, Moore, *ibid.* **95,** 243 (1909); **97,** 1099 (1910); Kariyone, Matsushima, *J. Pharm. Soc. Japan* no. **514,** 1061 (1924); from *Eucalyptus corynocalyx* F.v.M., *Myrtaceae:* Finnemore *et al., J. Proc. Roy. Soc. N.S. Wales* **69,** 209 (1936); from *Pteridium aquilinum* (L.) Kühn, *Polypodiaceae:* Kofod, Eyjolfssen, *Tetrahedron Letters* **1966,** 1289. Isoln of *dl*-form from *Prunus laurocerasus* L. and *Cotoneaster microphylla* Wall., *Rosaceae:* Winkler, Simon, *Ann.* **31,** 263 (1839); Hérissey, *J. Pharm. Chim.* **24,** 537 (1906). Isoln of *l*-form from *Sambucus nigra* L., *Caprifoliaceae:* Guignart, *Compt. Rend.* **141,** 16 (1905); Bourquelot, Danjot, *ibid.* 598 (1905). Prulaurasin is *dl*-mandelonitrile glucoside and sambunigrin is *l*-mandelonitrile glucoside: Caldwell, Courtauld, *J. Chem. Soc.* **91,** 671 (1907). Biosynthesis of *d*-mandelonitrile glucoside: Mentzer, Favre-Bonvin, *Compt. Rend.* **253,** 1072 (1961). Absolute configuration of isomers: U. Schwarzmaier, *Ber.* **109,** 3250 (1976).



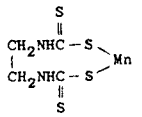
d-form

d-Form, *prunasin.* Needles from chloroform, mp 147-148°. $[\alpha]_D^{14}$ −29.94°. Soluble in water, alcohol, acetone. Converted by alkalies to prulaurasin.

dl-Form, *prulaurasin.* Slightly bitter needles from ethyl acetate + ether, mp 123-125°. $[\alpha]_D$ −54° (water). Soluble in water, alcohol; practically insol in ether. On hydrolysis yields *dl*-mandelic acid.

l-Form, *sambunigrin.* Bitter needles from hot ethyl acetate, mp 151-152°. $[\alpha]_D^{18}$ −75.1°. Soluble in water, alcohol, ethyl acetate. On hydrolysis yields *l*-mandelic acid.

5543. Maneb. *[[1,2-Ethanediylbis[carbamodithioato]]-(2−)]manganese; [ethylenebis(dithiocarbamato)]manganese;* ethylenebis[dithiocarbamic acid] manganous salt; manganous ethylenebis[dithiocarbamate]; Manzate; Dithane M-22. $C_4H_6MnN_2S_4$; mol wt 265.29. C 18.11%, H 2.28%, Mn 20.70%, N 10.56%, S 48.35%. Prepd from aq nabam soln by neutralizing with acetic acid and adding $MnCl_2$ soln: Flenner, U.S. pat. **2,504,404** (1950 to du Pont), *see also* Hester, U.S. pat. **2,317,765** (1943 to Rohm & Haas).



Yellow powder. Crystals from alcohol. Moderately sol in water. Sol in chloroform, pyridine.

USE: Agricultural fungicide.

5544. Manganese. Mn; at. wt 54.9380; at. no. 25; valences 2, 4, 7; 1, 3, 5, 6 rare. One stable isotope: 55; artificial radioactive isotopes 49-54; 56-58. Widely-distributed, abundant element; constitutes 0.085% of earth's crust. Occurs in the minerals pyrolusite, hausmannite, manganite, *manganosite* (MnO), *braunite* ($3Mn_2O_3.MnSiO_3$), and in several others; occurs in minute quantities in water, plants and animals. First isolated by Gahn in 1774. Prepn of the metal: John *et al.*, cited by Mellor, *A Comprehensive Treatise on Inorganic and Theoretical Chemistry,* **12,** 163 (1932); A. H. Sully, *Manganese* (Academic Press, New York, 1955) 305 pp. Review of physical properties: Meaden, *Met. Rev.* **13,** 97-114 (1968). Review of manganese and its compds: Kemmitt in *Comprehensive Inorganic Chemistry,* **vol. 3,** J. C. Bailar Jr. *et al.*, Eds. (Pergamon P 771-876; L. R. Matricardi, J. H. D *Encyclopedia of Chemical Technolog* science, New York, 3rd ed., 1981) p

Steel gray, lustrous, hard, brittle allotropic forms: α-form, body-cent 710° (approx), d^{20} 7.47; β-form, cu 710-1079°, d^{20} 7.26; γ-form or electr cubic, stable in the range 1079-11 body-centered cubic, stable from 1 γ-Mn when stabilized at room temp onal, d^{20} 7.21. mp 1244°. bp 2095°. latent heat of fusion: 3.5 kcal/g-at Superficially oxidized on exposure intense white light when heated in the cold, rapidly on heating; pure not attacked by water at ordinary t steam. Reacts with dil mineral aci drogen and formation of divalent with aq solns of sodium or potass heated in nitrogen above 2000° Converted by fluorine into the di rine into the dichloride. In form metallic oxides on heating. On he carbon, phosphorus, antimony or

Human Toxicity: Occurs by in fumes. Symptoms: languor, sleepi disburbances, spastic gait, paralysi kinsonism: E. Browning, *Toxicity* pleton-Century-Crofts, New York 225.

USE: In manuf of steel; for rock and crossings, wagon buffers; as alloys, *e.g.*, ferromanganese, copp

5545. Manganese Acetate. C_4 C 27.76%, H 3.50%, Mn 31.75% $COO)_2$.

Tetrahydrate, pale red, transpa d 1.59. Sol in water or alcohol. g/kg, Smyth *et al., Am. Ind. Hyg*

USE: As mordant in dyeing; ma and varnishes (1-1.5:1000).

5546. Manganese Borate. Ap Brownish-white powder. Insol on long contact with water; sol in

USE: In drying varnishes and o 1:500; also in leather industry.

5547. Manganese Bromide. M Mn; mol wt 214.76. Br 74.42%.

Tetrahydrate, rose-red, slightly with some decompn. Sol in 0.5 The aq soln is slightly acid. *Ke*

5548. Manganese Carbonate. 10.45%, Mn 47.79%, O 41.76%. some H_2O). Occurs in nature a

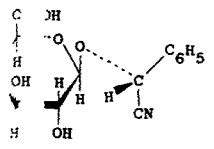
Pink to almost white powder w ually becomes light brown in the structure. d 3.1. Insol in water *Keep well closed.*

USE: As pigment—"manganese in feeds.

5549. Manganese Carbonyl. $C_{10}Mn_2O_{10}$; mol wt 389.99. 41.03%. $Mn_2(CO)_{10}$. First prep a Grignard reagent under CO p *Chem. Soc.* **71,** 1899 (1949). I *al., ibid.* **76,** 3831 (1954); Clo Podall *et al., ibid.* **82,** 1325 (196 **4,** 293 (1965). Crystal structure **16,** 419 (1963); molecular stru *Acta Chem. Scand.* **23,** 685 (196 *theses via Metal Carbonyls* vol. (Interscience, New York, 1968) *Khim.* **37,** 380-408 (1968); *Ru* (1968) (English translation).

Golden yellow, monoclinic c 155°. Stable under an atm of C

e Glucoside. α-(β-D-Glucopyrano
le. $C_{14}H_{17}NO_6$; mol wt 295.28. C
7 , O 32.51%. Prepn of d-form by
in: Fischer, *Ber.* **28**, 1508 (1895);
, 76 (1908). Isoln of d-form from
P. macrophylla Sieb et Zucc., *Rosac*
id. **95**, 243 (1909); **97**, 1099 (1910);
Pharm. Soc. Japan no. **514**, 1061
corynocalyx F.v.M., *Myrtaceae:*
Roy. Soc. N.S. Wales **69**, 209
ilinum (L.) Kühn, *Polypodiaceae:*
hedron Letters **1966**, 1289. Isoln of
rocerasus L. and *Cotoneaster micro-*
Winkler, Simon, *Ann.* **31**, 263
Chim. **24**, 537 (1906). Isoln of
ra L., *Caprifoliaceae:* Guignart,
1905); Bourquelot, Danjot, *ibid.* **598**
dl-mandelonitrile glucoside and sam-
glucoside: Caldwell, Courtauld,
l). Biosynthesis of *d*-mandeloni-
Favre-Bonvin, *Compt. Rend.* **253**,
e configuration of isomers: U.
, 3250 (1976).

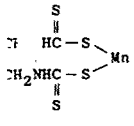


d-form

N iles from chloroform, mp 147-
S ible in water, alcohol, acetone.
ulaurasin.
. Slightly bitter needles from ethyl
3-125°. $[\alpha]_D$ −54° (water). Soluble
ic ly insol in ether. On hydrolysis

tter needles from hot ethyl ace-
−75.1°. Soluble in water, alcohol,
lysis yields *l*-mandelic acid.

hanediylbis[carbamodithioato]]-
e bis(dithiocarbamato)]manganese;
i cid] manganous salt; manga
arbamate]; Manzate; Dithane M-22.
265.29. C 18.11%, H 2.28%, Mn
3 %. Prepd from aq nabam soln by
a and adding $MnCl_2$ soln: Flen-
50 to du Pont), *see also* Hester,
Rohm & Haas).



a from alcohol. Moderately sol in
n yridine.
gicide.

Mn; at. wt 54.9380; at. no. 25; va-
One stable isotope: 55; artifi-
54; 56-58. Widely-distributed,
utes 0.085% of earth's crust.
yrolusite, hausmannite, manganite,
unite ($3Mn_2O_3.MnSiO_3$), and in sev-
quantities in water, plants and
Gahn in 1774. Prepn of the
fellor, *A Comprehensive Treatise*
tical Chemistry, **12**, 163 (1932); A.
ademic Press, New York, 1955) 305
properties: Meaden, *Met. Rev.* **13**,
manganese and its compds:
norganic Chemistry, **vol. 3**, J. C.
Bailar Jr. *et al.*, Eds. (Pergamon Press, Oxford, 1973) pp 771-876; L. R. Matricardi, J. H. Downing in Kirk-Othmer *Encyclopedia of Chemical Technology* **vol. 14**, (Wiley-Interscience, New York, 3rd ed., 1981) pp 824-843.

Steel gray, lustrous, hard, brittle metal. Exists in four allotropic forms: α-form, body-centered cubic, stable below 710° (approx), d^{20} 7.47; β-form, cubic, stable in the range 710-1079°, d^{20} 7.26; γ-form or electrolytic Mn, face-centered cubic, stable in the range 1079-1143°C, d^{1100} 6.37; δ-form, body-centered cubic, stable from 1143° to mp, d^{1143} 6.28. γ-Mn when stabilized at room temp is face-centered tetragonal, d^{20} 7.21. mp 1244°. bp 2095°. Sp heat 0.115 cal/g/°C; latent heat of fusion: 3.5 kcal/g-atom. Mohs' hardness 5.0. Superficially oxidized on exposure to air. Burns with an intense white light when heated in air. Dec water slowly in the cold, rapidly on heating; pure electrolytic manganese is not attacked by water at ordinary temp; slightly attacked by steam. Reacts with dil mineral acids with evolution of hydrogen and formation of divalent manganous salts. Reacts with aq solns of sodium or potassium bicarbonate. When heated in nitrogen above 2000° burns to form a nitride. Converted by fluorine into the di- and trifluoride, by chlorine into the dichloride. In form of powder reduces most metallic oxides on heating. On heating, reacts directly with carbon, phosphorus, antimony or arsenic.

Human Toxicity: Occurs by inhalation of the dust or fumes. Symptoms: languor, sleepiness, weakness, emotional disburbances, spastic gait, paralysis. Picture resembles parkinsonism: E. Browning, *Toxicity of Industrial Metals* (Appleton-Century-Crofts, New York, 2nd ed., 1969) pp 213-225.

USE: In manuf of steel; for rock crushers, railway points and crossings, wagon buffers; as a constituent of several alloys, e.g., ferromanganese, copper manganese, Manganin.

5545. Manganese Acetate. $C_4H_6MnO_4$; mol wt 173.03. C 27.76%, H 3.50%, Mn 31.75%, O 36.99%. $Mn(CH_3COO)_2$.

Tetrahydrate, pale red, transparent monoclinic crystals. d 1.59. Sol in water or alcohol. LD_{50} orally in rats: 3.73 g/kg, Smyth *et al., Am. Ind. Hyg. Assoc. J.* **30**, 470 (1969).

USE: As mordant in dyeing; manuf bister; drier for paints and varnishes (1-1.5:1000).

5546. Manganese Borate. Approx $MnB_4O_7.8H_2O$.

Brownish-white powder. Insol in water or alcohol. Dec on long contact with water; sol in dil acids.

USE: In drying varnishes and oils; as drier for linseed oil, 1:500; also in leather industry.

5547. Manganese Bromide. Manganese dibromide. Br_2Mn; mol wt 214.76. Br 74.42%, Mn 25.58%. $MnBr_2$.

Tetrahydrate, rose-red, slightly deliquesc crystals. mp 64° with some decompn. Sol in 0.5 parts water; sol in alcohol. The aq soln is slightly acid. *Keep well closed.*

5548. Manganese Carbonate. $CMnO_3$; mol wt 114.94. C 10.45%, Mn 47.79%, O 41.76%. $MnCO_3$. (Usually contains some H_2O). Occurs in nature as the mineral *rhodochrosite.*

Pink to almost white powder when freshly pptd, but gradually becomes light brown in the air. Rhombohedral, calcite structure. d 3.1. Insol in water or alcohol; sol in dil acid. *Keep well closed.*

USE: As pigment—"manganese white"; drier for varnishes; in feeds.

5549. Manganese Carbonyl. *Decacarbonyldimanganese.* $C_{10}Mn_2O_{10}$; mol wt 389.99. C 30.80%, Mn 28.17%, O 41.03%. $Mn_2(CO)_{10}$. First prepd by reduction of MnI_2 with a Grignard reagent under CO pressure: Hurd *et al., J. Am. Chem. Soc.* **71**, 1899 (1949). Improved prepns: Brimm *et al., ibid.* **76**, 3831 (1954); Closson, *ibid.* **80**, 6167 (1958); Podall *et al., ibid.* **82**, 1325 (1960); Calderazzo, *Inorg. Chem.* **4**, 293 (1965). Crystal structure: Dahl, Rundle, *Acta Cryst.* **16**, 419 (1963); molecular structure: Almenningen *et al., Acta Chem. Scand.* **23**, 685 (1969). *Reviews: Organic Syntheses via Metal Carbonyls* **vol. 1**, I. Wender, P. Pino, Eds. (Interscience, New York, 1968) *passim;* Anisimov *et al., Usp. Khim.* **37**, 380-408 (1968); *Russ. Chem. Rev.* **37**, 184-197 (1968) (English translation).

Golden yellow, monoclinic crystals. d^{25} 1.75. mp 154-155°. Stable under an atm of CO. In absence of CO, begins to dec at 110°. Sol in organic solvents, insol in water. Less stable to air, heat and light in soln.

USE: Catalyst; antiknock additive.

5550. Manganese Chloride. Manganous chloride; manganese dichloride. Cl_2Mn; mol wt 125.84. Cl 56.34%, Mn 43.66%. $MnCl_2$.

Tetrahydrate, reddish, slightly deliquesc, monoclinic crystals. d 2.01. mp 58°. Sol in 0.7 part water; sol in alcohol; insol in ether. pH of 0.2 molar aq soln 5.5. *Keep well closed.* LD s.c. in mice: 180-250 mg/kg; i.v. in dogs: 201.6 mg/kg, *Handbook of Toxicology,* **Vol. 1**, W. S. Spector, Ed. (Saunders, Philadelphia, 1956) pp 182-183.

USE: In dyeing (manganese bister); disinfecting; purifying natural gas; linseed oil drier; in electric batteries.

5551. Manganese Difluoride. Manganous fluoride; manganese fluoride. F_2Mn; mol wt 92.93. F 40.89%, Mn 59.11%. MnF_2. Prepd from manganese carbonate and hydrogen fluoride: Moissan, Venturi, *Compt. Rend.* **130**, 1158 (1900); Kwasnik in *Handbook of Preparative Inorganic Chemistry,* **Vol. 1**, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) pp 262-263.

Pink, quadratic prisms (tetragonal structure, rutile type) or reddish powder. *Poisonous!* d 3.98. mp 856°. Soly in water (g/100 ml): 0.66 (40°); 0.44 (60°); 0.48 (100°). Insol in alc. Sol in dil hydrofluoric acid, concd hydrochloric or nitric acid. Lowest published lethal dose in guinea pigs: 200 mg/kg orally; 700 mg/kg s.c., *Toxic Substances List,* H. E Christensen, Ed. (1973) p 574.

Tetrahydrate, obtained by dissolving manganese carbonate in hydrofluoric acid, evaporating, and drying *in vacuo.*

5552. Manganese Dioxide. Manganese binoxide; manganese peroxide; manganese superoxide; black manganese oxide. MnO_2; mol wt 86.94. Mn 63.19%, O 36.81%. Occurs in nature as the mineral *pyrolusite,* or made artificially (pptd). The native product is heavy, steel-gray when in lumps, black when powdered; the pptd product is a brownish-black, fine powder. Both usually contain some Mn_3O_4 and some water. When ignited evolves oxygen, leaving Mn_3O_4. Lab prepn: Moore *et al., J. Am. Chem. Soc.* **72**, 856 (1950); Covington *et al., Trans. Faraday Soc.* **58**, 1975 (1962). Review of use as reagent: J. S. Pizey, *Synthetic Reagents* **vol. 2** (John Wiley, New York, 1974) pp 143-174.

Tetragonal crystals (rutile structure). Insol in water, nitric or cold sulfuric acid; slowly dissolves in cold HCl with evolution of Cl_2; in presence of hydrogen peroxide or oxalic acid it dissolves in dil H_2SO_4 or HNO_3. *Caution: Manganese dioxide is a strong oxidizer, hence it should not be heated or rubbed with organic matter or other oxidizable substances, e.g., sulfur, sulfides, phosphides, hypophosphites, etc.* LD i.v. in rabbits: 45 mg/kg, *Handbook of Toxicology,* **Vol. 1**, W. S. Spector, Ed. (Saunders, Philadelphia, 1956) pp 182-183.

USE: The mineral is the source of manganese and all its compds; largely used in manuf manganese steel; oxidizer; in alkaline batteries (dry cells); for making amethyst glass, decolorizing glass; painting on porcelain, faience and majolica. The ppt is used in electrotechnics, pigments, browning gun barrels, drier for paints and varnishes, printing and dyeing textiles.

5553. Manganese Hypophosphite. $H_4MnO_4P_2$; mol wt 184.91. H 2.18%, Mn 29.71%, O 34.61%, P 33.50%. $Mn(H_2PO_2)_2$.

Monohydrate, pink, odorless, almost tasteless crystals or powder. When heated evolves spontaneously flammable phosphine. One gram dissolves in 6.5 ml water, 6 ml boiling water; insol in alcohol.

THERAP CAT: Pharmaceutic necessity.

5554. Manganese Iodide. Manganese diiodide. I_2Mn; mol wt 308.74. I 82.21%, Mn 17.79%. MnI_2.

Tetrahydrate, rose-red crystals; rapidly becomes brown on exposure to air and light, due to liberation of iodine. Very sol in water with gradual decompn; sol in alcohol. The aq soln is slightly acid. *Keep tightly closed and protected from light.*

5555. Manganese Nitrate. MnN_2O_6; mol wt 178.95. Mn 30.70%, N 15.65%, O 53.65%. $Mn(NO_3)_2$. Prepn: Deh-

nicke, Strähle, *Ber.* **97,** 1502 (1964). *Review: Gmelin's, Manganese* (8th ed.) **56,** part C3, 267-281 (1975).

Colorless; hygroscopic. Sol in water, dioxane, tetrahydrofuran, acetonitrile.

Tetrahydrate, pink, deliquesc cryst masses at temp below 20°. d 2.129. mp 37.1°. Very sol in water, sol in alcohol. The aq soln is slightly acid.

Hexahydrate, rose-colored, deliquesc, monoclinic needles (colorless after several crystns). d 1.8. mp 25.0°. Freely sol in water, alcohol.

USE: Intermediate in manuf of reagent grade MnO_2; in prepn of porcelain colorants.

5556. Manganese Oleate. Approx $Mn(C_{18}H_{33}O_2)_2$.

Brown, granular mass. Insol in water; sol in ether, oleic acid; slightly sol in alcohol.

USE: As a drier in varnishes.

5557. Manganese Oxalate. C_2MnO_4; mol wt 142.96. C 16.81%, Mn 38.43%, O 44.76%. MnC_2O_4.

Dihydrate, white cryst powder; dec at 150°. Slightly sol in water; sol in acids.

5558. Manganese Oxide. Manganomanganic oxide. Mn_3O_4; mol wt 228.79. Mn 72.03%, O 27.98%. Occurs in nature as the mineral *hausmannite.* Prepn: Moore *et al., J. Am. Chem. Soc.* **72,** 856 (1950).

Brownish-black powder. d 4.7. Insol in water; sol in HCl with evolution of chlorine.

5559. Manganese Phosphate, Dibasic. $HMnO_4P$; mol wt 150.92. H 0.67%, Mn 36.40%, O 42.41%, P 20.52%. $MnHPO_4$. Trihydrate. Exists in two modifications: gray form prepd by decompn of $MnCO_3$ by phosphoric acid; pink form prepd by reaction of $Mn_3(PO_4)_2$ with phosphoric acid (P_2O_5 concn 0.6-28%): Goloshchapov *et al., Russ. J. Inorg Chem.* **11,** 504 (1966).

Pink form, usually contains some tribasic phosphate. Very slightly sol in water; sol in dil acids. Gray form, sol only in hot concd HCl.

5560. Manganese Pyrophosphate. MnO_7P_2; mol wt 228.88. Mn 24.00%, O 48.93%, P 27.06%. MnP_2O_7.

Trihydrate, white or nearly white powder. Insol in water; sol in excess of alkali pyrophosphate, in acids.

5561. Manganese Selenide. MnSe; mol wt 133.89. Mn 41.02%, Se 58.98%. Prepd by the action of manganese salts on alkali selenides: Berzelius *et al.,* cited by Mellor, *A Comprehensive Treatise on Inorganic and Theoretical Chemistry* **10,** 798 (1930); by the action of a manganese salt on a soln of hydrogen selenide out of contact with air: Moser, Atynsky, *Monatsh.* **45,** 235 (1925).

Gray-black cubic crystals. d^{15} 5.59. Completely oxidized when heated to redness in oxygen. Insol in cold water. Dec in hot water and dil acids.

5562. Manganese Sesquioxide. Mn_2O_3; mol wt 157.86. Mn 69.59%, O 30.41%. Occurs in nature as the mineral *manganite,* $Mn_2O_3.H_2O$. Prepn: Moore *et al., J. Am. Chem. Soc.* **72,** 856 (1950).

Black, fine powder. d 4.50. Insol in water; sol in HCl with evolution of chlorine.

5563. Manganese Silicate. Approx $MnSiO_3$. Occurs in nature as the minerals *rhodonite, manganjustite, tephroite.*

Red crystals or yellowish-red powder. The pptd article is a yellowish-red powder. d of the mineral 3.48. Insol in water.

USE: As color for special glass; producing red glazes on pottery.

5564. Manganese Sulfate. MnO_4S; mol wt 151.00. Mn 36.38%, O 42.38%, S 21.23%. $MnSO_4$. Forms several hydrates. The article of commerce is usually a mixture of the tetra- and pentahydrates.

Monohydrate, pale red, slightly efflorescent crystals; loses all water at 400-450°. Sol in about 1 part cold, 0.6 part boiling water; insol in alcohol.

USE: In dyeing; for red glazes on porcelain; boiling oils for varnishes; in fertilizers for vines, tobacco; in feeds.

THERAP CAT (VET): Nutritional factor (essential trace element in all animals); prevention of perosis in poultry.

5565. Manganese Sulfide. Manganese monosulfide. MnS; mol wt 87.00. Mn 63.14%, S 36.86%. Occurs in nature as the mineral *alabandite* or *manganblende.* Prepn: Mehmed, Haraldsen, *Z. Anorg. Chem.* **235,** 194 (1938).

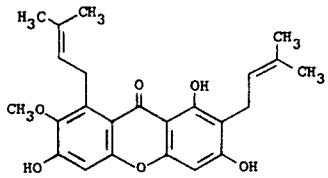
Pink, green or brown-green powder. Three cryst modifications: α-form, green cubic crystals; β-form, red cubic crystals; γ-form, red hexagonal crystals. Practically insol in water; sol in dil acids. In moist condition it readily oxidizes in air to the sulfate.

5566. Manganese Trifluoride. Manganic fluoride. F_3Mn; mol wt 111.93. F 50.93%, Mn 49.07%. MnF_3. Prepd by fluorination of manganese iodide according to the equation $2MnI_2 + 13F_2 \rightarrow 2MnF_3 + 4IF_5$: Moissan, *Compt. Rend.* **130,** 622 (1900); v. Wartenberg, *Z. Anorg. Allgem. Chem.* **244,** 346 (1940); Kwasnik in *Handbook of Preparative Inorganic Chemistry,* **vol. 1,** G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) pp 263-264.

Red mass; monoclinic crystals. d 3.54. Stable to 600°. Hydrolyzed by water. May be stored in glass ampuls.

USE: Fluorinating agent in organic chemistry.

5567. Mangostin. *1,3,6-Trihydroxy-7-methoxy-2,8-bis-(3-methyl-2-butenyl)-9H-xanthen-9-one;* 1,3,6-trihydroxy-7-methoxy-2,8-di(3-methyl-2-butenyl)xanthone. $C_{24}H_{26}O_6$; mol wt 410.45. C 70.23%, H 6.39%, O 23.39%. From various parts of the mangosteen tree *(Garcinia mangostana* L., *Guttiferae):* Schmid, *Ann.* **93,** 83 (1855); Dragendorff, *ibid.* **482,** 280 (1930). Structure: Yates, Stout, *J. Am. Chem. Soc.* **80,** 1691 (1958); Scheinmann, *Chem. Commun.* **1967,** 1015; Stout *et al., ibid.* **1968,** 211.



Yellow crystals from benzene, mp 181.6-182.6°. uv max (ethanol): 243, 259, 318, 351 nm (log ϵ 4.54, 4.44, 4.38, 3.86). Practically insol in water; sol in alcohol, ether, acetone, chloroform, ethyl acetate.

3,6-Dimethylmangostin, $C_{26}H_{30}O_6$, pale yellow needles from ethanol, mp 123.3-123.8°. uv max (ethanol): 245, 262, 314, 350 nm (log ϵ 4.50, 4.53, 4.36, 3.81).

5568. Manna. Dried exudation of *Fraxinus ornus* L., *Oleaceae. Habit.* Mediterranean Basin, Asia Minor, Spain. *Constit.* 40-60% mannitol; 10-16% mannotetrose; 6-16% mannotriose; glucose, mucilage, fraxin. One gram dissolves in 5 ml water, 150 ml 90% alcohol.

THERAP CAT: Cathartic.

5569. Mannitol. D-Mannitol; mannite; manna sugar; cordycepic acid; Manicol; Mannidex; Diosmol; Osmitrol; Osmosal. $C_6H_{14}O_6$; mol wt 182.17. C 39.56%, H 7.74%, O 52.70%. Widespread in plants and plant exudates; obtained from manna and seaweeds: *The Carbohydrates,* W. Pigman, Ed. (Academic Press, New York, 1957) pp 249-250. Prepd by electrolytic reduction of glucose: Creighton, *Can. Chem. Process Inds.* **26,** 690 (1942), *C.A.* **37,** 1088[5] (1943); Wolfrom *et al., J. Am. Chem. Soc.* **68,** 578 (1946). Prepn from seaweed: Sorensen, Kristensen, U.S. pat. **2,516,350** (1950); by hydrogenation of invert sugar, monosaccharides, and sucrose: Kasehagen, and Kasehagen, Luskin, U.S. pats. **2,642,462, 2,749,371,** and **2,759,024** (1953, 1956, and 1956, all to Atlas Powder). Review of prepn: Pigman, *loc. cit.* Novel synthesis: M. Makkee *et al., Chem. Commun.* **1980,** 930.

Orthorhombic needles from
taste. d^{20} 1.52. $bp_{3.5}$ 290-295°.
levorotatory in distilled water.
rate on addition of borax givir
+23° to 24° after 1 hr in a soln
borax + sufficient H_2O to ma
solves in about 5.5 ml water, 83
water; insol in ether; sol in pyri
kalies. One gram dissolves in 1
tables: Creighton, Klauder,
(1923). Ka at 19° = 3.4 × 1
molar compound with H_2O_2.

USE: Used with boric acid in
condensers for radio applicatio
and plasticizers; in pharmacy
solids and liqs; in analytical che
tions; in the manuf of mannit
food industry as anticaking an
agent, lubricant and release ag
and nutritive sweetener.

THERAP CAT: Diuretic; diagr

5570. Mannitol Hexanitrat
mannite; nitromannitol; Maxi
Moloid; Mannitrin; Nitranitol;
wt 452.17. C 15.94%, H 1.78%,
by nitration of mannitol. Flet
107 (1949).

Long needles in regular clus
Soluble in alc, in ether; insol in
sion. Its stability at ordinary
used commercially, but it is dis
glycerol at 75°. Its employ for
in admixture with carbohydrat
responding to 1 part of mann
parts of carbohydrate. In suc
trate is considered nonexplosiv

THERAP CAT: Vasodilator.

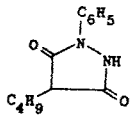
5571. Mannomustine. *1,6-dideoxy-*D-*mannitol dihydroch*
chloroethylamino)-D-mannito
chloroethylamino)-1,6-dideo
ride; mannitol nitrogen musta
$Cl_4N_2O_4$; mol wt 378.13. C 31
7.41%, O 16.93%. Prepn: Var
805.

Crystals from 80% ethanol.
(c = 1.81 in H_2O). [Free ba
water. Slightly sol in ethanol.
stable at room temps. Claime
than mechlorethamine. LD_{50}
et al., Arzneimittel-Forsch. **20,**

THERAP CAT: Antineoplastic

5572. D-Mannose. Semino
wt 180.16. C 40.00%, H 6.71%
by treating ivory nut shaving
Nat. Bur. Stand. **26,** 47 (1941

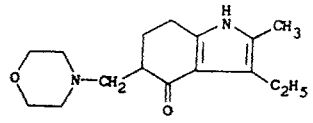
yl-3,5-dihydroxy-4-butylpyrazolidine; monophenylbutazone; Arcomonol Tablets; Mobutazon; Mobuzon; Monazan; Monobutyl; Monorheumetten; Reumatox. $C_{13}H_{16}N_2O_2$; mol wt 232.27. C 67.22%, H 6.94%, N 12.06%, O 13.78%. Preparation: Büchi *et al., Helv. Chim. Acta* **36**, 75 (1953); **Brit. pat. 839,057** (1960 to Comm. Farm. Milanese).



Crystals from ethanol + water, mp 102-103°. uv max (ethanol): 240, 275 nm ($E^{1\%}_{1cm}$ 443, 245). LD_{50} i.v. in mice: 600 mg/kg, Schoetensack, *Arch. Exp. Pathol. Pharmakol.* **233**, 365 (1958).

THERAP CAT: Anti-inflammatory.

6086. Molindone. *3-Ethyl-1,5,6,7-tetrahydro-2-methyl-5-(4-morpholinylmethyl)-4H-indol-4-one;* 3-ethyl-6,7-dihydro-2-methyl-5-(morpholinomethyl)indol-4(5*H*)-one. $C_{16}H_{24}N_2O_2$; mol wt 276.37. C 69.53%, H 8.75%, N 10.14%, O 11.58%. Prepn: **Belg. pat. 670,798** (1966 to Endo), *C.A.* **65**, 7148f (1966). Pharmacology: Sugerman, Herrmann, *Clin. Pharmacol. Ther.* **8**, 261 (1967); Claghorn, *Curr. Ther. Res.* **11**, 524 (1969); Guerrero-Figueroa *et al., ibid.* **15**, 508 (1973).

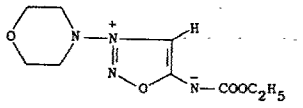


Crystals, mp 180-181°.

Hydrochloride, *EN 1733 A, Lidone, Moban.* LD_{50} orally in rats: 261 mg/kg, E. I. Goldenthal, *Toxicol. Appl. Pharmacol.* **18**, 185 (1971).

THERAP CAT: Antipsychotic.

6087. Molsidomine. *N-(Ethoxycarbonyl)-3-(4-morpholinyl)sydnone imine; N*-carboxy-3-morpholinosydnonimine ethyl ester; morsydomine; SIN-10; Corvaton; Molsidolat; Morial; Motazomin. $C_9H_{14}N_4O_4$; mol wt 242.23. C 44.62%, H 5.83%, N 23.13%, O 26.42%. A member of a class of non-benzene aromatic, heterocyclic and mesoionic type of compounds previously unknown in the pharmaceutical industry. Developmental work on sydnone imines: Brookes, Walker, *J. Chem. Soc.* **1957**, 4409. Prepn: Masuda *et al.*, **Japan. pat. 6,265('70)** (to Takeda), *C.A.* **73**, 25485g (1970) and *Chem. Pharm. Bull.* **19**, 72 (1971). Stability studies: Asahi *et al., ibid.* **19**, 1079 (1971). Pharmacological studies: Kikuchi *et al., Japan. J. Pharmacol.* **20**, 102, 187, 253 (1970); Hashimoto *et al., Arzneimittel-Forsch.* **21**, 1329 (1971). Metabolism: S. Tanayama *et al., Xenobiotica* **4**, 175 (1974). *Review: Japan. Med. Gaz.* **8**(9), 10 (1971).



Colorless crystals or white cryst powder, practically tasteless and odorless, mp 140-141° (toluene). Freely sol in $CHCl_3$. Sol in dil HCl, ethanol, ethyl acetate, methanol; sparingly sol in water, acetone, benzene. Very slightly sol in ether, petr ether. pK 3.0 ± 0.1 at 100°. Most stable in aq solns pH 5-7; least stable in very alkaline solns. uv max ($CHCl_3$): 326 nm. Sensitive to light of $\lambda < 320$ mμ. LD_{50} mouse, rat (g/kg): ≃0.76, 1.36 s.c.; ≃0.83, 0.80 i.v.; ≃0.73, 1.25 i.p.; ≃0.83, 1.13 orally.

THERAP CAT: Coronary vasodilator; antihypertensive.

6088. Molybdenum. Mo; at. wt 95.94; at. no. 42; valences 2,3,4,5,6. Naturally occurring isotopes: 98 (23.75%); 96 (16.5%); 95 (15.7%); 92 (15.86%); 94 (9.12%); 100 (9.62%); 97 (9.45%); artificial radioactive isotopes: 88-91; 93; 99; 101-105. Its most important ores are molybdenite, MoS_2, and wulfenite, $PbMoO_4$. Occurrence in the earth's crust: 1-1.5 ppm. Discovered in 1778 by Scheele; isolated in 1782 by Hjelm. Methods of preparation: L. Northcott, *Molybdenum* (Academic Press, New York, 1956) 222 pp; Hein, Herzog, in *Handbook of Preparative Inorganic Chemistry* **vol. 2**, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1965) pp 1401-1402. Important trace element; participates in biochemical redox reactions such as N_2-fixation: Spence, *Coord. Chem. Rev.* **4**, 475 (1969). Review of molybdenum and its compds: Rollinson, "Chromium, Molybdenum and Tungsten" in *Comprehensive Inorganic Chemistry* **vol. 3**, J. C. Bailar Jr. *et al.*, Eds. (Pergamon Press, Oxford, 1973) pp 622-623, 700-742; R. Q. Barr in Kirk-Othmer *Encyclopedia of Chemical Technology* **vol. 15** (Wiley-Interscience, New York, 3rd ed., 1981) pp 670-682. Biochemical review: *Bioinorganic Chemistry* **II**, K. N. Raymond, Ed. (A.C.S., Washington, 1977) pp 353-430.

Dark-gray or black powder with metallic luster or coherent mass of silver-white color; body-centered cubic structure. mp 2622°: Worthing, *Phys. Rev.* [2] **25**, 846 (1925); bp about 4825°. d 10.28. Spec heat 5.68 cal/g-atom/deg; heat of fusion: 6.6 kcal/g-atom; heat of vaporization: 142 kcal/g-atom: D. R. Stoll, G. C. Sinke, *Thermodynamic Properties of the Elements*, Advances in Chemistry Series **18**, (American Chemical Society, Washington, 1956) pp 23, 130-131. Fairly stable at ordinary temp; oxidized to the trioxide at a red heat; slowly oxidized by steam. Not attacked by water, by dil acids or by concd hydrochloric acid. Practically insol in alkali hydroxides or fused alkalies. Reacts with nitric acid, hot concd sulfuric acid, fused potassium chlorate or nitrate. Attacked by fluorine at ordinary temp, by chlorine or bromine at a red heat.

Human Toxicity: Limited data suggest low order of toxicity. *See* E. Browning, *Toxicity of Industrial Metals* (Appleton-Century-Crofts, New York, 1969) pp 243-248.

USE: In the form of ferromolybdenum for manufg special steels for tools, boiler plate, rifle barrels, propeller shafts; electrical contacts, spark plugs, x-ray tubes, filaments, screens and grids for radio tubes; in the production of tungsten; glass-to-metal seals; nonferrous alloys; in colloidal form as lubricant additive.

6089. Molybdenum Disulfide. MoS_2; mol wt 160.08. Mo 59.94%, S 40.06%. Occurs as the mineral *molybdenite*, which is the principal source of molybdenum. Lab prepn: Bell, Herfert, *J. Am. Chem. Soc.* **79**, 3351 (1957).

Lead-gray, lustrous powder; the artificially prepd sulfide is black and lustrous. d^{15}_{15} 5.06; mp 2375°. Begins to sublime at 450°. Insol in water or dil acids.

USE: Dry lubricant and lubricant additive. Hydrogenation catalyst.

6090. Molybdenum Hexafluoride. F_6Mo; mol wt 209.95. F 54.30%, Mo 45.70%. MoF_6. Prepd by direct fluorination of powdered molybdenum: Ruff, Ascher, *Z. Anorg. Allgem. Chem.* **196**, 418 (1931); from MoO_3 and SF_4: Oppengard *et al., J. Am. Chem. Soc.* **82**, 3825 (1960).

Volatile, white, cubic crystals. Very hygroscopic. d^{19}_{4} 2.543. mp 17.5°. bp 35.0°. Hydrolyzed by water. Forms blue-white clouds in moist air. Soly in anhydr HF: 1.5 moles/1000 g HF, Frlec, Hyman, *Inorg. Chem.* **6**, 1596 (1967). Should be stored in quartz ampuls.

6091. Molybdenum Sesquioxide. Mo_2O_3; mol wt 239.90. Mo 79.99%, O 20.01%.

Grayish-black powder. Very slightly sol in acids.

Combination with ferrous sulfate *Mol-Iron (obsolete).*

THERAP CAT: Hematinic (combination with ferrous sulfate).

6092. Molybdenum Trioxide. Molybdic anhydride. MoO_3; mol wt 143.95. Mo 66.66%, O 33.34%. Prepn from ammonium molybdate: Schumb, Hartford, *J. Am. Chem. Soc.* **56**, 2613 (1934).

White or slightly yellow to slightly bluish powder or granules. d^{26}_{4} 4.696. Melts at 795° to dark-yellow liquid which solidifies to a yellowish-white cryst mass; sublimes at higher temp; bp 1155°. Sol in water (28°) 0.490 g/liter. Sol in concd mineral acids, in solns of alkali hydroxides, ammonia or potassium bitartrate; after strong ignition it is very slightly sol in acids. LD_{50} oral
ing, *Toxicity of Industrial*
New York, 2nd ed., 1969
USE: Chiefly as a reage

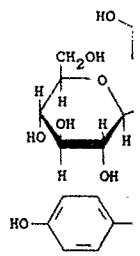
6093. Molybdic(VI) A
1.24%, Mo 59.24%, O 39
from ammonium molybd
in *Handbook of Preparat*
Brauer, Ed. (Academic P
1412-1413.
Monohydrate, white po
more in hot water; sol i

6094. Molybdic Acid
ammonium molybdate.
most widely used form o
White or slightly yello
water; sol in ammonia o
USE: Principally for th
phosphate and lead; also

6095. Monacetin. *1,2*
monoacetin; glyceryl mon
C 44.7[illegible]%, H 7.52%, O
tained along with the di-
with glacial acetic acid.
Colorless, very hygros
The commercial product
about 158°; bp_3 129-131°.
in ether; insol in benzene
USE: In manuf of smc
solvent for basic dyes; in

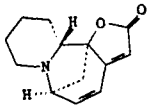
6096. Monarda. Am
Leaves of *Monarda punct*
to Florida, west to Texas
oils: thymol, carvacrol
cineole, γ-terpinene, α- a
analysis of the *oil of mor*
19, 601 (1965).
USE: Source for thymo
THERAP CAT: Aromatic

6097. Monardein Chl
gonidin-3-(6-*p*-coumaro
$C_{36}H_{37}ClO_{17}$; mol wt 777
O 35.00%. Coloring mat
balm"), *Labiatae:* Karre
(1927); Karrer, *ibid.* **11**,
al., Z. Naturforsch. **20b**,



Red powder. $[\alpha]_D$ −
(methanolic HCl): 286
methanol. The aq soln
by Na_2CO_3 and to light

6098. Monel®. A
tant alloys available in
USE: For acid-resista

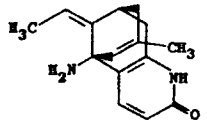


Yellow crystals from alcohol, mp 142-143°. $[\alpha]_D^{20}$ −1042° (c = 1 in alc). uv max (alc): 256, 330 nm (log ε 4.27, 3.30). Hydrochloride, mp 230°. $[\alpha]_D^{20}$ −259.2° (alcohol). Nitrate, mp 205°. $[\alpha]_D^{20}$ −312.12° (alcohol).

8271. Seidlitz Mixture. A mixture of 3 parts Rochelle salt and 1 part sodium bicarbonate. Ten grams of the mixture are employed with 2.17 g tartaric acid for one Seidlitz powder.

THERAP CAT: Cathartic.

8272. Selagine. *5-Amino-11-ethylidene-5,8,9,10-tetrahydro-7-methyl-5,9-methanocycloocta[b]pyridin-2(1H)-one.* $C_{15}H_{18}N_2O$; mol wt 242.31. C 74.35%, H 7.49%, N 11.56%, O 6.60%. Occurs in stem and leaves of *Lycopodium selago* L., *Lycopodiaceae:* Muszynski, *Quart. J. Pharm. Pharmacol.* **21,** 34 (1948). Structure: Valenta *et al., Tetrahedron Letters* **1960**(10), 26; Yoshimura *et al., ibid.* no. 12, 14. Proposed as substitute for pilocarpine and eserine in glaucoma: Miratynska-Ernestowa, *Klinika Oczna* **18,** 437 (1948).



Amorphous base, odor of coniine. mp 224-226°. $[\alpha]_D^{25}$ −99° (methanol). uv max (ethanol): 231, 313 nm (ε 10,700, 8500). pKa = 7.18. Forms deliquescent salts.

8273. Selenic Acid. H_2O_4Se; mol wt 144.98. H 1.39%, O 44.15%, Se 54.46%. H_2SeO_4. Prepd by treating lead selenate with hydrogen sulfide and concentrating the filtered soln by evaporation: Mitscherlich, *Pogg. Ann.* **9,** 623 (1827); **11,** 327 (1827); *Ann. Chim. Phys.* [2] **36,** 100 (1827); by treating calcium selenate with cadmium oxalate and hydrogen sulfide: von Hauer, *J. Prakt. Chem.* [1] **80,** 214, 317 (1860); by treating a soln of silver selenite with bromine and evaporating the filtered soln: Thomsen, *Ber.* **2,** 598 (1869); by oxidizing selenium oxide with 30% hydrogen peroxide and removing water: Gilbertson, King, *J. Am. Chem. Soc.* **58,** 180 (1936); *Inorg. Syn.* **3,** 137 (1950).

Hexagonal prisms; mp 58°; d_4^{15} 2.9508; bp 260°. Very sol in water; sol in sulfuric acid; insol in ammonia; dec in alcohol. Very deliquescent. Reduced by hydrobromic acid, hydriodic acid, hydrogen sulfide, hydroxylamine hydrochloride, phenylhydrazine, formic acid, oxalic acid, malonic acid, pyruvic acid, acetyl chloride, and several metals.

8274. Selenious Acid. Monohydrated selenium dioxide; selenous acid. H_2O_3Se; mol wt 128.98. H 1.56%, O 37.22%, Se 61.22%. H_2SeO_3. Prepd by dissolving selenium dioxide in hot water and cooling: Berzelius, *Acad. Handl. Stockholm* **39,** 13 (1818).

Deliquescent hexagonal prisms; d_4^{15} 3.004. Vapor press. (mm Hg): 2 at 15°; 4.5 at 35°; 7 at 40.3°. $K_1 = 0.0024$; $K_2 = 4.8 \times 10^{-9}$. Gives off water upon heating and selenium oxide sublimes. Oxidized to selenic acid by strong oxidizing agents such as ozone, hydrogen dioxide, chlorine. Reduced to selenium by most reducing agents including hydriodic acid, sulfurous acid, sodium hyposulfite, hydroxylamine salts, hydrazine salts, hypophosphorous acid, phosphorous acid. 90 parts dissolve in 100 parts water at 0°, 400 parts at 90°; very sol in alcohol; insol in ammonia.

USE: As a reagent for alkaloids; as oxidizing agent.

8275. Selenium. Se; at. wt 78.96; at. no. 34; valences 2, 4, 6. Six stable isotopes: 74 (0.87%); 76 (9.02%); 77 (7.58%); 78 (23.52%); 80 (49.82%); 82 (9.19%); artificial, radioactive isotopes: 70-73; 75; 79; 81; 83-85; 87. Discovered in 1817 by Berzelius. Constitutes about 0.09 ppm of the earth's crust. Occurs in nature usually in the sulfide ores of the heavy metals; found in small quantities in pyrite; in the minerals *clausthalite* (PbSe), *naumannite* [(Ag,Pb)Se], *tiemannite* (HgSe); in selenosulfur. Prepn: Waitkins *et al., Ind. Eng. Chem.* **34,** 899 (1942). Purification: Nielsen, Heritage, *J. Electrochem. Soc.* **106,** 39 (1959). Purification by distn from a mixture contg a small amount of Mg: Oberbacher, Schlier, U.S. pat. **2,930,678** (1960 to Norddeutsche Raffinerie). Essential trace element in animal diets at levels of approx 0.1 ppm. Toxic element at higher concentrations. Reviews of nutritional and toxic properties of selenium: I. Rosenfeld, O. A. Beath, *Selenium* (Academic Press, New York, 1964) 411 pp; E. Browning, *Toxicity of Industrial Metals* (Appleton-Century-Crofts, New York, 2nd ed., 1969) pp 286-295; E. J. Underwood, *Trace Elements in Human and Animal Nutrition* (Academic Press, New York, 1971) pp 323-368; Frost, *Crit. Rev. Toxicol.* **1,** 467-514 (1972); Allaway, *Cornell Vet.* **63,** 151-170 (1973); Frost, Lish, *Ann. Rev. Pharmacol.* **15,** 259-284 (1975). Symposium on organic selenium and tellurium compds: Y. Okamoto, W. H. H. Gunther, Eds., *Ann. N.Y. Acad. Sci.* **192,** 1-225 (1972). Reviews of selenium and its compds: K. W. Bagnall, *The Chemistry of Selenium, Tellurium and Polonium* (Elsevier, New York, 1966) 200 pp; Bagnall in *Comprehensive Inorganic Chemistry* **vol. 2,** J. C. Bailar, Jr. *et al.,* Eds. (Pergamon Press, Oxford, 1973) pp 935-1008; *Selenium,* R. A. Zingaro, W. C. Cooper, Eds. (Van Nostrand, Reinhold, New York, 1974) 835 pp; E. M. Elkin in Kirk-Othmer *Encyclopedia of Chemical Technology* **vol. 20** (Wiley-Interscience, New York, 3rd ed., 1982) pp 575-601.

Exists in several allotropic forms: amorphous, cryst or red, and gray or metallic. Liq is a brownish red, boils at 685° forming dark red vapors. Sol in dil aq caustic alkali solns; in aq potassium cyanide soln, in potassium sulfite soln. Burns in air with a bright blue flame forming the dioxide and emitting a characteristic odor resembling rotten horseradish. Combines directly with hydrogen, with the halogens (excluding iodine). Oxidized to selenious acid by nitric acid, to selenic acid by sulfuric acid. Reduces hot aqueous solutions of silver and gold salts with formation of silver selenide and metallic gold, respectively. Reacts with many metals.

Amorphous forms: Vitreous, black selenium; dark red-brown to bluish-black solid; formed when molten Se is cooled rapidly. d 4.28. Softens at 50-60° and becomes elastic at 70°. Red, amorphous form; formed by reduction of selenious acid in water; by condensation of Se vapor on a cold surface. d 4.26. Review of structural studies: Richter, Breitling, *Z. Naturforsch.* **26B,** 1699-1708, 2074-2075 (1971). When freshly precipitated, reacts with water at 50° forming selenious acid and hydrogen. Sol in carbon disulfide, methylene iodide, benzene, or quinoline.

Crystalline or red: Two monoclinic forms; dark red, transparent crystals. α-Form prepd by slow evaporation of CS_2 soln of Se; β-form by rapid evaporation of soln. mp below 200°. d (α-form) 4.46. Structure of α-form: Cherin, Unger, *Acta Cryst.* **28B,** 513 (1972); *see also* Bagnall, *loc. cit.* Both forms are metastable and change into gray form on heating.

Gray or metallic: Lustrous gray to black hexagonal crystals. The most stable form. d_4^{20} 4.81. mp 217°. Mohs' hardness: 2.0. Latent heat of fusion 16.4 cal/g. Latent heat of vaporization 20.6 kcal/mol. Linear coefficient of thermal expansion per degree $C = 37 \times 10^{-6}$. Specific heat (28°): 0.084 cal/g/°C. Surface tension (217°): 92.5 dynes/cm. Thermal conductivity (25°): 0.0007-0.00183 cal/(cm)(°C)(sec). Insol in water, alcohol; very slightly sol in carbon disulfide (2 mg/100 ml at ord temp). Sol in ether. Conducts electricity and rectifies alternating current; the conductivity increases up to a thousand times on exposure to light.

USE: As ingredient of toning baths in photography; as pigment in manuf ruby-, pink-, orange-, or red-colored glass; as metallic base in making electrodes for arc lights, electrical instruments and apparatus, as rectifier in radio and television sets; in selenium photocells, in semiconductor fusion mixtures, selenium cells, telephotographic apparatus; as vulcanizing agent in processing of rubber; as catalyst in determination of nitrogen by Kjeldahl method; for dehydrogenation of organic compds. *Caution:* Occupational exposure has caused pallor, nervousness, depression, garlic odor of breath and sweat, G.I. disturbances, dermatitis. Liver injury has been produced in exptl animals.

THERAP CAT (VET): Nutritional factor (interrelationship with vitamin E). Chiefly to p diseases.

8276. Selenium Bromide. Br_2Se_2; mol wt 317.75. Br 5(Prepd by mixing bromine and s portions: Schneider, *Pogg. Ann* 634 (1866); by treating seleniur acid: Lenher, Kao, *J. Am. Che* Dark red liquid. Unpleasant heated. Dec in water and moist bromide, carbon disulfide.

8277. Selenium Chloride. Cl_2Se_2; mol wt 228.83. Cl 30.99' from the elements: Sacc *et al.,* ((1930); by the action of PCl_5 on phosphorus or antimony, on Se mont, *Ann. Chim. Phys.* [4] **2,** 5 [2] **6,** 460 (1870); by the action (in fuming sulfuric acid: Divers, 194, 198, 201 (1884); from Se, S *J. Am. Chem. Soc.* **47,** 772 (192 Deep red, oily liquid. bp_{733} −85°. Sol in chloroform, ber carbon disulfide, fuming sulfuri

8278. Selenium Hexafluorid 59.08%, Se 40.92%. SeF_6. Prep over finely divided selenium in Henkel, *Z. Anorg. Allgem. Ch* Claussen, *J. Am. Chem. Soc.* 5 *Syn.* **1,** 121 (1939). *Review:* K *rine Chem.* **4,** 235 (1965).

Gas. mp −50.8°; sublimes Hg): 651.2 (−48.7°); 213.1 (− in water. Reacts with ammonia nitrogen, and hydrogen fluoride attack glass.

USE: Gaseous electric insulat

8279. Selenium Oxide. Sel hydride. O_2Se; mol wt 110.96. Prepd by burning selenium ir *Handl. Stockholm* **39,** 13 (1818). 225, 337 (1818); by burning sele dioxide: Lenher, *J. Am. Chem.* dizing selenium with nitric acid 1799 (1925). *Review:* Waitk 235-289 (1945).

Lustrous, tetragonal needles. ing sensation. Its yellowish gre smell. mp 340°; d_{15}^{15} 3.954. Va at 70°; 20.2 at 94°; 39.0 at 181°. n_D^{20} <1.76. Soly (parts/100 p (14°); in methanol: 10.16 (11.8° in acetone: 4.35 (15.3°); in ace concd H_2SO_4. Stable to light a hydrogen fluoride, hydrogen and hydrogen iodide to form oxyhalide. Reacts with ammo lenium; in alcohol soln form $HN_4(C_2H_5)SeO_3$. Yields nitr selenium with hydrazine; ni amorphous selenium with hy Forms selenic acid with nitric a other organic substances.

USE: In the manuf of other s agent for alkaloids; as oxidizi Fieser, *Reagents for Organic* (Wiley, 1967) p 992. *Caution:* (of skin, eyes: Cerwenka, Coo 189 (1961).

8280. Selenium Oxybromid bromide. Br_2OSe; mol wt 254 30.99%. $SeOBr_2$. Prepd by the fused selenium, and fused calci *Chem. Soc.* **44,** 1668 (1922). Red-yellow solid. mp 41. (dec). Dec in water. Chlorine by sulfur and hydrogen sulfide

...e *naumannite* [(Ag,Pb)Se], ...ulfur. Prepn: Waitkins *et al., Ind.* ... Purification: Nielsen, Heritage, ... 1959). Purification by distn ... amount of Mg: Oberbacher, ... 960 to Norddeutsche Raffine... ...nt in animal diets at levels of ap... ...ent at higher concentrations. Re... ...ervic properties of selenium: I. ...e *tium* (Academic Press, New ...B ...vning, *Toxicity of Industrial* ...crofts, New York, 2nd ed., ...Underwood, *Trace Elements in* ...*in* (Academic Press, New York, ... *it. Rev. Toxicol.* **1**, 467-514 ... **63**, 151-170 (1973); Frost, ... 259-284 (1975). Symposium ...ellurium compds: Y. Okamoto, *Ann. N.Y. Acad. Sci.* **192**, 1-225 ...n ...nd its compds: K. W. Bag... ...*'e ...m, Tellurium and Polonium* ... pp; Bagnall in *Comprehen...* ...I. 2, J. C. Bailar, Jr. *et al.*, Eds. ...973) pp 935-1008; *Selenium*, R. ... Eds. (Van Nostrand, Reinhold, ... M. Elkin in Kirk-Othmer *T ...nology* **vol. 20** (Wiley-Inter... ...82) pp 575-601.

...ic forms: amorphous, cryst or ... Liq is a brownish red, boils at ... Sol in dil aq caustic alkali ... ...e soln, in potassium sulfite ...g ... blue flame forming the diox... ...teristic odor resembling rotten ...ectly with hydrogen, with the ... Oxidized to selenious acid by ...b ... sulfuric acid. Reduces hot ...ir ... gold salts with formation of ...gold, respectively. Reacts with

...ous, black selenium; dark red... ...d ...ormed when molten Se is ...e ... at 50-60° and becomes elas... ...; ...m; formed by reduction of ... condensation of Se vapor on a ...v of structural studies: Richter, ... B, 1699-1708, 2074-2075 ...ed, reacts with water at 50° ...ogen. Sol in carbon disul... ...ne, or quinoline.

...noclinic forms; dark red, trans... ...d by slow evaporation of CS_2 ...oration of soln. mp below ... of α-form: Cherin, Unger, ... *also* Bagnall, *loc. cit.* Both ...nge into gray form on heating. ... gray to black hexagonal crys... ...$^{20}_{4}$ 4.81. mp 217°. Mohs' ... ...ion 16.4 cal/g. Latent heat ... ...inear coefficient of thermal ...7 × 10^{-6}. Specific heat (28°): ...sion (217°): 92.5 dynes/cm. ...0007-0.00183 cal/(cm)(°C)-... ...very slightly sol in carbon ...(p). Sol in ether. Conducts ...ng current; the conductivity ...mes on exposure to light.

...ing baths in photography; as ... , orange-, or red-colored ...k ... electrodes for arc lights, ...a ...us, as rectifier in radio and photocells, in semiconductor ...s, telephotographic apparatus; ...s ...g of rubber; as catalyst in ...K ...dahl method; for dehydro... *...ution:* Occupational expo... ...sness, depression, garlic odor ...sturbances, dermatitis. Liver ...xic animals.

...o ... factor (interrelationship with vitamin E). Chiefly to prevent muscle degenerative diseases.

8276. Selenium Bromide. Selenium monobromide. Br_2Se_2; mol wt 317.75. Br 50.30%, Se 49.70%. Se_2Br_2. Prepd by mixing bromine and selenium in the correct proportions: Schneider, *Pogg. Ann.* **128**, 327 (1866); **129**, 450, 634 (1866); by treating selenium dioxide with hydrobromic acid: Lenher, Kao, *J. Am. Chem. Soc.* **47**, 772 (1925).

Dark red liquid. Unpleasant odor. d_4^{15} 3.604. Dec when heated. Dec in water and moist air. Sol in chloroform, ethyl bromide, carbon disulfide.

8277. Selenium Chloride. Selenium monochloride. Cl_2Se_2; mol wt 228.83. Cl 30.99%, Se 69.01%. Se_2Cl_2. Prepd from the elements: Sacc *et al.*, cited in *Mellor's* **vol. X**, 894 (1930); by the action of PCl_5 on selenium, on the selenide of phosphorus or antimony, on SeO_2 or on $SeOCl_2$: Baudrimont, *Ann. Chim. Phys.* [4] **2**, 5 (1864); Michaelis, *Z. Chem.* [2] **6**, 460 (1870); by the action of HCl on a soln of selenium in fuming sulfuric acid: Divers, Shimose, *J. Chem. Soc.* **45**, 194, 198, 201 (1884); from Se, SeO_2 and HCl: Lenher, Kao, *J. Am. Chem. Soc.* **47**, 772 (1925); **48**, 1550 (1926).

Deep red, oily liquid. bp_{733} 127° (dec). d_4^{25} 2.7741. mp −85°. Sol in chloroform, benzene, carbon tetrachloride, carbon disulfide, fuming sulfuric acid; dec in water.

8278. Selenium Hexafluoride. F_6Se; mol wt 192.96. F 59.08%, Se 40.92%. SeF_6. Prepd by passing gaseous fluorine over finely divided selenium in a copper vessel: Klemm, Henkel, *Z. Anorg. Allgem. Chem.* **207**, 74 (1932); Yost, Claussen, *J. Am. Chem. Soc.* **55**, 885 (1933); Yost, *Inorg. Syn.* **1**, 121 (1939). *Review:* Kemmitt, Sharp, *Advan. Fluorine Chem.* **4**, 235 (1965).

Gas. mp −50.8°; sublimes −63.8°. Vapor press. (mm Hg): 651.2 (−48.7°); 213.1 (−64.8°); 30.4 (−87.5°). Insol in water. Reacts with ammonia gas at 200° to give selenium, nitrogen, and hydrogen fluoride. Covalently satd, does not attack glass.

USE: Gaseous electric insulator.

8279. Selenium Oxide. Selenium dioxide; selenious anhydride. O_2Se; mol wt 110.96. O 28.84%, Se 71.16%. SeO_2. Prepd by burning selenium in oxygen: Berzelius, *Acad. Handl. Stockholm* **39**, 13 (1818); *Ann. Chim. Phys.* [2] **9**, 160, 225, 337 (1818); by burning selenium in oxygen and nitrogen dioxide: Lenher, *J. Am. Chem. Soc.* **20**, 559 (1898); by oxidizing selenium with nitric acid: Julien, *Bull. Soc. Chim.* **47**, 1799 (1925). *Review:* Waitkins, Clark, *Chem. Rev.* **36**, 235-289 (1945).

Lustrous, tetragonal needles. Acidic taste; leaves a burning sensation. Its yellowish green vapor has a pungent, sour smell. mp 340°; d_{15}^{15} 3.954. Vapor pressure (mm Hg): 12.5 at 70°; 20.2 at 94°; 39.0 at 181°; 760.0 at 315°; 848.0 at 320°. n_D^{20} <1.76. Soly (parts/100 parts solvent) in water: 38.4 (14°); in methanol: 10.16 (11.8°); in 93% ethanol: 6.67 (14°); in acetone: 4.35 (15.3°); in acetic acid: 1.11 (13.9°). Sol in concd H_2SO_4. Stable to light and heat. Rapidly absorbs dry hydrogen fluoride, hydrogen chloride, hydrogen bromide, and hydrogen iodide to form the corresponding selenium oxyhalide. Reacts with ammonia to form nitrogen and selenium; in alcohol soln forms ammonium ethyl selenite, $HN_4(C_2H_5)SeO_3$. Yields nitrogen and black amorphous selenium with hydrazine; nitrogen and reddish-brown amorphous selenium with hydroxylamine hydrochloride. Forms selenic acid with nitric acid. Reduced by carbon and other organic substances.

USE: In the manuf of other selenium compounds; as a reagent for alkaloids; as oxidizing agent: L. F. Fieser, M. Fieser, *Reagents for Organic Chemistry* **vol. 1** (New York, Wiley, 1967) p 992. *Caution:* Causes intense local irritation of skin, eyes: Cerwenka, Cooper, *Arch. Environ. Health* **3**, 189 (1961).

8280. Selenium Oxybromide. *Seleninyl bromide;* selenyl bromide. Br_2OSe; mol wt 254.79. Br 62.73%, O 6.28%, Se 30.99%. $SeOBr_2$. Prepd by the reaction of selenium dioxide, fused selenium, and fused calcium bromide: Lenher, *J. Am. Chem. Soc.* **44**, 1668 (1922).

Red-yellow solid. mp 41.5-41.7°; d^{50} 3.38; bp_{760} 217° (dec). Dec in water. Chlorine displaces the bromine. Dec by sulfur and hydrogen sulfide. Sol in sulfuric acid, carbon disulfide, chloroform, benzene, toluene, xylene, carbon tetrachloride. Reacts explosively with sodium and potassium.

8281. Selenium Oxychloride. *Seleninyl chloride.* Cl_2OSe; mol wt 165.87. Cl 42.75%, O 9.65%, Se 47.60%. $SeOCl_2$. Prepd by passing chlorine into SeO_2 suspended in carbon tetrachloride: Lenher, *J. Am. Chem. Soc.* **42**, 2498 (1920); Hönigschmid, Görnhardt, *Z. Naturforsch.* **1**, 661 (1946); by dehydration of dichloroselenious acid: Smith, Jackson, *Inorg. Syn.* **3**, 130 (1950); from $SOCl_2$ and SeO_2: Paetzold, Aurich, *Z. Anorg. Allgem. Chem.* **315**, 72 (1962); from $AlCl_3$ and SeO_2: Drago, Whitten, *Inorg. Chem.* **5**, 677 (1966).

Nearly colorless or yellowish, corrosive liquid; fumes in the air. d_4^{16} 2.44. Solidif about 5°. bp 180°. n_D^{20} 1.651. Dec by water into HCl and selenious acid. Miscible with carbon tetrachloride, chloroform, carbon disulfide, benzene, toluene. It is an excellent solvent for many substances including metals. LD cutaneous in rabbits: <7 mg/kg.

Caution: Strong irritant, vesicant. Can cause fatal pulmonary edema.

8282. Selenium Oxyfluoride. *Seleninyl fluoride;* selenyl fluoride. F_2OSe; mol wt 132.97. F 28.58%, O 12.03%, Se 59.38%. F_2SeO. Prepd from selenium dioxide and fluorine: Aynsley *et al., J. Chem. Soc.* **1952**, 1231; from selenium oxychloride and sodium fluoride: Tullock, Coffman, *J. Org. Chem.* **25**, 2016 (1960); from selenium tetrafluoride and tellurium oxide: J. Carre *et al., J. Fluorine Chem.* **14**, 139 (1979).

Fuming liquid. Ozone-like odor. mp 15.0°; bp 126°. $d^{21.5}$ 2.8. Rapidly attacks glass.

Caution: Strong irritant, vesicant. Can cause fatal pulmonary edema.

8283. Selenium Sulfides. Prepn from selenious acid and H_2S; product may be a mixture of the elements: *Gmelin's Selenium* (8th ed.) **10** (part B), 159-176 (1949). Prepn by fusion of the elements; solid solns of sulfur (S_8), selenium (Se_8) and selenium sulfides (S_nSe_{8-n}; n = 1-7) formed: Fergusson *et al., J. Inorg. Nucl. Chem.* **24**, 157 (1962); Hawes, *Nature* **198**, 1267 (1963); Cooper, Culka, *J. Inorg. Nucl. Chem.* **27**, 755 (1965); **29**, 1217 (1967).

Se_4S_4, red tabular crystals from benzene, d 3.20. mp 113° (dec). Sol in CS_2. Solubility in benzene (20°): 0.4 g/l.

Se_2S_6, light-orange needles from benzene, d 2.44. mp 121.5°. Sol in CS_2. Solubility in benzene (20°): 12 g/l.

Selenium sulfide detergent prepn, *Exsel, Selenex, Sel-O-Rinse, Selsun.* Prepn: Baldwin, Young, **U.S. pat. 2,694,669** (1954 to Abbott). Safety evaluation: Cummins, Kimura, *Toxicol. Appl. Pharmacol.* **20**, 89 (1971). Review of use as antidandruff agent: Matson, *J. Soc. Cosmet. Chem.* **7**, 459-466 (1956).

THERAP CAT: Detergent prepn as topical antiseborrheic.

THERAP CAT (VET): Topically in eczemas and dermatomycoses.

8284. Selenium Tetrabromide. Br_4Se; mol wt 398.62. Br 80.19%, Se 19.81%. $SeBr_4$. Prepd by adding excessive bromine to selenium: Schneider, *Pogg. Ann.* **128**, 327 (1866); **129**, 450, 634 (1866); by dissolving selenium dioxide in hydrobromic acid: Muthmann, Schäfer, *Ber.* **26**, 1008 (1893).

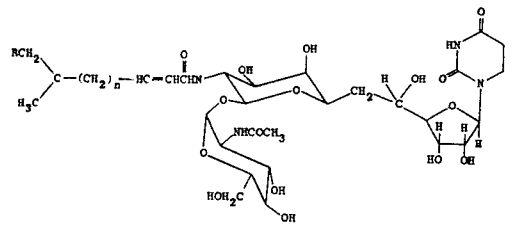
Red-brown, cryst powder. Unpleasant odor. Dec 70-80°. Dec in moist air and water. Sol in carbon disulfide, chloroform, ethyl bromide.

8285. Selenium Tetrachloride. Cl_4Se; mol wt 220.79. Se 35.76%, Cl 64.24%. $SeCl_4$. Prepd by the action of an excess of chlorine on selenium: Berzelius, cited in *Mellor's* **vol X**, 898 (1930); by the action of thionyl chloride or phosphorus trichloride on selenium oxychloride and by the action of phosphorus pentachloride on selenium oxide: Michaelis, *Z. Chem.* [2] **6**, 460 (1870); by the action of anhydr selenic acid on acetyl chloride at 0°: Lamb, *Am. Chem. J.* **30**, 209 (1903). Crystal structure: Shoemaker, Abrahams, *Acta Cryst.* **18**, 296 (1965).

White to pale yellow crystals. d 2.6. Sublimes when heated. Dec in water and moist air. Insol in liquid bromine. Dec by dry ammonia.

8286. Selenium Tetrafluoride. F_4Se; mol wt 154.96. F 49.04%, Se 50.96%. SeF_4. Fluorinating agent. Prepn from

tunicamycin by gel chromatography, HPLC, and hydrolysis: K. Eckardt *et al., ibid.* **33,** 908 (1980). Structures of streptovirudins and identity of components B_{2a} and C_2 with tunicamycin components: *eidem, ibid.* **34,** 1631 (1981); W. Ihn *et al., Tetrahedron* **38,** 1781 (1982). Biological activities of isolated streptovirudin and tunicamycin components, identity of streptovirudin C_2 with tunicamycin A: R. W. Keenan *et al., Biochemistry* **20,** 2968 (1981). Chemical and biological properties of streptovirudins: A. D. Elbein *et al., ibid.* 4210. Viral inhibition study: M. S. Kang *et al., Biochem. Biophys. Res. Commun.* **99,** 422 (1981).

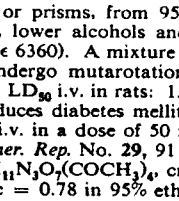


streptovirudins (series I)

A_1	n = 6,	R = H
B_1	n = 6,	R = CH_3
B_{1a}	n = 7,	R = H
C_1	n = 8,	R = H
D_1	n = 8,	R = CH_3

White amorphous solid. uv max (methanol): 212 nm. Sol in methanol, pyridine. Slightly sol in water, ethanol. Insol in chloroform, acetone, benzene, ethyl acetate. Stable up to 5 hours at 90°. No loss of activity was observed after standing at 37° for 4 weeks. LD_{50} in mice (mg/kg) of the antibiotic complex from culture filtrate: 250 orally; 15 s.c.; 15-17.5 i.p.; 17.5 i.v.; of the complex from mycelium: 150 orally; 5-10 s.c.; 3.5-7.5 i.p., H. Thrum *et al., loc. cit.*

8695. Streptozocin. *2-Deoxy-2-[[(methylnitrosoamino)-carbonyl]amino]-D-glucopyranose; 2-deoxy-2-(3-methyl-3-nitrosoureido)-D-glucopyranose;* streptozotocin; NSC-85998; U-9889; Zanosar. $C_8H_{15}N_3O_7$; mol wt 265.22. C 36.23%, H 5.70%, N 15.84%, O 42.23%. Isoln from *Streptomyces achromogenes* fermentation broth: Herr *et al., Antibiot. Ann.* **1959-1960,** 236; Bergy *et al.,* Fr. pat. **1,43-,920** (1966 to Upjohn), *C.A.* **65,** 17661h (1966). Structure and synthesis: Herr *et al., J. Am. Chem. Soc.* **89,** 4808 (1967); Hardegger *et al., Helv. Chim. Acta* **52,** 2555 (1969); Hessler, Jahnke, *J. Org. Chem.* **35,** 245 (1970); P. F. Wiley *et al., ibid.* **44,** 9 (1979). Antileukemic activity: Bhuyan *et al., Cancer Chemother. Rep. Part 1* **56,** 709 (1972). Biosynthetic study: S. Singaram *et al., J. Antibiot.* **32,** 379 (1979). Review and evaluation of studies of carcinogenicity in laboratory animals: *IARC Monographs* **4,** 221-227 (1974). *Review:* Rudas, *Arzneimittel-Forsch.* **22,** 830-861 (1972); P. F. Wiley, *Anticancer Agents Based on Natural Product Models,* J. M. Cassidy, J. D. Douros, Eds. (Academic Press, New York, 1980) pp 167-200.



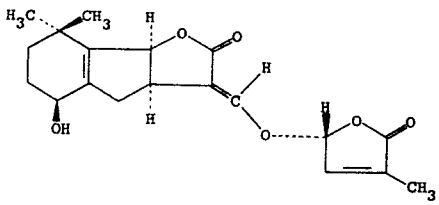
Pointed platelets or prisms, from 95% ethanol, mp 115° (dec). Sol in H_2O, lower alcohols and ketones. uv max (ethanol): 228 nm (ε 6360). A mixture of α and β anomers; aq solns rapidly undergo mutarotation to an equilibrium value of $[\alpha]_D^{25}$ +39°. LD_{50} i.v. in rats: 137.7 mg/kg; in dogs: 25-50 mg/kg. Produces diabetes mellitus in rats and dogs when administered i.v. in a dose of 50 mg/kg: Rakieten *et al., Cancer Chemother. Rep.* No. **29,** 91 (May, 1963).

Tetraacetate, $C_8H_{11}N_3O_7(COCH_3)_4$, crystals, mp 111-114° (dec). $[\alpha]_D^{25}$ +41° (c = 0.78 in 95% ethanol).

Note: This substance has been listed as a carcinogen by the EPA: *Second Annual Report on Carcinogens* (NTP 81-43, Dec. 1981) pp 224-225.

THERAP CAT: Antineoplastic.

8696. Strigol. *3-[[(2,5-Dihydro-4-methyl-5-oxo-2-furanyl)oxy]methylene]-3,3a,4,5,6,7,8,8b-octahydro-5-hydroxy-8,8-dimethyl-2H-indeno[1,2-b]furan-2-one.* $C_{19}H_{22}O_6$; mol wt 346.39. C 65.88%, H 6.40%, O 27.71%. Potent seed germination stimulant for the root parasite, witchweed, *Striga lutea* Lour. isolated from root exudates of cotton, *Gossypium hirsutum* L.: C. E. Cook *et al., Science* **154,** 1189 (1966). Structure: *eidem, J. Am. Chem. Soc.* **94,** 6198 (1972). Crystal structure: P. Coggan *et al., J. Chem. Soc. Perkin Trans. 2* **1973,** 465. Synthesis: J. B. Heather *et al., J. Am. Chem. Soc.* **98,** 3661 (1976); of (±)-form: G. A. MacAlpine *et al., Chem. Commun.* **1974,** 834; *eidem, J. Chem. Soc. Perkin Trans. 1* **1976,** 410. Synthesis of analogs: A. W. Johnson *et al., ibid.* **1981,** 1734. Witchweed seed germination stimulating activity: A. L. Hsiao *et al., Weed Sci.* **29,** 101 (1981); A. B. Pepperman *et al., ibid.* **30,** 561 (1982).



White needles from benzene-hexane, mp 200-202° (dec). $[\alpha]_D^{25}$ +293° (c = 0.15 in $CHCl_3$). uv max: 234 nm (ε 17,700). Sol in acetone, methylene chloride. Moderately sol in benzene; insol in hexane.

8697. Strobane®. Terpene polychlorinates; Dichloricide Aerosol; Dichloricide Mothproofer; Insecticide 3960-X14. A mixture of chlorinated terpene isomers. Preparation by chlorinating a mixture of camphene and pinenes contg dipentene: Schultz, Bloor, U.S. pat. **2,767,115** (1956 to B. F. Goodrich).

Viscous, amber liquid. d_{25} 1.6267. Misc with aromatic and aliphatic hydrocarbons. Slightly sol in alcohol.

USE: Insecticide. *Compare* Toxaphene. *Caution:* May be mildly irritating to skin.

8698. Stromeyerite. $Ag_2S.Cu_2S$—silver cuprous sulfide.

8699. Strontium. Sr; at. wt 87.62; at. no. 38; valence 2. An alkaline earth metal. Isotopes: 88 (82.56%); 86 (9.86%); 87 (7.02%); 84 (0.56%). Occurs as the sulfate, celestine; or the carbonate, strontianite; found in small quantities associated with calcium or barium minerals. First prepared in 1807 by Davy. Prepn: Glascock, *J. Am. Chem. Soc.* **32,** 1222 (1910); Matignon, *Compt. Rend.* **177,** 1116 (1923); *J. Chem. Soc.* **126**[ii], 44 (1924); Guntz *et al.,* cited in *Gmelin's, Strontium* (8th ed.) **29,** 35 (1931). Review of strontium and its compounds: Goodenough, Stenger, "Magnesium, Calcium, Strontium, Barium and Radium" in *Comprehensive Inorganic Chemistry,* **vol. 1,** J. C. Bailar, Jr. *et al.,* Eds. (Pergamon Press, Oxford, 1973) pp 591-774.

Silvery-white metal; face-centered cubic structure; rapidly becomes yellow on exposure to air and assumes an oxide film. The finely divided metal ignites spontaneously in air. d 2.6; mp 757° ± 1°; bp 1366°. E^0 (aq) Sr^{2+}/Sr −2.89 V. For a description of reactions which are characteristic of alkaline earth metals *see* Calcium. *Keep under liquid containing no oxygen.* The heated metal combines with hydrogen to form ***strontium hydride*** and with nitrogen to form ***strontium nitride.*** Strontium salts impart brilliant red color to a flame.

USE: In fireworks, in red signal flares; on tracer bullets. The artificial isotope ^{90}Sr, with a half life of 28 years, is being considered as a source of electric power. Heat liberated by decay would be changed to electrical energy.

Note: The problems of internal radiation hazards from radiostrontium are discussed by A. Engström *et al., Bone and Radiostrontium* (Wiley, New York, 1958).

8700. Strontium Acetate. C
23.36%, H 2.94%, O 31.11%, Sr
Hemihydrate, white cryst pow
on ignition is converted into Sr
slightly sol in alcohol. The aq
litmus. LD i.v. in rats: 238 m

8701. Strontium Bromate.
46.54%, O 27.95%, Sr 25.51%.
Monohydrate, white to slight
powder. Sol in 3 parts water.

8702. Strontium Bromide.
64.59%, Sr 35.41%. $SrBr_2$.
Hexahydrate, colorless, deliq
ules; bitter saline taste. mp 8
643° when anhydr. Loses all it
part water; sol in alcohol; insol
tral. *Incompat:* Soluble sulfates
THERAP CAT: Sedative, antico
THERAP CAT (VET): Has been
sant.

8703. Strontium Carbonate.
8.14%, Sr 59.35%, O 32.51%.
the mineral *strontianite.*
White, odorless, tasteless po
into SrO and CO_2. Sol in 100,0
parts of water saturated with C
USE: In pyrotechnics; man
sugar.

8704. Strontium Chlorate.
27.86%, O 37.72%, Sr 34.43%.
Colorless or white crystals. c
position and evolution of O_2. S
in alcohol. *Handle with caution*
USE: In pyrotechnics to prod

8705. Strontium Chloride.
44.73%, Sr 55.27%. $SrCl_2$
Hexahydrate, colorless, odor
ules. Effloresces in air; deliqu
loses $5H_2O$; at 150° all its H_2O;
heated; the anhydr salt melts
water, 0.5 part boiling water; s
neutral. *Keep well closed.* MI
USE: Manuf other strontiu
dental desensitizer under the n

8706. Strontium Chromate(
Sr 43.03%, Cr 25.54%, O 31.43
Yellow powder. d 3.89. Sol
about 5 parts boiling water; f
nitric or acetic acids.
USE: Corrosion inhibitor in
processes to control sulfate cor

8707. Strontium Fluoride.
30.25%, Sr 69.75%. SrF_2. Pre
excess of 40% HF and evapor
Pogg. Ann. **1,** 20 (1824); final d
in vacuo.
White powder or cubic cryst
2460°. Stable in air up to 100
dized to strontium oxide. Hea
ton const 28.6. Soly in water
sol in dil acids. Dec by strong
bottles.

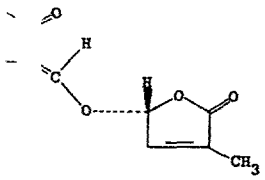
8708. Strontium Formate.
13.52%, H 1.13%, O 36.02%, S
Dihydrate, white crystals o
water.

8709. Strontium Hydroxide
O_2Sr; mol wt 121.64. H 1.
$Sr(OH)_2$.
Octahydrate, colorless, deliq
der; absorbs CO_2 from air form
its water at about 100°. Sol in
ing water. The soln is very alk
tightly closed.

…een listed as a carcinogen by *Report on Carcinogens* (NTP 81-…5.

…is …

5 …ihydro-4-methyl-5-oxo-2-fur…, ..5,6,7,8,8b-octahydro-5-hydr…no[1,2-b]furan-2-one. $C_{19}H_{22}O_6$; H 6.40%, O 27.71%. Potent seed …root parasite, witchweed, *Stri…* …oot exudates of cotton, *Gossy…* …ok *et al., Science* **154,** 1189 *J. Am. Chem. Soc.* **94,** 6198 P. Coggan *et al., J. Chem. Soc.* …nthesis: J. B. Heather *et al., J.* … 6); of (±)-form: G. A. Mac… …, **1974,** 834; *eidem, J. Chem.* …. Synthesis of analogs: A. W. …1734. Witchweed seed germina… A. L. Hsiao *et al., Weed Sci.* **29,** … *et al., ibid.* **30,** 561 (1982).



…zene-hexane, mp 200-202° (dec). …ICl$_3$). uv max: 234 nm (ε … …lene chloride. Moderately sol …

…ene polychlorinates; Dichloricide …thproofer; Insecticide 3960-X14. …ene isomers. Preparation by … …phene and pinenes contg di… …pat. **2,767,115** (1956 to B. F. …

d_{25} 1.6267. Misc with aromatic … Slightly sol in alcohol. …oxaphene. *Caution:* May be …

$g_2S.Cu_2S$—silver cuprous sulfide.

…wt 87.62; at. no. 38; valence 2. …pes: 88 (82.56%); 86 (9.86%); …rs as the sulfate, celestine; or …nd in small quantities associ… …um minerals. First prepared in …lascock, *J. Am. Chem. Soc.* **32,** … *t. Rend.* **177,** 1116 (1923); *J.* … *untz et al.*, cited in *Gmelin's* … 1). Review of strontium and …ugh, Stenger, "Magnesium, Cal… and Radium" in *Comprehensive* … C. Bailar, Jr. *et al.*, Eds. (Per… …) 591-774. …tered cubic structure; rapidly …re …o air and assumes an oxide …etal ignites spontaneously in air. …366°. E^0 (aq) Sr^{2+}/Sr −2.89 V. …which are characteristic of al… …t. *Keep under liquid contain…* …al combines with hydrogen to … with nitrogen to form *strontium* …part brilliant red color to a flame. …gnal flares; on tracer bullets. …a half life of 28 years, is being …ic power. Heat liberated by …electrical energy. …internal radiation hazards from …by A. Engström *et al., Bone* …w York, 1958).

8700. Strontium Acetate. $C_4H_6O_4Sr$; mol wt 205.71. C 23.36%, H 2.94%, O 31.11%, Sr 42.59%. $Sr(C_2H_3O_2)_2$.

Hemihydrate, white cryst powder. Loses its water at 150°; on ignition is converted into $SrCO_3$. Sol in 2.5 parts water; slightly sol in alcohol. The aq soln is practically neutral to litmus. LD i.v. in rats: 238 mg/kg.

8701. Strontium Bromate. Br_2O_6Sr; mol wt 343.44. Br 46.54%, O 27.95%, Sr 25.51%. $Sr(BrO_3)_2$.

Monohydrate, white to slightly yellow, hygroscopic, cryst powder. Sol in 3 parts water. *Keep well closed.*

8702. Strontium Bromide. Br_2Sr; mol wt 247.44. Br 64.59%, Sr 35.41%. $SrBr_2$.

Hexahydrate, colorless, deliquesc crystals or white granules; bitter saline taste. mp 88° when rapidly heated; mp 643° when anhydr. Loses all its water at 180°. Sol in 0.35 part water; sol in alcohol; insol in ether. The aq soln is neutral. *Incompat:* Soluble sulfates. LD_{50} i.p. in rats: 1.0 g/kg.

THERAP CAT: Sedative, anticonvulsant.

THERAP CAT (VET): Has been used as sedative, anticonvulsant.

8703. Strontium Carbonate. CO_3Sr; mol wt 147.64. C 8.14%, Sr 59.35%, O 32.51%. $SrCO_3$. Occurs in nature as the mineral *strontianite.*

White, odorless, tasteless powder. d 3.5. Dec at 1100° into SrO and CO_2. Sol in 100,000 parts water, in about 1000 parts of water saturated with CO_2; sol in dil acids.

USE: In pyrotechnics; manuf iridescent glass; refining sugar.

8704. Strontium Chlorate. Cl_2O_6Sr; mol wt 254.54. Cl 27.86%, O 37.72%, Sr 34.43%. $Sr(ClO_3)_2$.

Colorless or white crystals. d 3.15. mp 120° with decomposition and evolution of O_2. Sol in 0.6 part water, slightly in alcohol. *Handle with caution like potassium chlorate.*

USE: In pyrotechnics to produce red fire.

8705. Strontium Chloride. Cl_2Sr; mol wt 158.52. Cl 44.73%, Sr 55.27%. $SrCl_2$.

Hexahydrate, colorless, odorless crystals or white granules. Effloresces in air; deliquesces in moist air. At 100° loses $5H_2O$; at 150° all its H_2O; d 1.96; mp 61° when rapidly heated; the anhydr salt melts at 868°. Soluble in 0.8 part water, 0.5 part boiling water; sol in alcohol. The aq soln is neutral. *Keep well closed.* MLD i.v. in rats: 400 mg/kg.

USE: Manuf other strontium salts; in pyrotechnics; as dental desensitizer under the name *Elecol.*

8706. Strontium Chromate(VI). CrO_4Sr; mol wt 203.64. Sr 43.03%, Cr 25.54%, O 31.43%. $SrCrO_4$.

Yellow powder. d 3.89. Soluble in 840 parts cold water, about 5 parts boiling water; freely sol in dil hydrochloric, nitric or acetic acids.

USE: Corrosion inhibitor in pigments; in electrochemical processes to control sulfate concn of solns.

8707. Strontium Fluoride. F_2Sr; mol wt 125.63. F 30.25%, Sr 69.75%. SrF_2. Prepd by dissolving $SrCO_3$ in an excess of 40% HF and evaporating to dryness: Berzelius, *Pogg. Ann.* **1,** 20 (1824); final drying should be done at 150° *in vacuo.*

White powder or cubic crystals. d 4.24. mp ~1400°. bp 2460°. Stable in air up to 1000°. Above this temp it is oxidized to strontium oxide. Heat of evaporation 78.2. Trouton const 28.6. Soly in water (18°) 11.7mg/100 ml. More sol in dil acids. Dec by strong acids. May be stored in glass bottles.

8708. Strontium Formate. $C_2H_2O_4Sr$; mol wt 177.66. C 13.52%, H 1.13%, O 36.02%, Sr 49.32%. $Sr(HCOO)_2$.

Dihydrate, white crystals or granules. d 2.69. Sol in water.

8709. Strontium Hydroxide. Strontium hydrate. H_2O_2Sr; mol wt 121.64. H 1.66%, O 26.31%, Sr 72.03%. $Sr(OH)_2$.

Octahydrate, colorless, deliquesc crystals or white powder; absorbs CO_2 from air forming carbonate. Loses part of its water at about 100°. Sol in 50 parts water, 2.1 parts boiling water. The soln is very alkaline. pH about 13.5. *Keep tightly closed.*

USE: Refining beet sugar; separating crystallizable sugar from molasses.

8710. Strontium Iodide. I_2Sr; mol wt 341.42. I 74.34%, Sr 25.66%. SrI_2. The article of commerce is hydrated.

Hexahydrate, colorless to yellowish, deliquesc, fused masses or granules with bitterish saline taste; becomes yellow on exposure to air and light due to liberation of iodine. Melts when rapidly heated, at about 120°; melts when anhydr at 402°. d 4.42. Sol in 0.2 part water; sol in alcohol. The aq soln is practically neutral. *Keep well closed and protected from light.* LD_{50} i.p. in rats: 800 mg/kg.

THERAP CAT: Iodine source.

THERAP CAT (VET): Has been used in iodide therapy.

8711. Strontium Lactate. *2-Hydroxypropanoic acid strontium salt.* $C_6H_{10}O_6Sr$; mol wt 265.76. C 27.11%, H 3.79%, O 36.12%, Sr 32.97%. $(CH_3CHOHCOO)_2Sr$.

Trihydrate, *Strontolac.* White, odorless, granular powder. Loses its water of crystn at 120°. Sol in 3 parts water, 0.5 part boiling water; slightly sol in alcohol. The aq soln is practically neutral. LD_{50} i.p. in rats: 900 mg/kg.

8712. Strontium Nitrate. N_2O_6Sr; mol wt 211.65. N 13.24%, O 45.36%, Sr 41.40%. $Sr(NO_3)_2$.

White granules or powder. d 2.99. mp 570°. Sol in 1.5 parts water; slightly sol in alcohol or acetone. The aq soln is neutral. LD_{50} i.p. in rats: 540 mg/kg, Cochran *et al., Arch. Ind. Hyg.* **1,** 637 (1950).

Note: At low temps strontium nitrate crystallizes with $4H_2O$ (25.4%).

USE: In pyrotechnics (red fire), signal lights, marine signals, railroad flares, matches.

8713. Strontium Oxalate. *Ethanedioic acid strontium salt.* C_2O_4Sr; mol wt 175.64. C 13.67%, O 36.44%, Sr 49.89%. SrC_2O_4.

Monohydrate, white, odorless, cryst powder. Soluble in 20,000 parts water; in 1900 parts of 3.5% acetic acid, in 1115 parts of the 23% acid, but less sol in the 35% acid; readily sol in dil HCl or HNO_3.

8714. Strontium Oxide. Strontia; strontium monoxide. OSr; mol wt 103.63. O 15.44%, Sr 84.56%. SrO.

White to grayish-white, porous, caustic mass. d 4.7. mp 2430°. When treated with water, forms the hydroxide with evolution of much heat. *Keep tightly closed.*

USE: Manuf of strontium salts.

8715. Strontium Peroxide. O_2Sr; mol wt 119.63. O 26.75%, Sr 73.25%. SrO_2. The peroxide of commerce contains about 85% SrO_2.

White, odorless, tasteless powder; gradually dec on exposure to air. Almost insol in water, but is gradually dec by it with evolution of oxygen; forms hydrogen peroxide with dil acids. *Keep well closed.*

THERAP CAT: Antiseptic.

8716. Strontium Phosphate, Tribasic. $O_8P_2Sr_3$; mol wt 452.85. O 28.27%, P 13.68%, Sr 58.05%. $Sr_3(PO_4)_2$.

White, odorless powder. Insol in water; sol in acids.

8717. Strontium Selenate. O_4SeSr; mol wt 230.59. Sr 38.00%, Se 34.24%, O 27.75%. $SrSeO_4$. Prepared by roasting strontium carbonate with selenium or selenium oxide: Lenher, Wechter, *J. Am. Chem. Soc.* **47,** 1522 (1925).

Orthorhombic crystals. d 4.25. Sol in hot hydrochloric acid; insol in water.

8718. Strontium Sulfate. O_4SSr; mol wt 183.70. O 34.84%, S 17.46%, Sr 47.70%. $SrSO_4$. Occurs in nature as the mineral *celestine* or *celestite.*

White, odorless, crystalline powder. d 3.96. One gram dissolves in about 8800 ml water, 800 ml 2% HCl, 700 ml 3% HNO_3; appreciably sol in alkali chloride solns.

USE: In ceramics, pyrotechnics.

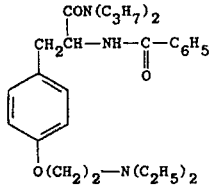
8719. Strontium Sulfide. SSr; mol wt 119.70. S 26.79%, Sr 73.21%. SrS. The article of commerce contains 65-75% SrS. Strontium sulfide made by reduction of the sulfate is not luminous; the luminous sulfide is prepared by heating strontium hydroxide with sulfur.

sulfonate; sodium catechol disulfonate; sodium pyrocatechol-2,4-disulfonate; disodium pyrocatechol-3,5-disulfonate; Tiferron. $C_6H_4Na_2O_8S_2$; mol wt 314.22. C 22.94%, H 1.28%, Na 14.63%, O 40.74%, S 20.41%. Prepd by heating 5-bromo-4-hydroxy-*m*-benzenedisulfonic acid with sodium hydroxide in water and acidifying product with hydrochloric acid: Fukayama *et al.*, **Japan.** pat. **4327('52)** (to Sanwa Pure Chem.), *C.A.* **48**, 5215c (1954).

Crystals, nonhygroscopic. Very freely sol in water. Produces water-sol, colored compds with metal salts. With ferric chloride the resulting complex yields a deep blue soln at pH below 5. Titanium salts give an orange color, copper salts produce a green-yellow, and hexavalent molybdenum a canary-yellow color.

USE: Colorimetric reagent for iron, manganese, titanium, molybdenum: Yoe, Jones, *Ind. Eng. Chem., Anal. Ed.* **16**, 111 (1944). Zirconium complexes: Intorre, Martell, *J. Am. Chem. Soc.* **82**, 358 (1960).

9301. Tiropramide. *α-(Benzoylamino)-4-[2-(diethylamino)ethoxy]-N,N-dipropylbenzenepropanamide;* DL-α-benzamido-*p*-[2-(diethylamino)ethoxy]-*N,N*-dipropylhydrocinnamamide; *O*-(2-diethylaminoethyl)-*N*-benzoyl-DL-tyrosyl-di-*n*-propylamide; CR 605; Maiorad. $C_{28}H_{41}N_3O_3$; mol wt 467.66. C 71.91%, H 8.84%, N 8.99%, O 10.26%. Antispasmodic deriv of tyrosine, *q.v.* Prepn: F. Makovec *et al.*, **Ger.** pat. **2,503,992** corresp to **U.S.** pat. **4,004,008** (1975, 1977 both to Rotta). Activity on gastrointestinal motility: P. Senin *et al., Gastrointestinal Motility in Health and Disease,* H. L. Duthie, Ed. (University Park Press, Baltimore, 1978) pp 417-427. Mechanism of action: R. R. Vidal y Plana *et al., J. Pharm. Pharmacol.* **33**, 19 (1981).



Cryst from petr ether, mp 65-67°. LD_{50} in rats: 33.9 mg/kg i.v., F. Makovec *et al., loc. cit.*

THERAP CAT: Relaxant (smooth muscle).

9302. Titanic(IV) Acid. Orthotitanic acid; titanic hydroxide. $Ti(OH)_4.xH_2O$. The H_2O content depends upon the method and time of drying.

White, amorphous powder. Insol in water; when freshly pptd it is sol in dil HCl or H_2SO_4 and in boiling caustic alkali solns; after drying it is almost insol.

9303. Titanium. Ti; at. wt 47.88; at. no. 22; valence 2, 3, 4 (mostly tetravalent). Five natural isotopes (mass numbers): 48 (73.94%); 46 (7.93%); 47 (7.28%); 49 (5.51%); 50 (5.34%). Artificial isotopes: 43-45; 51. Ninth most abundant element in earth's crust; 0.63% by wt. Occurs as the oxide in the minerals rutile, ilmenite, perovskite, anatase, or octahedrite and brookite; other minerals include *sphene* or *titanite* ($CaTiSiO_5$) and *benitoite* ($BaTiSi_3O_9$). Discovered by Gregor in 1789; investigated and named by Klaproth in 1795; isolated by Berzelius in 1825. Prepn: de Boer, *Ind. Eng. Chem.* **19**, 1256 (1927); Fast, *Z. Anorg. Chem.* **241**, 42 (1939); Ehrlich in *Handbook of Preparative Inorganic Chemistry* **vol. 2**, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1965) pp 1161-1172. *Reviews: Gmelin's, Titanium* (8th ed.) **41** (1951); Everhart, *Titanium and Titanium Alloys* (Reinhold, New York, 1954); Brophy *et al., Titanium Bibliography* 1900-1951 + suppl (Washington, 1954); McQuillan & McQuillan, *Titanium* (Butterworth's, London, 1956); Barksdale, *Titanium, Its Occurrence, Chemistry and Technology* (Ronald Press, New York, 2nd ed, 1966); Clark, "Titanium" in *Comprehensive Inorganic Chemistry* **vol. 3**, J. C. Bailar, Jr. *et al.*, Eds. (Pergamon Press, Oxford, 1973) pp 355-417.

Dark gray, lustrous metal. Dimorphic; α-form: hexagonal structure below 882.5°; β-form: body-centered cubic crystals above 882.5°. Brittle when cold; malleable when hot. Ductile only when free of oxygen; traces of oxygen or nitrogen increase strength. mp 1677°. bp 3277°. Calculated d (α- form): 4.506 (25°); (β-form): 4.400 (900°). Specific heat (25°): 5.98 cal/g-atom/°C. Decomposes steam at 700-800°. Combines with oxygen at a red heat. Can burn in an atm of oxygen under certain conditions: *Chem. & Eng. News* **36**, 36 (Aug. 4, 1958). Attacked by acids only on heating; oxidized by nitric acid to the dioxide. Reacts with fluorine at 150°, with chlorine at 300°, with bromine at 360°, with iodine above 360°. Combines with nitrogen at 800°. Forms alloys with aluminum, chromium, cobalt, copper, iron, lead, nickel, tin.

USE: As alloy with copper and iron in titanium bronze; as addition to steel to impart great tensile strength; to aluminum to impart resistance to attack by salt solns and by organic acids; to remove traces of oxygen and nitrogen from incandescent lamps.

THERAP CAT: Surgical aid (fracture fixation).

9304. Titanium Dichloride. Cl_2Ti; mol wt 118.81. Ti 40.32%, Cl 59.68%. $TiCl_2$. Prepn: Clifton, McWood, *J. Phys. Chem.* **60**, 311 (1956); Ehrlich *et al., Z. Anorg. Allgem. Chem.* **292**, 139 (1957).

Black crystals. mp 1035°. d 3.13. Burns like tinder when heated in air; dec by water. Sol in alcohol; practically insol in chloroform, ether, carbon disulfide. *Keep dry and well closed.*

9305. Titanium Dioxide. Unitane. O_2Ti; mol wt 79.90. O 40.05%, Ti 59.95%. TiO_2. Found in nature as the minerals *rutile* (tetragonal), *anatase* or *octahedrite* (tetragonal), *brookite* (orthorhombic), *ilmenite* ($FeTiO_3$), and *perovskite* ($CaTiO_3$). May be prepd by direct combination of titanium and oxygen; by treatment of titanium salts in aq soln; by the reaction of volatile, inorganic titanium compds with oxygen; by oxidation or hydrolysis of organic compds of titanium. Industrial prepn from ilmenite or rutile: Faith, Keyes & Clark's *Industrial Chemicals,* F. A. Lowenheim, M. K. Moran, Eds. (Wiley-Interscience, New York, 4th ed., 1975) pp 814-821. Prepn of synthetic rutile: Merker, **U.S.** pat. **2,760,874** (1956 to National Lead). Prepn of spectroscopically pure material by dissolving titanium in an ammoniacal soln of 90% H_2O_2: Czanderna *et al., J. Am. Chem. Soc.* **79**, 5407 (1957).

White powder, mp 1855°. d (rutile): 4.23; (anatase): 3.90; (brookite): 4.13. Insol in water, HCl, HNO_3, or dil H_2SO_4; sol in hot concd H_2SO_4, in HF. The reactivity depends on a previous heat treatment; prolonged heating produces a less sol material. Also made sol by fusion with potassium bisulfate or with alkali hydroxides or carbonates to form alkali titanates. Possesses perhaps the greatest hiding power of all inorganic white pigments. *Titania* is a name applied to large TiO_2 crystals (translucent water-white or with yellowish cast) suitable for use in jewelry. These crystals have a refractive index (2.7) higher than diamonds (2.4), but lack the hardness of diamonds. When substantially pure, a massive single crystal (boule) of rutile has the properties of a precious gem with a very light straw color and with reflectance, refraction and brilliance measuring greater than those of a diamond.

Note: The rutile structure is common among metal fluorides and oxides of the type MF_2 and MO_2.

USE: Airfloated ilmenite is used for titanium pigment manuf. Rutile sand is suitable for welding-rod-coating materials, as ceramic colorant, as source of titanium metal. As color in the food industry. Anatase titanium dioxide is used for welding-rod-coatings, acid resistant vitreous enamels, in specification paints, exterior white house paints, acetate rayon, white interior air-dry and baked enamels and lacquers, inks and plastics, for paper filling and coating, in water paints, tanners' leather finishes, shoe whiteners, and ceramics. High opacity and tint rutile-like pigments.

THERAP CAT: Protectant (topic

9306. Titanium Hydride. H 95.95%, H 4.04%. TiH_2. Prepd b oxide with calcium hydride in above 600°: Alexander, U.S. pat

Gray-black metallic powder. appreciable at 450°.

USE: Additive in powder metall nitrogen in electronic tubes; we metal seals; source of pure hydr

9307. Titanium Isopropylate $C_{12}H_{28}O_4Ti$; mol wt 284.26. C 5 Ti 16.85%. $Ti[OCH(CH_3)_2]_4$. *Chem. Soc.* **1952**, 5020. Comm nium Pigment Corp.

Liquid. Fumes in air. mp a Cowe, *The Organic Chemistry* Washington, 1965) p 36. bp_{760} Apparent viscosity 2.11 cp at 25° at 62 ' ilocycles. Dec rapidly in nol, ether, benzene, chloroform. *in handling to exclude water fro*

USE: Polymerization catalyst.

9308. Titanium Sesquisulfate Ti_2; mol wt 384.00. O 50.00%, $(SO_4)_3$. (Crystallizes also as a h

Green, cryst powder. Insol i sol in dil HCl or dil H_2SO_4, giv

USE: Same as titanium trichlo

9309. Titanium Sulfate. *Tita* O_5STi; mol wt 159.97. O 50.0 $TiOSO_4$. Prepn: Hayek, Eng (1949).

White or slightly yellow powd

Note: The name titanyl sulfa $Ti(SO_4)_2$.

USE: As mordant in dyeing.

THERAP CAT: Dermatologic.

9310. Titanium Tetrabromide 86.97%, Ti 13.03%. $TiBr_4$. Pr *Chem. Soc.* **54**, 2215 (1932).

Amber-yellow or orange, very 28.25°. bp 233.45°. d^{20} 3.25. A *Proc. Roy. Soc. London* **8**, 42 (1 abs ether, abs alcohol. *Keep tig*

9311. Titanium Tetrachlorid 74.75%, Ti 25.25%. $TiCl_4$. Purif *Chem. Soc.* **45**, 1228 (1923); **48**, parative methods: Ehrlich in *H ganic Chemistry,* **Vol. 2**, G. Br New York, 2nd ed., 1965) pp 1

Colorless liquid; penetrating from the air and evolves dense −24.1°. bp 136.4°. Sol in cold water. *Keep tightly closed.*

USE: Formerly used with pot dant in textile industry, and wit er; also as smoke-producing sc iridescent glass and artificial p eyes, respiratory tract.

9312. Titanium Tetrafluorid 61.34%, Ti 38.66%. TiF_4. Prep fluoride with titanium tetrachl 1777 (1903); Ruff, Plato, *ibid.* 3 of fluorine on the metal or the *Am. Chem. Soc.* **76**, 2177 (1954

Powdery white mass. d_4^{20} 2. >400°. Hisses on contact wit the dihydrate may be crystalliz obtained from solns of TiO_2 in slowly, and the existence of an established. Also sol in alcohol compds $TiF_4.2EtOH$ and TiF_4

ceramics. High opacity and tinting values are claimed for rutile-like pigments.

THERAP CAT: Protectant (topical).

9306. Titanium Hydride. H_2Ti; mol wt 49.92. Ti 95.95%, H 4.04%. TiH_2. Prepd by the reduction of titanium oxide with calcium hydride in the presence of hydrogen above 600°: Alexander, U.S. pat. 2,427,338 (1947).

Gray-black metallic powder. Stable in air. Dissociation appreciable at 450°.

USE: Additive in powder metallurgy; getter for oxygen and nitrogen in electronic tubes; wetting agent for ceramic to metal seals; source of pure hydrogen.

9307. Titanium Isopropylate. Isopropyl titanate(IV). $C_{12}H_{28}O_4Ti$; mol wt 284.26. C 50.70%, H 9.93%, O 22.51%, Ti 16.85%. $Ti[OCH(CH_3)_2]_4$. Prepn: Bradley *et al., J. Chem. Soc.* **1952,** 5020. Commercial development: Titanium Pigment Corp.

Liquid. Fumes in air. mp approx 20°: R. Feld, P. L. Cowe, *The Organic Chemistry of Titanium* (Butterworths, Washington, 1965) p 36. bp_{760} 220°; bp_{10} 104°. d_4^{20} 0.9711. Apparent viscosity 2.11 cp at 25°. Dielectric constant: 3.64 at 62 kilocycles. Dec rapidly in water. Sol in anhydr ethanol, ether, benzene, chloroform. *Precautions must be taken in handling to exclude water from solvents and diluents.*

USE: Polymerization catalyst.

9308. Titanium Sesquisulfate. Titanous sulfate. $O_{12}S_3Ti_2$; mol wt 384.00. O 50.00%, S 25.05%, Ti 24.95%. $Ti_2(SO_4)_3$. (Crystallizes also as a hydrate with $8H_2O$).

Green, cryst powder. Insol in water, alc, concd H_2SO_4; sol in dil HCl or dil H_2SO_4, giving violet-colored solns.

USE: Same as titanium trichloride.

9309. Titanium Sulfate. *Titanyl sulfate;* titanoxy sulfate. O_5STi; mol wt 159.97. O 50.01%, S 20.05%, Ti 29.94%. $TiOSO_4$. Prepn: Hayek, Engelbrecht, *Monatsh.* **80,** 640 (1949).

White or slightly yellow powder; dec by water.

Note: The name titanyl sulfate is sometimes applied to $Ti(SO_4)_2$.

USE: As mordant in dyeing.

THERAP CAT: Dermatologic.

9310. Titanium Tetrabromide. Br_4Ti; mol wt 367.56. Br 86.97%, Ti 13.03%. $TiBr_4$. Prepn: Olsen, Ryan, *J. Am. Chem. Soc.* **54,** 2215 (1932).

Amber-yellow or orange, very hygroscopic crystals. mp 28.25°. bp 233.45°. d^{20} 3.25. Also reported as 2.6: Duppa, *Proc. Roy. Soc. London* **8,** 42 (1857). Dec by water; sol in abs ether, abs alcohol. *Keep tightly closed.*

9311. Titanium Tetrachloride. Cl_4Ti; mol wt 189.73. Cl 74.75%, Ti 25.25%. $TiCl_4$. Purification: Baxter *et al., J. Am. Chem. Soc.* **45,** 1228 (1923); **48,** 3117 (1926). Survey of preparative methods: Ehrlich in *Handbook of Preparative Inorganic Chemistry,* **Vol. 2,** G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1965) pp 195-199.

Colorless liquid; penetrating acid odor; absorbs moisture from the air and evolves dense white fumes. d 1.726. mp −24.1°. bp 136.4°. Sol in cold water, alcohol; dec by hot water. *Keep tightly closed.*

USE: Formerly used with potassium bitartrate as a mordant in textile industry, and with dyewoods in dyeing leather; also as smoke-producing screen with ammonia; manuf iridescent glass and artificial pearls. *Caution:* Irritant to eyes, respiratory tract.

9312. Titanium Tetrafluoride. F_4Ti; mol wt 123.90. F 61.34%, Ti 38.66%. TiF_4. Prepd by the reaction of hydrogen fluoride with titanium tetrachloride: Ruff, Ipsen, *Ber.* **36,** 1777 (1903); Ruff, Plato, *ibid.* **37,** 673 (1904); by the action of fluorine on the metal or the dioxide: Haendler *et al., J. Am. Chem. Soc.* **76,** 2177 (1954).

Powdery white mass. d_4^{20} 2.798. Sublimes at 284°. mp >400°. Hisses on contact with water. Very hygroscopic; the dihydrate may be crystallized from aqueous soln (also obtained from solns of TiO_2 in HF). Aq solns hydrolyze slowly, and the existence of an oxyfluoride, $TiOF_2$, has been established. Also sol in alcohol and pyridine from which the compds $TiF_4.2EtOH$ and $TiF_4.C_5H_5N$ have been isolated. Insol in ether. Dry ammonia is absorbed at room temp to form $TiF_4.4NH_3$, but at 120° $TiF_4.2NH_3$ is the stable phase. This is sol in water and is sufficiently stable to sublime. TiF_4 is also sol in phosphorus oxychloride, but at 30° a reaction occurs and POF_3 is evolved. *See also* Emeléus in *Fluorine Chemistry* **vol. 1,** J. H. Simons, Ed. (Academic Press, New York, 1950) p 47.

9313. Titanium Trichloride. Titanous chloride. Cl_3Ti; mol wt 154.27. Cl 68.95%, Ti 31.05%. $TiCl_3$. Prepn by reduction of the tetrachloride: Ingraham *et al., Inorg. Syn.* **6,** 52 (1960); Sherfey, *ibid.* 57.

Dark red-violet, unstable, deliquesc crystals; dec on heating above 500°. The dry powder is pyrophoric in air. Very reactive and readily dissociated by moisture in air. Sol in water, exothermic process; sol in alcohol. Practically insol in ether. *Keep tightly closed.*

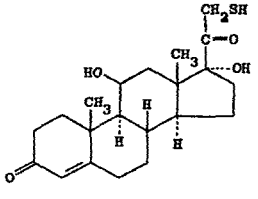
USE: A powerful reducing agent. Reduces nitrate to ammonia; when boiled with aq SO_2, sulfur is separated; hence is used as an aq soln for estimation of nitro groups, ferric ions, per-salts, etc. Removes stains, etc. (stripper) in laundering.

9314. Titanocene Dichloride. *Dichlorobis(η^5-2,4-cyclopentadien-1-yl)titanium; dichlorodi-π-cyclopentadienyltitanium;* biscyclopentadienyltitanium(IV) dichloride. $C_{10}H_{10}Cl_2Ti$; mol wt 248.99. C 48.24%, H 4.05%, Cl 28.47%, Ti 19.24%. $(C_5H_5)_2TiCl_2$. Also Cp_2TiCl_2. Prepn: Wilkinson, Birmingham, *J. Am. Chem. Soc.* **76,** 4281 (1954). Structure: Clearfield *et al., Can. J. Chem.* **53,** 1622 (1975).

Bright red acicular crystals from toluene. mp 289 ± 2°. d 1.60. Moderately sol in toluene, chloroform, alcohol, other hydroxylic solvents; sparingly sol in water, petr ether, benzene, ether, carbon disulfide, carbon tetrachloride.

USE: Catalyst; with aluminum alkyls as Ziegler-Natta polymerization catalyst.

9315. Tixocortol. *11,17-Dihydroxy-21-mercaptopregn-4-ene-3,20-dione;* 11β,17α-dihydroxy-21-thio-3,20-dioxo-4-pregnene. $C_{21}H_{30}O_4S$; mol wt 378.53. C 66.63%, H 7.99%, O 16.91%, S 8.47%. Synthesis and biological activity: S. S. Simons *et al., J. Steroid Biochem.* **13,** 311 (1980). Use in fluorescent chemoaffinity labeling: *eidem, Biochemistry* **18,** 4915 (1979). Prepn of the 21-pivalate: D. R. Torossian *et al.,* Ger. pat. 2,357,778 corresp to U.S. pat. 4,014,909 (1974, 1977 both to Jouveinal). Series of articles on pharmacology, *in vitro* and *in vivo* activity of the pivalate: *Arzneimittel-Forsch.* **31,** 453-469 (1981).



Fine white solid, dec 220-221°. uv max (95% ethanol): 241 nm (ε 1.65 × 10^4).

21-Pivalate. $C_{26}H_{38}O_5S$, *21-[(2,2-dimethyl-1-oxopropyl)-thio]-11β,17-dihydroxypregn-4-ene-3,20-dione, JO 1016, Pivalone.* Cryst from ethanol, mp 195-200°. $[\alpha]_D^{20}$ +145° (c = 1 in dioxane). uv max (methanol): 229 nm (log ε 4.259).

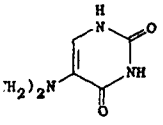
USE: Free thiol in chemoaffinity labeling.

THERAP CAT: 21-Pivalate as an anti-inflammatory agent.

9316. TMD. *Decahydro-1,1,4a-trimethyl-2-naphthalenol;* 1,1,10-trimethyl-*trans*-2-decalol; 4,4,10β-trimethyl-*trans*-decal-3β-ol. $C_{13}H_{24}O$; mol wt 196.33. C 79.53%, H 12.32%, O 8.15%. Prepn: B. Gaspert *et al., J. Chem. Soc.* **1958,** 624; C. Djerassi, D. Marshall, *J. Am. Chem. Soc.* **80,** 3986 (1958); T. G. Halsall *et al., J. Chem. Soc.* **1959,** 2798; S. L. Mukherjee, P. C. Dutta, *ibid.* **1960,** 67. Inhibitor of cholesterol biosynthesis: J. A. Nelson *et al., J. Am. Chem. Soc.* **100,** 4900 (1978); T.-Y. Chang *et al., J. Biol. Chem.* **254,** 11258 (1979).

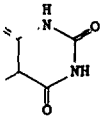
...l). Almost insol in alc, ether; sol in other alkalies. pK = 9.45. research.

...d *5-[Bis(2-chloroethyl)amino]-2,4-*
...e *-[bis(2-chloroethyl)amino]uracil;*
...hloroethyl]aminopyramidine; 5-[di-racil; uramustine; demethyldopan; 34462; U-8344. $C_8H_{11}Cl_2N_3O_2$; mol ... 5.40%, Cl 28.13%, N 16.67%, O ... aminouracil: Lyttle, Petering, *J.* ... 958); Lyttle, U.S. pat. 2,969,364



... water, dec 206°, sparingly sol ... H_2SO_4 in 95% ethanol): 257 nm ...lly in rats: 3.7; about 7.5 mg/kg. ...lastic.

...*2,4,6(1H,3H,5H)-pyrimidinetri-* ...*one;* dialuramide; 5-amino-2,4,6-... $C_4H_5N_3O_3$; mol wt 143.10. C ...37%, O 33.54%. Prepd by boiling ...m chloride: Wöhler, Liebig, *Ann.* ... of 5-nitrobarbituric acid with ...eppard, *Org. Syn.* coll. vol. II, ... acid, sodium nitrite and sodium ...obins, *J. Am. Chem. Soc.* 80, 2751



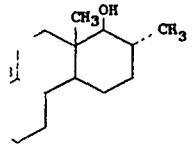
...ne air. Does not melt below 400°. ...er, chloroform; sparingly sol in hot ...ali hydroxides, in ammonia and in ...ly sol lead salt.

...lymerized urea-formaldehyde ...n. Prepn of a fertilizer contg 40% ...formaldehyde: Darden, U.S. pat. ...

...a ...f small particle size. Essential-

...for turfs and ornamentals.

...*Methyl-D-homoandrostane-3,17a-* ...0.50. C 78.69%, H 11.32%, O ...s' urine: Marker *et al., J. Am.* ...561, 2719 (1938); Klyne, *Bio-*Brooks *et al., ibid.* 51, 694 (1952). ...166, 559 (1950). Formation by ...eanane-3β,20β-diol: Hirschmann, ...2305 (1963). Configuration: ...em. 31, 375 (1966).



...p 216-219°. Sublimes at 180° ...+3.7° (c = 1.8 in chloroform). ...tes from aq methanol, mp 159.5-...0.1 mm. $[\alpha]_D^{20}$ −30.4° (c = 1.4 ...ethanol).

Dibenzoate, $C_{38}H_{44}O_8$, leaflets from chloroform + methanol, mp 209-210°. $[\alpha]_D^{20}$ +18.6° (c = 1.05 in chloroform). uv max: 230, 272 nm (log ε 4.43, 3.26).

9656. Uranium. U; at. wt 238.0289; at. no. 92; valence 6, 5, 4, 3. Three naturally occurring isotopes: 238 (99.276%), 235 (0.718%), 235 (0.0056%); artificial isotopes: 227-233; 236; 237; 239; 240. Occurrence in the earth's crust 2 × 10^{-5}%. Discovered by Klaproth in 1789; isolated by Peligot in 1841: Peligot, cited in *Mellor's* vol. XII, 10 (1932). Occurs in pitchblende, which is chiefly U_3O_8, found in Colorado, Utah, Bear Lake in Canada, Zaire, Joachimstahl in Czechoslovakia, Cornwall. The uranium ore is digested with nitric acid to form uranyl nitrate, this is extracted with tributylphosphate + kerosene. The nitrate is calcined to UO_3. Uranium trioxide is reduced to UO_2 in furnaces supplied with hydrogen. The uranium dioxide is converted to UF_4 with anhydr HF. Pure uranium metal is obtained by reduction of UF_4 in a Thermit type of reaction carried out in metal bombs. Flowsheet and details: *Chem. Eng.* 62, no. 10, 113 (1955); Spedding *et al.*, U.S. pat. 2,852,364 (1958 to U.S.A.E.C.). *Reviews:* C. D. Harrington, A. R. Ruehle: *Uranium Production Technology* (Van Nostrand, Princeton, 1959); E. H. P. Cordfunke, *The Chemistry of Uranium* (Elsevier, New York, 1969) 250 pp; several authors in *Handb. Exp. Pharmakol.* 36, 3-306 (1973).

Silver-white, lustrous, radioactive metal; malleable and ductile. On vigorous shaking the metallic particles exhibit luminescence. A black powder when obtained by reduction. Three allotropic modifications: orthorhombic α-form to 667.7°; tetragonal, β-form from 667.7° to 774.8°; body-centered cubic, γ-form from 774.8° to mp. mp 1132.3°. d about 19.05. $T_{½}$ (^{238}U) 4.51 × 10^9 years. Spec heat (25°): 6.65 cal/g-atom/°C; heat of fusion: 2.9 kcal/g-atom. Ignites in oxygen at about 170°; the ignition temp depends on the state of subdivision of the metal. Burns in air at 150-175° with formation of U_3O_8. When finely powdered, slowly decomposes cold water, more quickly boiling water. Burns in fluorine to produce mainly a green volatile tetrafluoride; in chlorine at 180°, in bromine at 240°; forms an iodide at 260°. Attacked by dry hydrogen chloride at a dull red heat with formation of a stable chloride; combines with sulfur at 500°, with nitrogen at 1000°. Reacts with acids with liberation of hydrogen and formation of salts of tetravalent uranium. Not attacked by alkalies.

Caution: Uranium and its salts are highly toxic. Dermatitis, renal damage, acute necrotic arterial lesions, death may occur. Radiation hazard from inhalation of fine particles of approx 1μ. Insol particles in lung may be long-term carcinogenic hazard. *See* L. T. Fairhall, *Industrial Toxicology* (Hafner, New York, 2nd ed., 1969) pp 129-131.

USE: ^{235}U is used in atom and hydrogen bombs. ^{234}U and ^{235}U are used as nuclear fuel in power reactors.

9657. Uranium Dioxide. Uranous oxide; black uranium oxide. O_2U; mol wt 270.07. O 11.85%, U 88.15%. UO_2. Occurs in nature as the minerals *uraninite* or *pitchblende.* Review of uranium oxides: Keller in *Comprehensive Inorganic Chemistry* vol. 5, J. C. Bailar, Jr. *et al.*, Eds. (Pergamon Pre... Oxford, 1973) pp 224-233.

Brown to black powder, or cubic crystals. d 10.97. mp 2865°. When obtained by heating the urano-uranic oxide or the oxalate in hydrogen, it is brown or copper-red in color and is pyrophoric. Insol in water, dil acids; sol in concd acids.

USE: Nuclear fuel.

9658. Uranium Hexafluoride. F_6U; mol wt 352.07. F 32.38%, U 67.62%. UF_6. Prepd by the action of fluorine on uranium metal or carbide; on uranium pentachloride; on uranium tetrafluoride; on triuranium octaoxide in the presence of carbon. It appears that all uranium compds when heated with fluorine to a sufficiently high temp give UF_6: National Nuclear Energy Series VIII-5, J. J. Katz, E. Rabinowitch, *The Chemistry of Uranium,* part I (New York, 1951) pp 396-449.

Volatile, white monoclinic cryst solid. $d_4^{20.7}$ 5.09. d^{70} (liq) 3.595. mp 64.8°. Sublimes at 56.5°. Critical temp 230.2°, crit pressure 45.5 atm: Oliver *et al., J. Am. Chem. Soc.* 75, 2827 (1953). Reacts vigorously with water, forming mainly UO_2F_2 and HF. Sol in liq chlorine and bromine. Dissolves in nitrobenzene to give a dark red soln fuming in air. Sol in carbon tetrachloride, chloroform, and *sym*-tetrachloroethane, $Cl_2CHCHCl_2$, which forms the most stable soln, extensive reaction occurring only after several days at room temp. Sol in fluorocarbons (C_6F_{12} or C_7F_{16}) without reaction. Best handled in copper apparatus.

9659. Uranium Peroxide. O_4U; mol wt 302.03. O 21.19%, U 78.81%. UO_4. Exists as a di- or tetrahydrate. Prepd from $UO_2(NO_3)_2.6H_2O$: Watt *et al., J. Am. Chem. Soc.* 72, 3341 (1950); Boggs, El-Chehabi, *ibid.* 79, 4258 (1957); Sato, *J. Appl. Chem.* 13, 361 (1963).

Dihydrate, hygroscopic, pale yellow crystals. Dec slowly in the temp range 90-195° to form a different peroxide U_2O_7, an orange, hygroscopic solid which dec to UO_3 and oxygen on contact with water, and to uranyl salts and oxygen on contact with acids. At temps of 200° and above, the dec of $UO_4.2H_2O$ leads to UO_3 without the formation of U_2O_7.

9660. Uranium Tetrachloride. Cl_4U; mol wt 379.90. Cl 37.33%, U 62.67%. UCl_4. Prepd from uranium(VI) oxide dihydrate and hexachloropropene: Hermann, Suttle, *Inorg. Syn.* 5, 143 (1957).

Dark green octahedral crystals (tetragonal symmetry). Oxidizes in air and dec on contact with water. Should be stored in sealed ampuls. d_4^{25} 4.725. mp 590°, bp_{760} 791°. Heat of formation (solid) 250.9 kcal/mol at 0°. Freely sol in water (dec). Also sol in polar organic solvents. Insol in nonpolar solvents such as hydrocarbons and ethyl ether.

9661. Uranium Tetrafluoride. F_4U; mol wt 314.07. F 24.20%, U 75.80%. UF_4. Prepd from uranyl oxide and dichlorodifluoromethane: Booth *et al., J. Am. Chem. Soc.* 68, 1969 (1946); also prepd by the action of hydrogen fluoride on uranium dioxide or by addition of hydrofluoric acid to a U(IV) soln: Emeléus in *Fluorine Chemistry,* vol. I, J. H. Simons, Ed. (Academic Press, New York, 1950) p 59.

Monoclinic green crystals, mp > 1100°. Changes to U_3O_8 when heated in air. Insol in water. Sol in concd acids and alkalies with decompn.

Hemipentahydrate, orthorhombic green crystals, insol in water.

9662. Uranium Trichloride. Cl_3U; mol wt 344.44. Cl 30.88%, U 69.12%. UCl_3. Prepd by hydrogen reduction of uranium(IV) chloride: Suttle, *Inorg. Syn.* 5, 145 (1957).

Dark purple crystals. Less hygroscopic than uranium(IV) chloride. d 5.51. mp 842°. Heat of formation at 25° 212.0 kcal/mol. Freely sol in water, giving a purple soln, which evolves hydrogen and turns green because of oxidation to uranium(IV). Less sol in polar organic solvents than uranium(IV) chloride and insol in nonpolar solvents.

9663. Uranium Trioxide. Uranic oxide; red uranium oxide. O_3U; mol wt 286.07. O 16.78%, U 83.22%. UO_3. Review of uranium oxides: Keller in *Comprehensive Inorganic Chemistry* vol. 5, J. C. Bailar, Jr. *et al.*, Eds. (Pergamon Press, New York, 1973) pp 224-233.

Red or brownish-yellow powder. d 7.29. Insol in water; sol in acids.

9664. Uranyl Acetate. $C_4H_6O_6U$; mol wt 388.15. C 12.38%, H 1.56%, O 24.73%, U 61.33%. $UO_2(C_2H_3O_2)_2$.

Dihydrate, yellow, cryst powder; slight acetic odor. d 2.89. Sol in 10 parts of water, usually incompletely, due to the presence of basic salt. Freely sol in water acidulated with acetic acid, slightly in alcohol.

USE: As a reagent for pptn of sodium; in dry copying inks, and as activator in bacterial oxidation processes.

9665. Uranyl Chloride. Uranium dioxydichloride. Cl_2O_2U; mol wt 340.98. U 69.82%, O 9.38%, Cl 20.80%. UO_2Cl_2. Prepd by the reaction of O_2 with uranium(IV) chloride at 300-350°: Leary, Suttle, *Inorg. Syn.* 5, 148 (1957).

Bright yellow crystals. Orthorhombic system. Very hygroscopic. Appreciably volatile above 775°. Dec *in vacuo* above 450° yielding chlorine and UO_2 plus U_3O_8. Very freely sol in water. Forms cryst hydrates. Sol in polar organic solvents such as acetone and alcohol, but insol in less polar solvents such as benzene. Aq solns are unstable.

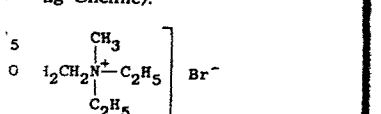
9666. Uranyl Nitrate. N_2O_8U; mol wt 394.04. N 7.11%, O 32.48%, U 60.41%. $UO_2(NO_3)_2$.

LD_{50} i.v. in mice: 1290±53 mg/kg, *Acta Pharmacol. Toxicol.* **18,** 141

e ıl n-valerate. Liquid. d_4^{20} 0.877. ısol in water; misc with alcohol,

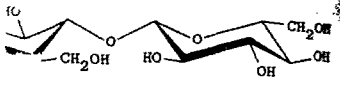
perfumery.

Bromide. *N,N-Diethyl-N-methyl-2-pentyl)oxy]ethanaminium bro-ric acid diethyl(3-hydroxyethyl)-ıe ester;* 2-phenyl-3-methylvaleric yl ester bromomethylate; 3-methyl-ethylaminoethyl ester methyl bro-yl 2-phenyl-3-methylvalerate hydroxyethyl)methylammonium bromide; Resitan; Epidosin; ıol wt 386.38. C 59.06%, H 8.35%, 8.28%. Prepn: Stühmer, Funke, ; **1,112,989** (all 1958 to Kali-ier. pat. **1,091,124** and U.S. pat. ag-Chemie).



+ ether or acetone, mp 100-101°. in alcohol. Practically insol in o storage; 0.6% ampuled solns ır at room temp.
nergic.

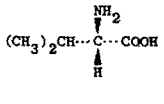
ntibiotic complex produced by *limoneus.* Consists of valida-t), B, C, D, E, and F. Isoln, chemical properties of validamycins A *ntibiot.* **24,** 107, 119 (1971). Isoln alidamycins C, D, E, F: Horii *et* nuf: Horii *et al.,* **Japan.** pat. **78,** 122657a (1973). Structure ameda, *Chem. Commun.* **1972,** Suami *et al., J. Antibiot.* **33,** 98 Iwasa *et al., ibid.* **24,** 114 (1971).



lidamycin A

$_{13}$. ***1,5,6-Trideoxy-3-o-β-D-ethyl)-1-[[4,5,6-trihydroxy-3-1-yl]amino]-D-chiro-inositol,*** ıless hydrophilic powder. Does ıs at 100°, dec at 135°. $[\alpha]_D^{24}$ +110° ıe), 92° (c = 1 in DMF). pKa 6.0. , DMSO; sparingly sol in etha-etate, diethyl ether.
.HCl. Cryst powder, mp 95° in water). Sol in water, alcohols; ther.

.C abbrev.); 2-aminoisovaleric acid; α-aminoisovaleric acid; acid. $C_5H_{11}NO_2$; mol wt 117.15. .96%, O 27.32%. An amino acid maintaining growth of rats. n nutrition, not synthesized by the human body. Occurs esp in fibrous proteins. Isoln by hydrolysis of fish proteins: Abderhalden, Landan, *Z. Physiol. Chem.* **71,** 458 (1911). Structure: Fischer, *Ber.* **39,** 2320 (1906). Prepared by the action of ammonia and hydrogen cyanide on isobutyraldehyde (Strecker synthesis) followed by hydrolysis: Lipp, *Ann.* **205,** 18 (1880); by the action of ammonia on α-bromoisovaleric acid: Clark, Fittig, *Ann.* **139,** 202 (1866); Schmidt, Sachtleben, *Ann.* **193,** 105 (1878); C. S. Marvel, *Org. Syn.* **coll. vol. III,** 848 (1955). Production through a hydantoin intermediate: Goldsmith, Tishler, U.S. pat. **2,480,644** (1949 to Merck & Co.); White, U.S. pats. **2,557,920; 2,700,054** (1951, 1955 to Dow).

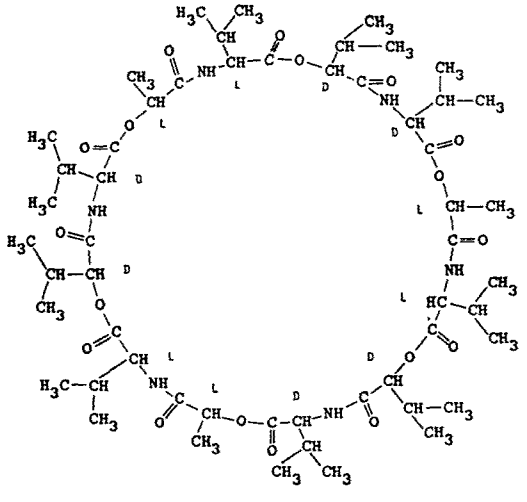


L-valine

L-Form: leaflets from water + alcohol, mp 315° (closed capillary). d 1.230. Sublimes. $[M]_D$ +33.1° (5*N* HCl); +72.6° (glacial acetic acid); $[\alpha]_D^{26}$ +13.9° (p = 0.9); $[\alpha]_D^{23}$ +22.9° (c = 0.8 in 20% HCl). Soly in water at 0°: 83.4 g/l; at 25°: 88.5 g/l; at 50°: 96.2 g/l; at 65°: 102.4 g/l. Almost insol in cold alcohol, ether, acetone.

DL-Form, sublimes without melting at ordinary speed of heating. Dec 298° (closed capillary, very rapid heating). pK_1 2.29; pK_2 9.72. One part dissolves in 11.7 parts of water at 15°, in 14.1 parts of water at 25°. Almost insol in cold alcohol and ether.

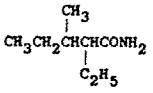
9714. Valinomycin. $C_{54}H_{90}N_6O_{18}$; mol wt 1111.36. C 58.36%, H 8.16%, N 7.56%, O 25.92%: Cyclododecadepsipeptide ionophore antibiotic produced by *Streptomyces fulvissimus* and related to the enniatins, *q.v.* Composed of 3 moles each of L-valine, D-α-hydroxyisovaleric acid, D-valine, and L-lactic acid linked alternately to form a 36-membered ring: Brockmann *et al., Ber.* **88,** 57 (1955); *Ann.* **603,** 216 (1957). Structural studies: Shemyakin *et al., Tetrahedron Letters* **1963,** 351; *Tetrahedron* **19,** 995 (1963). Proposed structure: Brockmann *et al., Naturwiss.* **50,** 689 (1963). Structure and synthesis: Shemyakin *et al., Tetrahedron Letters* **1963,** 1921. Solid phase synthesis: Gisin *et al., J. Am. Chem. Soc.* **91,** 2691 (1969); Losse, Klengel, *Tetrahedron* **27,** 1423 (1971). Biosynthesis: Smirnova *et al., C.A.* **73,** 97347m (1970); Ristow *et al., FEBS Letters* **42,** 127 (1974). Conformation: Ivanov *et al., Biochem. Biophys. Res. Commun.* **34,** 803 (1969); Onishi, Urry, *ibid.* **36,** 194 (1969); Duax *et al., Science* **176,** 911 (1972). *Review:* Y. A. Ovchinnokov, V. T. Ivanov, "The Cyclic Peptides: Structure, Conformation, and Function", in *The Proteins,* **vol. V,** H. Neurath, R. L. Hill, Eds. (Academic Press, New York, 3rd ed., 1982) pp 563-573.



Shiny rectangular platelets from dibutyl ether, mp 190° (hot stage). $[\alpha]_D^{20}$ +31.0° (c = 1.6 in benzene). Neutral reaction. Practically insol in water. Freely sol in petr ether, ether, benzene, chloroform, glacial acetic, butyl acetate, acetone. Active *in vitro* against *Mycobacterium tuberculosis.*

USE: Insecticide, nematocide, Patterson, Wright, U.S. pat. **3,520,973** (1970 to Am. Cyanamid).

9715. Valnoctamide. *2-Ethyl-3-methylpentanamide; 2-ethyl-3-methylvaleramide;* α-ethyl-β-methylvaleramide; valmethamide; McN-X-181; Axiquel; Nirvanil. $C_8H_{17}NO$; mol wt 143.22. C 67.09%, H 11.96%, N 9.78%, O 11.17%. Prepn by hydrolysis of 5-ethyl-5-(1-methylpropyl)barbituric acid: Freifelder *et al., J. Org. Chem.* **26,** 203 (1961).



Crystals, mp 113.5-114°.

THERAP CAT: Tranquilizer.

9716. Valproic Acid. *2-Propylpentanoic acid; 2-propylvaleric acid;* di-*n*-propylacetic acid; Mylproin. $C_8H_{16}O_2$; mol wt 144.21. C 66.62%, H 11.19%, O 22.19%. $(CH_3CH_2CH_2)_2CHCOOH$. Prepn: Oberreit, *Ber.* **29,** 1998 (1896); Keil, *Z. Physiol. Chem.* **282,** 137 (1947); Wiemann, Thuan, *Bull. Soc. Chim. France* **1958,** 199. Pharmacology: Meunier *et al., Therapie* **18,** 435 (1963); Lebreton *et al., ibid.* **19,** 451 (1964); Carraz *et al., ibid.* **20,** 419 (1965). Activity of deriv: Meunier, U.S. pat. **3,325,361** (1967 to Chemetron); *idem,* Fr. pat. CAM **244** (1969 to Lab. Berthier), *C.A.* **74,** 146380y (1971). Mechanism of action: B. Meldrum, *Brain Res. Bull.* **5,** Suppl. 2, 579 (1980). Review of clinical studies: Carraz *et al., Encephale* **54,** 458 (1965). Use in infantile spasms: D. S. Bachman, *Arch. Neurol.* **39,** 49 (1982). Comprehensive description: Z. L. Chang in *Analytical Profiles of Drug Substances* **vol. 8,** K. Florey, Ed. (Academic Press, New York, 1979) pp 529-556. For a discussion of potential teratogenicity of valproic acid, *see* R. W. Hurd *et al., Lancet* **1,** 181 (1983). *Review:* R. M. Pinder *et al., Drugs* **13,** 81-123 (1977); A. T. Dren *et al.,* in *Pharmacological and Biochemical Properties of Drug Substances* **vol. 2,** M. E. Goldberg, Ed. (Am. Pharm. Assoc., Washington, DC, 1979) pp 58-97.

Colorless liquid, bp_{14} 120-121°; bp_{20} 128-130°. $n_D^{24.5}$ 1.425. d_{25} 0.904. pKa 4.6. Very slightly sol in water. LD_{50} orally in rats: 670 mg/kg, Jenner *et al., Food Cosmet. Toxicol.* **2,** 327 (1964).

Sodium salt (1:1), $C_8H_{15}NaO_2$, ***sodium valproate, DPA sodium, Convulex, Depakene, Dépakine, Epilim, Ergenyl, Eurekene, Labazene, Leptilan, Orfiril.*** White crystals. pKa 4.8. Hygroscopic. LD_{50} orally in mice: 1700 mg/kg (U.S. pat. **3,325,361**).

Sodium salt (2:1), $C_{16}H_{31}NaO_4$, ***sodium hydrogen bis(2-propylpentanoate), Abbott-50711, Depakote.***

Magnesium salt, $C_{16}H_{30}MgO_4$, ***Logical.***

THERAP CAT: Anticonvulsant; antiepileptic.

9717. Valpromide. *2-Propylpentanamide; 2-propylvaleramide;* 2-propylpentamide; dipropylacetamide; Dépamide. $C_8H_{17}NO$; mol wt 143.23. C 67.08%, H 11.97%, N 9.78%, O 11.17%. $(CH_3CH_2CH_2)_2CHCONH_2$. Method of prepn: Fischer, Dilthey, *Ber.* **35,** 853 (1902); Tiffeneau, Deux, *Compt. Rend.* **212,** 105 (1941); Wiemann, Thuan, *Bull. Soc. Chim. France* **1958,** 199; Benoit-Guyod *et al., ibid.* **1965,** 1660. Patents: Meunier, U.S. pats. **3,301,754** and **3,325,361** (both 1967 to Chemetron). Pharmacology: Carraz *et al., Therapie* **19,** 468 (1964); Eymard, Werbenac, *ibid.* **27,** 11 (1972).

White, odorless and bitter crystalline powder, mp 125-126°. Practically insol in water.

THERAP CAT: Anticonvulsant.

9718. Vanadium. V; at. wt 50.9415; at. no. 23; valences 2, 3, 4, 5. Two naturally occurring isotopes: ^{51}V (99.75%); ^{50}V (0.25%); the latter is radioactive: $T_{1/2}$ 6 × 10^{15} years. Artificial isotopes: 46-49; 52-54. Abundance in earth's crust: 0.01% by wt. Widespread in nature; over 65 minerals known including ***patronite*** (polysulfide), ***vanadinite*** ($9PbO.3V_2O_5.PbCl_2$), ***roscoelite*** ($[2K_2O.2Al_2O_3.(Mg,Fe)O.3V_2O_5.$-

$10SiO_2.4H_2O$] and *carnotite* ($K_2O.2U_2O_3.V_2O_5.3H_2O$). [Carnotite is also an imporant source of uranium]. Discovered by Selström in 1830; prepd by Roscoe in 1869. Prepn: Prandtl, Manz, *Z. Anorg. Allgem. Chem.* **79**, 209 (1912); Marden, Rich, *J. Ind. Eng. Chem.* **19**, 786 (1927); McKechnie, Seybolt, *J. Electrochem. Soc.* **97**, 311 (1950); Gregory, Lilliendahl, *ibid.* **98**, 395 (1951); *Handbook of Preparative Inorganic Chemistry* **vol. 2**, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1965) pp 1252-1255. *Review:* Clark, "Vanadium" in *Comprehensive Inorganic Chemistry* **vol. 3**, J. C. Bailar, Jr. *et al.*, Eds. (Pergamon Press, Oxford, 1973) pp 491-551.

Light gray or white lustrous powder, fused hard lumps or body-centered cubic crystals; not tarnished in air and not appreciably affected by moisture at ordinary temp. mp 1917°. $d^{18.7}$ 6.11. Sp heat (20-100°) 0.12 cal/g/°C. Electrical resistivity 24.8 microhms/cm. Insol in water. Not attacked by hot or cold hydrochloric acid, by cold sulfuric acid. Reacts with hot sulfuric acid, hydrofluoric acid, nitric acid, aqua regia. Not attacked by bromine water, or by aq alkalies. The metal precipitates gold, silver and platinum from their salts; reduces mercuric salts to mercurous, ferric salts to ferrous.

USE: Manuf rust-resistant vanadium steel

9719. Vanadium Carbonyl. Vanadium hexacarbonyl. C_6O_6V; mol wt 219.00. C 32.90%, O 43.84%, V 23.26%. $V(CO)_6$. Prepn: Natta *et al.*, *C.A.* **54**, 16252 (1960); Ercoli *et al.*, *J. Am. Chem. Soc.* **82**, 2966 (1960); Hileman in *Preparative Inorganic Reactions* **1**, 107 (1964).

Blue-green pyrophoric crystals. Sensitive to air. Should be stored under nitrogen. Dec 60-70° in a nitrogen-filled tube.

9720. Vanadium Pentafluoride. F_5V; mol wt 145.95. V 34.91%, F 65.09%. VF_5. Prepd from vanadium tetrafluoride by thermal disproportionation at 650° in N_2 current according to the eq $2VF_4 \rightarrow VF_5 + VF_3$: Ruff, Lickfett, *Ber.* **44**, 2548 (1911); Kwasnik in *Handbook of Preparative Inorganic Chemistry*, **vol. 1**, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 253; from the elements: Trevorrow, *et al.*, *J. Am. Chem. Soc.* **79**, 5167 (1957); Clark, Emeleus, *J. Chem. Soc.* **1957**, 2119. Review of transition metal pentafluorides: Peacock, *Advan. Fluorine Chem.* **7**, 113-145 (1973).

Liquid. mp 19.5°; bp 47.9°. $d_4^{9.5}$ 2.502. Heat of vaporization 10.60 kcal/mole. Appreciable vapor pressure at room temp. Hydrolyzed by water, dil alkali. Soly in anhydrous HF: 3.3 moles/l. Freely sol in alcohol, chloroform, acetone, ligroin. Insol in carbon disulfide. Dec toluene and ether. Etches glass slowly at room temp; more rapidly in presence of moisture with formation of yellow color. May be stored in sealed vessels made from iron, nickel, copper, platinum.

9721. Vanadium Pentoxide. Vanadic anhydride. O_5V_2; mol wt 181.90. O 43.98%, V 56.02%. V_2O_5. Prepd by heating ammonium metavanadate, NH_4VO_3.

Yellow to rust-brown orthorhombic crystals; d 3.35; mp 690°. Loses oxygen reversibly in the region 700-1125°. One gram dissolves in about 125 ml water; sol in concd acids, forming red to yellow solns; sol in alkalies, forming vanadates; insol in alcohol. Its acid solutions are reduced by SO_2, Zn + HCl, and by evaporation with HCl.

Human Toxicity: Reported to be a respiratory irritant and to cause skin pallor, greenish-black tongue, chest pain, cough, dyspnea, palpitation, lung changes. When ingested, causes G.I. disturbances. May also cause a papular skin rash: Zenz *et al.*, *Arch. Environ. Health* **5**, 542 (1962); E. Browning, *Toxicity of Industrial Metals* (Appleton-Century-Crofts, New York, 2nd ed., 1969) pp 340-347.

USE: As catalyst in the oxidation of SO_2 to SO_3, alcohol to acetaldehyde, etc.; for the manuf of yellow glass; inhibiting ultraviolet light transmission in glass; depolarizer; as developer in photography; in form of ammonium vanadate as mordant in dyeing and printing fabrics and in manuf of aniline black.

9722. Vanadium Tetrafluoride. F_4V; mol wt 126.95. V 40.13%, F 59.87%. VF_4. Prepd from VCl_4 and HF or from the elements: Ruff, Lickfett, *Ber.* **44**, 2539 (1911); Cavell, Clark, *J. Chem. Soc.* **1962**, 2692; Kwasnik in *Handbook of Preparative Inorganic Chemistry*, **vol. 1**, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) pp 252-253.

Bright lime-green powder; very hygroscopic; hydrolyzes to form a brown powder and eventually a blue paste. d 3.15. Sublimes at 100-120° in a vacuum. Also disproportionates to VF_3 and VF_5 at 100-120° in a vacuum. Freely sol in water with blue color, in acetone deep green, in glacial acetic acid blue green. Sparingly sol in alc, chloroform, SO_2Cl_2. May be stored in sealed iron or copper vessels.

9723. Vanadium Trifluoride. F_3V; mol wt 107.95. V 47.20%, F 52.80%. VF_3. Prepd from VCl_3 and HF: Ruff, Lickfett, *Ber.* **44**, 2539 (1911); from VCl_2 and HF: Emeleus, Gutmann, *J. Chem. Soc.* **1949**, 2979; by thermal decompn in an inert atm of $(NH_4)_3VF_6$: Sturm, Sheridan, *Inorg. Syn.* **7**, 87 (1963).

Greenish-yellow powder. d 3.363. mp approx 1406°. Sublimes at bright red heat. Almost insol in water, alcohol, acetone, ethyl acetate, acetic anhydride, glacial acetic acid, toluene, carbon tetrachloride, chloroform, carbon disulfide. Black color with NaOH soln. Aq solns have strong reducing properties.

Trihydrate, dark green rhombohedral crystals, obtained by crystallizing vanadium trioxide dissolved in hydrofluoric acid, or by electrolytic reduction of a soln of vanadium pentoxide in aq HF. Loses one molecule of water at 100°. Dissolves in water to some extent, forming autocomplexes.

9724. Vanadium Trioxide. Vanadium sesquioxide; vanadic oxide. O_3V_2; mol wt 149.90. V 67.98%, O 32.02%. V_2O_3. Prepd by reduction of V_2O_5 with hydrogen or carbon monoxide.

Black powder. On exposure to air it is gradually converted into indigo-blue crystals of V_2O_4. d 4.87; mp 1940°. Insol in water; difficultly sol in acids.

USE: Catalyst, e.g., when making ethanol from ethylene.

9725. Vanadium Trisulfate. $O_{12}S_3V_2$; mol wt 390.10. O 49.22%, S 24.66%, V 26.12%. $V_2(SO_4)_3$. Prepd by the reduction of V_2O_5 in sulfuric acid with elemental sulfur: Auger, *Compt. Rend.* **173**, 306 (1921); Riveng, *Bull. Soc. Chim. France* **4**, 1697 (1937); Claunch, Jones, *Inorg. Syn.* **7**, 92 (1963).

Lemon-yellow powder. When heated in vacuum at or slightly below 410°, it dec into $VOSO_4$ and SO_2. Stable in dry air. Upon exposure to moist air for several weeks, a green hydrate forms. Very slowly sol in water at room temp, somewhat faster in boiling water; practically insol in concd sulfuric acid; sol in dil and concd nitric acid. Powerful reducing agent.

9726. Vanadium Trisulfide. Vanadium sesquisulfide. S_3V_2; mol wt 198.10. V 51.44%, S 48.56%. V_2S_3.

Greenish-black powder; d 4.7. Dec when heated. Insol in water, cold HCl, dil H_2SO_4; sol in hot HCl, hot dil H_2SO_4, HNO_3.

9727. Vanadyl Dichloride. Vanadium oxydichloride. Cl_2OV; mol wt 137.86. V 36.96%, O 11.61%, Cl 51.44%. $VOCl_2$. Usually contains some water. Prepd according to the eq $V_2O_5 + 3VCl_3 + VOCl_3 \rightarrow 6VOCl_2$: Funk, Weiss, *Z. Anorg. Allgem. Chem.* **295**, 327 (1958); Oppermann, *ibid.* **351**, 113 (1967).

Green, very deliquesc tabular crystals. d 2.88. Disproportionates at 384° to VOCl and $VOCl_3$. Slowly dec by water. Sol in abs alcohol, glacial acetic acid. *Keep tightly closed.*

USE: Has been used as mordant in printing fabrics.

9728. Vanadyl Sulfate. Vanadium oxysulfate. O_5SV; mol wt 163.00. O 49.08%, S 19.67%, V 31.25%. $VOSO_4$.

Dihydrate, blue, cryst powder. Sol in water.

USE: Dihydrate as mordant in dyeing and printing textiles; manuf colored glass; for blue and green glazes on pottery.

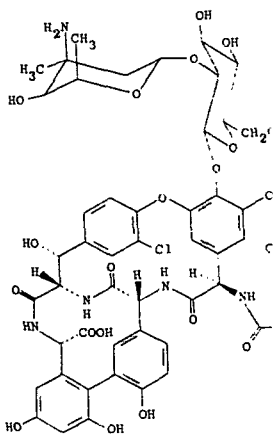
9729. Vanadyl Trichloride. Vanadium oxytrichloride. Cl_3OV; mol wt 173.32. Cl 61.37%, O 9.23%, V 29.40%. $VOCl_3$. Prepd by the action of dry Cl_2 on V_2O_3 or V_2O_5: Brown, Griffitts, *Inorg. Syn.* **1**, 106 (1939); **4**, 80 (1953); Oppermann, *Z. Anorg. Allgem. Chem.* **351**, 113 (1967).

Yellow liquid, emitting red fumes on exposure to moist air. d 1.84; bp 126-127°; solidif −77°. Dec in presence of moisture into vanadic acid and H of water is added, it becomes t because of formation of vanadi LD_{50} in rats: 0.14 g/kg orally. *Assoc. J.* **30**, 470 (1969).

9730. Vanaspati. Manuf by oils, peanut, cottonseed and ses. vated-Ni catalyst: Gupta, *In* (1961), *C.A.* **56**, 15895h (1962) free fatty acid (as oleic) 0.25%.

USE: Hydrogenated shortenin

9731. Vancomycin. Vancoci 1449.22. C 54.69%, H 5.22%, C Amphoteric glycopeptide antibi *Streptomyces orientalis* from I which inhibits bacterial mucope tion of complexes. Isoln: M. H *Ann.* **1955-56**, 606; U.S. pat. Structure studies: F. J. Mars (1965); W. D. Weringa *et al.*, J **1972**, 443; K. A. Smith *et al.*, *it* ture determination by x-ray ana *Nature* **271**, 223 (1978). Revise liamson, D. H. Williams, *J.* (1981). Complex formation: M *chem. J.* **123**, 789 (1971). Mode J. R. Kalman, *J. Am. Chem. Soc* clinical studies: J. W. Lightbow *apy* **vol. III**, R. J. Schitzer, F. I London, 1964) pp 278-289. G nolds, in *Antibiotics* **vol. 3**, J. W (Springer-Verlag, New York, 1



Shows marked instability at glycine buffers in pH range 3 Higgins *et al.*, *Antibiot. Ann.* 19 911].

Hydrochloride, white solid; 40). Soly in water: > 100 m methanol. Insol in the higher concns of urea increase the sol nium sulfate and sodium chl acidic solns. LD_{50} in mice: 48 5000 mg/kg s.c. and orally, R *Ann.* **1956-57**, 75.

THERAP CAT: Antibacterial.

9732. Vanilla. Cured, full- *planifolia* Andr., *Orchidaceae.* Reunion, Mauritius, Seychelle about 4% resin; vanillic acid, a

USE: In manuf of confecti products; perfumery; flavor fo

THERAP CAT: Pharmaceutic a

9733. Vanillic Acid. *4-Hy*

ane. Less sol in boiling methanol
ıyll.
O.. *physalien, physalin.* Fine yellow
er ne, mp 97°. Isoln from *Physalis*
r. l, 1489 (1930).

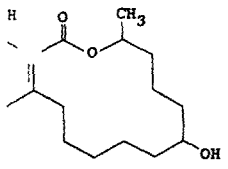
olamine; an alcohol-soluble protein
2.5-10% (dry basis) in corn *(Zea mays*
gr··ter part of zein has a mol wt of
t: lysine or tryptophan. Extracted
tc meal with dil isopropanol: Swal-
3.., 394 (1941). Improved method:
2,002,337 (1971 to Nutrilite Prod.),
1). *Review:* Mossé, *Ann. Physiol.*

l powder. d 1.226. When com-
a to 200° without visible signs of
q alcohols, the glycols, the ethyl ether
uryl alcohol, tetrahydrofurfuryl alco-
(pH 11.5 (or greater). Tends to
n soln and becomes insol. Insol in
:a y sol in acetone-water mixtures
60-80% acetone by volume. Insol in
methanol.
paper coatings, adhesives, substitutes
b rd, in solid color printing, films,
d ffs.

rystalline, hydrated alkali-aluminum
l formula $M_{2/n}O.Al_2O_3.ySiO_2.wH_2O$
:r··p IA or IIA element, *n* is the cat-
:r ter and *w* is the number of water
channels or interconnected voids
tc eations are mobile and capable of
ge. Zeolites occur naturally in sedi-
rocks, altered basalts, ores, clay de-
n olite minerals and a great number
e ailable commercially. Ref: Mil-
13 959 to Union Carbide). *Reviews:*
nderson, "Molecular Sieves" in Kirk-
of Chemical Technology **vol. 15** (Wiley-
k 3rd ed., 1981) pp 638-669; P. L.
n News **60,** 10 (Sept. 27, 1982); J.
ec 3, 1982). *Books: Molecular Sieve*
ances in Chemistry Series **101, 102**
1971) 526 pp, 459 pp; *Molecular*
iemistry Series **121** (A.C.S., Washing-
. Breck, *Zeolite Molecular Sieves*
or 1974) 771 pp; *Natural Zeolites:*
..se, L. B. Sand, F. A. Mumpton,
rd, 1978). Studies on fibrous zeolites
ital hazards: A. N. Rohl *et al., Sci-*
. Baris, *Arch. Environ. Health* **37,**

ves, filters, adsorbents, catalysts,
exchangers, dispersing agents, deter-

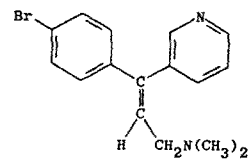
,7,8,9,10,11,12-Decahydro-7,14,16-
2-benzoxacyclotetradecin-1-one;
yl)-β-resorcylic acid μ-lactone;
P-1496; Ralgro; Ralabol; Ralone;
ol wt 322.41. C 67.05%, H 8.13%, O
z alenone, *q.v.*: Hodge *et al.,* **U.S.**
o ommercial Solvents). Metabolism
r. *Anim. Sci.* **34,** 176 (1972).



water mixtures yield two crystalline
h more soluble melts at 146-148°;
ol The less soluble melts at 178-180°;
$[\alpha]_D^{25} \sim +46°$ (methanol) with uv max (methanol): 218, 265 and 304 nm.

THERAP CAT (VET): Anabolic.

9924. Zimelidine. *3-(4-Bromophenyl)-N,N-dimethyl-3-(3-pyridinyl)-2-propen-1-amine; (Z)-*3-(4'-bromophenyl)-3-(3''-pyridyl)dimethylallylamine; zimeldine; *cis*-H 102/09. $C_{16}H_{17}BrN_2$; mol wt 317.24. C 60.58%, H 5.40%, Br 25.19%, N 8.83%. Antidepressant that inhibits membranal 5-hydroxytryptamine uptake. Prepn: P. B. Berntsson *et al.,* **S. Afr.** pat. **72 01,503** corresp to **U.S.** pat. **3,928,369** (1972, 1975 both to AB Hassle). X-ray crystallographic study: S. Abrahamsson *et al., Acta Chem. Scand.* **A30,** 609 (1976). *In vivo* study in rats and humans: S. B. Ross *et al., Life Sci.* **19,** 205 (1976). Pharmacokinetics: D. Brown, *Eur. J. Clin. Phamacol.* **17,** 111 (1980). Mode of action: K. Fuxe *et al., Neurosci. Letter* **13,** 307 (1979). Metabolism: J. Lundström *et al., Arzneimittel-Forsch.* **31,** 486 (1981). Clinical studies: A. Georgotas *et al., Am. J. Psychiatry* **139,** 1057 (1982); E. Syvalahti *et al., J. Int. Med. Res.* **10,** 250 (1982). Profile of antidepressant action: S. A. Montgomery *et al., Advan. Biochem. Psychopharmacol.* **32,** 35 (1982). Review of pharmacology and therapeutic efficacy: R. C. Heel *et al., Drugs* **24,** 169-206 (1982).



Dihydrochloride monohydrate, $C_{16}H_{19}BrCl_2N_2.H_2O$, *Normud, Zelmid.* Crystals, mp 193°.

THERAP CAT: Antidepressant.

9925. Zinc. Zn; at. wt 65.38; at. no. 30; valence 2. Group 2b element. Abundance in earth's crust: 0.02% by wt. Natural isotopes: 64 (48.89%); 66 (27.81%); 68 (18.57%); 67 (4.11%); 70 (0.62%); eight radioactive isotopes and two isomers. Occurs in smithsonite or zinc spar, sphalerite or zinc blende, zincite, willemite, *franklinite,* [(Zn,Mn,Fe)O.(Fe.Mn_2)O_3] or *gahnite* ($ZnAl_2O_4$). Has been known since very early times. Commercial forms: ingots; lumps; sheets; wire; shot; strips; sticks; granules; mossy; powder (dust). Prepn: Gowland, Bannister, *Metallurgy of Non-Ferrous Metals* (Griffin, London, 1930); *Zinc Production, Properties and Uses* (Zinc Development Association, London, 1968). *Reviews: Zinc,* C. H. Mathewson, Ed., A.C.S. Monograph Series no. **142** (Reinhold, New York, 1959) 721 pp; Schlechter, Thompson, "Zinc and Zinc Alloys" in Kirk-Othmer, *Encyclopedia of Chemical Technology,* **vol. 22** (Interscience, New York, 2nd ed., 1970) pp 555-603; Aylett, "Group IIB" in *Comprehensive Inorganic Chemistry,* **vol. 3,** J. C. Bailar, Jr. *et al.,* Eds. (Pergamon Press, Oxford, 1973) pp 187-328.

Bluish-white, lustrous metal; distorted hexagonal close-packed structure; stable in dry air; becomes covered with a white coating of basic carbonate on exposure to moist air. mp 419.5°; bp 908°; d^{25} 7.14; Cp (25°) 6.07 cal/mole deg. Mohs' hardness 2.5. When heated to 100-150° becomes malleable, at 210° becomes brittle and pulverizable. Burns in air with a bluish-green flame. Loses electrons in aqueous systems to form Zn^{2+} E° (aq) Zn/Zn^{2+} 0.763 V. Slowly attacked by H_2SO_4 or HCl; oxidizing agents or metal ions, e.g. Cu^{2+}, Ni^{2+}, Co^{2+}, accelerate the process. Reacts slowly with ammonia water and acetic acid; rapidly with HNO_3. Reacts with alkali hydroxides to form "*zincates*", ZnO_3^{2-}, which are actually hydroxo complexes such as $Zn(OH)_3^-$; $Zn(OH)_4^{2-}$, $[Zn(OH)_4(H_2O)_2]^{2-}$.

Human Toxicity: Inhalation of fumes may result in sweet taste, throat dryness, cough, weakness, generalized aching, chills, fever, nausea, vomiting. Zinc chloride fumes have caused injury to mucous membranes and skin irritation. Ingestion of sol salts may cause nausea, vomiting, purging. *See* E. Browning, *Toxicity of Industrial Metals* (Appleton-Century-Crofts, New York, 2nd ed., 1969) pp 348-355.

USE: Galvanizing sheet iron; as ingredient of alloys such as bronze, brass, Babbitt metal, German silver, and special alloys for die-casting; as a protective coating for other metals to prevent corrosion; for electrical apparatus, especially dry cell batteries, household utensils, castings, printing plates, building materials, railroad car linings, automotive equipment; as reducing agent in organic chemistry; for deoxidizing bronze; extracting gold by the cyanide process, purifying fats for soaps; bleaching bone glue; manuf sodium hydrosulfite; insulin zinc salts; as reagent in analytical chemistry, e.g., in the Marsh and Gutzeit test for arsenic; as a reducer in the determination of iron. It is a nutritional trace element.

9926. Zinc Acetate. $C_4H_6O_4Zn$; mol wt 183.46. C 26.18%, H 3.30%, O 34.88%, Zn 35.64%. $Zn(C_2H_3O_2)_2$. Prepn of anhydr salt from zinc nitrate and acetic anhydride: Späth, *Monatsh.* **33,** 235 (1912).

Dihydrate, crystallizes from dil acetic acid; faint, acetous odor; astringent taste; slightly efflorescent. d 1.735; mp 237°. One gram dissolves in 2.3 ml water, 1.6 ml boiling water, 30 ml alcohol, about 1 ml boiling alcohol. The aq soln is neutral or slightly acid to litmus; pH about 5-6. *Keep in well-closed containers. Incompat.* with zinc salts in general: Acacia, alkalies and their carbonates, oxalates, phosphates, sulfides, lime water, vegetable astringent decoctions and infusions. LD_{50} orally in rats: 2.46 g/kg, Smyth *et al., Am. Ind. Hyg. Assoc. J.* **30,** 470 (1969).

USE: Preserving wood; as mordant in dyeing; manuf glazes for painting on porcelain. As a reagent in testing for albumin, tannin, urobilin, phosphate, blood.

THERAP CAT: Styptic, astringent, emetic.

THERAP CAT (VET): Antiseptic, astringent, protective (topical). Has been used as an emetic.

9927. Zinc Bacitracin. *Bacitracin zinc complex*; bacitracin zinc salt; Baciferm. Contains about 7% Zn. Prepd by the action of zinc salts on bacitracin broth: Anker *et al., J. Bacteriol.* **55,** 249 (1948); Hodge, Lafferty as cited in **U.S.** pat. **2,803,584** (1957 to CSC). The potency is usually between 50 and 60 units/mg of bacitracin activity: Gross, *Drug Cosmet. Ind.* **75,** 612 (1954); Gross *et al., J. Am. Pharm. Assoc., Sci. Ed.* **45,** 447 (1956).

Creamy powder contg 1-4% H_2O. Less bitter than bacitracin. Soly in water at 25° = 0.23-0.45% (w/w). Solubilities determined by Weiss *et al., Antibiot. & Chemother.* **7,** 374 (1957) in mg/ml at about 28°: water 5.1; methanol 6.55; ethanol 2.0; isopropanol 0.16; ethyl acetate 1.3; chloroform 0.01; petr ether 0.025. More stable than bacitracin at room and elevated temps. Zinc bacitracin can be used in formulations requiring heat processing.

USE: In ointments, tablets, implantation pellets, suppositories, and troches, either alone or in combination with other antibiotics or therapeutic agents: Hodge, Lafferty, *loc. cit.*

THERAP CAT: Antibacterial.

THERAP CAT (VET): Antimicrobial.

9928. Zinc Benzoate. $C_{14}H_{10}O_4Zn$; mol wt 307.60. C 54.66%, H 3.28%, O 20.81%, Zn 21.25%. $Zn(C_7H_5O_2)_2$. Prepd from zinc sulfate and sodium benzoate: Davidson, *Pharm. J.* **91,** 686 (1913).

Powder. Sol in 62 parts water at 60°.

9929. Zinc Bromide. Br_2Zn; mol wt 225.21. Br 70.97%, Zn 29.03%. $ZnBr_2$. Usually contains at least 97% $ZnBr_2$, the remainder being chiefly water.

Very hygroscopic, granular powder; sharp, metallic taste. d 4.22; mp 394°; bp 697° with partial decompn. One gram dissolves in 0.25 ml water, 0.5 ml 90% alcohol; sol in ether, solns of alkali hydroxides. The aq soln is acid to litmus; pH about 4. *Keep tightly closed.*

USE: Making silver bromide collodion emulsions for photography; in the shielding of viewing windows for nuclear reactions.

9930. Zinc Caprylate. *Octanoic acid zinc salt.* $C_{16}H_{30}O_4Zn$; mol wt 351.79. C 54.63%, H 8.60%, O 18.19%, Zn 18.58%. $Zn(C_8H_{15}O_2)_2$. Prepd from ammonium caprylate and zinc sulfate: van Renesse, *Ann.* **171,** 380 (1874).

Lustrous scales from alc, mp 136°. Sparingly sol in boiling water; moderately sol in boiling alcohol. *Keep well closed.* Dec in moist atm giving off caprylic acid.

$C_{14}H_{10}O_6Zn$; mol wt 339.60. C 49.51%, H 2.97%, O 28.27%, Zn 19.25%. $Zn[C_6H_4(OH)COO]_2$. Prepd from sodium salicylate and zinc sulfate: Clark, Kao, *J. Am. Chem. Soc.* **70,** 2151 (1948).

Trihydrate, needles or cryst powder. Sol in water, alc. The aq soln is practically neutral to litmus.

THERAP CAT: Antiseptic; astringent.

9962. Zinc Selenate. O_4SeZn; mol wt 208.34. O 30.72%, Se 37.90%, Zn 31.38%. $ZnSeO_4$. Heptahydrate prepd by the action of selenic acid on zinc carbonate: Banks, *J. Chem. Soc.* **1934,** 1010.

Pentahydrate, triclinic crystals. Dec above 50°. d_4^{20} 2.591. Sol in water.

Hexahydrate, tetragonal crystals. d 2.325.

9963. Zinc Selenide. SeZn; mol wt 144.34. Se 54.70%, Zn 45.30%. ZnSe. Prepd by mixing a soln of a zinc salt and potassium selenide: Berzelius, cited in *Mellor's Comprehensive Treatise on Inorganic and Theoretical Chemistry* **10,** 776 (1930); by passing selenium vapor over zinc heated *in vacuo:* Moser, Doctor, *Z. Anorg. Chem.* **118,** 284 (1921); by passing H_2Se into a methanol soln of zinc acetate: Nitsche, U.S. pat. **2,805,917** (1957 to du Pont); from $ZnSe.N_2H_4$ (zinc selenide hydrazinate): Conn *et al.,* U.S. pat. **3,014,779** (1961 to Merck & Co.).

Yellow, cubic crystals. d_4^{15} 5.42. mp > 1100°. Dec in air. Insol in water. Dec in dil nitric acid.

USE: Commercial phosphor.

9964. Zinc Silicate. Zinc orthosilicate. O_4SiZn_2; mol wt 222.85. O 28.72%, Si 12.60%, Zn 58.68%. Zn_2SiO_4. Occurs in nature as the mineral *willemite.* Prepd by heating the proper amounts of ZnO and SiO_2 at about 1200°.

White powder, insol in water or dil acids.

USE: In television screens.

9965. Zinc Stearate. *Octadecanoic acid zinc salt.* $C_{36}H_{70}O_4Zn$; mol wt 632.33. C 68.38%, H 11.16%, O 10.12%, Zn 10.34%. $Zn(C_{18}H_{35}O_2)_2$. Usually occurs as a mixture of the zinc salts of stearic and palmitic acids, and usually with some excess of zinc oxide. Contains 13.5-15% ZnO. Prepd from stearic acid and zinc chloride: Vold, Hattiangdi, *Ind. Eng. Chem.* **41,** 2311 (1949).

Fine, soft, bulky powder; slight characteristic odor; neutral reaction. Repels water. mp about 120°. Insol in water, alcohol, ether; sol in benzene; dec by dil acids.

USE: In tablet manuf; in cosmetic and pharmaceutical powders and ointments; as a flatting and sanding agent in lacquers; as a drying lubricant and dusting agent for rubber; as a plastic mold releasing agent; as a waterproofing agent for concrete, rock wool, paper, textiles.

THERAP CAT: Dusting powder.

THERAP CAT (VET): Antiseptic, astringent, protective (topical).

9966. Zinc Sulfate. White vitriol; zinc vitriol; Medizinc; Optraex; Solvezink; Zincate; Zincomed. O_4SZn; mol wt 161.44. O 39.64%, S 19.86%, Zn 40.50%. $ZnSO_4$. Effects of oral zinc sulfate in acne treatment: G. Michaelsson *et al., Arch. Dermatol.* **113,** 31 (1977).

Monohydrate, *dried zinc sulfate.* Powder or granules. Loses H_2O above 238°. Sol in water; practically insol in alcohol.

Heptahydrate, *Op-Thal-Zin, Verazinc.* Odorless crystals or granules or powder; astringent taste. Efflorescent in dry air. d 1.97; mp 100°. At 280° loses all H_2O; dec above 500°. One gram dissolves in 0.6 ml water, 2.5 ml glycerol; insol in alcohol. The aq soln is acid to litmus; pH about 4.5. *Keep well closed.*

Note: The monohydrate does not cake as the heptahydrate does, and hence is more convenient for use during the warm season and in warm climates.

USE: As mordant in calico-printing; preserving wood and skins; with hypochlorite for bleaching paper; manuf lithopone and other zinc salts; clarifying glue; electrodepositing Zn; also as reagent in analytical chemistry. *Caution:* Irritating to skin, mucous membranes.

THERAP CAT: Astringent (ophthalmic).

THERAP CAT (VET): Astringent. Has been used as an emetic.

9967. Zinc Sulfide. Zinc Blende. SZn; mol wt 97.45. S 32.91%, Zn 67.09%. ZnS. Occurs in nature as the minerals *wurtzite* (hexagonal, d 4.087) and *sphalerite* (cubic, d 4.102). Precipitated zinc sulfide of commerce usually contains 15-20% water of hydration. The dried precipitate may have been heated to 725° in the absence of air to obtain substantial conversion to wurtzite, the form peferred by the pigment industry.

White to grayish-white or yellowish powder. When contg water, it slowly oxidizes in air to sulfate. Insol in water, alkalies; sol in dil mineral acids.

USE: Pigment for paints, oilcloths, linoleum, leather, dental rubber, etc., especially in the form of lithopone; mixed with ZnO as "mineral white." Anhydr zinc sulfide is used in x-ray screens and with a trace of a radium or mesothorium salt in luminous dials of watches, etc.; also television screens.

9968. Zinc Tannate. Sal barnit. Compd of ZnO and tannin in variable proportions. Prepd from an aq tannin soln and zinc hydroxide in excess ammonium hydroxide plus an ammonium salt: Ger. pat. **479,229** (1926 to Lab. Reumella Adolf Boas), *C.A.* **23,** 4778[1] (1929).

Yellowish, odorless powder. Practically insol in water, alcohol; sol in dil acids.

THERAP CAT: Astringent; antiseptic.

9969. Zinc Tartrate. $C_4H_4O_6Zn$; mol wt 213.44. C 22.51%, H 1.89%, O 44.97%, Zn 30.63%. $ZnC_4H_4O_6$. Prepd from potassium tartrate and zinc chloride: Cantoni, Zachoder, *Bull. Soc. Chim.* [3] **33,** 747 (1905).

Dihydrate, cryst powder. Soly in water: Cantoni, Zachoder, *loc. cit.*

9970. Zinc Telluride. TeZn; mol wt 192.99. Te 66.12%, Zn 33.88%. ZnTe. Prepd by fusing Zn and Te: Braithwaite, *Proc. Phys. Soc. (London)* **64B,** 274 (1951); Bube, *Proc. IRE* **43,** 1836 (1955), *see also* Dennis, Anderson, *J. Am. Chem. Soc.* **36,** 882 (1914). From zinc oxide and powdered tellurium in aq alkaline medium: Montignie, *Bull. Soc. Chim. (France)* **1947,** 750.

Gray or brownish-red powder. Ruby-red crystals (cubic system) by sublimation. Stable in dry air. d_4^{15} 6.34. mp 1239°. Forms a monohydrate. Prolonged contact with water or dil HCl yields H_2 and H_2Te.

USE: In semiconductor research, as photoconductor.

9971. Zinc Thiocyanate. Zinc sulfocyanate. $C_2N_2S_2Zn$; mol wt 181.55. C 13.23%, N 15.43%, S 35.32%, Zn 36.02%. $Zn(SCN)_2$.

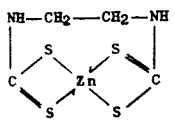
White, deliquesc crystals. Sol in water, alcohol. The aq soln is only slightly acid to litmus. *Keep well closed and protected from light.*

USE: To assist in textile dyeing.

9972. Zinc Valerate. *Pentanoic acid zinc salt.* $C_{10}H_{18}O_4Zn$; mol wt 267.62. C 44.88%, H 6.78%, Zn 24.43%, O 23.91%. $Zn(C_5H_9O_2)_2$. The article of commerce is usually basic. Prepd from valeric acid and zinc hydrate: Lieben, Rossi, *Ann.* **159,** 58 (1871).

Dihydrate, lustrous scales or powder; valerian odor; sweetish taste. Gradually dec on exposure to air. One gram dissolves in 70 ml water or in 22 ml alcohol when free from basic salt; dec by acid. *Keep tightly closed and in cool place.*

9973. Zineb. *[[1,2-Ethanediylbis[carbamodithioato]]-(2−)]zinc; [ethylenebis(dithiocarbamato)]zinc;* zinc ethylenebis(dithiocarbamate); ethylenebis(dithiocarbamic acid) zinc salt; ENT 14874; Parzate; Lonacol; Dithane Z-78. $C_4H_6N_2S_4Zn$; mol wt 275.75. C 17.42%, H 2.19%, N 10.16%, S 46.51%, Zn 23.71%. Prepd from a zinc salt and disodium ethylenebis(dithiocarbamate): Luginbuhl, U.S. pat. **2,690,448** (1954 to du Pont).

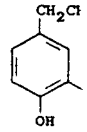


Powder or crystals from chloroform + alcohol. Practically insol in water. The powder spreads easily on water, also forms aq suspensions. Sol in carbon disulfide, pyridine.

LD_{50} orally in rats: > 5000 ... *Appl. Pharmacol.* **14,** 515 (19...

USE: Fungicide. *Caution:* ... membranes has been reported

9974. Zingerone. *4-(4-H... butanone;* (4-hydroxy-3-meth... tone; vanillylacetone; zingher... mol wt 194.22. C 68.02%, H ... from ginger root or prepd fr... lowed by catalytic hydrogena... **111,** 769 (1917); *idem,* U.S. pa... (1919); Cotton, U.S. pat. 2,... Prod.); K. Banno, T. Mukai... **49,** 1453 (1976).



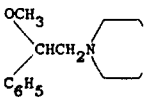
Crystals from acetone, petr... 40-41°. bp_{14} 187-188°. Sparin... in ether, dil alkalies.

9975. Zinostatin. Neoca... NCS; NSC 69856; Neocarzino... antibiotic consisting of 2 com... 10,700 containing 109 amino a... labile non-protein chromoph... biological activity of NCS. Is... *Streptomyces carcinostaticus* va... *Antibiot.* **18A,** 68 (1965). Char... *Ibid.* **19A,** 253 (1966). Prodn... **3,334,022** (1967 to Empire Co... Meienhofer *et al., Science* **178,** ... structural studies: *eidem, Pr...* II, S. Lande, Ed. (Gordon and ... 295-306. Spectral characteri... chromophore: M. A. Napier ... *Commun.* **89,** 635 (1979). Pa... phore: G. Albers-Schönberg ... Roles of chromophore and apo... L. S. Kappen *et al., Proc. N...* (1980). Molecular basis of a... *Mol. Biol. Biochem. Biophys.* ... distribution, excretion: K. T... *biot.* **28,** 64 (1975). Review o... man *et al.,* in *Advances in E...* Weber, Ed. (Pergamon Press, ...

White powder, mp 260° (de... ($E1_{cm}^{1\%}$ 15). Isoelectric pt: pH ... 11 (1977)]. Sol in water; insol ... *See* M. Kohno *et al., Japan.* ... stability of aq solns. LD_{50} ir... 0.96 i.v., K. Toriyama *et al.,* ...

THERAP CAT: Antineoplastic

9976. Zipeprol. *4-(2-Met... oxyphenylmethyl)-1-piperazin...* yl)-4-(β-methoxyphenethyl)-1... droxy-3-methoxy-3-phenylpr... ylethyl)piperazine; 1-(2-meth... droxy-3-methoxy-3-phenylpro... mol wt 384.52. C 71.84%, H ... Prepd from 1-(2-methoxy-2... 3-methoxy-3-phenylpropylen... Ger. pat. **2,109,366** corresp t... 1973 both to Mauvernay). Ph... *Arzneimittel-Forsch.* **26,** 523 (... 848.



Occurs in nature as the minerals
) and *sphalerite* (cubic, d 4.102).
commerce usually contains 15-
dried precipitate may have
ıce of air to obtain substan-
orm peferred by the pigment

yellowish powder. When contg
o sulfate. Insol in water, al-
d
oths, linoleum, leather, den-
n the form of lithopone; mixed
Anhydr zinc sulfide is used in
of a radium or mesothorium
, etc.; also television screens.

arnit. Compd of ZnO and
ons. Prepd from an aq tannin
excess ammonium hydroxide plus
479,229 (1926 to Lab. Reu-
78¹ (1929).
Practically insol in water,

antiseptic.

O_4Zn; mol wt 213.44. C
30.63%. $ZnC_4H_4O_6$. Prepd
ıc chloride: Cantoni, Zacho-
, 747 (1905).
Soly in water: Cantoni, Zacho-

; mol wt 192.99. Te 66.12%,
sing Zn and Te: Braithwaite,
4B, 274 (1951); Bube, *Proc. IRE*
Dennis, Anderson, *J. Am. Chem.*
: oxide and powdered telluri-
Montignie, *Bull. Soc. Chim.*

owder. Ruby-red crystals (cubic
Stable in dry air. d_4^{15} 6.34. mp
Prolonged contact with wa-
I_2Te.
rch, as photoconductor.

Zinc sulfocyanate. $C_2N_2S_2Zn$;
N 15.43%, S 35.32%, Zn 36.02%.

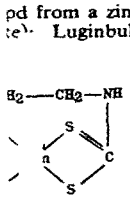
ol in water, alcohol. The aq
itmus. *Keep well closed and*

dyeing.

anoic acid zinc salt. $C_{16}H_{18}$-
.88%, H 6.78%, Zn 24.43%,
article of commerce is usually
acid and zinc hydrate: Lieben,

or powder; valerian odor;
on exposure to air. One gram
22 ml alcohol when free from
ep tightly closed and in cool place.

thanediylbis[carbamodithioato]]-
h arbamato)]zinc; zinc ethylene-
bis(dithiocarbamic acid) zinc
acol; Dithane Z-78. $C_4H_6N_2$-
17.42%, H 2.19%, N 10.16%, S
pd from a zinc salt and disodium
Luginbuhl, U.S. pat. 2,690,-

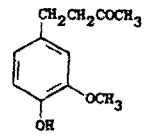


n chloroform + alcohol. Practi-
wder spreads easily on water,
ol in carbon disulfide, pyridine.

LD_{50} orally in rats: > 5000 mg/kg, T. B. Gaines, *Toxicol. Appl. Pharmacol.* **14,** 515 (1969).

USE: Fungicide. *Caution:* Irritation of skin and mucous membranes has been reported.

9974. Zingerone. *4-(4-Hydroxy-3-methoxyphenyl)-2-butanone;* (4-hydroxy-3-methoxyphenyl)ethyl methyl ketone; vanillylacetone; zingherone; zingiberone. $C_{11}H_{14}O_3$; mol wt 194.22. C 68.02%, H 7.27%, O 24.71%. Isolated from ginger root or prepd from vanillin and acetone followed by catalytic hydrogenation: Nomura, *J. Chem. Soc.* **111,** 769 (1917); *idem,* U.S. pats. **1,263,796** (1918); **1,306,710** (1919); Cotton, U.S. pat. **2,381,210** (1945 to Penn. Coal Prod.); K. Banno, T. Mukaiyama, *Bull. Chem. Soc. Japan* **49,** 1453 (1976).



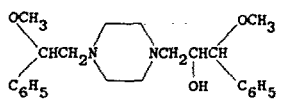
Crystals from acetone, petr ether, ether + petr ether, mp 40-41°. bp_{14} 187-188°. Sparingly sol in water, petr ether; sol in ether, dil alkalies.

9975. Zinostatin. Neocarcinostatin; neocarzinostatin; NCS; NSC 69856; Neocarzinostatin K. An antitumor acidic antibiotic consisting of 2 components: a protein of mol wt 10,700 containing 109 amino acid residues of 18 kinds and a labile non-protein chromophore which possesses the full biological activity of NCS. Isoln from the culture filtrate of *Streptomyces carcinostaticus* var. F-41: N. Ishida *et al., J. Antibiot.* **18A,** 68 (1965). Characterization: H. Maeda *et al., ibid.* **19A,** 253 (1966). Prodn: N. Ishida *et al.,* U.S. pat. **3,334,022** (1967 to Empire Corp.). Amino acid sequence: J. Meienhofer *et al., Science* **178,** 875 (1972). Review of protein structural studies: *eidem, Progress in Peptide Research* **vol. II,** S. Lande, Ed. (Gordon and Breach, New York, 1972) pp 295-306. Spectral characterization and separation of the chromophore: M. A. Napier *et al., Biochem. Biophys. Res. Commun.* **89,** 635 (1979). Partial structure of the chromophore: G. Albers-Schönberg *et al., ibid.* **95,** 1351 (1980). Roles of chromophore and apo-protein in biological activity: L. S. Kappen *et al., Proc. Nat. Acad. Sci. USA* **77,** 1970 (1980). Molecular basis of action: I. H. Goldberg *et al., Mol. Biol. Biochem. Biophys.* **32,** 308 (1980). Absorption, distribution, excretion: K. Toriyama *et al., Japan. J. Antibiot.* **28,** 64 (1975). Review of pharmacology: T. A. Beerman *et al.,* in *Advances in Enzyme Regulation* **vol. 14,** G. Weber, Ed. (Pergamon Press, New York, 1976) pp 207-228.

White powder, mp 260° (dec). uv max (water): 278 nm ($E_{1cm}^{1\%}$ 15). Isoelectric pt: pH 3.26 [*Japan. Med. Gaz.* **14**(3), 11 (1977)]. Sol in water; insol in most common org solvents. *See* M. Kohno *et al., Japan. J. Antibiot.* **27,** 707 (1974) for stability of aq solns. LD_{50} in mice (mg/kg): 1050 orally, 0.96 i.v., ᵛ Toriyama *et al., loc. cit.*

TH.. ᵘP CAT: Antineoplastic.

9976. Zipeprol. *4-(2-Methoxy-2-phenylethyl)-α-(methoxyphenylmethyl)-1-piperazineethanol;* α-(α-methoxybenzyl)-4-(β-methoxyphenethyl)-1-piperazineethanol; 1-(2-hydroxy-3-methoxy-3-phenylpropyl)-4-(2-methoxy-2-phenylethyl)piperazine; 1-(2-methoxy-2-phenylethyl)-4-(2-hydroxy-3-methoxy-3-phenylpropyl)piperazine. $C_{23}H_{32}N_2O_3$; mol wt 384.52. C 71.84%, H 8.39%, N 7.28%, O 12.48%. Prepd from 1-(2-methoxy-2-phenylethyl)piperazine and 3-methoxy-3-phenylpropylene oxide: Mauvernay *et al.,* Ger. pat. **2,109,366** corresp to U.S. pat. **3,718,650** (1971, 1973 both to Mauvernay). Pharmacology: G. Rispat *et al., Arzneimittel-Forsch.* **26,** 523 (1976); D. Cosnier *et al., ibid.* **848.**

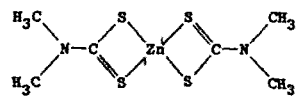


Crystals from abs ethanol, mp 83°.

Dihydrochloride, $C_{23}H_{34}Cl_2N_2O_3$, *3024 CERM, Respilene, Zitoxil.* Crystals from abs ethanol, mp 231°. Very stable in aq soln. LD_{50} orally in mice: 301 mg/kg, G. Rispat *et al., loc. cit.*

THERAP CAT: Antitussive.

9977. Ziram. *Bis(dimethylcarbamodithioato-S,S')zinc; bis(dimethyldithiocarbamato)zinc;* zinc dimethyldithiocarbamate; dimethyldithiocarbamic acid zinc salt; zinc bis(dimethylthiocarbamoyl) disulfide; methyl cymate; Methasan; Zimate; Zirberk; Karbam White; Corozate; Fuclasin; Fuklasin; Zerlate. $C_6H_{12}N_2S_4Zn$; mol wt 305.82. C 23.56%, H 3.96%, N 9.16%, S 41.94%, Zn 21.38%. Prepd from zinc oxide, dimethylamine, and carbon disulfide: Olin, Deger, U.S. pat. **2,492,314** (1949 to Sharples Chemicals). Crystal structure: Klug, *Acta Cryst.* **21,** 536 (1966).



Crystals from hot chloroform + alcohol, mp 250°. *Can form a flammable dust.* d_4^{25} 1.66. Practically insol in water. Soly per 100 ml of solvent at 25°: < 0.2 g, alcohol; < 0.5 g, acetone; < 0.5 g, benzene; < 0.2 g, carbon tetrachloride, more sol in chloroform; < 0.2 g, ether; 0.5 g, naphtha. Sol in dil caustic solns. LD_{50} orally in rats: 1.4 g/kg, Hodge *et al., J. Pharmacol. Exp. Ther.* **118,** 174 (1956).

USE: Rubber vulcanization accelerator; agricultural fungicide. *Caution:* Irritant to skin and mucous membranes.

9978. Zirconium. Zr; at. wt 91.22; at. no. 40; valence 4; also 3. Five naturally occurring isotopes: 90 (51.46%); 91 (11.23%); 92 (17.11%); 94 (17.40%); 96 (2.80%); artificial radioactive isotopes: 81-89, 93, 95, 97-99. Occurrence in earth's crust: 0.023%. Occurs in the minerals zircon, malacon, baddeleyite, zirkelite, eudialyte; frequently found in the rare-earth minerals; in monazite sand. Discovered by Klaproth in 1789; prepd by Berzelius in 1824. Prepn: Fast, *Z. Anorg. Chem.* **239,** 145 (1938); purification of zirconium by ion exchange columns: Ayres, *J. Am. Chem. Soc.* **69,** 1879 (1947). Sepn of zirconium and hafnium: Fischer *et al., Angew. Chem. Int. Ed.* **5,** 15 (1966). Reviews of zirconium and its compds: W. B. Blumenthal, *The Chemical Behavior of Zirconium* (Van Nostrand, Princeton, 1958); *Gmelin's Handb. Anorg. Chem., Zirconium* (8th ed.) **42,** (1958) 448 pp; Larsen, "Zirconium and Hafnium Chemistry" in *Advan. Inorg. Chem. Radiochem.* **13,** 1-333 (1970); Bradley, Thornton, "Zirconium and Hafnium" in *Comprehensive Inorganic Chemistry,* **vol. 3,** J. C. Bailar, Jr. *et al.,* Eds. (Pergamon Press, Oxford, 1973) pp 419-490.

Bluish-black, amorphous powder or grayish-white lustrous metal (platelets or flakes) of hexagonal lattice below 865°, body-centered cubic above 865°, mp 1857°; bp 3577°. d 6.5. Brinnell hardness: 85. Can absorb up to 10 atoms per cent of oxygen or nitrogen. Reacts with hydrofluoric acid, aqua regia, hot phosphoric acid. Not attacked by cold, very slightly attacked by hot, concd sulfuric or hydrochloric acid; not attacked by nitric acid. Attacked by fused potassium hydroxide or nitrate. On prolonged heating the compact form combines with oxygen, nitrogen, carbon, and the halogens. The powder form has a very low ignition temp and is very explosive when mixed with oxidizing agents.

Human Toxicity: Zirconium and its salts generally have low systemic toxicity. A granulomatous disease of the skin, particularly in the axilla, has been reported in users of a deodorant contg sodium zirconium lactate: *see* E. Browning, *Toxicity of Industrial Metals* (Appleton-Century-Crofts, New York, 2nd ed., 1969) pp 356-360. Consult latest Government regulations on use in aerosol antiperspirants.

USE: Pure zirconium (hafnium-free) is a valuable structural material for atomic reactors because of its low nuclear cross-section and high corrosion and heat resistance. Because of hafnium's high neutron absorption characteristics, it must be removed from zirconium which is to be used in nuclear reactors; removal unnecessary for other commercial purposes. As an ingredient of priming or explosive mixtures;

flashlight powders; as deoxidizer in metallurgy; as "getter" in vacuum tubes; in constructing rayon spinnerets in lamp filaments, flash bulbs.

9979. Zirconium Chloride. Zirconium tetrachloride. Cl_4Zr; mol wt 233.05. Cl 60.86%, Zr 39.14%. $ZrCl_4$. Lewis acid. In large-scale prepns zirconium oxide is converted to the carbide, which is chlorinated to yield the tetrachloride: Kroll *et al., J. Electrochem. Soc.* **94,** 1 (1948). Process not easily adaptable to lab use. Lab prepn based on the equation $ZrO_2 + 2CCl_4 \rightarrow ZrCl_4 + 2COCl_2$: Hummers *et al., Inorg. Syn.* **4,** 121 (1953).

Lustrous monoclinic crystals: Krebs, *Angew. Chem. Int. Ed.* **8,** 146 (1969); *idem, Z. Anorg. Allgem. Chem.* **378,** 263 (1970). Tetrahedral symmetry in gas phase with the Zr-Cl distance of 2.33 Å. Extremely hygroscopic, forms HCl vapor and gives off fumes in moist air. d 2.803. Sublimes at 331°. mp 437° under its own pressure which is about 25 atm at this temp. Decomposed by water to form $ZrOCl_2$ and HCl; sol in alcohol, ether. LD_{50} in mice, rats: 655, 1688 mg/kg orally, *Toxic Substances List,* H. E. Christensen, Ed. (1972) p. 547.

USE: Friedel-Crafts catalyst. Component of Ziegler-type catalysts in the condensation of ethylene. Starting material in the synthesis of a number of organic derivs of zirconium, such as alkoxides and zircocene. The alkoxides have been shown to be of value in the curing of silicone plastic films. The alkoxyzirconium carboxylates are said to be useful in the water-repellent treatment of textiles and other fibrous materials. *Review:* Blumenthal, *J. Chem. Ed.* **39,** 604-610 (1962).

9980. Zirconium Fluoride. Zirconium tetrafluoride. F_4Zr; mol wt 167.22. Zr 54.55%, F 45.45%. ZrF_4. Prepd by thermal decompn of $(NH_4)_2ZrF_6$: v. Hevesy, Dullenkamp, *Z. Anorg. Allgem. Chem.* **221,** 161 (1934); according to the equation $ZrCl_4 + 4HF \rightarrow ZrF_4 + 4HCl$: Wolter, *Chemiker-Ztg.* **51,** 607 (1908); from zirconium oxide and fluorine: Haendler *et al., J. Am. Chem. Soc.* **76,** 2177 (1954).

Strongly refractive, crystalline mass (monoclinic system). d^{16} 4.6. Sublimes above 600°. Solubility in water (20°): 1.32 g/100 ml. Does not react with water; forms stable trihydrate. Freely soluble in hydrofluoric acid. LD_{50} in mice: 98 mg/kg orally: *Toxic Substances List,* H. E. Christensen, Ed. (1972) p 547.

9981. Zirconium Hydride. Ideal composition: ZrH_2. Prepd by the reduction of zirconium oxide with calcium hydride in the presence of hydrogen above 600°: Alexander, U.S. pat. 2,427,339 (1947 to Metal Hydride).

Gray-black metallic powder. Stable, no reaction with water.

USE: Powerful reducing agent in acid solution or at high temps; hydrogenation catalyst; in the vacuum tube industry and powder metallurgy.

9982. Zirconium Hydroxide. H_4O_4Zr; mol wt 159.25. H 2.53%, O 40.19%, Zr 57.28%. $Zr(OH)_4$. Proposed structures of freshly pptd and aged compds, cyclic tetramers: Zaitsev, *Russ. J. Inorg. Chem.* **11,** 900 (1966).

White, bulky, amorphous powder; d 3.25. Insol in water; sol in mineral acids when freshly pptd; less sol when aged. It colors turmeric paper brown.

USE: In the pigment, dye, and glass industries.

9983. Zirconium Iodide. Zirconium tetraiodide. I_4Zr; mol wt 598.86. I 84.77%, Zr 15.23%. ZrI_4. Prepd from the elements at a furnace temp of 450°: Eberly, *Inorg. Syn.* **7,** 52 (1963).

Orange-colored, crystalline solid. Sublimes at 431°. mp 499° (elevated pressure). Fumes heavily in air. Dissolves in water with the liberation of steam. Heat of formation: 90 kcal/mol at 25°. Magnetic susceptibility -0.238×10^{-6} c.g.s. electromagnetic units.

9984. Zirconium Nitrate. $N_4O_{12}Zr$; mol wt 339.25. N 16.52%, O 56.59%, Zr 26.89%. $Zr(NO_3)_4$. Prepn according to the equation $ZrCl_4 + 4N_2O_5 \rightarrow Zr(NO_3)_4 + 4NO_2Cl$: Field, Hardy, *Proc. Chem. Soc.* **1962,** 76. Pentahydrate obtained from strong nitric acid. The zirconium nitrate of commerce is usually somewhat basic.

Pentahydrate, white, very hygroscopic crystals or white pieces or scales. Very sol in water; sol in alcohol. The aq soln is acid to litmus. *Keep tightly closed.*

9985. Zirconium Oxide. Zirconia; zirconium dioxide; zirconic anhydride. O_2Zr; mol wt 123.22. Zr 74.03%, O 25.97%. ZrO_2. Occurs in nature as the mineral *baddeleyite.* Prepn: Clark, Reynolds, *Ind. Eng. Chem.* **29,** 711 (1937); Henderson, Higbie, *J. Am. Chem. Soc.* **76,** 5878 (1954).

White, heavy, amorphous, odorless, tasteless powder or monoclinic crystals. Also forms tetragonal crystals above ~1100°; cubic above ~1900°. d 5.85. mp 2680°. bp 4300°. Practically insol in water; slightly sol in HCl, HNO_3; slowly sol in HF; dissolves on heating with a mixt of 2 parts H_2SO_4 and 1 part H_2O. Fusion with sodium carbonate results in the formation of sodium zirconate which dec hydrolytically with water to form sodium hydroxide and practically insol zirconium hydroxide.

USE: Instead of lime for the oxyhydrogen light; with earths of the yttrium group in incandescent lighting (Nernst lamps); as pigment, abrasive; manuf enamels, white glass, refractory crucibles, and furnace linings.

THERAP CAT: Dermatologic.

9986. Zirconium Silicate. Zirconium orthosilicate. O_4SiZr; mol wt 183.31. O 34.91%, Si, 15.32%, Zr 49.76%. $ZrSiO_4$. Occurs in nature as the mineral *zircon.* Widely scattered in all kinds of rocks and in beach sand (South Carolina, Northeast Florida). Usually separated from sand by electrostatic and electromagnetic elutriation, yielding 99% pure $ZrSiO_4$. Prepn from SiO_2 and ZrO_2 in an arc furnace: Curtis, Sowman, *J. Am. Ceram. Soc.* **36,** 195 (1953); can also be made from solns of zirconium salts and sodium silicate.

Tetragonal, bipyramidal crystals. Should be colorless. Colors are from impurities and radioactive bombardment, often removable by calcination. Dissociates to ZrO_2 and SiO_2 when heated above 1540°. Recombines when cooled slowly, but forms a mixture of monoclinic ZrO_2 and vitreous SiO_2 when rapidly quenched. Undissociated (α-form) $ZrSiO_4$ has a high sp gr, 4.7, and a high birefringence; the dissociated, γ-form has a lower sp gr, 3.9-4.0, and a low birefringence. Hardness of α-form about the same as that of quartz (6-7.5). Very inert chemically. Unaffected by aq reagents.

USE: In refractories, ceramics, glazes, cements, coatings for casting molds, polishing materials, gem stones, catalyst in alkyl and alkenyl hydrocarbon manuf, in fritted glass filters, as stabilizer in silicone rubbers. In Europe in cosmetic creams and powders.

9987. Zirconium Sulfate. Disulfatozirconic acid. O_8S_2Zr; mol wt 283.34. O 45.18%, S 22.63%, Zr 32.19%. $Zr(SO_4)_2$. Tetrahydrate usually prepd by treating zirconium oxychloride with hot concd H_2SO_4: Blumenthal, *J. Chem. Ed.* **39,** 604 (1962).

Tetrahydrate, crystalline solid. Converted to monohydrate at 100°; to anhydr form at 380°. Soly in water (18°): 52.5 g/100 g of soln. A soln at room temp deposits a solid on standing. The more dilute the soln, the more rapid the deposition. The composition of the solid is $4ZrO_2.3SO_3 \cdot 15H_2O$, known as *Hauser's salt:* Hauser, Herzfeld, *Z. Anorg. Allgem. Chem.* **67,** 369 (1910). This pptn does not take place if the soln has been heated above 64°. LD_{50} in rats: 3.5 g/kg orally; 175 mg/kg i.p.: Cochran *et al., Arch. Ind. Hyg. Occup. Med.* **1,** 637 (1950).

USE: Catalyst support; precipitation of amino acids and proteins; in the tanning industry.

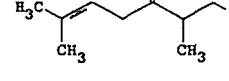
9988. Zirconyl Acetate. Diacetatozirconic acid. Approx formula: $Zr(OH)_2(C_2H_3O_2)_2$. Obtained as aq soln by adding acetic acid to an aq slurry of carbonated hydrous zirconia: Blumenthal, *J. Chem. Ed.* **39,** 604 (1962).

Available as 22% ZrO_2 soln. d 1.46. Freezes at $-7°$. pH 3.8-4.2. Stable at room temp. Also available as 13% ZrO_2 soln. d 1.20. pH 3.3-4.0. Undergoes exchange with anion exchange resins, but not with cation exchangers. Evaporation of the solns under reduced pressure yields the solid compd. It is resinous or glue-like in appearance and amorphous under x-rays. Its properties indicate it to be a highly polymerized product. The powdered solid readily dissolves when added slowly to rapidly swirling water. On heating, the solns yield a solid hydrolyzate, which is a more basic

acetate with the compn ZrOO
allowed to cool and stand at
redissolves. LD_{50} in rats: 4.1
Cochran *et al., Arch. Ind. Hyg*
USE: Precipitating agent for
and paper; water-repellent for
nation with silicones).

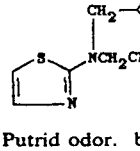
9989. Zirconyl Chloride.
nium oxychloride; basic zirconi
178.13. Cl 39.81%, O 8.98%,
from $ZrCl_4$ and Cl_2O: Dehnic
Chem. **331,** 121 (1964). Octah
crystn of an aq soln of zirco
Zander, *Wissenschaftl. Veröff.*
Blumenthal, *J. Chem. Ed.* **39,**
Octahydrate, tetragonal cry
contain tetramers of the form
Mak, *Can. J. Chem.* **46,** 3491
alcohol. The pH is about equa
molarity. LD_{50} in rats: 400
Cochran *et al., Arch. Ind. Hyg*
USE: To make other zirconiu
dyes; to prepare high quality
properties of color lakes. Aq
able solvent action on sparingly
sulfate. The free acid in ZrO
and a sol compd ZrOOHCl.xH
highly polymerized in soln and
has been used in the prepn of t
spirant preparations.

9990. Zoapatanol. *9-[3-H*
ene)-2-methyl-2-oxepanyl]-2,
$C_{20}H_{34}O_4$; mol wt 338.49. C 7
Oxepane diterpenoid isolated fr
plant, *Montanoa tomentosa.* C
used by Mexican women to pr
and labor. Isoln and structu
Kanojia, U.S. pat. 4,086,358 (1
et al., J. Am. Chem. Soc. **101,** 3
al., J. Org. Chem. **47,** 1310 (19
B. Smith *et al., Life Sci.* **28,** 274
(±)-form: R. Chen, D. A. Rov
6609 (1980); K. C. Nicolau *et a*
L. Doyle, *Tetrahedron Letters* 2
sp
C. J. Shaw, *Org. Mass Sp*
NMR study: M. L. Cotter, *O*



Pale yellow oil.

9991. Zolamine. *N-[(4-Me*
dimethyl-N-2-thiazolyl-1,2-eth
aminoethyl)(p-methoxybenzyl
methyl-*N*-(2-thiazolyl)-*N*-(*p*-r
amine. $C_{15}H_{21}N_3OS$; mol wt
N 14.42%, O 5.49%, S 11.00%.
amine, *q.v.*, and is prepd acc
Pharm. Soc. Japan **72,** 1009 (19



Oily liquid. Putrid odor. bp
Hydrochloride, $C_{15}H_{22}ClN_3OS$
crystals from alc. Slightly bitter
in water. Ingredient of *Otodyne*
THERAP CAT: Antihistaminic;

THE MERCK INDEX

AN ENCYCLOPEDIA OF
CHEMICALS, DRUGS, AND BIOLOGICALS

TENTH EDITION

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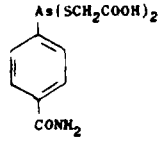
USE: Manuf medicinal arsenicals.

THERAP CAT (VET): Growth promotant; to improve feed efficiency. To control swine dysentery.

811. Arsenamide. *[[[4-(Aminocarbonyl)phenyl]arsinidene]bis(thio)]bisacetic acid; [[(p-carbamoylphenyl)arsylene]dithio]diacetic acid;* bis[carboxymethylmercapto](*p*-carbamylphenyl)-arsine; *p*-[bis(carboxymethylmercapto)arsino]-benzamide; dithioglycolyl *p*-arsenobenzamide; 4-carbamylphenyl bis[carboxymethylthio]arsenite; thioarsenite; thiacetarsamide; Caparsolate; Caparside. $C_{11}H_{12}AsNO_5S_2$; mol wt 377.26. C 35.02%, H 3.21%, As 19.86%, N 3.71%, O 21.21%, S 17.00%. Prepd by the condensation of *p*-arsenosobenzamide and thioglycolic acid: Gough, King *J. Chem. Soc.* **1930**, 669; Maren, *J. Am. Chem. Soc.* **68**, 1864 (1946).



White crystalline powder. Sparingly sol in cold water; appreciably sol in water above 90°. Sparingly sol in cold methanol, ethanol; very sol in these solvents when they are warm. Insol in warm isopropyl ether. pKa = 4. The disodium salt is stoichiometrically formed in aq soln at pH 7-8.

THERAP CAT: Anthelmintic.

THERAP CAT (VET): Heartworm infection in dogs, especially the adult stages.

812. Arsenic. Grey arsenic; metallic arsenic; arsen (German). As; at. wt 74.9216; at. no. 33; valence 3, 5. One natural isotope: 75; artificial, radioactive isotopes: 68-74; 76-81. Arsenic compds were described and used in antiquity, their reduction to the element was known to medieval alchemists, and the first precise directions for the prepn of As are found in Paracelsus' writings (*ca.* 1520 A.D.). Arsenic occurs probably throughout the universe. Meteorites contain from 0.0005 to 0.1% As. Occurrence in the earth's crust: 0.0005%. Found to a small extent as the element, mostly as an arsenide of true metals. Usually produced as the trioxide when smelting ores for such metals. Reduction with carbon (sugar charcoal) and sublimation in N_2 current yields very pure As: Krepelka, *Coll. Czech. Chem. Commun.* **2**, 255 (1930); E. H. Archibald, *The Preparation of Pure Inorganic Substances* (Wiley, New York, 1932) p 269. Other methods: Schenk in *Handbook of Preparative Inorganic Chemistry* vol. 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) pp 591-593. *Reviews: Gmelin's, Arsenic* (8th ed.) **17**, 475 pp (1952); Smith, "Arsenic, Antimony and Bismuth" in *Comprehensive Inorganic Chemistry* vol. 2, J. C. Bailar, Jr. *et al.*, Eds. (Pergamon Press, Oxford, 1973) pp 547-683. Review of carcinogenicity studies of arsenic and arsenic compds: *IARC Monographs* **23**, 39-141 (1980).

Gray, shiny, brittle, metallic-looking rhombohedra. Can be heated to burn in air with bluish flame, giving off an odor of garlic and dense white fumes of As_2O_3. Loses its luster on exposure to air, forming a black modification + As_2O_3. Brinell hardness: 147; Mohs' scale: 3.5. d_4^{25} 5.727. Sublimes$_{760}$ 615° without melting. Vaporization becomes apparent at 100° and is already rapid at 450°. mp 818° at 36 atm. Heat of vaporization 11.2 kcal/g-atom. Heat of sublimation 30.5 kcal/g-atom. Heat of fusion: 22.4 kcal/g-atom: *Gmelin's, loc. cit.* pp 135-136. Also reported: heat of fusion: 6.620 kcal/g-atom; heat of sublimation 7.63 kcal/g-atom: D. R. Stull, G. C. Sinke, *Thermodynamic Properties of the Elements*, Advances in Chemistry Series **18** (A.C.S., Washington, 1956) pp 11, 44. Specific heat: 0.0822 for 0° to 100°. Dielectric constant = 10.23 at 20° and 60 cycles. Electrical and magnetic properties of crystalline As: Taylor *et al., J. Phys. Chem. Solids* **26**, 69 (1965). Insol in water; not attacked by cold H_2SO_4 or HCl; converted by HNO_3 or hot H_2SO_4 into arsenous or arsenic acid.

A yellow modification which has no metallic properties is obtained by sudden cooling of As-vapor. This yellow arsenic is converted back to the gray modification upon very short exposure to ultraviolet light.

Note: In German and other languages *Arsenik* means arsenic trioxide.

Caution: Most forms of arsenic are toxic. *Acute* symptoms following ingestion relate to irritation of the G.I. tract: nausea, vomiting, diarrhea which can progress to shock and death. *Chronic* poisoning can result in exfoliation and pigmentation of skin, herpes, polyneuritis, altered hematopoiesis, degeneration of liver and kidneys: Vallee *et al., Arch. Ind. Health* **21**, 132 (1960); E. Browning, *Toxicity of Industrial Metals* (Appleton-Century-Crofts, New York, 2nd ed., 1969) pp 36-60. This substance and certain arsenic compounds have been listed as carcinogens by the EPA: *Second Annual Report on Carcinogens* (NTP 81-43, Dec. 1981) pp 31-36.

USE: In metallurgy for hardening copper, lead, alloys. In the manufacture of certain types of glass. The artificial isotope ^{76}As as radioactive tracer in toxicology.

813. Arsenic Acid. Orthoarsenic acid. AsH_3O_4; mol wt 141.93. As 52.78%, H 2.13%, O 45.09%. H_3AsO_4. Exists only as the hemihydrate. Excessive drying produces $As_2O_5 \cdot 5/3H_2O$. Conveniently prepd from As_2O_3 and HNO_3: Simon, Thaler, *Z. Anorg. Allgem. Chem.* **161**, 143 (1927); **246**, 19 (1941).

Hemihydrate, hygroscopic crystals. *Poisonous!* Converted to As_2O_5 by heating above 300°. Freely sol in water, alcohol, glycerol. LD_{50} i.v. in rabbits: 6 mg/kg, Joachimoglu, *Biochem. Z.* **70**, 144 (1915).

USE: In the manuf of arsenates.

814. Arsenic Disulfide. *Arsenic sulfide;* red arsenic sulfide; realgar; red orpiment; ruby arsenic; red arsenic glass; C.I. Pigment Yellow 39; C.I. 77085. As_4S_4; mol wt 427.92. As 70.03%, S 29.97%. Prepn: *Gmelin's, Arsenic* (8th ed.) **17**, pp 417-422 (1952); Schenk in *Handbook of Preparative Inorganic Chemistry* vol 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 603.

Deep red, lustrous monoclinic crystals. mp 320°; bp 565°; d 3.5. Ignites at high temp. Practically insol in water; sol in alkali hydroxides; decomposed by HNO_3; very slightly sol in hot CS_2 and benzene.

USE: As pigment in painting; in fireworks as blue fire and to give an intense white flame; manuf shot; calico printing and dyeing; tanning and depilating hides.

815. Arsenic Hemiselenide. As_2Se; mol wt 228.78. As 65.49%, Se 34.51%. Prepd by melting arsenic and selenium in the correct proportions in a sealed tube filled with nitrogen: Szarvasy, *Ber.* **28**, 2654 (1895); **30**, 1244 (1897); *Gmelin's, Arsenic* (8th ed.) **17**, p 462 (1952).

Black crystals with a metallic luster. Insol in the usual organic and inorganic solvents. Dec in boil. alkali hydroxide solns; slowly decompd by concd hydrochloric and sulfuric acids.

USE: Manuf of glass.

816. Arsenic Pentafluoride. AsF_5; mol wt 169.91. As 44.09%, F 55.91%. Prepd from As + F_2: Ruff *et al., Z. Anorg. Allgem. Chem.* **206**, 59 (1932); Seel, Detmer, *ibid.* **301**, 113 (1959); Kwasnik in *Handbook of Preparative Inorganic Chemistry* vol. 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 198. *Reviews:* Burg in *Fluorine Chemistry* vol. 1, J. Simons, Ed. (Academic Press, New York, 1950) p 102; Kemmitt, Sharp, *Advan. Fluorine Chem.* **4**, 208 (1965).

Colorless gas. Forms white clouds in moist air. $d_{4.0}^{25.8}$ 2.33. mp −79.8°. bp −53.2°. Instantly hydrolyzed by water. Sol in alcohol, ether, benzene. Dry AsF_5 does not attack glass, but a minute trace of moisture or HF catalyzes the etching reaction to the point of total destruction.

817. Arsenic Pentaselenide. As_2Se_5; mol wt 544.62. As 27.51%, Se 72.49%. Prepd by melting the correct proportions of arsenic and selenium in a sealed tube containing nitrogen: Szarvasy, *Ber.* **28**, 2654 (1895); **30**, 1244 (1897); by the action of an arsenic salt on a solution of hydrogen selenide: Moser, Atynsky, *Monatsh.* **45**, 235 (1925).

Black, brittle solid with a metallic luster. *Poisonous!* Dec when heated in air. Sol in alkali hydroxides and sulfides; insol in water, dilute acids, concd hydrochloric acid, alcohol, ether, carbon disulfide; dec in nitric acid.

818. Arsenic Pentasulfide. Diarsenic pentasulfide. As_2S_5; mol wt 310.12. As 48.31%, S 51.69%. Prepd from As_2S_3 and H_2S: Schenk in *Handbook of Preparative Inorganic Chemistry* vol 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 603.

Brownish-yellow, glassy, amorphous, highly refractive mass. Insol in water; sol in alkalies and alkali sulfides. Dec into As_2O_3, S, and As_2S_3 when boiled with water.

USE: In thin sheets as a light filter; in pigments.

819. Arsenic Pentoxide. Arsenic acid anhydride. As_2O_5; mol wt 229.82. As 65.20%, O 34.81%. Prepn: *Gmelin's Arsenic* (8th ed.) 17, pp 273-277 (1952).

Amorphous lumps or powder. *Poisonous!* Gradually deliquesces on exposure to air. Freely sol in water or alc. Combines very slowly with H_2O to form H_3AsO_4. *Keep well closed.*

USE: Manuf of colored glass; in adhesives for metals; in wood preservatives; in weed control; as fungicide.

820. Arsenic Tribromide. $AsBr_3$; mol wt 314.66. As 23.81%, Br 76.19%. Prepn: Oddo, Giachery, *Gazz. Chim. Ital.* 53, 56 (1923); Schenk in *Handbook of Preparative Inorganic Chemistry* vol. 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 597.

Deliquescent, orthorhombic prisms. *Intensely poisonous!* d_4^{25} 3.397; d_4^{50} (liq) 3.3282; d_4^{75} 3.2623; d_4^{100} 3.1995. mp 31.1°. bp_{760} 221°; bp_{11} 89°. Dipole moment 1.66. Heat of fusion 8.93 cal/g. Fumes in moist air. Dec by water with the formation of As_2O_3 and HBr. Miscible with ether, benzene. Sol in hydrocarbons, chlorinated hydrocarbons, carbon disulfide, oils and fats.

821. Arsenic Trichloride. Butter of arsenic; fuming liquid arsenic. $AsCl_3$; mol wt 181.28. As 41.32%, Cl 58.68%. Prepn: Smith, *Ind. Eng. Chem.* 11, 109 (1919); Reisener in *Ullman's Encyklopädie der Technischen Chemie* vol. 3, (Urban & Schwarzenberg, Munich, 1953) p 850; Schenk in *Handbook of Preparative Inorganic Chemistry* vol. 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 596.

Oily liquid. *Intensely poisonous!* Fumes in air. d_4^{25} 2.1497. mp −16°. bp 130.21°; bp_{11} 25°. Dipole moment: 2.17. Heat of vaporization 8.9 kcal/mol. Specific heat: 3.19 cal/-mol/°C. n_D^{20} 1.6006. Dec by water to form $As(OH)_3$ and HCl. One mol $AsCl_3$ can be dissolved in 9 mols H_2O, this soln (d 1.53) may be diluted again with another 9 mols H_2O giving a soln with d 1.346. Further dilution results in the precipitation of As_2O_3. Also dec by ultraviolet light. Miscible with, or solvent for, chloroform, carbon tetrachloride, ether, iodine, phosphorus, sulfur, alkali iodides, oils and fats.

USE: In the ceramic industry; in syntheses of chlorine-contg arsenicals, e.g., chloro derivs of arsine.

822. Arsenic Trifluoride. AsF_3; mol wt 131.91. As 56.79%, F 43.21%. Prepn: Russell *et al., J. Am. Chem. Soc.* 63, 2825 (1941); Woolf, Greenwood, *J. Chem. Soc.* 1950, 2200; Hoffman, *Inorg. Syn.* 4, 151 (1953); Kwasnik in *Handbook of Preparative Inorganic Chemistry* vol. 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) pp 197-198. *Review:* Kemmitt, Sharp, *Advan. Fluorine Chem.* 4, 208-209 (1965).

Mobile liquid. *Very poisonous!* Fumes in air. Etches glass. $d_{15.5}^{15.5}$ 2.73. mp −5.95°. bp 57.8°. Also reported as mp −8.5°; bp 63°: Kwasnik, *loc. cit.* Hydrolyzed by water. Sol in alcohol, ether, benzene. May be stored in iron vessels.

Human Toxicity: Extremely toxic.

823. Arsenic Triiodide. AsI_3; mol wt 455.67. As 16.44%, I 83.56%. Prepd from the elements or from $AsCl_3$ and KI: Bailar, *Inorg. Syn.* I, 103 (1939).

Orange-red, trigonal rhombohedra from acetone. Reacts slowly with O_2 from air, liberating iodine. d_4^{25} 4.688. Some tendency to sublime below 100°. mp 140.9° forming a red liquid. bp_{760} about 400°. One gram dissolves in 12 ml water forming a yellow soln. Does not hydrolyze rapidly and may be recovered from the water soln unchanged within 5 hrs. Aqueous solns are strongly acid (pH of 0.1 *N* soln about 1.1) and ultimately form HI and As_2O_3, although an equilibrium $AsI_3 + 3H_2O = H_3AsO_3 + 3HI$ has been observed. Freely sol in carbon disulfide, chloroform, benzene, toluene, xylene. Less sol in alc, ether.

THERAP CAT: Formerly in dermatitides.

824. Arsenic Trioxide. Arsenous acid; arsenous acid anhydride; arsenous oxide; arsenic sesquioxide; white arsenic. As_2O_3; mol wt 197.82. As 75.74%, O 24.26%. Prepn: Schenk in *Handbook of Preparative Inorganic Chemistry* vol. I, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 600.

White or transparent. glassy, amorphous lumps or cryst powder. Two cryst modifications, *claudetite* (monoclinic, mp 313°) and *arsenolite* (cubic, mp 275°). bp 465°. *Intensely poisonous!* When slowly heated sublimes unchanged; when rapidly heated the cryst sublimes without fusion, while the amorphous first fuses, then sublimes. Sparingly and extremely slowly sol in cold water; sol in 15 parts boiling water, in dil HCl, in alkali hydroxide or carbonate solns; practically insol in alc, chloroform, ether. LD_{50} orally in mice, rats: 39.4, 15.1 mg/kg, J. Harrison *et al., Arch. Ind. Health* 17, 118 (1958).

Incompat. Tannic acid, infusion cinchona and other vegetable astringent infusions and decoctions; iron in soln.

USE: It is the primary material for all arsenic compounds. Used in manuf of glass, Paris green, enamels, weed killers, metallic arsenic; for preserving hides; killing rodents, insects; in sheep dips and weed killers; textile mordant.

THERAP CAT (VET): Formerly as parasiticide, also for nonparasitic skin and blood diseases; in rheumatism, asthma and heaves, and as an alterative.

825. Arsenic Triselenide. Arsenious selenide; arsenous selenide. As_2Se_3; mol wt 386.70. As 38.74%, Se 61.26%. Prepd by melting arsenic and selenium in the correct proportions: Uelsmann, *Ueber Selenverbindungen*, Göttingen (1860); *Ann.* 116, 122 (1860); by the action of an arsenic salt on a soln of hydrogen selenide: Moser, Atynsky, *Monatsh.* 45, 235 (1925).

Dark brown solid. d 4.75. mp 260°. Sol in nitric acid, alkali-lye, alkali sulfide solutions; insol in water.

826. Arsenic Trisulfide. Yellow arsenic sulfide; orpiment; auripigment; arsenic yellow; king's yellow; king's gold. As_2S_3; mol wt 246.00. As 60.90%, S 39.10%. The article of commerce contains much less sulfur than theory. Prepn: *Gmelin's Arsenic* (8th ed.) 17, pp 422-433 (1952).

Yellow or orange powder. mp reported from 300° to 325°. d 3.46. Practically insol in water; sol in alkalies, alkali sulfides or carbonates; slowly sol in hot HCl; dec by HNO_3.

USE: Manuf of glass, particularly infrared-transmitting glass; manuf of oil cloth, linoleum; in electrical semiconductors, photoconductors; as pigment; for depilating hides; in pyrotechnics.

827. Arsenious Acid Solution. Arsenic chloride solution. *Poisonous!* Prepared with 1 g As_2O_3, 5 ml dil HCl and water to 100 ml.

THERAP CAT (VET): Has been used in skin and blood disorders.

828. Arsenoacetic Acid. *Arsenodiacetic acid;* diarsenoacetic acid. $C_4H_6As_2O_4$; mol wt 267.93. C 17.93%, H 2.26%, As 55.92%, O 23.89%. $HOOCCH_2As{=}AsCH_2COOH$. Prepd by dissolving sodium arsonoacetate and sodium hypop[illegible]

Chem. Soc. 45,

Minute yello

not melt below

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ide and dil sod

Disodium sa

Tonarsan. Yel

used as injecta

Acid (Disodiun

829. Arsin

AsH_3; mol wt 7

Landauer, *J. A*

Inorg. Syn. 7, 4

Inorganic Chem

New York, 2nd

Colorless, ne

Page 118

mc. 13.84. (1952).

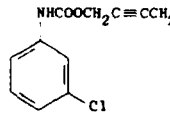
ed or when 1.0113. mp exane, pentane.

HOCH2

podium.

oxide coated asbestos. mbustion analysis.

...kins *et al., J. Org. Chem.* **24**, 2040 (1959); U.S. pat. ...,614 (1959 to Spencer Chem.); Baskakov *et al., Zh. ...ch. Khim.* **33**, 46 (1963). Activity as an herbicide: ...ffmann *et al., Weeds* **8**, 198 (1960). Metabolism: Gru... *et al., Food Cosmet. Toxicol.* **8**, 277 (1970). *Review:* ...bel, *Rep. Progr. Appl. Chem.* **47**, 552 (1962).



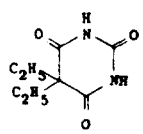
Crystals from *n*-hexane + benzene, mp 75-76°. Practically insol in water (soly at 25° = 11 ppm); slightly sol in hexane; readily sol in benzene, ethylene dichloride. Hydrolyzed by alkali with liberation of the terminal chlorine. Hydrolysis under acidic conditions gives 3-chloroacrylic acid. LD_{50} orally in rats: 600 mg/kg, Bailey, White, *Residue Rev.* **10**, 97 (1965).

USE: Selective herbicide for wild oats. *Caution:* May cause skin irritation.

958. Barbasco. Name applied in the Spanish-speaking countries of the New World to many unrelated plants used to poison or stun fish. In Mexico it usually means roots of *Dioscorea composita* Hemsl., or of *Dioscorea tepinapensis* Uline, *Dioscoreaceae* which yield up to 5% of their dry weight in diosgenin: *Chem. Week* **79**, no. 2, p 20 (July 14, 1956). Isoln procedure: Julian, U.S. pat. **3,019,220** (1962 to Julian Labs.). Book: D. G. Coursey, *Yams* (Longmans, London, 1967) 230 pp, an account of the nature, origins, cultivation and utilization of the useful members of the *Dioscoreaceae*. *Compare* Yam, Mexican.

959. Barberry Bark. Berberis bark; jaundice berry; woodsour; sowberry; pepperidge bush; sour-spine. Root bark of *Berberis vulgaris* L., *Berberidaceae*. *Habit.* Europe and Western Asia; also U.S. (New England States, Pennsylvania and Virginia). *Constit.* Berberine, berbamine, oxyacanthine, tannin, wax, fat, resin. *Ref:* Neugebauer, Brunner, *Pharm. Zent.* **80**, 113 (1939).

960. Barbital. *5,5-Diethyl-2,4,6(1H,3H,5H)-pyrimidinetrione; 5,5-diethylbarbituric acid;* barbitone; diethylmalonylurea; Veronal; Malonal; Veroletten; Sédeval; Dormonal; Hypnogène; Deba; Vespéral; Uronal. $C_8H_{12}N_2O_3$; mol wt 184.19. C 52.16%, H 6.57%, N 15.21%, O 26.08%. Prepd by the condensation of the diethyl ester of diethylmalonic acid with urea in sodium ethoxide soln: Fischer, Dilthey, *Ann.* **335**, 334 (1904); Ger. pat. **146,496** (1903), *Frdl.* **7**, 651, *Chem. Zentr.* **1903, II**, 1483; Fischer, v. Mering, *Therapie der Gegenwart*, March 1903; *Therapeutische Monatsh.* **17**, 208 (1903), *Chem. Zentr.* **1903, I**, 1155.



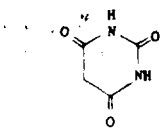
Faintly bitter needles (trigonal in the stable phase) from water, mp 188-192°. Can be sublimed *in vacuo*. Acid to litmus. K at 25° = 3.7×10^{-8}. One gram dissolves in about 130 ml water, 13 ml boiling water, 14 ml alcohol, 75 ml chloroform, 35 ml ether. Sol in acetone, ethyl acetate, alkalies, petr ether, acetic acid, amyl alcohol, pyridine, aniline, nitrobenzene. LD orally in mice: 600 mg/kg.

Sodium salt, $C_8H_{11}N_2NaO_3$, *barbital sodium, sodium 5,5-diethylbarbiturate, barbitone sodium, soluble barbital, sodium diethylmalonylurea, Veronal sodium, Medinal, Embinal.* Bitter crystals or powder. One gram dissolves in 5 ml water, 2.5 ml boiling water, 400 ml alc. Aq soln is alkaline to litmus and phenolphthalein. pH of 0.1 molar aq soln, 9.4. *Caution:* Abuse may lead to habituation or addiction.

THERAP CAT: Central depressant (hypnotic, sedative).

THERAP CAT (VET): Sedative, hypnotic.

961. Barbituric Acid. *2,4,6(1H,3H,5H)-pyrimidinetrione;* malonylurea; 2,4,6-trioxohexahydropyrimidine. $C_4H_4N_2O_3$; mol wt 128.09. C 37.50%, H 3.15%, N 21.87%, O 37.47%. Prepn from hydurilic acid + nitric acid: Baeyer, *Ann.* **127**, 199 (1863); *ibid.* **130**, 129 (1864). Structure: Mulder, *Ber.* **6**, 1233 (1873). Prepd from ethyl malonate and urea using sodium ethoxide as a condensing agent: Dickey, Gray, *Org. Syn. coll. vol. II*, 60 (1943). Crystal structure: Bolton, *Nature* **201**, 987 (1964). Unsubstituted barbituric acid has no hypnotic properties. *Review:* Carter, *J. Chem. Ed.* **28**, 524 (1951).



Dihydrate, rhombs from water. mp about 248° when anhydrous, with some decompn. Strong acid. K at 25° = 9.9×10^{-5}. uv spectrum: Hartley, *J. Chem. Soc.* **87**, 1808 (1905). Difficultly sol in cold water; freely sol in hot water, in dil acids. Forms salts with metals. LD_{50} orally in male rats: > 5000 mg/kg, E. I. Goldenthal, *Toxicol. Appl. Pharmacol.* **18**, 185 (1971).

USE: Manuf plastics, pharmaceuticals.

962. Barium. Ba; at. wt 137.33; at. no. 56; valence 2. An alkaline earth metal. Abundance in earth's crust 0.05% by wt. Isotopes: 138 (71.66%); 137 (11.32%); 136 (7.81%); 135 (6.59%); 134 (2.42%); 132 (0.097%); 130 (0.101%). Occurs in barite and witherite. First prepared as a mercury amalgam by Davy in 1808. Toxicity studies of barium compds: Syed, Hosain, *Toxicol. Appl. Pharmacol.* **22**, 150 (1972). *Reviews: Gmelin's Handb. Anorg. Chem., Barium* (8th ed.) **30**, (1960); Goodenough, Stenger, "Magnesium, Calcium, Strontium, Barium and Radium" in *Comprehensive Inorganic Chemistry* Vol. 1, J. C. Bailar, Jr. *et al.*, Eds. (Pergamon Press, Oxford, 1973) pp 591-664; C. J. Kunesh in Kirk-Othmer *Encyclopedia of Chemical Technology* vol. 3 (Wiley-Interscience, New York, 3rd ed., 1978) pp 457-463.

Yellowish-white, slightly lustrous lumps; body-centered cubic structure; somewhat malleable; very easily oxidizable; must be kept under petroleum or other oxygen-free liquid to exclude air. d 3.6. mp approx 710°. bp approx 1600°. E^0 (aq) Ba^{2+}/Ba −2.91 V. Description of reactions which are characteristic of alkaline earth metals *see* Calcium. Solns of sol barium salts give a white ppt with H_2SO_4 or sol sulfates; they also color nonluminous flame green.

USE: Carrier for radium. The β- and γ-radiation emitted by ^{140}Ba + ^{140}La makes a large contribution to the activity of the fission products of uranium rods during the first few weeks after their withdrawal from the reactor. Alloys of Ba with Al or Mg are used as getters in electronic tubes. The emissions from ^{133}Ba and ^{137m}Ba are used as standards in γ-spectrometry: Haissinsky, Adloff, *Radiochemical Survey of the Elements* (Elsevier, 1965) pp 12-14. *Caution:* All water or acid soluble barium compounds are *poisonous!*

963. Barium Acetate. $C_4H_6BaO_4$; mol wt 255.45. C 18.81%, H 2.37%, Ba 53.77%, O 25.05%. $Ba(C_2H_3O_2)_2$. Prepn: *Gmelin's, Barium* (8th ed.) **30**, 315 (1932) and supplement, 478 (1960).

Monohydrate. *Poisonous!* d 2.19. Loses its H_2O of hydration at 110°. One gram dissolves in 1.5 ml cold or boiling water, in 700 ml alc. The aq soln is neutral or slightly acid to litmus. LD_{50} in ICR mice: 23.31 mg Ba^{2+}/kg i.v., Syed, Hosain, *Toxicol. Appl. Pharmacol.* **22**, 150 (1972).

USE: Mordant for printing fabrics; in lubricating oil and grease; as catalyst for organic reactions.

964. Barium Benzenesulfonate. *Benzenesulfonic acid barium salt.* $C_{12}H_{10}BaO_6S_2$; mol wt 451.70. C 31.91%, H 2.23%, Ba 30.41%, O 21.25%, S 14.20%. Prepn: Freund, *Ann.* **120**, 76 (1861).

Monohydrate, white, nacreous leaflets. *Poisonous!* Freely sol in water; slightly sol in alc.

USE: Lubricating oil additives.

965. Barium Bromate. $BaBr_2O_6$; mol wt 393.19. Ba 34.93%, Br 40.65%, O 24.42%. $Ba(BrO_3)_2$. Prepd from

potassium bromate and barium chloride: Pearce, Russell, *Inorg. Syn.* **2**, 20 (1946).

Monohydrate, monoclinic crystals from hot water. *Poisonous!* May develop slight odor of bromine on long standing. d 3.99. Dec. at 260°. Sol in water (g/100 ml): 0.44 (10°); 0.96 (30°); 5.39 (100°). Sol in acetone. Practically insol in alc, most other organic solvents.

USE: In the prepn of rare earth bromates; as corrosion inhibitor for low-C steel.

966. Barium Bromide. $BaBr_2$; mol wt 297.19. Ba 46.22%, Br 53.78%. Prepn: *Gmelin's, Barium* (8th ed.) **30**, 223 (1932) and supplement 380-381 (1960).

Dihydrate, crystals or granules; loses $1H_2O$ at 75° and all the H_2O at 120°. *Poisonous!* mp about 850° when anhydr. Very sol in water; sol in methanol; almost insol in ethanol, ethyl acetate, acetone, dioxane.

USE: In the manuf of other bromides; in the prepn of phosphors.

967. Barium Carbonate. $CBaO_3$; mol wt 197.37. C 6.09%, Ba 69.58%, O 24.32%. $BaCO_3$. Occurs in nature as the mineral *witherite.* Prepn: *Gmelin's, Barium* (8th ed) **30**, 301-303 (1932) and supplement, 186-188, 461-466 (1960). The barium carbonate of commerce is made by precipitation and is 98-99% pure. Manuf: Faith, Keyes & Clark's *Industrial Chemicals,* F. A. Lowenheim, M. K. Moran, Eds. (Wiley-Interscience, New York, 4th ed., 1975) pp 121-125.

White, heavy powder. *Poisonous!* d (witherite) 4.2865. At about 1300° dec into BaO and CO_2. Almost insol in water, 0.024 g in a liter; slightly sol (1:1000) in CO_2-water; sol in dil HCl, HNO_3 or acetic acid; also sol in soln NH_4Cl or NH_4NO_3. LD_{50} orally in rats: 800 mg/kg.

Human Toxicity: Acute: excessive salivation, vomiting, colic, violent diarrhea, convulsive tremors, increased blood pressure, hemorrhages in G.I. tract and kidneys, muscular paralysis.

USE: Rat poison; in ceramics, paints, enamels, marble substitutes, rubber; manuf of paper, barium salts, electrodes, optical glasses; as an analytical reagent.

968. Barium Chlorate. $BaCl_2O_6$; mol wt 304.27. Ba 45.14%, Cl 23.31%, O 31.55%. $Ba(ClO_3)_2$. Prepn: Vanino, *Handb. Präp. Chem., Anorgan. Teil* (2.Aufl., Stuttgart, 1925) p 297; Schmeisser in *Handbook of Preparative Inorganic Chemistry,* **Vol. 1**, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 314. Large-scale process: Munroe, *Chem. Met. Eng.* **23**, 188 (1920). Also prepd by electrolysis of barium chloride.

Monohydrate, monoclinic prismatic crystals. *Poisonous!* d 3.179. Loses its water of hydration at 120°, begins to give off oxygen at 250°, mp 414°. Freely sol in water; sol in hydrochloric acid; moderately sol in ethylamine; very sparingly sol in alc, somewhat more in acetone. Practically insol in ethyl acetate, pyridine. Fire hazard when in contact with combustible material.

USE: In pyrotechnics (green fire); manuf of explosives and matches; mordant in dyeing.

969. Barium Chloride. $BaCl_2$; mol wt 208.27. Ba 65.95%, Cl 34.05%. Prepn: *Gmelin's, Barium* (8th ed) **30**, 171-175 (1932) and supplement, 179-181, 324-325 (1960). Toxicity studies: Syed, Hosain, *Toxicol. Appl. Pharmacol.* **22**, 150 (1972).

Dihydrate, crystals or granules or powder; bitter salty taste. d 3.86; mp 963. *Poisonous!* Very sol in water; sol in methanol; almost insol in ethanol, acetone, ethyl acetate. LD_{50} in ICR mice: 19.2 mg/kg i.v. (as Ba^{2+}).

USE: Manuf pigments, color lakes, glass, mordant for acid dyes; weighting and dyeing textile fabrics; in Al refining; as pesticide; boiler compds for softening water; tanning and finishing leather.

THERAP CAT: Cardiac stimulant. Radioactive compd as exptl bone scanning agent.

THERAP CAT (VET): Formerly used as purgative in horses, ruminatoric in cattle.

970. Barium Chromate(VI). C.I. 77103; C.I. Pigment Yellow 31; Baryta yellow; lemon yellow; permanent yellow; Steinbühl yellow; ultramarine yellow. $BaCrO_4$; mol wt 253.37. Ba 54.21%, Cr 20.53%, O 25.26%. Prepn: Beyer, Rieman, *J. Am. Chem. Soc.* **65**, 971 (1943); *Colour Index* **vol. 4** (3rd ed., 1971) p 4656.

Yellow, heavy, monoclinic, orthorhombic crystals. *Poisonous!* d 4.50. Practically insol in water, dil acetic or chromic acids; dissolved or dec by mineral acids.

USE: As a pigment almost entirely in anticorrosion jointing pastes to prevent electro-chemical corrosion at junctions of dissimilar metals; some use in artists' colors and in coloring glass, ceramics, porcelain. Also used in metal primers, pyrotechnic compositions.

971. Barium Cyanide. C_2BaN_2; mol wt 189.40. C 12.68%, Ba 72.52%, N 14.79%. $Ba(CN)_2$. Prepn: **Brit. pat. 602,393** (1948 to I.C.I.); *Gmelin's, Barium* (8th ed.) **30**, 327 (1932) and supplement 483 (1960).

Crystals; slowly dec in air. *Very poisonous!* Very sol in water; sol in alcohol.

USE: In electroplating processes; in metallurgy.

972. Barium Dithionate. Barium "hyposulfate". BaO_6S_2; mol wt 297.48. Ba 46.17%, O 32.27%, S 21.55%. BaS_2O_6. Prepn: Pfanstiel, *Inorg. Syn.* **2**, 170 (1946).

Dihydrate, crystals. *Poisonous!* d 4.54. Loses SO_2 on heating above 150° forming $BaSO_4$. Sol in 4 parts water; more sol in hot water; slightly sol in alcohol.

973. Barium Ferrocyanide. *Barium hexacyanoferrate(II).* $C_6Ba_2FeN_6$; mol wt 486.68. C 14.81%, Ba 56.45%, Fe 11.48%, N 17.27%. $Ba_2Fe(CN)_6$. Prepn: Grat-Cabanac, *Bull. Soc. Chim. France* **1956**, 1743.

Hexahydrate, yellowish rectangular monoclinic crystals; loses most of water at 40° becoming colorless. Dec at 80°, evolving HCN. Almost insol in water, alcohol.

974. Barium Fluoride! BaF_2; mol wt 175.36. Ba 78.33%, F 21.67%. Prepd by dissolving $BaCO_3$ in excess HF, evaporating to dryness, and heating to red heat: W. Olbrich, *Thesis* (Technische Hochschule, Breslau, 1929), p 2; Kwasnik in *Handbook of Preparative Inorganic Chemistry* **vol. I**, G. Brauer, Ed., (Academic Press, New York, 2nd ed., 1963) p 234.

Transparent cubic crystals (fluorite lattice). *Poisonous!* d 4.83. mp 1353. bp 2260. Soly in water (g/l): 1.586 (10°); 1.607 (20°); 1.620 (30°). Also sol in hydrochloric, nitric, hydrofluoric acids and in aq solns of ammonium chloride. May be stored in glass bottles.

USE: As a flux and opacifier in vitreous enamels; in the manuf of carbon brushes for D.C. motors and generators; in heat-treating metals; in embalming; in glass manuf.

975. Barium Formate. $C_2H_2BaO_4$; mol wt 227.40. C 10.56%, H 0.89%, Ba 60.40%, O 28.14%. $Ba(HCOO)_2$. Prepn: *Gmelin's, Barium* (8th ed) **30**, 311 (1932), and supplement, 477 (1960).

Crystals. *Poisonous!* d 3.21. Soluble in 4 parts cold, 3 parts boiling water; practically insol in alcohol.

976. Barium Hexafluorosilicate. Barium fluosilicate; barium silicofluoride. BaF_6Si; mol wt 279.45. Ba 49.15%, F 40.79%, Si 10.05%. $BaSiF_6$. Prepd from $BaCl_2$ and H_2SiF_6: Truchot, *Compt. Rend.* **98**, 821 (1884); Hoffmann, Gutowsky, *Inorg. Syn.* **4**, 145 (1953).

Orthorhombic needles. d_4^{25} 4.29. Dec at 300°. Heat of formation (solid) −677.42 kcal/mol. Soly in water (g/100 ml H_2O): 0.015 (0°); 0.0235 (25°); 0.091 (100°). Prolonged contact with water produces hydrolysis which is much accelerated by the presence of alkali. Slightly sol in dil acids; sol in ammonium chloride soln; practically insol in alc.

USE: Prepn of silicon tetrafluoride; as pesticide. *Caution:* Highly toxic, especially when brought into soln by alkali.

977. Barium Hydroxide. Barium hydrate; caustic baryta. BaH_2O_2; mol wt 171.38. Ba 80.15%, H 1.18%, O 18.67%. $Ba(OH)_2$. Prepn: *Gmelin's, Barium* (8th ed) **30**, 106-111 and supplement 175-177, 289 (1960).

Monohydrate, *dried barium hydroxide.* Usually contains 92-95% $Ba(OH)_2.H_2O$. White powder. *Poisonous!* d 3.743. Slightly sol in water; sol in dil acids.

Octahydrate, transparent crystals or white masses. Very alkaline; rapidly absorbs CO_2 from air, becoming incompletely sol in water. *Poisonous!* mp 78°. Freely sol in water;

methanol; slightly sol in ethanol. *Keep tightly closed.*

USE: In manuf of alkali, glass, ization, in corrosion inhibitor pesticides, sugar industry; b animal and vegetable oils; soa

978. Barium Hypophosph 267.34. Ba 51.38%, H 1.51%, $PO_2)_2$. Prepd by treating white droxide: $8P + 3Ba(OH)_2.8H$ $H_2O + 2PH_3$: Rose, *Pogg. A Handbook of Preparative Ino* Brauer, Ed. (Academic Press p 557.

Monohydrate, monoclinic from hot water. *Poisonous!* d 28.6 (17°); 33.3 (100°). Practi

USE: In nickel plating.

979. Barium Iodate. Ba 28.19%, I 52.10%, O 19.71%. Yasada, *Inorg. Syn.* 7, 13 (19

Monohydrate, crystals; bec *Poisonous!* Sol in 3350 parts water; sol in HCl or HNO_3

980. Barium Iodide. BaI 64.89%. Prepn: *Gmelin's* (1932) and supplement, 394 (

Dihydrate, colorless, odo white granules; rapidly becor liberation of iodine. *Poisonou* the aq soln is neutral or slig acetone. *Keep well closed an*

USE: In the manuf of other

981. Barium Manganate tel's green; Rosenstiehl's gre Ba 53.60%, Mn 21.43%, O Stems, *J. Am. Chem. Soc.* **46**, *Nucl. Chem.* **13**, 329 (1960); N **11**, 56 (1968); Bayan, Aymor

Dark green powder. d 4.8 or dil acid to form $Ba(MnO_4$

USE: As pigment in fresc green because not so poisono

982. Barium Mercuric I rate(II); mercuric barium io Ba 16.24%, Hg 23.72%, I 60.

Yellow or reddish, delique even when kept in sealed tube alc. *Keep well closed!*

USE: As an aq soln known rating minerals of different d of 3.5; also for microchemica

983. Barium Nitrate. 52.55%, N 10.72%, O 36.73% *Barium* (8th ed) **30**, 149-15 179, 305 (1960).

Crystals or cryst powder. 590°; dec at higher temp. F sol in alcohol, acetone. LD Ba^{2+}/kg, Syed, Hosain, *To* (1972).

USE: Manuf BaO_2; pyrotec lights; in the vacuum-tube ir

984. Barium Nitrite. 39.88%, N 12.21%, O 27.90% *Barium* (8th ed) **30**, 144-14 Monohydrate, crystals. *P* practically insol in alc.

USE: In diazotization react and bars; in explosives.

985. Barium Oxalate. aO_4; mol wt 225.38. C C_2O_4. Prepn: *Gmelin's* 32) and supplement, 480 Monohydrate, cryst powc

ethanol; slightly sol in ethanol; practically insol in acetone. *Keep tightly closed.*

USE: In manuf of alkali, glass; in synthetic rubber vulcanization, in corrosion inhibitors, drilling fluids, lubricants, pesticides, sugar industry; boiler scale remedy; refining animal and vegetable oils; softening water; fresco painting.

978. Barium Hypophosphite. $BaH_4O_4P_2$; mol wt 267.34. Ba 51.38%, H 1.51%, O 23.94%, P 23.17%. $Ba(H_2PO_2)_2$. Prepd by treating white phosphorus with barium hydroxide: $8P + 3Ba(OH)_2.8H_2O + H_2O \rightarrow 3Ba(H_2PO_2)_2 + H_2O + 2PH_3$: Rose, *Pogg. Ann.* **9**, 370 (1827); Klement in *Handbook of Preparative Inorganic Chemistry*, Vol. 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 557.

Monohydrate, monoclinic platelets with nacreous sheen from hot water. *Poisonous!* d_4^{17} 2.90. Soly (g/100 ml H_2O): 28.6 (17°); 33.3 (100°). Practically insol in alcohol.

USE: In nickel plating.

979. Barium Iodate. BaI_2O_6; mol wt 487.18. Ba 28.19%, I 52.10%, O 19.71%. $Ba(IO_3)_2$. Prepn: Lambert, Yasada, *Inorg. Syn.* **7**, 13 (1963).

Monohydrate, crystals; becomes anhydr at 130°. d 5.00. *Poisonous!* Sol in 3350 parts water at 25°, 625 parts boiling water; sol in HCl or HNO_3; practically insol in alcohol.

980. Barium Iodide. BaI_2; mol wt 391.18. Ba 35.11%, I 64.89%. Prepn: *Gmelin's, Barium* (8th ed) **30**, 238-239 (1932) and supplement, 394 (1960).

Dihydrate, colorless, odorless, transparent crystals or white granules; rapidly becomes reddish in the air due to liberation of iodine. *Poisonous!* d 5.15. Freely sol in water; the aq soln is neutral or slightly alkaline. Sol in alcohol, acetone. *Keep well closed and protected from light.*

USE: In the manuf of other iodides.

981. Barium Manganate(VI). Manganese green; Cassel's green; Rosenstiehl's green. $BaMnO_4$; mol wt 256.29. Ba 53.60%, Mn 21.43%, O 24.97%. Prepn: Schlesinger, Stems, *J. Am. Chem. Soc.* **46**, 1965 (1924); Jellinek, *J. Inorg. Nucl. Chem.* **13**, 329 (1960); Nyholm, Woolliams, *Inorg. Syn.* **11**, 56 (1968); Bayan, Aymonino, *Ber.* **101**, 3337 (1968).

Dark green powder. d 4.85. Disproportionates in water or dil acid to form $Ba(MnO_4)_2$ and MnO_2.

USE: As pigment in fresco painting instead of Scheele's green because not so poisonous as latter.

982. Barium Mercuric Iodide. Barium tetraiodomercurate(II); mercuric barium iodide. $BaHgI_4$; mol wt 845.65. Ba 16.24%, Hg 23.72%, I 60.03%.

Yellow or reddish, deliquesc crystals; said to become red even when kept in sealed tubes. *Poison!* Very sol in water or alc. *Keep well closed!*

USE: As an aq soln known as *Rohrbach's Soln*, for separating minerals of different densities the concd soln has a d of 3.5; also for microchemical detection of alkaloids.

983. Barium Nitrate. BaN_2O_6; mol wt 261.38. Ba 52.55%, N 10.72%, O 36.73%. $Ba(NO_3)_2$. Prepn: *Gmelin's, Barium* (8th ed) **30**, 149-151 (1932) and supplement, 178-179, 305 (1960).

Crystals or cryst powder. *Poisonous!* d 3.24. mp about 590°; dec at higher temp. Freely sol in water; very slightly sol in alcohol, acetone. LD_{50} i.v. in ICR mice: 20.10 mg Ba^{2+}/kg, Syed, Hosain, *Toxicol. Appl. Pharmacol.* **22**, 150 (1972).

USE: Manuf BaO_2; pyrotechnics for green fire; green signal lights; in the vacuum-tube industry.

984. Barium Nitrite. BaN_2O_4; mol wt 229.38. Ba 59.88%, N 12.21%, O 27.90%. $Ba(NO_2)_2$. Prepn: *Gmelin's, Barium* (8th ed) **30**, 144-147 (1932) and suppl, 303 (1960).

Monohydrate, crystals. *Poisonous!* d 3.187. Sol in water; practically insol in alc.

USE: In diazotization reactions; prevention of corrosion of steel bars; in explosives.

985. Barium Oxalate. *Ethanedioic acid barium salt.* C_2BaO_4; mol wt 225.38. C 10.66%, Ba 60.95%, O 28.40%. BaC_2O_4. Prepn: *Gmelin's, Barium* (8th ed) **30**, 320-323 (1932) and supplement, 480-482 (1960).

Monohydrate, cryst powder. *Poisonous!* d 2.66. Sol in 10,000 parts cold, 5000 parts boiling water; sol in dil HNO_3 or HCl.

986. Barium Oxide. Barium monoxide; barium protoxide; calcined baryta. BaO; mol wt 153.36. Ba 89.57%, O 10.43%. Prepn: Ehrlich in *Handbook of Preparative Inorganic Chemistry*, vol. 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 933.

White to yellowish-white powder or lumps. Very alkaline; absorbs moisture and CO_2 on exposure to air. *Poisonous!* On contact with water it forms $Ba(OH)_2$ with evolution of much heat. At 450° combines with oxygen to form BaO_2, which is reduced to BaO above 600°. d 5.7. mp about 1920°. Sol in water, dil acids. Slowly, but considerably sol in methanol, ethanol forming barium alcoholate. *Keep tightly closed.*

USE: Porous grades are marketed especially for drying gases and solvents (particularly alcohols, aldehydes and petroleum solvents). Swells, but does not become sticky upon absorption of moisture. Used in manuf of lubricating oil detergents. Also used for making barium methoxide.

987. Barium Perchlorate. $BaCl_2O_8$; mol wt 336.27. Ba 40.85%, Cl 21.09%, O 38.06%. $Ba(ClO_4)_2$. Prepn: *Gmelin's, Barium* (8th ed) **30**, 218 (1932) and supplement, 373 (1960).

Trihydrate, crystals. *Poisonous!* Sol in water, methanol; slightly sol in ethanol, ethyl acetate, acetone; practically insol in ether.

USE: In the determination of ribonuclease; as absorbent for water in C and H analysis.

988. Barium Permanganate. Barium manganate(VII). $BaMn_2O_8$; mol wt 375.22. Ba 36.61%, Mn 29.28%, O 34.12%. $Ba(MnO_4)_2$. Prepn: Lux in *Handbook of Preparative Inorganic Chemistry*, vol. 1, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 1462.

Brownish-violet to black crystals. *Poisonous!* d 3.77. Sparingly sol in water; dec by alcohol.

USE: As dry cell depolarizer.

989. Barium Peroxide. Barium dioxide; barium superoxide. BaO_2; mol wt 169.36. Ba 81.11%, O 18.89%. Prepn: *Gmelin's, Barium* (8th ed) **30**, 92-98 (1932) and supplement, 177, 296 (1960). The article of commerce contains about 85% BaO_2; the remainder is chiefly BaO.

White or grayish-white, heavy powder. *Poisonous!* Dec slowly in air. Insol in water, but slowly dec by contact with it; dec by dil acid or CO_2 in presence of H_2O forming H_2O_2. Combines with water to form octahydrate. *Keep well closed.*

USE: Bleaching animal substances, vegetable fibers and straw; glass decolorizer; manuf H_2O_2 and oxygen; dyeing and printing textiles; with powdered aluminum in welding; in cathodes; in igniter compositions. Oxidizing agent in organic synthesis.

990. Barium Phosphate, Dibasic. Secondary barium phosphate. $BaHO_4P$; mol wt 233.35. Ba 58.86%, H 0.43%, O 27.43%, P 13.28%. $BaHPO_4$. Prepn: *Gmelin's, Barium* (8th ed) **30**, 340 (1932) and supplement, 492 (1960).

Crystals. *Poisonous!* d 4.16. Practically insol in water; sol in dil HCl or HNO_3.

USE: In fireproofing compositions; in prepn of phosphors.

991. Barium Platinous Cyanide. Barium tetracyanoplatinate(II); barium cyanoplatinate(II); barium platinocyanide; platinous barium cyanide. C_4BaN_4Pt; mol wt 436.66. C 11.00%, Ba 31.46%, N 12.83%, Pt 44.71%. $BaPt(CN)_4$.

Tetrahydrate, large dichroic crystals; yellowish-green by transmitted, bluish-violet by reflected light. *Poison!* d 3.05. Sol in about 35 parts water; more sol in hot water.

USE: An aq soln mixed with some adhesive and painted on paper or wood exhibits luminescence when exposed to the invisible ultraviolet rays of the spectrum or to Roentgen, radium, or cathode rays; hence used in radiography for making x-ray screens.

992. Barium Selenide. BaSe; mol wt 216.32. Ba 63.50%, Se 36.50%. Prepn: Henglein, *Z. Anorg. Chem.* **120**, 77 (1921); *Z. Electrochem.* **30**, 11 (1924); *Gmelin's, Barium* (8th ed) **30**, 290 (1932) and supplement, 453 (1960).

Cubic microcrystalline powder. d 5.02. Turns red on exposure to air. Dec in water.

...ic acid: Akhmedli, Negretov, ...5 (1950).
...crystals or gray-green powder, ...O and CO_2. Sol in water; concd ... t light, red under transmitted

...skeins; in leather tanning and

... *Chromium hydroxide;* chro... hydrous. CrH_3O_3; mol wt ... O 46.59%. $Cr(OH)_3$. Occurs ...Kuthroff, *Inorg. Syn.* 2, 190 *Handbook of Preparative Inorganic* ...ner, Ed. (Academic Press, New ...-1346.
... or $Cr_2O_3.9H_2O$, blue-green ... water; sol in dil mineral acids blue or green soln; becomes insol

...ous, jet-black particles. Use... tion of alcohols and paraffins,

...nning industry; as mordant; as ns.

...rN_3O_9; mol wt 238.03. Cr ... $Cr(NO_3)_3$. Prepn of anhydr ...6. Addison, Chapma, *J. Chem.* ...nahydrate from $Cr(OH)_3$ and dil ...rO_3 in the presence of HNO_3; ...d., A.C.S. Monograph Series, ... 1956) pp 203-204.
...uesc powder. Non-volatile. ...er, ethyl acetate, DMSO; practi... $CHCl_3$; reacts with ether, some-

...hombic, monoclinic crystals. ... Sol in water, alcohol. Aq ...on heating and rapidly recovers ...cooling. LD_{50} in rats: 3.25 g/kg ...rd *Hyg. Assoc. J.* 30, 470 (1969). ... in textile printing; corrosion

...Anadonis green; chrome green; ...de green; green cinnabar; green ...e; leaf green; oil green; ultra...reen 17; C.I. 77288. Cr_2O_3; ... 31.57%. Prepd by reaction of ...omate with sulfur: Copson in ...y, Ed., ACS Monograph Series ..., 1956) pp 277-278. *Review:* ...2), 11 (1955). *See also Colour* ... 4662.
... hexagonal crystals. mp about ...22. Turns brown on heating but ...oling. Cryst Cr_2O_3 is extremely ... to zircon. Practically insol in ... in acids, alkalies.
... materials, electric semicon...larly in coloring glass; in alloys; ...tes; as catalyst for organic and

... CrO_4P; mol wt 146.99. Cr ...%. $CrPO_4$. Prepn: Ness *et al., J.* ...(1952); Eickhoff, Kebrich, U.S. ...nal Lead); Wegenknecht, Ger. ... 34 (1959).
... s of amorphous solid. Does ...4. Partially oxidizes to CrO_3 on ...nsol in water, acetic acid, HCl,

... *lon's green, Plessy's green.* ...actically insol in water; sol in

...als. Loses water gradually on ...fter one hour at 800° or 3-4 hrs ...l insol in water; slightly sol in ... acid solns; readily sol in mineral acids, alkalis, oxalic ... solns.
... radioactive form, $Cr^{32}PO_4$. *Phosphocol.*
... Green pigment; in wash primers; in catalysts for de...hydrogenation of hydrocarbons or polymerization of olefins.
THERAP CAT: $Cr^{32}PO_4$ as radioactive agent.

2208. Chromic Potassium Oxalate. *Tripotassium tris-(ethanedioato)chromate(3−); tripotassium tris(oxalato)chromate(3−);* potassium trioxalatochromate(III); potassium chromic oxalate. $C_6CrK_3O_{12}$; mol wt 433.38. C 16.63%, Cr 12.00%, K 27.06%, O 44.30%. $K_3[Cr(C_2O_4)_3]$. Prepd by treatment of oxalic acid and $K_2C_2O_4$ with $K_2Cr_2O_7$: Bailar, Jr., Jones, *Inorg. Syn.* 1, 37 (1939); Hein, Herzog in *Handbook of Preparative Inorganic Chemistry* vol. 2, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1965) p 1372.

Trihydrate, *potassium trioxalatotriaquochromate(III).* Black-green, monoclinic scales with transparent blue edges. Freely sol in water; practically insol in alcohol.

USE: In tanning industry; dyeing chromate colors on wool.

2209. Chromic Potassium Sulfate. Potassium chromic sulfate; potassium disulfatochromate(III). $CrKO_8S_2$; mol wt 283.23. Cr 18.36%, K 13.81%, O 45.19%, S 22.64%. $KCr(SO_4)_2$. Dodecahydrate produced by reduction of $K_2Cr_2O_7$ with SO_2: Copson in *Chromium* vol. 1, M. J. Udy, Ed., A.C.S. Monograph Series no. 132 (Reinhold, New York, 1956) p 281; electrolytic manuf: Nishihara *et al.*, Japan. pat. 2164('60), *C.A.* 55, 5200e (1961).

Dodecahydrate, *chrome alum,* $K[Cr(SO_4H_4)_2(H_2O)_2].6H_2O$: Duval, *Chim. Anal. (Paris)* 44, 102 (1962), *C.A.* 57, 9479d (1962). Large, violet-red to black, octahedral, cubic crystals; ruby-red under transmitted light. d^{25} 1.83. mp 89°; at 400° loses all its H_2O. Sol in 4 parts cold, 2 parts boiling water; practically insol in alcohol. The aq soln is violet when cold, green when hot. The violet color returns after a few weeks at room temp.

USE: Mordant for dyeing fabrics uniformly; tanning leather; printing calico; rendering glue and gum insol; manuf ink, other chromium salts; waterproofing fabrics; hardening photographic emulsions.

2210. Chromic Sulfate. $Cr_2O_{12}S_3$; mol wt 392.20. Cr 26.52%, O 48.95%, S 24.52%. $Cr_2(SO_4)_3$. Prepn of anhydr salt by dehydration of hydrated forms: Rollinson, Bailar, Jr., *Inorg. Syn.* 2, 197 (1946).

Peach-colored solid. d 3.012. Practically insol in water and acids. MLD i.v. in mice: 247 mg/kg, *Handbook of Toxicology* vol. 1, W. S. Spector, Ed. (Saunders, Philadelphia, 1956) pp 70-71.

Hydrates are known in both green and violet modifications, and have several degrees of hydration up to $18H_2O$: Lukaszewski, Redfern, *Nature* 190, 805 (1961); Udy in *Chromium* vol. 1, M. J. Udy, Ed., A.C.S. Monograph Series no. 132 (Reinhold, New York, 1956) pp 213-217, 288. The technical product comes in the form of a finely granular, dark-green flake or powder approximating the formula $Cr_2(SO_4)_3.10H_2O$. Readily sol in water; almost insol in alc.

Basic chromic sulfates of the type $Cr(OH)SO_4.nH_2O$ are of importance in the tanning industry: Udy, *loc. cit.* and pp 278-280, 305-308. Technical grades are available in two degrees of basicity, one-third and one-half, as finely granular dark-green flakes or powder contg about 25% Cr_2O_3. Readily sol in water.

USE: Insolubilization of gelatin; in catalyst prepn; as mordant in textile industry; in tanning of leather; in chrome plating; in manuf of Cr, CrO_3, and Cr alloys; to improve dispersibility of vinyl polymers in water; in manuf of green varnishes, paints, inks, glazes for porcelain.

2211. Chromium. Cr; at. wt 51.996; at. no. 24; valences 1-6. Four naturally occurring isotopes: 50 (4.35%); 52 (83.79%); 53 (9.50%); 54 (2.36%); artificial radioactive isotopes: 46-49; 51; 55; 56; longest-lived isotope is ^{51}Cr ($T_{1/2}$ 27.8 days) prepd by (n,γ) reaction from ^{50}Cr. Reported abundance in earth's crust varies from 100 to 300 ppm. Discovered by 1797 by Vauquelin. Obtained from chrome ore, *chromite* ($FeCr_2O_4$), by a silicothermic or aluminothermic process. Reviews of chromium, its alloys and compds: *Chromium*, M. J. Udy, Ed., A.C.S. Monograph Series, no. 132 (Reinhold, New York, 1956) vol. 1, 433 pp; vol. 2, 402 pp; Rollinson, "Chromium, Molybdenum and Tungsten" in *Comprehensive Inorganic Chemistry* vol. 3, J. C. Bailar, Jr. *et al.*, Eds. (Pergamon Press, Oxford, 1973) pp 623-700; J. H. Westbrook in Kirk-Othmer *Encyclopedia of Chemical Technology* vol. 6 (Wiley-Interscience, New York, 3rd ed., 1979) pp 54-82. Important trace element. Review of biological function of the chromium(III) ion: Mertz, *Physiol. Rev.* 49, 163-239 (1969). Review of carcinogenicity studies of chromium and chromium compds: *IARC Monographs* 2, 100-125 (1973); *ibid.* 23, 205-323 (1980).

Steel-gray, lustrous metal; body-centered cubic structure; hard as corundum and less fusible than platinum. Takes a high polish. d 7.14. mp 1900°. bp 2642°. Heat capacity (25°): 5.58 cal/g-atom deg. Latent heat of fusion: approx 3.5 kcal/g-atom; latent heat of vaporization: approx 81.7 kcal/g-atom. Reacts with dil HCl, H_2SO_4; not with HNO_3; attacked by caustic alkalies and alkali carbonates. Not oxidized by air, even in presence of much moisture.

Caution: Chromic acid or chromate salts constitute industrial hazards. Irritant effects on the skin and respiratory passages lead to ulceration. Oral ingestion may lead to severe irritation of the gastrointestinal tract, circulatory shock and renal damage. Chromium(III) compounds show little or no toxicity. This substance and certain chromium compounds have been listed as carcinogens by the EPA: *Second Annual Report on Carcinogens* (NTP 81-43, Dec. 1981) pp 81-87.

USE: In manuf of chrome-steel or chrome-nickel-steel alloys (stainless steel); for greatly increasing resistance and durability of metals; for chromeplating of other metals. The man-made ^{51}Cr isotope as tracer in various blood diseases and in the determination of blood volume (as the chloride or as Na chromate).

2212. Chromium Carbonyl. Chromium hexacarbonyl. C_6CrO_6; mol wt 220.07. C 32.75%, Cr 23.63%, O 43.62%. $Cr(CO)_6$. Prepn from Cr salts and CO in the presence of a Grignard reagent: Owen *et al., Inorg. Syn.* 3, 156 (1950); in the presence of Mg and ether: Wender, U.S. pat. 3,012,858 (1961 to Diamond Alkali); in the presence of Na and diglyme: Podall *et al., J. Am. Chem. Soc.* 83, 2057 (1961); in the presence of Na and an aromatic hydrocarbon: Pruett, Wyman, U.S. pat. 3,053,629 (1962 to Union Carbide); in the presence of I_2 and a nitrile: Wotiz, U.S. pat. 3,100,687 (1963 to Diamond Alkali).

Orthorhombic, highly refractive crystals. Sublimes at room temp. Sinters at 90°; dec at 130°; explodes at 210°. Burns with a luminous flame. d^{18} 1.77. Vapor pressure (mm): 0.04 (0°); 1.0 (48°); 66.5 (100°). Almost insol in water, ethanol, methanol; sol in ether, $CHCl_3$, other organic solvents. Solns or impure solid dec by light. LD_{50} in mice: 100 mg/kg i.v., Strohmeier, *Z. Naturforsch.* 19b, 540 (1964).

USE: In catalysts for olefin polymerization and isomerization; gasoline additive to increase octane number; prepn of chromous oxide, CrO.

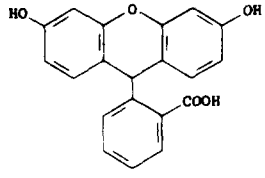
2213. Chromium Dioxide. CrO_2; mol wt 84.00. Cr 61.90%, O 38.10%. Prepn: Wöhler, *Ann.* 111, 117 (1859); Thamer *et al., J. Am. Chem. Soc.* 79, 547 (1957); Swoboda *et al., J. Appl. Phys.* 32, Suppl. no. 3, 374 (1961); Arthur; Arthur, Ingraham, U.S. pats. 2,959,955; 3,117,093 (1960, 1964 both to du Pont). *Reviews:* Hund, *Farbe + Lack* 78, 11-16 (1972); Rollinson in *Comprehensive Inorganic Chemistry* vol 3, J. C. Bailar, Jr. *et al.*, Eds. (Pergamon Press, Oxford, 1973) pp 689-690.

Black, ferromagnetic crystals; rutile structure. d 4.89. Metastable in air; various temperatures (250-500°) reported for decompn to Cr_2O_3.

USE: In magnetic recording tapes; as catalyst.

2214. Chromium Tetrafluoride. CrF_4; mol wt 128.01. Cr 40.63%, F 59.37%. Prepd by reaction of F_2 with Cr or $CrCl_3$: von Wartenberg, *Z. Anorg. Allgem. Chem.* 247, 136 (1941); Clark, Sadana, *Can. J. Chem.* 43, 50 (1964).

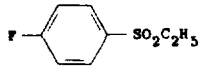
Very dark greenish-black, amorphous solid; on exposure to moist air becomes brown on surface due to hydrolysis. mp (estimated) 277°: Fergusson in *Halogen Chemistry* Vol. 3, V. Gutmann, Ed. (Academic Press, New York, 1967) p 242. bp about 400° evolving steel-blue vapor; sublimes *in vacuo* above 100°; d 2.89. Less reactive than CrF_3; does not readily form Werner complexes; does not react with NH_3,



Bright yellow powder, mp 125-127°. Readily oxidizes to fluorescein. Practically insol in water; sol in alkali hydroxides or carbonates, alcohol, ether. *Keep well closed.*

USE: Reagent for oxidases, peroxides.

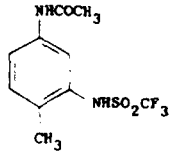
4064. Fluoresone. *1-(Ethylsulfonyl)-4-fluorobenzene; ethyl p-fluorophenyl sulfone; p*-fluorophenyl ethyl sulfone; Bripadon; Caducid. $C_8H_9FO_2S$; mol wt 188.24. C 51.05%, H 4.82%, F 10.09%, O 17.00%, S 17.04%. Prepn: G. Thuillier *et al., Compt. Rend.* **248**, 2492 (1959); P. Rumpf, G. Thuillier, Fr. pat. M399 corresp to U.S. pat. **3,084,101** (1962, 1963 both to Centre Nat. Recher. Scient.); A. A. Mignot, P. Rumpf, *Bull. Soc. Chim. France* **1968**, 435. Pharmacology: J. Thuillier *et al., Proc. Meeting Coll. Int. Neuropsychopharmacol., 3rd. Munich* **1962**, 317-326 (Publ. 1964). Clinical evaluation: H. Akimoto, S. Taen, *ibid.* 326. Gas chromatography: E. Marozzi *et al., Farmaco Ed. Prat.* **31**, 180 (1976).



Crystals, mp 41°. LD_{50} orally in mice: 2.5 g/kg, G. Thuillier *et al., loc. cit.*, also reported as 850 mg/kg, J. Thuillier *et al., loc. cit.*; 542 mg/kg, H. Akimoto, S. Taen, *loc. cit.*

THERAP CAT: Anti-epileptic; tranquilizer.

4065. Fluoridamid. *N-[4-Methyl-3-[[(trifluoromethyl)-sulfonyl]amino]phenyl]acetamide;* 5-acetamido-2-methyltrifluoromethanesulfonanilide; 3-trifluorosulfonamido-*p*-acetotoluidide; Sustar. $C_{10}H_{11}F_3N_2O_3S$; mol wt 296.27. C 40.54%, H 3.74%, F 19.24%, N 9.45%, O 16.20%, S 10.82%. Prepn: Harrington *et al.*, U.S. pat. **3,639,474** (1972 to Minnesota Mining & Mfg).



mp 175-176.5°.

USE: Plant growth retardant.

4066. Fluorine. F; at. wt 18.998403; at. no. 9; valence 1; elemental state F_2. A halogen. Occurrence in earth's crust 0.065% by wt. Natural abundance of isotopes: ^{19}F 100%; ^{18}F ($T_{1/2}$ 109.7 min) is prepared in nuclear reactors. Does not occur in elemental state in nature. Most important sources are fluorite, cryolite and florapatite, *q.v.*: Finger, "Fluorine Resources and Fluorine Utilization" in *Advances in Fluorine Chemistry*, **vol. 2**, M. Stacey *et al.*, Eds. (Butterworths, London, 1961) pp 35-54. Discovered in 1771 by Scheele. Isolated in 1886 by electrolyzing a soln of potassium fluoride in anhydr hydrogen fluoride at −23°, using platinum-iridium electrodes: Moissan, *Compt. Rend.* **102**, 1543 (1886); **103**, 202, 256. Subsequent methods of prepn: Ruff, *Ber.* **69**, 181 (1936); Henne, *J. Am. Chem. Soc.* **60**, 96 (1938). ^{18}F has been used to study fluorine exchange reactions: Dave, Sowerby, "Isotopic Halogen Exchange Reactions" in *Halogen Chemistry*, **vol. 1**, V. Gutmann, Ed. (Academic Press, New York, 1967) pp 41-132. *Reviews:* A. J. Rudge, *The Manufacture and Use of Fluorine and its Compounds* (Oxford University Press, 1962); O'Donnell, "Fluorine" in *Comprehensive Inorganic Chemistry*, **vol. 2**, J. C. Bailar, Jr. *et al.*, Eds. (Pergamon Press, Oxford, 1973) pp 1009-1106; A. J. Woytek in Kirk-Othmer *Encyclopedia of Chemical Technology* **vol. 10** (Wiley-Interscience, New York, 3rd ed., 1980) pp 630-654.

Pale yellow, diatomic gas. mp −219.61° (53.54°K); bp −188.13° (85.02°K); d (liq, −188.13°) 1.5127; vapor pressure data: Hu *et al., J. Am. Chem. Soc.* **75**, 5642 (1953); White *et al., ibid.* **76**, 2584 (1954). Crit temp: −129°; crit pressure: 55 atm. Most reactive nonmetal; higher oxidation potential than ozone; most electronegative element; E° (calc) $\frac{1}{2}F/F^-$ 2.9 V. F-F bond weaker than Cl-Cl and Br-Br bonds; enthalpy of dissociation: 37.7 kcal. Reacts vigorously with most oxidizable substances at room temp, frequently with ignition. Combines directly or indirectly, to form fluorides with all the elements except helium, neon and argon. Dec water, giving hydrofluoric acid, HF, oxygen fluoride, OF_2, hydrogen peroxide, oxygen and ozone. Reacts with nitric acid, forming the explosive gas, fluorine nitrate, NO_2F; with sulfuric acid, giving fluorosulfuric acid, $HFSO_3$. Yields the metal fluorides, water, oxygen and oxygen fluoride when made to react with metal hydroxides in the cold. Reacts violently with organic compds, usually with disintegration of the molecule. Under controlled conditions, however, hydrocarbon vapors may be fluorinated with elemental fluorine. Solid fluorine explodes when brought in contact with liquid hydrogen. Under ordinary conditions it does not react directly with oxygen, nor does it react with oxides of sodium, potassium or calcium. LC_{50} (1 hr) inhalation by rats, mice, guinea pigs: 185, 150, 170 ppm (by vol). Keplinger, Suissa, *Am. Ind. Hyg. Assoc. J.* **29**, 10 (1968).

Caution: Dangerous to inhale. Strong caustic action on eyes, skin, mucous membranes. Chronic absorption can cause mottled enamel of teeth, osteosclerosis and calcification of ligaments.

4067. Fluorine Dioxide. Dioxygen difluoride. F_2O_2; mol wt 70.00. F 54.29%, O 45.71%. Prepd from O_2 and F_2: Ruff, Menzel, *Z. Anorg. Allgem. Chem.* **211**, 204 (1933); **217**, 85 (1934); Goetschel *et al., J. Am. Chem. Soc.* **91**, 4702 (1969). Chemical behavior: Streng, *ibid.* **85**, 130 (1963). *Review:* Kemmitt, Sharp, *Advan. Fluorine Chem.* **4**, 214-215 (1965).

Thermally unstable gas at room temp; begins to dec into fluorine and oxygen at −100°. Pale yellow solid or yellow liq at low temp. mp −154°C (119°K). Early prepns, described as brown gas, red liq and orange solid (mp −163.5°), probably contained other fluorine-oxygen compounds as impurities: Goetschel *et al., loc. cit.* Strong oxidizing and fluorinating agent.

4068. Fluorine Monoxide. *Oxygen fluoride;* fluorine oxide. F_2O; mol wt 54.00. F 70.37%, O 29.63%. Prepd by passing fluorine slowly through an aq NaOH soln: Yost, *Inorg. Syn.* **1**, 109 (1939); Schnizlein *et al., J. Phys. Chem.* **56**, 233 (1952). *Review:* Kemmitt, Sharp, *Advan. Fluorine Chem.* **4**, 213-314 (1965).

Colorless gas. Yellowish-brown when liq. Peculiar smell. *Attacks lungs. More poisonous than fluorine; delayed appearance of symptoms.* Does not attack glass in the cold. Corrodes mercury. Reacts very slowly with water. The gas may be kept over water unchanged for a month. d (liq; −224°) 1.90. mp −223.8°. bp −145.3°. Trouton constant 20.65. Soly in water (0°) 6.8 ml gas/100 ml H_2O. LC_{50} (1 hr) inhalation by rats, mice: 2.6, 1.5 ppm; Darmer *et al., Am. Ind. Hyg. Assoc. J.* **33**, 661 (1972).

4069. Fluorine Nitrate. *Nitroxy fluoride;* nitrogen trioxyfluoride; nitryl hypofluorite. FNO_3; mol wt 81.01. F 23.45%, N 17.29%, O 59.25%. $FONO_2$. Prepd by the action of fluorine on nitric acid: Cady, *J. Am. Chem. Soc.* **56**, 2635 (1934); Ruff, Kwasnik, *Angew. Chem.* **48**, 238 (1935); Kwasnik in *Handbook of Preparative Inorganic Chemistry*, **vol. 1**, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) pp 187-189. *Reviews:* Kemmitt, Sharp, *Advan. Fluorine Chem.* **4**, 216-218 (1965); Woolf, *ibid.* **5**, 1-30 (1965); Schmutzler, *Angew. Chem. Int. Ed.* **7**, 440-455 (1968).

Colorless gas. Moldy, acrid odor. mp −175°. bp −45.9°. d (liq at bp) 1.507. $d^{-193.3}$ (solid) 1.951. Trouton const 20.8. The liq explodes on slight percussion. Hydrolyzed by water to OF_2, O_2, HF and HNO_3. Sol in acetone. Conflagrates on contact with alcohol, ether, aniline. May be stored in vacuum-sealed glass ampuls cooled by liq oxygen. Powerful oxidizing agent.

USE: Oxidizing agent in r

4070. Fluorine Perchlor $ClFO_4$; mol wt 118.46. Cl $FOClO_3$. Prepd by passing chloric acid in platinum app *Chem. Soc.* **69**, 677 (1947).

Colorless gas. Pungent, a *traces.* Explodes on the sli tact with rough surfaces, d distilling, etc. mp −167.3°

4071. Fluoroacetamide. fluoroacetamide; 1081; Flu mol wt 77.06. C 31.17%, H 20.76%. CH_2FCONH_2. fluoroacetyl chloride and N **70**, 2828 (1948).

Crystals. Sublimes on he acetone; sparingly sol in chl mg/kg.

USE: Rodenticide. Insect fruits to combat scale insec

4072. Fluoroacetic Acid poison. $C_2H_3FO_2$; mol wt 24.35%, O 41.00%. CH_2F *Dichapetalum cymosum* (H Hook.), *Dichapetalaceae*, or habitat South Africa. Pre heating with silver fluorid methyl chloroacetate by h followed by saponification Swarts, *Bull. Soc. Chim.* [3 Trochimowski *et al., Rec.* view and biochemical aspe (1954); Peters *et al., Bioche* toxicity: *Clinical Toxicolog* Gosselin *et al.*, Eds. (Williar 1976) Section III, pp 163-460-462 (1973).

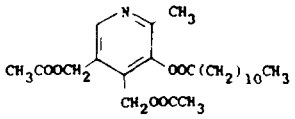
Crystals. Burns with a g Sodium salt, C_2H_2FNaO A fine white powder, sol in Methyl ester, CH_2FCOC d_4^{25} 1.1613. bp 104.5°. Sol i Ethyl ester, CH_2FCOOC $d^{20.5}$ 1.0926. bp_{758} 121.6°.

USE: The sodium salt is cide. *Caution:* Extremely ventricular fibrillation. Or mated to be 2-5 mg/kg h where inhalation or food co it is an irritant.

4073. 3-Fluoro-D-alani noic acid; FA. C_3H_6FNO 5.65%, F 17.74%, N 13.08 photofluorination of D-ala form: Kollonitsch, Kahar 867; 2,229,245 (both 19 100053p (1972); 78, 72586 ture 243, 346 (1973); Kollc to Merck & Co.). The 2- prepared.

Crystals from water, dec ...C). Stable at acid pH; ... THERAP CAT: Exptl antib

4074. p-Fluoroaniline. ...l wt 111.12. C 64.85% ...d by reduction of 1 ...al: Benington *et al.*, ...er *et al., J. Am. Chem*



Crystals, mp 44°. Practically insol in water; sol in ether, chloroform, ethanol, ethylene dichloride.

THERAP CAT: Antiseborrheic.

5221. Lauryl Bromide. *1-Bromododecane;* dodecyl bromide. $C_{12}H_{25}Br$; mol wt 249.24. C 57.82%, H 10.11%, Br 32.06%. $CH_3(CH_2)_{10}CH_2Br$. Prepd by the action of hydrobromic acid on primary *n*-lauryl alcohol in the presence of sulfuric acid: Kamm, Marvel, *Org. Syn.* **1**, 7 (1921).

Liquid. bp_{45} 175-180°. Insol in water. Sol in alc, ether.

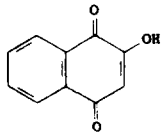
5222. Lavender. Garden lavender; true lavender. Flowers of *Lavandula officinalis* Chaix (*L. vera* DC.), *Labiatae. Habit.* Mediterranean region. *Constit.* Volatile oil.

USE: For fumigating; in perfumery; to keep moths from clothes; manuf oil lavender.

THERAP CAT: Pharmaceutic aid (perfume).

5223. Lawrencium. Lr; formerly Lw; at. wt (longest-lived known isotope, $T_{1/2}$ ~ 3 minutes) 260; at. no. 103; valence 3. Known isotopes 255-260. Discovery of first isotope claimed by Ghiorso *et al., Phys. Rev. Letters* **6**, 473 (1961). Prepared by bombardment of californium with boron ions; originally assigned mass number 257; later changed to 258 ($T_{1/2}$ 4.2 seconds, α-emitter): Eskola *et al., Phys. Rev. C* **4**, 632 (1971). Prepn of ^{256}Lr ($T_{1/2}$ ~ 45 seconds) by irradiating ^{243}Am with ^{18}O ions: Donets *et al., At. Energ. (USSR)* **19**, 109 (1965), *C.A.* **64**, 1542c (1966). Prepn of isotopes 255-260 by bombardment of transuranium elements with heavy ions: Eskola *et al., loc. cit.* Reviews of history, prepn and properties: C. Keller, *The Chemistry of the Transuranium Elements* (Verlag Chemie, Weinheim, English Ed., 1971) pp 609-612; Silva, "Trans-Curium Elements" in *MFP Int. Rev. Sci.: Inorg. Chem., Ser. One* vol. 8, A. G. Maddock, Ed. (University Park Press, Baltimore, 1972) pp 71-105; Ghiorso, *Handb. Exp. Pharmakol.* **36**, 691-715 (1973); Taylor, *ibid.* 717-738.

5224. Lawsone. *2-Hydroxy-1,4-naphthalenedione; 2-hydroxy-1,4-naphthoquinone.* $C_{10}H_6O_3$; mol wt 174.15. C 68.96%, H 3.47%, O 27.56%. From leaves of *Lawsonia inermis* L. and *L. alba* Lam., *Lythraceae:* Latif, *Indian J. Agr. Sci.* **29**, No. 2-3, 147 (1959), *C.A.* **55**, 14828g (1961). Synthesis: Fieser, *J. Am. Chem. Soc.* **70**, 3165 (1948); Jain, Seshadri, *Proc. Indian Acad. Sci.* **35A**, 233 (1952); Eistert, Müller, *Ber.* **92**, 2071 (1959).



Yellow prisms from acetic acid, dec 195-196°.

THERAP CAT: Sunscreen agent.

5225. Lazurite. Lapis lazuli; lasurite. Composition: $(Na,Ca)_4(AlSiO_4)_3(SO_4,S,Cl)$, E. S. Dana, *A System of Mineralogy* (John Wiley, New York, 6th ed., 1901) pp 432-433; C. S. Hurlbut, Jr., *Dana's Manual of Mineralogy* (John Wiley, New York, 17th ed., 1959) p 503.

Blue, blue-violet or greenish-blue, translucent, cubic or dodecahedral crystals. d 2.4. Dec by HCl with pptn of SiO_2 and evolution of H_2S.

USE: In manuf of vases, ornamental furniture, mosaics; in paints, jewelry.

5226. LBF. Lactobacillus bulgaricus factor. Growth factor occurring in products derived from both animal and plant sources and in culture filtrate of certain microorganisms: Williams *et al., J. Biol. Chem.* **177**, 933 (1949); Vitucci *et al., Arch. Biochem. Biophys.* **34**, 409 (1951); Peters *et al., J. Am. Chem. Soc.* **75**, 1688 (1953). Contains pantetheine *q.v.* which is oxidized during purification to the disulfide, pantethine *q.v.* Natural occurrence of several different forms of LBF each being a mixed disulfide of pantetheine: Rasmussen *et al., Proc. Soc. Exp. Biol. Med.* **73**, 658 (1950); Brown, Snell, *J. Biol. Chem.* **198**, 375 (1952). Coenzyme A digested with intestinal phosphatase shows 2-4 LBF-active components: Long, Williams, *J. Bacteriol.* **61**, 195 (1951). *Review:* Snell, Brown, "Pantethine and Related Forms of the Lactobacillus Bulgaricus Factor (LBF)" in *Advan. Enzymol.* **14**, 49-71 (1953).

5227. Lead. Pb; at. wt 207.2; at. no. 82; valence 2, 4. Four naturally occurring isotopes: 204 (1.40%); 206 (25.2%); 207 (21.7%); 208 (51.7%); artificial, radioactive isotopes: 195-203; 205; 209-214. One of the metals known to the ancient world. Extent of occurrence in earth's crust about 15 g/ton, also expressed as 0.002% (depth of crust: 16 km). Occurs chiefly as sulfide in galena, other minerals include anglesite ($PbSO_4$), *cerussite* ($PbCO_3$), *mimetite* [$PbCl_2.3Pb_3(AsO_4)_2$] and *pyromorphite* [$PbCl_2.3Pb_3(PO_4)_2$]. Recovery from ore and purification: Heuser, *Metall.* **9**, 675 (1955); *C.A.* **49**, 14609 (1955); Ziegfeld, *Eng. Mining J.* **153**, 82 (1952), *C.A.* **46**, 2975 (1952). Prepn of high purity lead: Piontelli, Fagnani, *Chim. Ind. (Milan)* **34**, 629 (1952), *C.A.* **47**, 12062 (1953); Giesen, *Technik (Berlin)* **2**, 393 (1947), *C.A.* **42**, 852 (1948); Hughes *J. Electrochem. Soc.* **101**, 267 (1954); Baralis, Marone, *Met. Ital.* **59**, 494 (1967), *C.A.* **67**, 119613a (1967). Reviews of lead, its alloys and compds: W. Hofmann, *Lead and Lead Alloys, Properties and Technology* (Springer, New York, Eng. Ed., 1970) 551 pp; Abel in *Comprehensive Inorganic Chemistry* vol. 2, J. C. Bailar, Jr. *et al.* Eds. (Pergamon Press, Oxford, 1973) pp 105-146; H. E. Howe in Kirk-Othmer *Encyclopedia of Chemical Technology* vol. 14 (Wiley-Interscience, New York, 3rd ed., 1981) pp 98-139. Review of carcinogenicity studies of lead and lead compds: *IARC Monographs* **23**, 325-415 (1980).

Bluish-white, silvery, gray metal. Highly lustrous when freshly cut, tarnishes upon exposure to air. Very soft and malleable, easily melted, cast, rolled, and extruded. Cubic crystal structure. mp 327.4°; bp 1740°. d_4^{20} 11.34; d at mp 10.65: Schneider *et al., Naturwiss.* **41**, 326 (1954). Heat of vaporization (1740°) 206 cal/g. Heat capacity (20°): 0.031 cal/g/°C. Resistivity (μ-ohm-cm) at 20°: 20.65; at 100°: 27.02; at 320°: 54.76; at 330°: 96.74. Vapor pressure at 1000°: 1.77 mm Hg. E° (aq) Pb/Pb^{2+} +0.126 v. Coefficient of linear expansion (0-100°) 29 × 10^{-6}, (20-300°) 31.3 × 10^{-6}, (−183° to +14°) 27 × 10^{-6}; thermal conductivity varies from 0.083 at 50° to 0.077 at 225°: Francl, Kingery, *J. Am. Ceram. Soc.* **37**, 80 (1954); viscosity of molten lead (327.4°) 3.2 centipoises, (400°) 2.32 cp, (600°) 1.54 cp, (800°) 1.23 cp. Heat capacity and heat of fusion study: Douglas, Dever, *J. Am. Chem. Soc.* **76**, 4824 (1954); hardness 1 on Mohs' scale; Brinell hardness (high purity Pb) 4.0: McLellan, *Am. Mineralogist* **30**, 635 (1945). Reacts with hot concd nitric acid, with boiling concd hydrochloric or sulfuric acid. Attacked by pure water, weak organic acids in the presence of oxygen. Resistant to tap water, hydrofluoric acid, brine, solvents.

Human Toxicity: Acute: most common in young children with history of pica; anorexia, vomiting, malaise, convulsions due to increased intracranial pressure. May leave permanent brain damage. Blood lead increased above 0.08 mg %. *Chronic:* children show weight loss, weakness, anemia. Lead poisoning in adults is usually occupational due mainly to inhalaton of lead dust or fumes. Wristdrop and colic rarely occur. More often there are vague G.I. and CNS complaints. Pb content of blood > 0.05 mg % and of urine > 0.08 mg per liter support a diagnosis of Pb poisoning. Provocative excretion test using Edathamil may be helpful in confirming excess Pb absorption. Review of toxicity: *Clinical Toxicology of Commercial Products,* R. E. Gosselin *et al.* Eds. (Williams & Wilkins, Baltimore, 4th ed., 1976) Sect. III, pp 194-202; *Lead Toxicity,* R. L. Singhal, J. A. Thomas Eds. (Urban & Schwarzenberg, Baltimore, 1980) 514 pp.

USE: Construction material for tank linings, piping, and other equipment handling corrosive gases and liqs used in the manuf of sulfuric acid, petr refining, halogenation, alkylation, extraction, condensation; for x-ray and atomic radiation protection; manuf of tetraethyllead, pigments for paints, and other organic and inorganic lead compds; ba

metal and alloys; stor
electronic devices; in
other lead alloys; in
tals. *Review* of uses,
Eng. Chem. **49**, 1607

5228. Lead Acetate.
tate; sugar of lead; sa
25.28. C 14.77%, H 1.
$(CH_3COO)_2$.
Trihydrate, colorless cr
t acetic odor; slowly
O_2 from air and become
en rapidly heated; at
tic acid; dec completel
1.6 ml water, 0.5 ml b
l in glycerol. Aq solns
ide. pH of 5% aq soln
mpat: Acids, sol sul
onates, alkalies, tann
phenol, chloral hyc
tures. LD_{50} i.p. in rat
l. Med. **10**, *Ind. Hyg.*
Warning! Avoid brea
oved by U.S. Bureau
oroughly before eating
food products. This su
in the *Second Annu*
Dec. 1981) pp 149-15
: Dyeing and printi
salts, chrome-yellow
es, e.g. detection of
O_2.
ERAP CAT: Astringen
ERAP CAT (VET): Astr
) for bruises and su
internally in diarrhe

5229. Lead Antimona
$(SbO_4)_2$.
Orange-yellow powder.
: As pigment in oil
porcelain.

5230. Lead Arsenate.
ture as the mineral *sch*
White, heavy powder.
s H_2O and is convert
sol in HNO_3, causti
rox 825, 125 mg/kg
c. **37**, 122 (1948).
: As constituent o
y moth, boll weevil.
ERAP CAT (VET): Has

5231. Lead Arsenite.
White powder. *Poison*
HNO_3.
: As insecticide like

5232. Lead Azide. N_6
14%. $Pb(N_3)_2$. Prepd
nk in *Handbook of P*
G. Brauer, Ed. (Acad
) p 763. Most comp
Encyclopedia of Explo
y. Arsenal, Dover, N
adles or white powd
Heat of formation
: 0.023% at 18°: 0.0
in NH_4OH.
As primer in expl
trinated lead azide.

Lead Borate. A
e powder. *Poison*
NO_3.
Drier for varnish
Ag) in galvanopla
s on glass, pottery

ing metal and alloys; storage batteries; in ceramics, plastics, and electronic devices; in building construction; in solder and other lead alloys; in the metallurgy of steel and other metals. *Review* of uses, corrosion metallurgy: Mullarkey, *Ind. Eng. Chem.* **49**, 1607 (1957).

5228. Lead Acetate. Neutral lead acetate; normal lead acetate; sugar of lead; salt of Saturn. $C_4H_6O_4Pb$; mol wt 325.28. C 14.77%, H 1.86%, Pb 63.70%, O 19.67%. $Pb(CH_3COO)_2$.

Trihydrate, colorless crystals or white granules or powder; slight acetic odor; slowly effloresces. *Poisonous!* Takes up CO_2 from air and becomes incompletely sol. d 2.55. mp 75° when rapidly heated; at a little above 100° it begins to lose acetic acid; dec completely above 200°. One gram dissolves in 1.6 ml water, 0.5 ml boiling water, 30 ml alcohol; freely sol in glycerol. Aq solns of lead acetate dissolve lead monoxide. pH of 5% aq soln at 25° = 5.5-6.5. *Keep well closed. Incompat:* Acids, sol sulfates, citrates, tartrates, chlorides, carbonates, alkalies, tannin, phosphates, resorcinol, salicylic acid, phenol, chloral hydrate, sulfites, vegetable infusions, tinctures. LD_{50} i.p. in rats: 200 mg/kg, Bradley, Frederick, *Ind. Med.* **10**, *Ind. Hyg. Sect.* **2**, 15 (1941).

Warning! Avoid breathing dust. Wear dust mask approved by U.S. Bureau of Mines for this purpose. Wash thoroughly before eating or smoking. Keep away from feed or food products. This substance has been listed as a carcinogen in the *Second Annual Report on Carcinogens* (NTP 81-43, Dec. 1981) pp 149-151.

USE: Dyeing and printing cottons; weighting silks; manuf lead salts, chrome-yellow; also for various analytical procedures, *e.g. detection of sulfide, determination of* CrO_3, MoO_3.

THERAP CAT: Astringent.

THERAP CAT (VET): Astringent and sedative (usually in lotions) for bruises and superficial inflammation. Has been used internally in diarrheas.

5229. Lead Antimonate(V). Naples yellow. Approx $Pb_3(SbO_4)_2$.

Orange-yellow powder. Insol in water, dil acids.

USE: As pigment in oil painting, staining glass, crockery and porcelain.

5230. Lead Arsenate. Approx $PbHAsO_4$. Occurs in nature as the mineral *schultenite.*

White, heavy powder. *Poisonous!* d 5.79. At about 280° loses H_2O and is converted into pyroarsenate. Insol in water; sol in HNO_3, caustic alkalies. LD_{50} in rats, rabbits: approx 825, 125 mg/kg orally, Voigt *et al., J. Am. Pharm. Assoc.* **37**, 122 (1948).

USE: As constituent of various insecticides for larvae of gypsy moth, boll weevil, etc.

THLRAP CAT (VET): Has been used as a teniacide; insecticide.

5231. Lead Arsenite. Approx $Pb(AsO_2)_2$.

White powder. *Poisonous!* d 5.85. Insol in water; sol in dil HNO_3.

USE: As insecticide like the arsenate.

5232. Lead Azide. N_6Pb; mol wt 291.26. N 28.86%, Pb 71.14%. $Pb(N_3)_2$. Prepd from sodium azide and lead nitrate: Schenk in *Handbook of Preparative Inorganic Chemistry* **vol. 1**, G. Brauer, Ed. (Academic Press, New York, 2nd ed., 1963) p 763. Most complete description: B. T. Fedoroff *et al., Encyclopedia of Explosives and Related Items* **vol. 1** (Picatinny Arsenal, Dover, N.J., 1960) pp A545-A587.

Needles or white powder. Explodes at 350° or on percussion. Heat of formation (25°): +110.5 kcal/mol. Soly in water: 0.023% at 18°: 0.09% at 70°. Freely sol in acetic acid. Insol in NH_4OH.

USE: As primer in explosives. Generally used in the form of dextrinated lead azide.

5233. Lead Borate. Approx $Pb(BO_2)_2.H_2O$.

White powder. *Poisonous!* Insoluble in water; soluble in dil HNO_3.

USE: Drier for varnishes and paints; with other metals (e.g., Ag) in galvanoplasty for production of conducting coatings on glass, pottery, porcelain, and chinaware.

5234. Lead Bromate. Br_2O_6Pb; mol wt 463.01. Br 34.52%, O 20.73%, Pb 44.75%. $Pb(BrO_3)_2$.

Monohydrate, colorless crystals. *Poisonous!* d 5.53. Dec at 180°. Slightly sol in cold water, moderately in hot water.

Note: Pure lead bromate is not dangerous, but when made by pptng lead acetate with an alkali bromate, it may detonate or explode on heating, striking or rubbing because some acetate is occluded.

5235. Lead Bromide. Br_2Pb; mol wt 367.04. Br 43.55%, Pb 56.45%. $PbBr_2$.

White, cryst powder. *Poisonous!* d 6.66. mp 373°. On solidifying forms a horn-like mass. Sol in about 200 parts cold water, 20 parts boiling water; insol in alcohol.

5236. Lead Butyrate. *Butyric acid, lead salt.* $C_8H_{14}O_4Pb$; mol wt 381.40. C 25.19%, H 3.70%, O 16.78%, Pb 54.33%. $Pb(C_4H_7O_2)_2$.

Colorless scales or viscid mass. *Poisonous!* mp about 90°. Insol in water; sol in dil HNO_3.

5237. Lead Chlorate. Cl_2O_6Pb; mol wt 374.12. Cl 18.95%, O 25.66%, Pb 55.39%. $Pb(ClO_3)_2$.

Colorless, deliquesc crystals. *Poisonous!* d 3.9. Dec at 230°. Sol in 0.7 part water, freely in alcohol.

5238. Lead Chloride. Cl_2Pb; mol wt 278.12. Cl 25.49%, Pb 74.50%. $PbCl_2$. Occurs in nature as the mineral *cotunnite.*

White, cryst powder. *Poisonous!* d 5.85. mp 501°. bp 950°. Sol in 93 parts cold water, 30 parts boiling water; readily sol in soln of NH_4Cl, NH_4NO_3, alkali hydroxides; slowly in glycerol. MLD orally in guinea pigs: 1.5-2.0 g/kg, *Handbook of Toxicology* **vol. 1**, W. S. Spector, Ed. (Saunders, Philadelphia, 1956) pp 176-177.

USE: Manuf Pattison's white lead, Verona Yellow, Turner's Patent Yellow, lead oxychloride; as solder and flux.

5239. Lead Chromate(VI). Chrome yellow; Cologne yellow; King's yellow; Leipzig yellow; Paris yellow; C.I. Pigment Yellow34; C.I. 77600. CrO_4Pb; mol wt 323.22. Cr 16.09%, O 19.80%, Pb 64.11%. $PbCrO_4$. Occurs in nature as the minerals *crocoite, phoenicochroite.* Ref: *Colour Index* **vol. 4** (3rd ed., 1971) p 4677.

Yellow or orange-yellow powder. d 6.3. mp 844°. It is one of the most insol salts (0.2 mg/l H_2O). Insol in acetic acid; sol in solns of fixed alkali hydroxides, in dil HNO_3. LD_{75} i.p. in guinea pigs: 156 mg/kg, *Handbook of Toxicology* **vol. 1**, W. S. Spector, Ed. (Saunders, Philadelphia, 1956) pp 176-177.

USE: Pigment in oil and water colors; printing fabrics, decorating china and porcelain; in chemical analysis of organic substances; in traffic paints.

Note: Basic lead chromates of various shades of color from brown-yellow to red are used as pigments.

5240. Lead Chromate(VI) Oxide. *Chromic acid lead-(2+) salt (1:2);* basic lead chromate; red lead chromate; chrome red; chromium lead oxide; Persian red; Austrian cinnabar. $CrPb_2O_5$; mol wt 546.40. C 9.52%, Pb 75.84%, O 14.64%. $PBCrO_4.PbO$. *See: Colour Index* **vol. 4**, (3rd ed., 1971) p 4677.

Red powder. Insol in water.

USE: As pigment.

5241. Lead Dioxide. Lead oxide brown; lead peroxide; lead superoxide. O_2Pb; mol wt 239.21. O 13.38%, Pb 86.62%. Occurs in nature as the mineral *plattnerite.* Lab prepn from lead acetate and calcium hypochlorite: Newell, Maxson, *Inorg. Syn.* **1**, 45 (1939); by hydrolysis of lead acetate: Kuhn, Hammer, *Ber.* **83**, 413 (1950).

Dark-brown powder; evolves oxygen when heated, first forming Pb_3O_4, at high temp PbO. d 9.38. Insol in water; sol in HCl with evolution of Cl; in dil HNO_3 in presence of H_2O_2, oxalic acid, or other reducers; sol in alkali iodide solns with liberation of iodine; soluble in hot caustic alkali solns. LD_{50} i.p. in guinea pigs: 200 mg/kg, *Handbook of Toxicology* **vol. 1**, W. S. Spector, Ed. (Saunders, Philadelphia, 1956) pp 176-177.

USE: Electrodes in batteries; oxidizing agent in manuf dyes; as discharge in dyeing with indigo; manuf rubber sub-

stitutes; with amorphous phosphorus as ignition surface for matches; pyrotechny; manuf pigments; in anal. chemistry.

5242. Lead Fluoride. Lead difluoride; plumbous fluoride. F_2Pb; mol wt 245.21. F 15.50%, Pb 84.50%. PbF_2. Prepd by treating lead carbonate or hydroxide with hydrogen fluoride and evaporating the soln; by mixing solns of potassium fluoride and lead acetate; by precipitation from the soln of a lead salt by HF; by the action of fluorine on lead: Ruff, *Die Chemie des Fluors* (Springer, Berlin, 1920) p 33; Emeléus in *Fluorine Chemistry* vol. 1, J. H. Simons, Ed. (Academic Press, New York, 1950) p 51; Kwasnik in *Handbook of Preparative Inorganic Chemistry* vol. 1, G. Brauer, Ed. (Academic Press, New York, 1963) pp 218-219. *Review:* Kemmitt, Sharp, *Advan. Fluorine Chem.* 4, 188 (1965).

White to colorless crystals. *Poisonous!* Dimorphous: orthorhombic, converted to cubic above 316°. d (orthorhombic) 8.445; d (cubic) 7.750. mp 824°. bp 1293°. Soly in water (g/100 ml): 0.057 (0°); 0.065 (20°). The soly increases in the presence of HNO_3 or nitrates.

5243. Lead Formate. $C_2H_2O_4Pb$; mol wt 297.25. C 8.08%, H 0.68%, O 21.53%, Pb 69.71%. $Pb(CHO_2)_2$.

White, lustrous prisms or needles. *Poisonous!* d 4.63. Dec at 190°. Sol in 65 parts cold water, 6 parts boiling water; insol in alcohol.

5244. Lead Hexafluorosilicate. Lead fluosilicate; lead silicofluoride. F_6PbSi; mol wt 349.28. C 32.64%, Pb 59.32%, Si 8.04%. $PbSiF_6$.

Dihydrate, colorless crystals. Sol in water. *Poisonous!*

USE: In refining lead by electrolytic methods.

5245. Leadhillite. $Pb(OH)_2.PbSO_4.2PbCO_3$—basic lead carbonate sulfate.

5246. Lead Hydroxide. Lead oxide hydrate; basic lead hydroxide. $H_2O_4Pb_3$; mol wt 687.59. H 0.29%, O 9.30%, Pb 90.40%. $3PbO.H_2O$. Prepn and structure: Oswald *et al., Helv. Chim. Acta* 51, 1389 (1968).

White powder; absorbs CO_2 from the air. d 7.41. *Poisonous!* Insol in H_2O; sol in dil acids, fixed alkali hydroxides.

5247. Lead Hypophosphite. $H_4O_4P_2Pb$; mol wt 337.20. H 1.20%, O 18.98%, P 18.37%, Pb 61.45%. $Pb(H_2PO_2)_2$.

Hygroscopic, cryst powder; dec at elevated temps. *Poisonous!* Slightly sol in cold water; more in hot water; insol in alcohol. *Keep well closed and protected from light.*

5248. Lead Iodide. I_2Pb; mol wt 461.05. I 55.06%, Pb 44.94%. PbI_2.

Bright yellow, heavy odorless powder. *Poisonous!* d 6.16. mp 402°. One gram dissolves in 1350 ml cold, 230 ml boiling water; sol in concd solns of alkali iodides; freely sol in soln of sodium thiosulfate; sol in 200 parts cold 90 parts hot aniline; insol in alcohol or cold HCl. *Protect from light.*

USE: Bronzing, gold pencils, mosaic gold, printing, photography.

5249. Lead Lactate. $C_6H_{10}O_6Pb$; mol wt 385.35. C 18.70%, H 2.62%, O 24.91%, Pb 53.77%. $Pb(C_3H_5O_3)_2$.

White, heavy, cryst powder. *Poisonous!* Slowly absorbs CO_2 from the air, becoming partly insol. Sol in water, hot alcohol. *Keep well closed.*

5250. Lead Molybdate(VI). MoO_4Pb; mol wt 367.16. Mo 26.13%, O 17.43%, Pb 56.44%. $PbMoO_4$. Occurs as the mineral *wulfenite.*

Yellow powder. Insol in water; sol in HNO_3 or NaOH when freshly pptd.

USE: In pigments.

5251. Lead Monoxide. Lead oxide yellow; plumbous oxide; litharge; massicot; lead protoxide. OPb; mol wt 223.21. Pb 92.83%, O 7.17%. PbO. Prepn of high purity PbO: Kwestroo, Huizing, *J. Inorg. Nucl. Chem.* 27, 1591 (1965); Kwestroo *et al., ibid.* 29, 39 (1967). Mfg processes: Faith, Keyes & Clark's *Industrial Chemicals,* F. A. Lowenheim, M. K. Moran, Eds. (Wiley-Interscience, New York, 4th ed., 1975) pp 509-513.

Exists in two forms: red to reddish-yellow, tetragonal crystals, stable at ordinary temp; yellow, orthorhombic crystals, stable above 489°: Petersen, *J. Am. Chem. Soc.* 63, 2617 (1941). *Poisonous!* At 300-450° in the air, it converts slowly into Pb_3O_4, but at higher temp reverts to PbO. d 9.53. mp 888°. Insol in water, alcohol; sol in acetic acid, dil HNO_3, in warm solns of fixed alkali hydroxides. LD_{50} i.p. in rats: 430 mg/kg, Bradley, Fredrick, *Ind. Med.* 10, *Ind. Hyg. Sect.* 2, 15 (1941).

Caution: Avoid breathing dust. Wear dust mask approved by U.S. Bureau of Mines for this purpose. Wash thoroughly before eating or smoking. Keep away from feed or food products.

USE: In ointments, plasters; preparing soln of lead subacetate. Glazing pottery; glass flux for painting on porcelain and glass; lead glass; varnishes; with glycerol as metal cement; producing iridescent colors on brass and bronze; coloring sulfur-containing substances, *e.g.,* hair, nails, wool, horn; manuf artificial tortoise shell and horn; pigment for rubber; manuf boiled linseed oil; in assay of gold and silver ores.

5252. Lead Nitrate. N_2O_6Pb; mol wt 331.23. N 8.46%, O 28.98%, Pb 62.55%. $Pb(NO_3)_2$.

White or colorless translucent crystals. d 4.53. *Poisonous!* One g dissolves in 2 ml cold, 0.75 ml boiling water, in 2500 ml abs alcohol, 75 ml abs methanol; insol in concd HNO_3. The aq soln is slightly acid. pH of 20% aq soln at 25° = 3.0-4.0.

USE: Manuf matches and special explosives; as mordant in dyeing and printing on textiles; mordant for staining horn, mother-of-pearl; oxidizer in dye industry; sensitizer in photography; process engraving.

THERAP CAT (VET): Has been used as a caustic in equine canker.

5253. Lead Oleate. *Oleic acid lead salt.* Approx $Pb(C_{18}H_{33}O_2)_2$.

Granular, wax-like mass. Insol in water; sol, when fresh, in alc, benzene, ether, oil turpentine. LD orally in guinea pigs: 8.0 g/kg, *Handbook of Toxicology* vol. 1, W. S. Spector, Ed. (Saunders, Philadelphia, 1956) pp 176-177.

USE: In varnishes; in extreme pressure lubricants.

5254. Lead Oxalate. C_2O_4Pb; mol wt 295.23. C 8.14%, O 21.68%, Pb 70.19%. PbC_2O_4.

White, heavy powder. Dec at 300°. d 5.28. *Poisonous!* Insol in water; sol in dil HNO_3, fixed alkali hydroxides; sparingly sol in acetic acid.

5255. Lead Phosphate. $O_8P_2Pb_3$; mol wt 811.54. O 15.77%, P 7.63%, Pb 76.59%. $Pb_3(PO_4)_2$.

White powder. d 6.9. mp 1014°. *Poisonous!* Insol in water, alcohol; sol in HNO_3, fixed alkali hydroxides.

Note: This substance has been listed as a carcinogen in the *Second Annual Report on Carcinogens* (NTP 81-43, Dec. 1981) pp 149-151.

USE: Stabilizer for plastics.

5256. Lead Selenate. O_4PbSe; mol wt 350.17. O 18.28%, Pb 59.17%, Se 22.55%. $PbSeO_4$. Prepd by adding a soln of lead nitrate to sodium selenate: Lenher, Kao, *J. Am. Chem. Soc.* 47, 1521 (1925).

Orthorhombic crystals. d_4^{20} 6.37. Dec by heat. Sol in concd acids; insol in water.

5257. Lead Selenite. O_3PbSe; mol wt 334.17. O 14.36%, Pb 62.01%, Se 23.63%. $PbSeO_3$. Prepd by adding selenious acid or an alkali selenite to a soln of lead chloride or nitrate: Berzelius, cited in *Mellor's* vol. X, 833 (1930).

Powder. Melts at about 500° forming a yellow liquid. Dec at a bright-red heat giving off selenium oxide. Very sparingly sol in water; difficultly dec by boiling sulfuric acid.

5258. Lead Sesquioxide. Lead trioxide; plumbous plumbate. O_3Pb_2; mol wt 462.42. O 10.38%, Pb 89.62%. Pb_2O_3.

Reddish-yellow powder; converted at 370° in air to Pb_3O_4; dec at about 530° to PbO. Insol in water; dec by concd HCl or H_2SO_4 with the liberation of Cl or oxygen, respectively.

5259. Lead Sodium Thiosulfate. Lead sodium hyposulfite. $Na_4O_6PbS_6$; mol wt 635.59. Na 14.47%, O 22.66%, Pb 32.60%, S 30.27%. $Na_4Pb(S_2O_3)_3$.

White, small, heavy crystals. *Poisonous!* Sparingly sol in water, more in thiosulfate solns.

USE: Manuf matches.

5260. Lead Stearate. *Ste*
$Pb(C_{18}H_{35}O_2)_2$.
White powder, mp about 12
sol in hot alcohol.
USE: In extreme pressure lu

5261. Lead Subacetate. *L*
sic lead acetate. $C_4H_{10}O_8Pb_3$;
1.25%, O 15.85%, Pb 76.96%.
White, heavy powder. *Pois*
parts boiling water with alkal
air absorbs CO_2 and becomes
closed.
USE: In sugar analysis to
from solns before polarizing;
other solns of organic substan

5262. Lead Sulfate. O_4Pb
Pb 68.32%, S 10.57%. PbS
anglesite, lanarkite.
White, heavy, cryst powder.
Sol in about 2225 parts water
HNO_3, less in dil H_2SO_4; sol
or tartrate soln; sol in concd h
LD_{75} i.p. in guinea pigs: 290 r
gy vol. 1, W. S. Spector, Ed.
pp 178-179.
USE: Instead of white lead a
ic batteries; manuf minium, in
drying oil varnishes; weightin

5263. Lead Sulfide. PbS;
13.40%. Occurs as the miner
Black powder. Insol in wat
LD_{50} i.p. in rats: 1.8 g/kg, Br
Ind. Hyg. Sect. 2, 15 (1941).
USE: Glazing earthenware.

5264. Lead Telluride. PbT
Te 38.11%. Found in nature
from lead nitrate, sodium car
um: Montignie, *Bull. Soc. Chi*
single crystals by heating stc
elements in a graphite cup or
Electrochem. Soc. 101, 466 (19
Silver-gray cubic crystals. d
crystal is *p*-type, the *n*-type
surface layer. Energy gap 0.2
cm^2/volt-sec. Hole mobility
0.005 ohm-cm (*p*-type), 0.00
attacked by hydrochloric, hyd
acids or their mixtures; not at
sium hydroxide or of alkali n
turns the surface black, whil
lighter gray surface and turns
concd sulfuric acid produces a
USE: In photoconductor cel

5265. Lead Tetraacetate.
21.67%, H 2.73%, O 28.87%,
Prepd from Pb_3O_4 and glacial
presence of some acetic anhydr
56, 1375 (1923); Bailar, *Inorg.*
Handbook of Preparative In
Brauer, Ed. (Academic Press
p 767. Prepn by electrolys
Akad. Nauk SSSR 112, 303
Sataev *et al., Khim. Prom. (M*
49005x (1971). Reviews of pr
Criegee "Oxidations with Lea
Organic Chemistry, Part A, H
Press, New York, 1965) pp 27
13, 569-581 (1966).
Colorless monoclinic pris
Turns pink easily. Unstable
with the formation of brown
Avoid contact with skin. d_4^{17} 2.
glacial acetic acid, benzene, c
nitrobenzene. Dissolves in con
mation of haloplumbic acids. I
be stored in sealed, evacuated

INCOMPLETE DOCUMENT

Reference 32: Geologic map of the Bluewater Quadrangle

Preliminary Assessment, Brown Uranium Mines

COULD NOT BE LOCATED DURING THE FILE REORGANIZATION

5-7-98

RECORD OF COMMUNICATION

SUBJECT: Brown-Vanderver Uranium Mine

FROM: Patrick Malloy,
Navajo Superfund Office

TO: Deborah A. Vaughn-Wright
Site Assessment Section

Mr. Malloy contacted me regarding the referenced site. The Navajo Superfund Office has designated this site to receive a Preliminary Investigation under the Superfund Pre-Remedial Program. During their initial evaluation, it was realized that the site has people living on-site and the levels of radiation are well above background.

Approximately 70 residents live on-site, including 30 children. background readings were 1.7 x10 3 CPM using an ESP2. on-site readings were as high as 1x10 5 CPM, reading from a road bed made with the mine tailings.

There are several adits and air shafts with very poor security and easy access to the residents. Further, the shafts and adits are very deep. He did not provide information on drinking water supplies or food chain.

Mr. Malloy strongly felt that due to the high readings and the fact residents live on-site, that emergency action may be neccessary. He specifically requested that I contact Craig Carlton with ERB, who has worked with the NSO in the past.

The site is near Haystack Butte, west of Grants, NM.

Carl Hickam - ATSDR
NMD 986666 9117

Patrick Malloy
602 - 871 - 4941 SUPERFUND

6/11
→6H-EA

THE NAVAJO NATION

LEONARD HASKIE
INTERIM PRESIDENT
NAVAJO NATION

IRVING BILLY
INTERIM VICE PRESIDENT
NAVAJO NATION

NSO-90-62

April, 06 1990

Mark Satterwhite
Superfund Indian Coordinator
U.S. EPA Region VI
1445 Ross Avenue
Dallas, Texas 75202

Dear Mr. Satterwhite:

Enclosed is the Preliminary Assessment (PA) Package for the Brown Vandever Uranium Mine, located near Bluewater, New Mexico. This report receives NSO internal approval and is now ready for your review and comment.

Please call myself or Patrick Molloy, the Health Physicist who prepared the package, for any questions you may have regarding the report. We would appreciate a response in the form of comments or approval at your earliest convenience. You may reach myself or staff at (602) 871-6859, 6860 or 6861.

Sincerely,

Clara Bia
Navajo Superfund Director

Enclosures

cc: Peter Sam, William Taylor, Superfund Site Assessment Section
Deborah Vaughn-Wright

Cross reference to Brown Uranium Mines, NMD986669117, Vol. 01, Preliminary Assessment.
X SA, VOL 1

REFERENCE # 24

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

Journal of Geochemical Exploration, 13 (1980)
Elsevier Scientific Publishing Company, Amsterdam — Printed in The Netherlands

GROUNDWATER PROSPECTING FOR SANDSTONE-TYPE URANIUM DEPOSITS: A PRELIMINARY COMPARISON OF THE MERITS OF MINERAL-SOLUTION EQUILIBRIA, AND SINGLE-ELEMENT TRACER METHODS

D. LANGMUIR and J.R. CHATHAM

Department of Chemistry and Geochemistry, Colorado School of Mines, Golden, CO 80401 (U.S.A.)

(Received May 8, 1980)

ABSTRACT

Langmuir, D. and Chatham, J.R., 1980. Groundwater prospecting for sandstone-type uranium deposits: a preliminary comparison of the merits of mineral solution equilibria, and single-element tracer methods. In: R.H. Carpenter (Editor), Geochemical Exploration for Uranium. *J. Geochem. Explor.*, 13: 201–219.

Groundwater quality data was collected from published sources and estimated when necessary for three sandstone-type uranium deposits in Texas and Wyoming. The purpose of the study was to compare the merits of using the computed saturation state of the groundwater with respect to uranium minerals, to that of single-element tracers in groundwater for geochemical prospecting. The uranium minerals considered were carnotite and tyuyamunite within oxidized deposits in the Catahoula Tuff in southern Texas, and uraninite and coffinite in reduced deposits within the Oakville Sandstone in southern Texas, and Wasatch Formation in northeast Wyoming. Groundwater chemical maps and profiles were constructed for the three sites, showing locations of known and probable uranium mineralization. The single tracer elements and parameters considered in the comparison were pH, Fe, SO_4, V, U, Ra, As, Mo and Se. Mineral-saturation results were the most dependable evidence for uranium mineralization, and showed systematic trends towards saturation at distances as great as 300 m from the ore. In general, the next best indicators of ore were uranium concentrations, and vanadium concentrations in the oxidized deposit. Single tracer species As, Mo, Se and V were at or below detection in groundwaters near the reduced deposits, and except for V, provided ambiguous information in the oxidized deposit. Because of its high mobility, radium was displaced from the mineralization in the direction of groundwater flow at the Oakville Site, although its success as an ore pathfinder was equal to that of dissolved uranium at the Wasatch Site.

INTRODUCTION

The use of groundwater as a prospecting tool to locate sandstone-type uranium deposits has generally been limited to appraising the distribution of so-called pathfinder species, such as He, Ra, Rn, Mo, V, As, Se, and U in the groundwater (cf. Dyck, 1975; Dyck et al., 1976; Nichols et al., 1977; Arendt

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et al., 1978; Asikainen and Kahlos, 1979; Cadigan and Felmlee, 1979; Rose and Korner, 1979). Although these species can provide indirect evidence of an ore body, solution-mineral equilibria concepts suggest that chemical maps of such species may be inadequate. The concentration of uranium in groundwater, for example, may be lower within an ore body than in surrounding areas (DeVoto, 1978; Childers, 1979). Most uranium ore, however, contains discrete uranium minerals with which the groundwater may equilibrate. The state of saturation of the groundwater with respect to these ore minerals can provide the most direct proof of the existence of an ore body.

This paper will examine which is the better indicator of the presence, location, and size of an ore body; the saturation state of the groundwater with respect to uranium minerals, or the distribution of pathfinder or tracer elements in the groundwater. To properly consider this question, detailed information is required on the groundwater geochemistry, hydrology and geology of strata that contain known uranium ore bodies. This type of published information, when available, is found in United States government reports, including NURE (National Uranium Resources Evaluation) reports of the United States Department of Energy, and in environmental impact statements submitted by the uranium mining industry to state governments for permitting purposes. Unfortunately, details of the mineralogy, geology and hydrology are usually sparse, and specific locations of known mineralization tend to be vague. In addition, the groundwater chemical analyses may be incomplete and of poor quality, lacking data for both major and trace constituents. The absence of a field measured oxidation potential (Eh) or dissolved oxygen, and field measured pH is the most serious general deficiency in such data.

In some cases then, estimated values are needed before one can make mineral-equilibria calculations. The obvious question this raises is, in spite of the need for such estimates, are the resultant mineral saturation values accurate enough to be useful for prospecting? The above questions are addressed in this paper for sandstone-type uranium deposits in the Catahoula Tuff and Oakville Sandstone in southern Texas, and in the Wasatch Formation in northeastern Wyoming. Measured and estimated groundwater quality data from areas of these deposits have been introduced into an extensively expanded version of the computer program WATEQF (Plummer et al., 1976) which includes the thermodynamic data for uranium and vanadium minerals and solutes given by Langmuir (1977; 1978).

This same computer program was used by McNally and Langmuir (1977) to examine the status of uranium-mineral equilibria in oxidized groundwaters within Kent and Dickens Counties in northwest Texas. Using a combination of estimated data, and published groundwater chemical data from the Texas Water Development Board (Anonymous, 1972) and NURE Program (Nichols et al., 1976), they concluded that the groundwater was locally

saturated with respect to carnotite. More recently Applin and Langmuir (1978) sampled and analyzed shallow groundwaters from 68 wells (average depth 12 m) and springs in uraniferous sediments of northeast and eastern Pennsylvania. Field measurements of pH, and of Eh or dissolved oxygen were taken of most samples, along with laboratory measurements of major and minor elements, and Cl, HCO_3, PO_4 and SO_4. Computer calculation of the status of uranium-solution mineral equilibria showed that all the waters were undersaturated with respect to uranium minerals by at least three orders of magnitude. This result probably reflected the paucity of uranium mineralization, and the relatively high dilution of these shallow groundwaters in fractured, Paleozoic rock by groundwater recharge under climatic conditions typical of the eastern United States (average precipitation in this case about 125 cm/yr).

Using the thermodynamic data for uranium minerals and complexes given by Langmuir (1978), and estimated Eh values, Lueck (1978), Lueck et al. (1978), and Runnells et al. (1980) have shown the useful application of uranium-solution mineral equilibria concepts to the genesis of, and exploration for sandstone-type uranium and vanadium deposits of the western United States, and to their mining by in-situ leaching methods. However, no one to date has contrasted the merits of the mineral-saturation and single tracer approaches to exploration for these deposits using groundwater prospecting methods. Further, our groundwater quality data base for the western deposits is considerably larger than that evaluated by Runnells et al. (1980).

ESTIMATION OF GROUNDWATER QUALITY DATA

The use of published data to compute the status of uranium-solution mineral equilibria has required the estimation of concentrations for unmeasured species such as Ca, Mg, K, Cl, Si, and Eh. Groundwater analyses from the Catahoula Tuff in the Seguin Quadrangle (Arendt et al., 1978) lacked Si and K data. Values of 80 ppm (as SiO_2) and K = 10 ppm were assumed for these species based on average values for Catahoula groundwaters given by Weeks and Eargle (1963). Chloride was also lacking from these analyses, but because it was the major anion chloride could be estimated with good accuracy from large differences in the epm (equivalent per million) balance between cations and anions.

Nichols et al. (1977) did not measure the species Si, K, Cl, Na, Mg, Ca, and Eh in groundwaters from the Crystal City-Beeville Quadrangle immediately to the south of the area studied by Arendt et al. (1978). We estimated Na, Mg and Ca in these waters by determining the best correlation between these species and Cl, HCO_3, specific conductance, and total epm anions using the data for the Seguin Quadrangle from Arendt et al. (Corresponding r values ranged from 0.88 to 0.98). The slope and intercept of the best-fit line were then utilized with the same independent variable to predict

data missing in the report of Nichols et al. (1977). Chloride was correlated with specific conductance (SpC) after an adjustment to remove occasionally large known effects of SO_4 and HCO_3 (r = 0.98 for the plot of Cl versus SpC). This was accomplished by dividing the conductivity by 100, which approximates the total cation or anion value in epm (Brown et al., 1970). The contributions of SO_4 and HCO_3 were removed by subtracting their known epm values from the total estimated epm value for the anions. Magnesium was strongly correlative with total anions (epm) and also with HCO_3. Na and Ca were estimated from both the total epm of anions and from Cl. (For example, r = 0.94 for Na versus SpC, and r = 0.98 for Na versus Cl).

Estimates of concentrations of major species are usually possible with fair to good accuracy using this combination of statistical methods and epm balances. Trace species concentrations, however, were usually poorly correlated with major species concentrations, so that their estimation was rarely defensible. Estimates of Eh also must be made with considerable caution. Explanation and justification for Eh estimates is given below.

In oxidized groundwater environments the most common uranium ore minerals in sandstone-type deposits of the southwestern United States are carnotite and tyuyamunite. In reduced groundwater environments uraninite and coffinite are the usual ore minerals. The stabilities of carnotite and uraninite in terms of Eh and pH are shown in Fig. 1 for conditions fairly typical of the sandstone-type deposits. Waters that contain detectable dissolved oxygen (> 0.1 ppm) lie at the top of the carnotite field (see Lang-

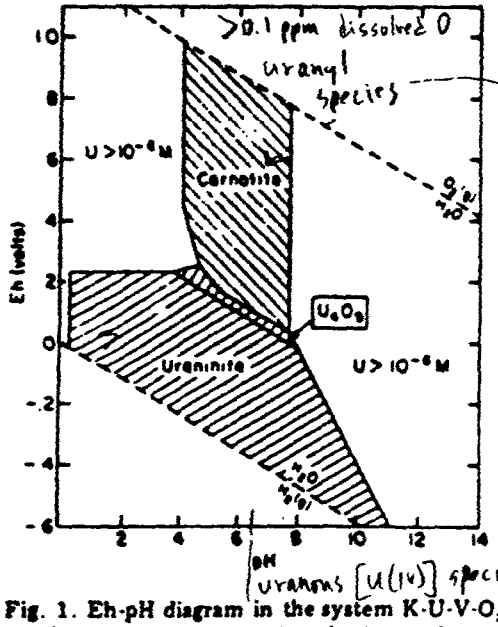

Fig. 1. Eh-pH diagram in the system K-U-V-O_2-H_2O-CO_2 at 25°C. Given: K = 10^{-3} M, U = 10^{-6} M (0.24 ppm) at mineral-solution boundaries; V = 10^{-8} M (0.1 ppm as VO_4), and P_{CO_2} = 10^{-3} atm. The figure is taken from Langmuir (1978).

muir, 1971). Under these conditi[illegible] ll occur entirely as uranyl species. Groundwaters in [illegible] rite or marcasite or organic matter, or which contain [illegible] will generally lie near the bottom of the diagram within the uraninite field. At pHs above 6.5 to 7.0, usual values in sandstone-type deposits, nearly all of the dissolved uranium will occur as uranous [U(IV)] species. (See Langmuir, 1978, Fig. 2).

For these high and low redox conditions, respectively, exact Eh values are not needed to compute the saturation state of the water with respect to carnotite or uraninite. When plotted on a similar Eh-pH diagram the stability fields of tyuyamunite and coffinite are nearly identical to those of carnotite and uraninite, respectively, so the same generality applies to these minerals as well. Where intermediate Eh values are likely to exist however, their estimation is subject to serious error. For example, as one of three methods of estimating Eh, Runnells et al. (1980) used the measured pH and ferrous iron concentration, and the reaction:

$$Fe(OH)_3(s) + 3H^+ + e^- = Fe^{2+} + 3H_2O$$

and assumed a constant stability for solid $Fe(OH)_3$. However, Langmuir and Whittemore (1971) and Whittemore and Langmuir (1975) showed that the stability of $Fe(OH)_3$ can vary by nearly five orders of magnitude in a single aquifer system. The corresponding measured change in Eh was 360 mv. Eh can be inferred to be oxidizing from the presence of significant nitrate concentrations (high nitrate indicates uranyl species only), and can sometimes be estimated from the presence of redox-sensitive trace elements if such data is available.

CALCULATION OF MINERAL-SATURATION RESULTS

The measured and estimated chemical data were input into a modified and expanded version of the computer program WATEQF (Plummer et al., 1976) utilizing a DEC-SYSTEM 10 computer to perform the calculations. The thermodynamic data for U and V species and minerals in the program were taken from Langmuir (1978) except for the Gibbs free energy (ΔG°_f) of coffinite ($USiO_4$). Based upon the footnotes to table 1 in Langmuir (1978), ΔG°_f should equal −449.9 kcal/mol for coffinite instead of −452.0 kcal/mol, the value given in that table. The corresponding corrected enthalpy (ΔH°_f) value is −475.7 kcal/mol.

The modified WATEQF program computes ionic strength, activity coefficients, activities and concentrations of 370 dissolved species including complexes, and ion activity products of 239 minerals and other solid phases. The computed ion activity products of minerals are then divided by their respective solubility products. The logarithm of each quotient represents the saturation index (SI value) for that particular mineral. Positive numbers indicate the groundwater is supersaturated with respect to a particular mineral, whereas a value of zero or negative values represent saturated and undersaturated conditions, respectively.

THE THREE STUDY AREAS

In our study we examined the groundwater geochemistry of three sandstone-type uranium deposits. These included an oxidized deposit in the Catahoula Tuff in southern Texas, and two reduced deposits: one in the Oakville Sandstone in southern Texas, and a second in the Wasatch Formation in northeast Wyoming.

The Catahoula Tuff

Reports prepared as part of the NURE program (Nichols et al., 1977; Arendt et al., 1978) were used to obtain groundwater quality data for the Miocene Catahoula Tuff of southern and southeastern Texas (Fig. 2). Galloway (1979) describes the unit as an ash-rich, complexly interweaving fluvial system, with dip-oriented sand belts that tend to diverge from a point source northwest of the present outcrop. Fluvial channel-fill, crevasse splay, floodplain, and coastal lake facies are predominant. Montmorillonitic clay from the subsequently altered, abundant volcanic ash is a common constituent. The sand content of the Catahoula ranges from less than 10 to 50% of the total section.

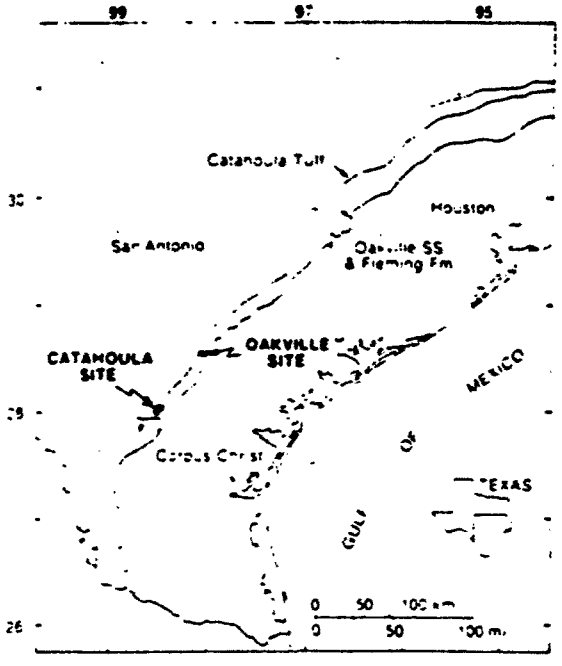

Fig. 2. Location of the Catahoula and Oakville Sites, within the Catahoula Tuff, and Oakville Sandstone and Fleming Formation, respectively. Groundwater quality data were collected from throughout the stippled portion of the Catahoula Tuff.

Uranium mineralization occurs as ragged and poorly developed roll-fronts along margins of the medium to fine-grained channel-fill and crevasse-splay facies. H_2S and HS^- from nearby faults apparently altered existent Fe-Ti oxyhydroxide minerals in the tuff, producing FeS_2 (chiefly pyrite), which was subsequently oxidized in part by U(VI)-bearing groundwaters, to produce a coffinite-pitchblende type ore (Goldhaber et al., 1978; Galloway, 1979). The ore is often Mo, Se, and V-enriched, especially in surface or shallow subsurface oxidized deposits (Weeks and Eargle, 1963). In the oxidized deposits the ore minerals are probably carnotite and tyuyamunite. Weeks and Eargle also identified autunite in the Catahoula Tuff. (We could not assess autunite solution-equilibria in this study because PO_4 groundwater analyses were lacking.)

Within the Catahoula, meteoric groundwater generally flows downdip (coastward) along ancient, fluvial channel networks, eventually to be discharged through thick, overlying aquitards, while saline formation water moves updip within the aquifer or along faults (Galloway, 1979). Some groundwater has been diverted to the surface due to stream incision of the outcrop (Galloway, 1977).

Groundwaters of the Catahoula Tuff are generally of the Ca or Na-Cl type. Calcium or Na-SO_4 waters are also occasionally present. Since analyses from the Catahoula covered a large geographic area (stippled in Fig. 2), the ranges of pH values and of dissolved species were large. The pH ranged from 6.5 to 10.7 (average 7.2), while total dissolved solids ranged from 325 to 4725 ppm (average 1529 ppm). Analyses from 12 wells widely distributed across the outcrop (stippled) area gave dissolved oxygen (DO) values ranging from 0.9 to 5.0 ppm. The DO data are consistent with the oxidized ore mineralogy.

The Eh of the groundwater was estimated from the average DO concentration of 3.0 ppm in these waters, and the reaction:

$$\tfrac{1}{2}O_2 + 2H^+ + 2e^- = H_2O$$

(Plummer et al., 1976), for which, at 25°C

$$Eh = 1.27 + 0.0148 \log [O_2] - 0.0592\ pH$$

In this expression $[O_2]$ is the DO concentration in moles per liter. This equation indicates that at a given pH, the theoretical Eh increases by only 11 mv as DO increases from 0.9 to 5 ppm. Thus, the average DO value of 3 ppm leads to an estimated Eh which is within 4—7 mv of the Eh value that corresponds to the highest and lowest measured DO values.

Computed carnotite and tyuyamunite saturation indices (SI values) and pH are plotted in Fig. 3, which is based on data from a profile that includes 15 wells trending parallel to strike (southwest to northeast) across the Catahoula site located in Fig. 2. The present groundwater flow direction is perpendicular to the plot. The obvious inverse relationship between pH and the SI curves reflects the fact that a major control on computed SI values is the measured pH, particularly because the DO is assumed constant. The figure

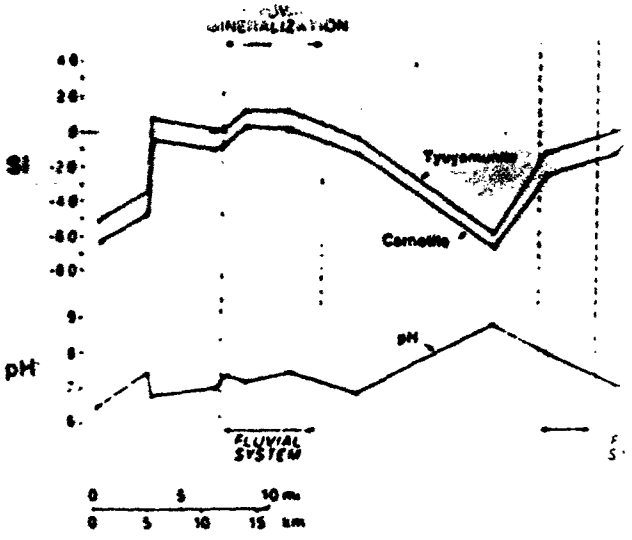

Fig. 3. Carnotite and tyuyamunite and saturation indices in ground-
waters along a profile across the Catahoula Site.

shows SI values near or above saturation with r otite and
tyuyamunite in a known zone of mineralization, a ional ore
should be sought further southwest and about 35 k st.

Commercially economic uranium deposits in the in south
Texas have been reported within and south of -Beeville
Quadrangles. No significant discoveries have been e Seguin
Quadrangle or in areas further north. Our data sup ations in
that a number of groundwaters within and south o drangles
were saturated or slightly supersaturated with tite and
tyuyamunite. Some of these localities correspond t minera-
alization, while others do not. In contrast, all Cat thin the
Seguin Quadrangle were undersaturated with respec < -1.1)
and tyuyamunite ($SI < -0.6$).

Uranium and vanadium profiles across this same ffer the
same general information, with the highest U and s found
near zones of known or probable carnotite and tyu ization.
In this groundwater U would be expected to occur and tri-
carbonate complexes, and V as $H_2VO_4^-$ and HVO_4^{2-}.

Profiles of Mo, As, and Se in Fig. 5 are less usefu lements
are not constituents of uranium minerals, and may e their
original deposition. They occur in the groundwater MoO_4^{2-},
$HAsO_4^{2-}$, and SeO_4^{2-} (cf. Howard, 1977), too soluble specific
minerals under these conditions. In general these o tend to
be adsorbed by positively charged ferric oxyhydroxi low pH
5.5—8.5). Selenium concentrations are lowest in the is also

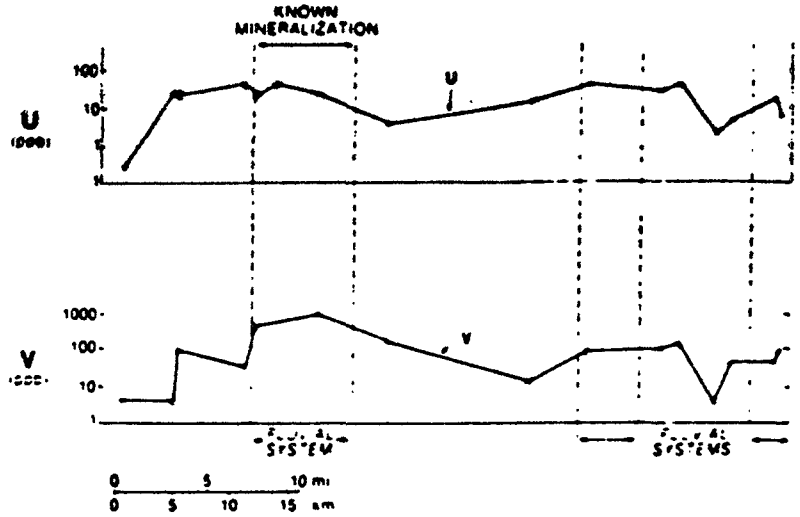

Fig. 4. Uranium and vanadium concentrations in groundwaters along a profile across the Catahoula Site.

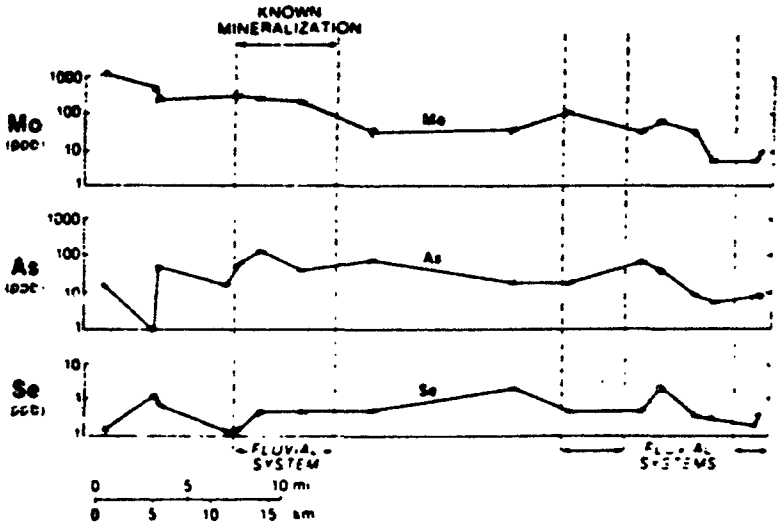

Fig. 5. Molybdenum, arsenic, and selenium concentrations in groundwaters along a profile across the Catahoula Site.

where the groundwater pH is lowest (6.5 to 7.5). However, Mo variations appear unrelated to uranium mineralization or to pH. Among these three elements, arsenic variations best mirror the saturation plots for carnotite and tyuyamunite. Unfortunately, our use of an estimated Eh to compute SI values, and especially the lack of mineralogical data from cores, makes geochemical interpretation of the concentration variations of these elements ambiguous.

The Oakville Formation

A second study area was selected within the Miocene Oakville Formation of southern Texas (Fig. 2). Fault-related deposits of coffinite and uraninite are present within a 6–18 m thick, basal section of fluvial, arkosic sandstone. Normal, down-to-the-coast growth faults which strike parallel to the present coastline are believed to have acted as conduits for reductant H_2S gas. The H_2S at different times may have been derived from the underlying Edwards Limestone or from other hydrocarbon-bearing formations (Goldhaber et al., 1979). Organic matter is sparse in the Oakville but 2 to 3% pyrite and ore-stage marcasite is ubiquitous. The basal sand is often calcite-cemented, especially along the fault. The ore occurs along a re-reduced roll front in sand and clay zones within the upthrown fault block (Goldhaber et al., 1979). Molybdenum probably forms a broad halo around the ore, with Se also present in locally anomalous amounts (Klohn and Pickens, 1970). The molybdenum is presumably within jordisite (amorphous MoS_2). The selenium may occur as native Se, ferroselite ($FeSe_2$), or in solid solution within the iron sulfides.

Hydrologic data from the site (Anonymous, 1978a, b) suggest that the present groundwater flow direction is northeasterly, with a gradient of from 1 to 3 m per kilometer. No leakage into adjacent aquifers or along the fault was detected during pumping tests conducted at the site. Groundwaters are mostly of the Ca or Na-Cl type, with Ca and Na-SO_4 predominant waters occasionally reported. Total dissolved solids ranged from 1692 to 2702 ppm (average about 2100 ppm). The pH ranged from 6.8 to 8.3 (average 7.4). The groundwater Eh was assumed constant at −120 mV. (Based on our own measurements in eight wells at the site, Eh ranged from −45 to −170 mV, and averaged −117 mV.) This average is consistent with the presence of H_2S in the eight wells we sampled, and with Eh values measured by Klohn and Pickens (1970) at the Exxon Felder Mine. For these Eh and pH conditions dissolved uranium is present chiefly as $U(OH)_4^\circ$.

Uraninite SI values were computed and plotted on a map of the Oakville site in Fig. 6. Values above zero indicate supersaturation with respect to crystalline uraninite $UO_2(c)$. However, the UO_2, if present, is probably relatively fine-grained and poorly crystalline pitchblende which is more soluble than crystalline uraninite. This would account for the apparent supersaturations shown on the map. A map of coffinite SI values (not shown) has a very similar appearance to Fig. 6. It may be noted from the probable general location of the ore shown in Fig. 6, that the saturation contours provide a good reflection of the position and size of the ore zone. Uraninite saturation contours increase towards the ore body from as far away as 300 m (the limit of available well control), providing remote evidence of the ore.

Profiles of uraninite and coffinite SI values and of pH (Fig. 7) were drawn along the section labelled *A-B* in Fig. 6 which approximates the present

Fig 6. Map of the Oakville Site, showing well locations (•), contoured saturation indices of the groundwater with respect to uraninite, and locations of mineralized zones (cross-hatched areas). *U* and *D* denote up- and down-thrown fault blocks.

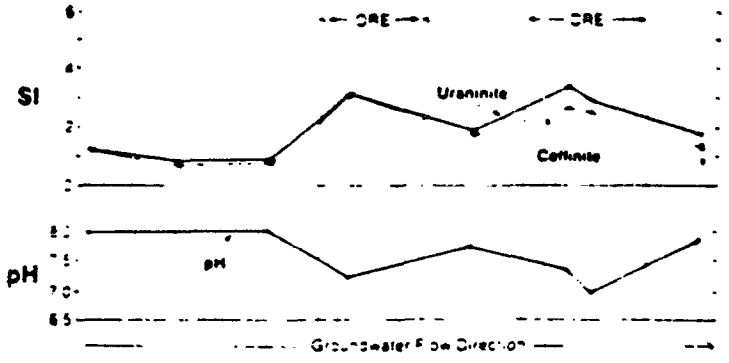

Fig 7 Coffinite and uraninite saturation indices and pH in groundwaters at the Oakville Site along profile *A-B* in Fig 6.

groundwater flow direction. Because Eh has been held constant, SI values plot as the inverse of pH. (Again, this is because Eh and pH are the chief controls on computed SI values.) As before, the lowest pH values occur within the ore zone.

Uranium and radium profiles were also plotted along section *A-B* (Fig. 8). Maximum U values are found in the ore zones, however the values are not as exceptionally high in these zones as are the SI values. Uranium concentrations elsewhere within the ore zone shown in Fig. 6 were as low as 1 ppb. Radium activity is high within the right (east) ore zone, however, no Ra maximum is evident in the left (west) ore zone. Radium anomalies may be displaced in the groundwater flow direction relative to the ore.

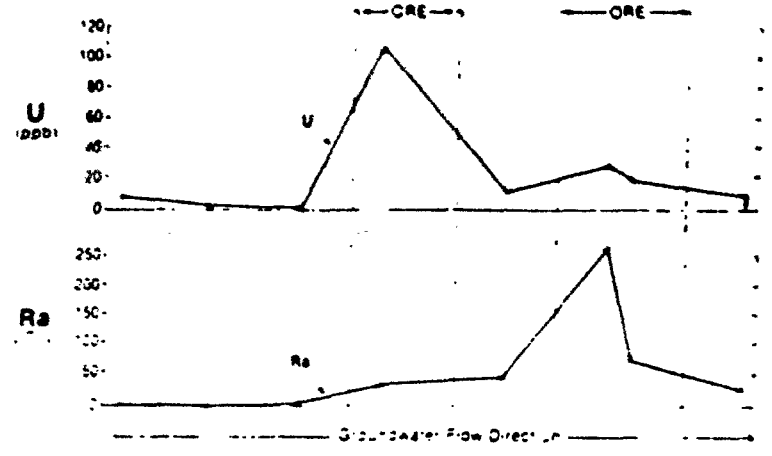

Fig. 8. Uranium concentrations and radium activity in groundwaters at the Oakville Site along profile *A*-*B* in Fig. 6.

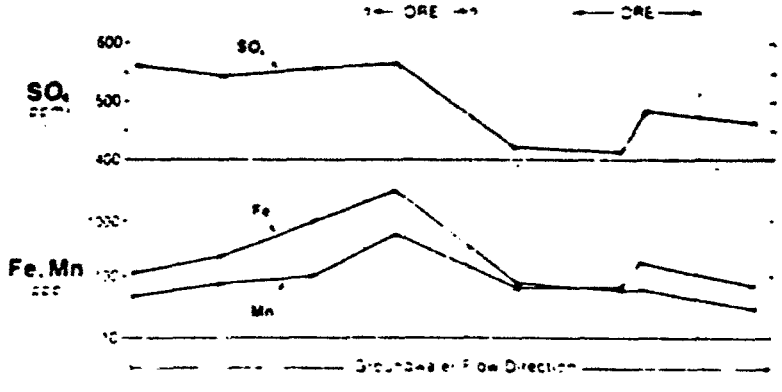

Fig. 9. Sulfate, iron and manganese in groundwaters at the Oakville Site along profile *A*-*B* in Fig. 6.

Profiles of SO_4, Fe, and Mn in the groundwater were plotted in Fig. 9 along the same section. Maxima in these species occur within the ore zones, and are inverse to pH, except for Fe in the right (east) zone. This suggests that slight oxidation of pyrite, enriched in the ore, has led to the drop in pH and increases in Fe, Mn and SO_4. A similar drop in pH due to oxidation of pyrite was suggested by Granger and Warren (1969) and DeVoto (1978) along classical roll-front deposits. The constancy of Fe in the right-hand ore zone is not readily explained.

Limited trace-element data is available for Oakville groundwaters, and many of the values are below detection limits. Variations in Cu, Mo, As and Se are generally ambiguous. Copper and Mo have both maxima and minima

within the ore zone. Arsenic is inversely proportional to iron in one profile. These elements may be tied up in relatively insoluble sulfides and selenides and as native As or Se in the reduced sediments.

The Wasatch site

The third site studied was in northeast Wyoming on the west flank of the Powder River Basin (Fig. 10). Uranium mineralization occurs within an arkosic sandstone, approximately 30 m thick within the fluvial Wasatch Formation (Anonymous, 1978c). The sandstone unit, which includes several thin, interbedded claystones, is confined above and below by thick claystone-coal sequences. The ore minerals uraninite and coffinite occur in classical roll-front type deposits. Reduction to form the ore was by inorganic sulfur species and possibly also by carbonaceous material.

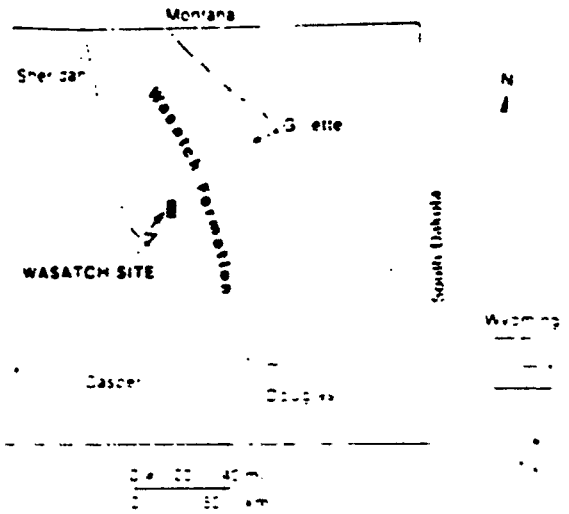

Fig 10 Location of the Wasatch Site in northeast Wyoming.

Descriptions of the groundwater hydrology at the site are ambiguous. Regional piezometric contour maps for the Wasatch Formation indicate a general north to northwest groundwater flow direction (Anonymous, 1978c). However, piezometric maps of the host sand suggest a due westward movement. Noses of the roll-fronts are oriented eastward in a direction reverse to present groundwater flow. Groundwater is of the Na-SO_4 type with a total dissolved solids concentration range from 340 to 629 ppm (average 425 ppm). The range in pH is from 8.3 to 10.5 (average 9.0). Groundwater Eh was assumed constant at −200 mV. This Eh is consistent with the ore mineralogy, and assures that all of the dissolved uranium is present as uranous species (chiefly as $U(OH)_3^+$).

A map of coffinite saturation values for the Wyoming site is shown in Fig. 11. The SI plot for uraninite (not shown) has a similar appearance. The probable location of ore indicated in the figure again correlates well with increasing SI values.

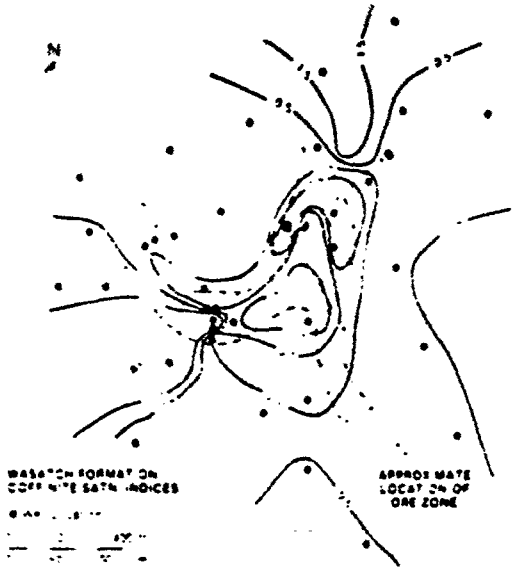

Fig 11. Map of the Wasatch Site, showing well locations (•), contoured saturation indices with respect to coffinite, and the location of the mineralized zone (crosshatched area).

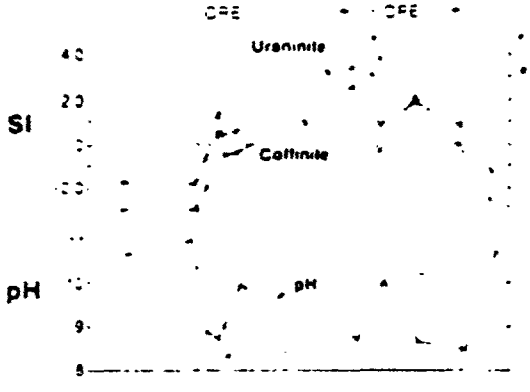

Fig 12. Coffinite and uraninite saturation indices and pH in groundwaters at the Wasatch Site along profile *A-B* in Fig. 11.

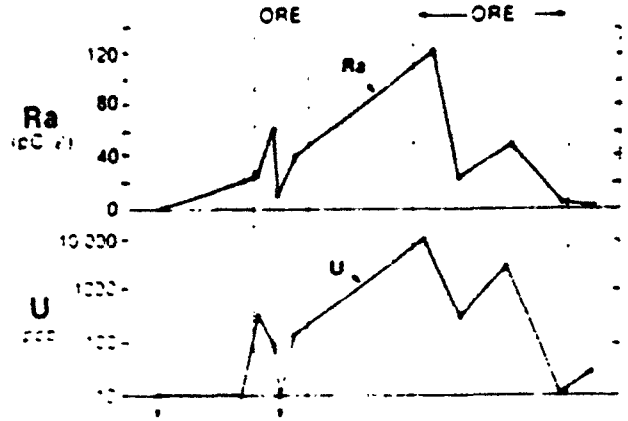

Fig. 13 Uranium concentrations and radium activities in groundwaters at the Wasatch Site along profile *A-B* in Fig. 11. Vertical arrows denote uranium concentrations below the detection limit of 10 ppb.

A profile *A-B* in Fig. 11 is approximately perpendicular to the present groundwater flow direction (assumed to the northwest). A plot of uraninite and coffinite SI values and of pH along *A-B* in Fig. 12, shows that maximal SI values occur in the ore zones. Again, pH minima occur within the ore zones. As before this may reflect slight oxidation of pyrite present there. Profiles of U and Ra in Fig. 13 show that both elements vary approximately parallel to the saturation indices, with maxima in the ore.

As at the Oakville site, profiles of Fe and SO_4 in Fig. 14 are roughly parallel within mineralized zones, probably reflecting mild pyrite oxidation.

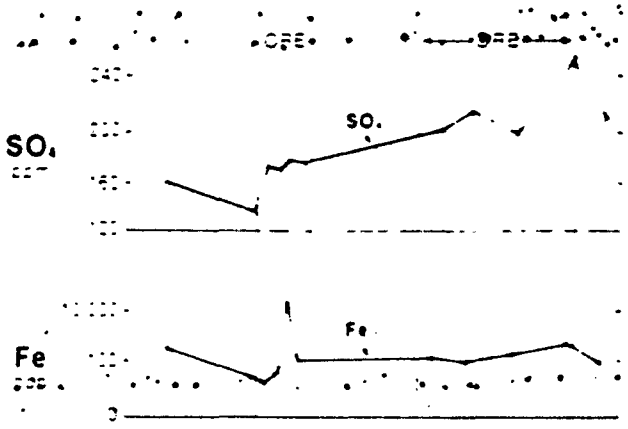

Fig. 14 Sulfate and iron concentrations in groundwaters at the Wasatch Site along profile *A-B* in Fig. 11.

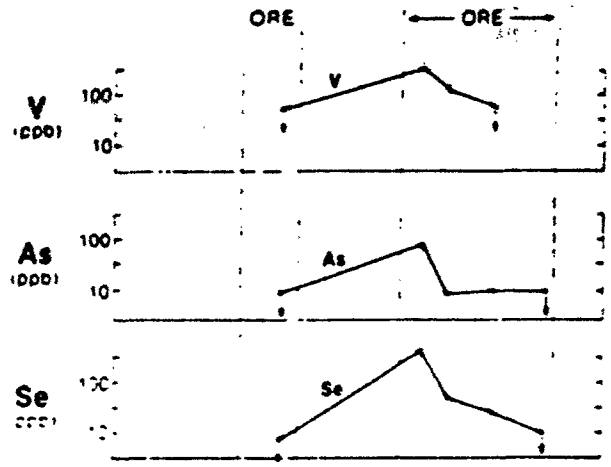

Fig. 15. Vanadium, arsenic, and selenium concentrations in groundwaters at the Wasatch Site along profile *A-B* in Fig 11. Vertical arrows indicate that concentrations in the samples so labelled and in samples to the left and right of them, respectively, were below detection.

Most V, As, and Se concentrations are below detection limits (Fig. 15) and are thus relatively poor ore pathfinders at this site. High values are present in one ore body, but values are below detection in the other.

CONCLUSIONS AND DISCUSSION

Whether in oxidized or reduced sandstone-type deposits, uranium mineral-solution equilibria plotted in groundwater maps and profiles provide the most reliable index to the location of uranium deposits. Saturation index maps will often indicate the direction to ore at significant distances from the actual ore zone.

Uranium alone and vanadium in oxidized deposits of carnotite and tyuyamunite are apparently the next best indicators of ore among the species considered here. Uranium itself may be a useful regional pathfinder in oxidizing groundwaters, because of its great mobility under acid or alkaline conditions, but anomalies may be displaced by groundwater flow (Dyck, 1975; DeVoto, 1978). Uranium anomalies may even be entirely misleading as in northeastern Colorado and southeastern Wyoming (Childers, 1979) where large anomalies have been proven by drilling to be related to only traces of uranium mineralization. Childers (1979) also reports water samples that contain less than 2 ppb uranium from reduced aquifers in close proximity to ore bodies.

Radium data are useful, but Ra maxima may also be displaced from the ore zone by groundwater flow. Dyck (1975) reported that, because of its short half life ($\leq$ 3.8 days) radon is best suited to use in semi-detailed geochemical exploration surveys. Radium mobility is limited to a large extent

by its adsorption onto Fe and Mn oxides, clays, and organic matter (Rose and Korner, 1978), as well as coprecipitation with sulfates such as barite and probably also gypsum. In the analysis of groundwaters from over 300 wells in the Helsinki region, Asikainen and Kahlos (1979) reported large concentrations of U, Ra, and Rn, but found no significant correlation between U and Ra or U and Rn in individual well waters. Nevertheless, U, Ra, and Rn correlated strongly with each other on an areal basis.

Arsenic, Se and Mo are occasionally helpful ore pathfinders in oxidized deposits where they occur as soluble oxyanions, but they tend to be below detection limits in reduced sediments, except within some ore zones. In the latter case their low concentrations reflect the insolubility of native As and Se, and of sulfides and selenides containing these elements.

Utilizing saturation indices for uranium minerals in groundwater, although promising as an exploration tool, does have limitations. In this study it was necessary to estimate values for Eh and such species as K, Ca, Mg, Cl and Si. Obviously, accurate field-measured values for DO or Eh, and pH, and complete laboratory analyses of filtered samples for their dissolved species content would have been preferable. In spite of the estimates needed to compute mineral-saturation status in this study, maps of the saturation results were shown to be an excellent guide to the location of uranium ore bodies. We conclude that a similar approach could be taken elsewhere with equal success, utilizing groundwater analyses, and geologic and hydrologic data already available in reports provided by the NURE program and from industry.

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We thank David Shuck and R.E. Iwanicki of Wyoming Mineral Corporation (WMC) for providing us with copies of reports prepared by WMC describing the geology, hydrology, and groundwater quality of the eastern portion of the Oakville Site (Anonymous, 1978c). We also thank Velu Annamalai of International Energy Corporation (IEC) for providing us with a similar report prepared by IEC describing the western portion of the Oakville Site (Anonymous, 1978b). R.E. Iwanicki of WMC and Velu Annamalai of IEC also graciously contributed additional information for the Oakville Site, and granted us permission to take field Eh and pH measurements, and to collect water samples from selected wells at that site. A review of the paper by Martin B. Goldhaber is greatly appreciated. This research was funded by the U.S. Department of Energy through Subcontract 79-361-E administered by the Bendix Field Engineering Corporation of Grand Junction, Colorado (Technical Monitor: Newton K. Stablein).

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REFERENCE # 25

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The thermodynamic properties of radium

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Abstract—The enthalpy, Gibbs free energy, and entropies of aqueous radium species and radium solids have been evaluated from empirical data, or estimated when necessary for 25°C and 1 bar. Estimates were based on such approaches as extrapolation of the thermodynamic properties of Ca, Sr, and Ba complexes and solids plotted against cationic radii and charge to radius functions, and the use of the Fuoss or electrostatic mathematical models of ion pair formation (LANGMUIR, 1979). Resultant log K (assoc) and ΔH^0 (assoc) (kcal/mol) values are: for $RaOH^+$ 0.5 and 1.1; $RaCl^+$ −0.10 and 0.50; $RaCO_3^0$ 2.5 and 1.07; and $RaSO_4^0$ 2.75 and 1.3. Log Ksp and ΔH^0 (dissoc) (kcal/mol) values for $RaCO_3$(c) and $RaSO_4$(c) are −8.3 and −2.8, and −10.26 and −9.4, respectively.

Trace Ra solid solution in salts of Pb and of the lighter alkaline earths, has been appraised based on published distribution coefficient (D) data, where $D \simeq (mM^{2+})(N_{RaX})/(mRa^{2+})(N_{MX})$ (m and N are the aqueous molality and mole fraction of Ra and cation M in salt X, respectively. The empirical solid solution data have been used to derive both enthalpies and Gibbs free energies of solid solution of trace Ra in sulfate and carbonate minerals up to 100°C. Results show that in every case D values decrease with increasing temperature. Among the sulfate and carbonate minerals, D values decrease for the following minerals in the order: anhydrite > celestite > anglesite > barite > aragonite > strontianite > witherite > cerussite.

INTRODUCTION

THE GEOCHEMISTRY of radium in the environment is of considerable interest because of the potential danger the element poses to human and animal health. Radium activities in excess of the U.S. ENVIRONMENTAL PROTECTION AGENCY (1977) limit of 5 pCi/l for Ra-226 plus Ra-228 in drinking water are found in ground waters from uraniferous rocks and in waters associated with uranium mining and mill tailings, and can be expected in waters that have contacted low or high level nuclear wastes.

To accurately model and predict the environmental behavior of radium in any of these situations, we need a reliable and complete thermodynamic data base for radium. Such a data base does not exist. Nearly all of the thermodynamic data for radium given by the National Bureau of Standards (WAGMAN *et al.*, 1982) has been estimated (PARKER, 1984, oral commun.). Such estimation is based on smoothly varying and known (usually) properties of the other alkaline earth aquo-complexes and solids. Of all the aqueous species and solids listed by WAGMAN *et al.* (1982), only Ra^{2+} ion and $RaSO_4$(c) are likely to have any significance in the environment. On the other hand, $RaCO_3$(c) as a solid solution component, and the complexes $RaOH^+$, $RaCl^+$, $RaCO_3^0$ and $RaSO_4^0$ should influence radium mobility in some waters. However, no thermodynamic data are available for these entities.

THERMODYNAMIC DATA FOR PURE RADIUM SOLIDS AND AQUEOUS SPECIES

In this study, several approaches were used to estimate the thermodynamic properties of radium solids and aqueous species. The increase in cation radius of the divalent alkaline earths from Ca to Sr and Ba to Ra suggests that the bonding between these cations and common ligands should be more ionic or electrostatic for Ra than for Ba, Sr or Ca. Thus, plots of the thermodynamic properties of the alkaline earth sulfate complexes, for example, against the cation radii should approach Fuoss or electrostatic model behavior as one moves from Ca towards Ra (see LANGMUIR, 1979). The comparison is, however, best made among cations likely to have the same coordination number with a given ligand. For Ra, the coordination number is 8 or 12 in its solids (SHANNON, 1976). In a few instances, as in aragonite, Ca exists in 8-fold coordination (radius 1.12 Å); however, the best comparison is between Sr, Ba and Ra in 8-fold coordination, with effective radii of 1.26, 1.42 and 1.48, respectively (SHANNON, 1976).

Examination of ΔG^0 and ΔS^0 of association of the alkaline earth sulfate complexes, plotted against a charge to radius function (LANGMUIR, 1979), shows that the ΔG^0 data approach pure electrostatic behavior from $CaSO_4^0$ to $BaSO_4^0$. Similar behavior is evident for ΔS^0 of complexation. This suggests that if the empirical ΔG^0 of formation of a complex can be accurately modeled with the electrostatic model, then

ΔS° of complexation can be similarly predicted. These, and other approaches used to compute or estimate the thermodynamic properties of the radium solids and aqueous species listed in Table 1, are detailed in the footnotes to the table. Shown in Table 2 are formation constants of the complexes, and solubility products of the solids listed in Table 1 and their enthalpies of reaction at 25°C.

Concentrations of radium in natural waters, and in waters associated with uranium mining and nuclear waste disposal are probably never high enough to reach saturation with a pure radium solid such as $RaSO_4(c)$. Maximum Ra concentrations are limited instead by adsorption or solid solution formation. Adsorption control on aqueous Ra concentrations will be examined in detail by RIESE and LANGMUIR (in preparation). The solid solution behavior of trace Ra in major element salts has been summarized by GOLDSCHMIDT (1940) and WEIGEL (1977). In this paper we develop a comprehensive thermodynamic model with which in the absence of measured values, one can predict the solid solution behavior of Ra in divalent metal salts between 25 and 100°C.

Ra(c) and Ra^{2+}. The tabulated data are from WAGMAN *et al.* (1982). All values are estimates. A heat capacity (Cp°) of 6.86 cal/mol deg for Ra(c) may be estimated from a plot of Cp° values for Ca(c), Sr(c), Ba(c) and Ra(c) from WAGMAN *et al.* (1982) against the effective ionic radii of the divalent ions in 8-fold coordination from SHANNON (1976). A similar plot for the divalent aquo-ions with heat capacities from HELGESON *et al.* (1981) leads to $Cp^\circ(Ra^{2+}) = -12.2$ cal/mol deg.

$RaOH^+$. BAES and MESMER (1981) give formation constants (log K values) of 1.15 ± 0.2, 0.71 ± 0.2, and 0.53 ± 0.2 for $CaOH^+$, $SrOH^+$ and $BaOH^+$ respectively, at 25°C. SMITH and MARTELL (1976) suggest log $K = 0.6 \pm 0.1$ for $BaOH^+$ at 25°C. Plotting the log K values of Baes and Mesmer against the effective ionic radii of Ca^{2+}, Sr^{2+}, Ba^{2+} and Ra^{2+} in 8-fold coordination (SHANNON, 1976), leads to log $K = 0.5$ for $RaOH^+$ from which ΔG_f° has been computed. The other thermodynamic data for $RaOH^+$ have been calculated assuming $\Delta H^\circ = 1.1$ kcal/mol given for $BaOH^+$ formation is also correct for $RaOH^+$.

$RaCl^+$. SMITH and MARTELL (1976) give log $K = -0.13$ at 18°C for the formation constant of $BaCl^+$. Estimated with the Fuoss equation (LANGMUIR, 1979), and effective ionic radii for Ba^{2+} (8-fold) and Cl^-, (6-fold), log $K = -0.10$ at 25°C. The tabulated thermodynamic properties of $RaCl^+$ have been similarly estimated using the Fuoss equation, supported by its applicability to $BaCl^+$.

$RaCO_3^\circ$. Empirical log K (assoc) values for $CaCO_3^\circ$ and $SrCO_3^\circ$ complexes are 3.20 (PLUMMER and BUSENBERG, 1982), and 2.81 (PLUMMER, 1983, oral commun.), respectively. The latter value compares with 2.82 for $SrCO_3^\circ$ estimated by the oxalate method (LANGMUIR, 1979). Assuming the validity of that method, we can similarly estimate log $K = 2.56$ for $BaCO_3^\circ$. Linear extrapolation of the log K values for $SrCO_3^\circ$ from PLUMMER (1983, oral commun.) and $BaCO_3^\circ$ (estimated above) plotted against the effective 8-fold cation radii (SHANNON, 1976), leads to log $K = 2.5$ for $RaCO_3^\circ$, from which ΔG_f° has been computed. Bonding of the alkaline earth carbonate complexes probably becomes more electrostatic with increasing cation size. Based on this assumption, one can compute the apparent effective radius of CO_3^{2-}, in each complex with the equation log K (assoc) = $12.44 \times 10^{-8}/(r_{M^{2+}} + r_{CO_3^{2-}})$, where the radii are in centimeters (see LANGMUIR, 1979). Resultant $r_{CO_3^{2-}}$ values increase to about 3.55×10^{-8} cm for $BaCO_3^\circ$. A similar calculation for $RaCO_3^\circ$ assuming log $K = 2.5$ from above gives $r_{CO_3^{2-}} = 3.5 \times 10^{-8}$ cm. This suggests, as has been done, that the electrostatic model may be used to estimate S° and ΔH_f° for $RaCO_3^\circ$.

$RaCO_3(c)$. −Log K_{sp} values of 9.27 ± 0.02 for strontianite (BUSENBERG *et al.*, 1984), and 8.58 for witherite computed from Gibbs' free energy data given by WAGMAN *et al.* (1982) and LANGMUIR (1978), plotted against effective ionic radii of Ba^{2+} and Ra^{2+} in 8-fold coordination (SHANNON, 1976) leads to −log $K_{sp} = 8.3$ for $RaCO_3(c)$. The entropy of $RaCO_3(c)$ may be estimated by Latimer's method with entropies of the ions from NAUMOV *et al.* (1974), giving 27.6 cal/mol deg. An equally valid approach is to assume $\Delta S^\circ = 0$ for the reaction: $Ra(c) + BaCO_3(c) = Ba(c) + RaCO_3(c)$. With entropy data from WAGMAN *et al.* (1982), this leads to $S^\circ(RaCO_3(c)) = 28.8$ cal/mol deg. The average of these two values is adopted and tabulated.

$RaSO_4^\circ$. SMITH and MARTELL (1976) and MARTELL and SMITH (1982) give log K (assoc) values of 2.32, 2.55 and 2.7 for $CaSO_4^\circ$, $SrSO_4^\circ$ and $BaSO_4^\circ$. REARDON (1984, oral commun.) suggests log K (assoc) = 2.29 ± 0.02 for $SrSO_4^\circ$. Examination of Fig. 11 in LANGMUIR (1979) indicates that log K (assoc) values for the alkaline earth sulfate complexes become increasingly electrostatic with cation size. The electrostatic model predicts log K (assoc) = 2.78 for $BaSO_4^\circ$ in good agreement with the value of Smith and Martell. The electrostatic model leads to log K (assoc) = 2.75 for $RaSO_4^\circ$. A linear extrapolation of the log K (assoc) values for $SrSO_4^\circ$ and $BaSO_4^\circ$ given by SMITH and MARTELL (1976) plotted against effective cation radii from SHANNON (1976) suggests log K (assoc) = 2.76 for $RaSO_4^\circ$. ΔS° (assoc) computed from the electrostatic model is 17 cal/mol deg. The tabulated data are based upon the electrostatic model.

TABLE 1. Thermochemical data for radium solids and aqueous species, and for auxiliary aqueous species at 25°C and 1 bar. Sources of data and methods of estimation and computation are given in the footnotes.

Solid or Aqueous Species	ΔH_f° (kcal/mol)	ΔG_f° (kcal/mol)	S° (cal/mol deg)
Ra(c)	0	0	17
Ra^{2+}	-126.1	-134.2	13
$RaOH^+$	-179.98	-172.30	16
$RaCl^+$	-165.54	-165.44	28
$RaCO_3^\circ$	-288.67	-263.78	16
$RaSO_4^\circ$	-350.21	-342.64	28
$RaSO_4(c)$	-352.88	-326.15	33
OH^-	-54.977	-37.604	-2.560
Cl^-	-39.933	-31.379	13.56
CO_3^{2-}	-161.84	-126.17	-13.6
SO_4^{2-}	-217.40	-177.95	4.50

...g K(assoc) values)
...reactants (log K_{sp}
...halpies of reaction
...thermodynamic data in Table 1.

	log K (assoc)	ΔH° (kcal/mol)
1) $Ba^{2+} + OH^- = BaOH^+$	0.5	1.1
2) $Ba^{2+} + Cl^- = BaCl^+$	-0.10	0.50
3) $Ba^{2+} + CO_3^{2-} = BaCO_3^\circ$	2.5	1.07
4) $BaCO_3(c) = Ba^{2+} + CO_3^{2-}$	-8.3	-2.6
5) $Ba^{2+} + SO_4^{2-} = BaSO_4^\circ$	2.75	1.3
6) $BaSO_4(c) = Ba^{2+} + SO_4^{2-}$	-10.26	-9.4

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...ATSCHEFF (1933) have performed a careful and thorough study of ...solutions. They measured ...ater (5 runs) and in Na_2SO_4 solutions (3 runs). Total concentrations, ionic strength (I) values, total molal concentration products (K_{sp} = ΣmRa · $\Sigma m SO_4$), and computed thermodynamic solubility products for I = 0 (−log Ksp values) are ...

Runs	ΣmRa	ΣmNa	$\Sigma m SO_4$	I (molal)	−logKsp'	−logKsp
1–5	6.52×10^{-6}	0	6.52×10^{-6}	2.56×10^{-5}	10.37	10.39
6	1.07×10^{-4}	1.00×10^{-4}	5.11×10^{-5}	1.54×10^{-4}	10.26	10.32
7	1.45×10^{-3}	1.00×10^{-3}	5.00×10^{-4}	1.50×10^{-3}	10.14	10.37
8	3.06×10^{-4}	1.00×10^{-2}	5.00×10^{-3}	1.50×10^{-2}	9.82	10.56

The −log Ksp value from run 8 is entirely inconsistent with the other values, and is therefore rejected. The average of the results for runs 1–7 is 10.38 ± 0.02, where the uncertainty is twice the standard deviation of the mean. The following assumptions were made in order to calculate −log Ksp values in the above table:

a) log K (assoc) ($RaSO_4^0$) = 2.74 at 20°C. This is based on the 25°C value of 2.76, corrected to 20° using the van't Hoff equation and enthalpy data from Table 1.

b) log K (assoc) ($NaSO_4^-$) = 0.81 at 20°C. This is based on a 25°C value of 0.82 (REARDON, 1975), ΔH^0 (assoc) = 1.1 kcal/mol at 25°C (SMITH and MARTELL, 1976), and the van't Hoff equation. This species is negligible in all but run 8.

c) Activity coefficients may be computed using the Debye-Hückel equation, assuming $\gamma_{Ra^{2+}} = \gamma_{Ba^{2+}}$, and $\gamma_{NaSO_4^-} = \gamma_{Na^+}$; and the equation log $\gamma_{RaSO_4^0} = 0.5I$ (REARDON and LANGMUIR, 1976). Our selected −log Ksp value of 10.38 ± 0.02 may be compared with 10.37 given by SMITH and MARTELL (1976) also for 20°C and based on the work of Nikitin and Tolmatscheff (*ibid*).

Data given by WAGMAN *et al.* (1982) leads to ΔH^0 (assoc) = 0.55 kcal/mol for celestite. BLOUNT (1977) suggests ΔH^0 (assoc) = −6.35 kcal/mol for barite. A linear plot of these values against the effective ionic radii of the cations in 8-fold coordination (SHANNON, 1976) extrapolates to ΔH^0 (assoc) = −9.3 kcal/mol for $RaSO_4$(c). Substituted into the van't Hoff equation, ... this leads to log Ksp = 10.26 ± 0.02 at 25°C for $RaSO_4$(c). Based on this constant and the enthalpy of association, and with entropy data from Table 1, S^0 = 33.3 cal/mol deg for $RaSO_4$(c). $S^0(RaSO_4(c))$ may be estimated independently using Latimer's method with entropy data from NAUMOV *et al.* (1974), which leads to S^0 = 32.0 cal/mol deg. A second estimate, made with entropy data from WAGMAN *et al.* (1982), and based on the assumption that ΔS^0 = 0 for the reaction Ra(c) + $BaSO_4$(c) = Ba(c) + $RaSO_4$(c), gives 33.6 cal/mol deg. The excellent agreement among these three entropy values supports the empirical and estimated −log Ksp and ΔH^0 (assoc) values for $RaSO_4$(c). An entropy of 33 cal/mol deg, the same as chosen by WAGMAN *et al.* (1982), is adopted and tabulated. ΔH_f^0 for the solid is computed assuming this entropy and −log Ksp = 10.26.

LIND *et al.* (1918) measured the solubility of $RaSO_4$(c) in 0.01 N H_2SO_4 solutions at 25 and 35°C, and obtained 2 × 10^{-6} g/L and 3 × 10^{-6} g/L, respectively. This solubility increase with temperature corresponds to an increase in log Ksp of 0.18 units between 25 and 35°C. Using the van't Hoff equation and the ΔH^0 value for $RaSO_4$(c) dissolution given in Table 2, we may compute a −log Ksp increase of 0.22 units for this same temperature interval, in good agreement with the results of Lind and others.

A fairly accurate determination of the effect of temperature on the solubility of $RaSO_4$(c) above 25°C may be made by assuming that the heat capacity is zero at all temperatures for the reaction

$$Ra^{2+} + BaSO_4(c) = Ba^{2+} + RaSO_4(c).$$

With enthalpy and free energy data from this paper and from LANGMUIR and MELCHIOR (1985) we compute ΔG^0 = −396 cal/mol, ΔH^0 = −3050 cal/mol, and thus ΔS^0 = 8.9 cal/mol deg. Assuming ΔC_p^0 = 0 for this reaction, and introducing the temperature function for log Ksp (barite) at 1 bar from LANGMUIR and MELCHIOR (1985) (see also BLOUNT, 1977), leads to

$$\log Ksp\ (RaSO_4) = 137.98 - 8346.87/T - 48.595 \log T$$

where T is in kelvins. The effect of pressure on log Ksp ($RaSO_4$) may be assumed equal to that effect for barite (LANGMUIR and MELCHIOR, 1985).

OH^- and Cl^-: CODATA (1976)
CO_3^{2-}: WAGMAN *et al.* (1982)
SO_4^{2-}: CODATA (1977).

SOLID SOLUTION FORMATION

The tendency for trace radium concentrations to coprecipitate and form a solid solution with barite is well known (*cf.* DOERNER and HOSKINS, 1925; and CHURCH, 1979), and is the basis for radium removal from mine waters and acid sulfate and uranium mill tailings solutions or raffinates by the addition of soluble barium salts (*cf.* SEBESTA *et al.*, 1981). Less well known is the solid solution behavior of trace Ra concentrations in other minerals, or the importance of Ra solid solutions generally as controls on Ra in natural waters. Published data on radium solid solutions in which Ra is the trace component are given for Ra-$BaSO_4$ by DOERNER and HOSKINS (1925), and for numerous other solid solutions by GOLDSCHMIDT (1940) and WEIGEL (1977). Much of the data has been cast in terms of an empirically determined distribution coefficient, D, where

$$\frac{mRa^{2+}}{mM^{2+}} \cdot D = \frac{N_{RaA}}{N_{MA}} \qquad (1)$$

or the ratio of molal aqueous concentrations of radium to the major ion times D, equals the corresponding ratio of their mole fractions in the solid solution. This expression is called the "Nernst-Berthelot equation" (WEIGEL, 1977), or "Henderson-Kraczek equation" (O'NIONS and POWELL, 1977), and applies to solid solution formation from an aqueous solution of constant composition, or in other words, to the formation of a compositionally homo-

geneous solid solution. (Crystallization of a zoned solid solution from an aqueous solution of changing composition (usually in a closed system) is described by the equation of DOERNER and HOSKINS (1925); see also RAISWELL and BRIMBLECOMBE (1977), and WEIGEL (1977)). The exchange reaction for a solid solution involving trace Ra and a major carrier or host divalent metal salt, may be written

$$Ra^{2+} + MX = M^{2+} + RaX \quad (2)$$

for which

$$Kex = \frac{\gamma_{M^{2+}} m_{M^{2+}}}{\gamma_{Ra^{2+}} m_{Ra^{2+}}} \cdot \frac{\lambda_{RaX} N_{RaX}}{\lambda_{MX} N_{MX}} \quad (3)$$

where the γ and m terms are the ion activity coefficients and molal concentrations in aqueous solution, and the λ and N terms the rational activity coefficients and mole fractions in the solid solution. We can compute Kex directly from Gibbs free energy data for the reaction through

$$\Delta G^0_{ex} = -RT \ln Kex \quad (4)$$

or from the fact that $Kex = Ksp(MX)/Ksp(RaX)$.

Inspection of expressions (1) and (3) leads to the statement

$$Kex = D \cdot \frac{\gamma_{M} \lambda_{RaX}}{\gamma_{Ra} \lambda_{MX}}. \quad (5)$$

In every case considered in this study, M is a divalent cation, and in dilute solutions we may generally assume $\gamma_{M^{2+}} = \gamma_{Ra^{2+}}$. Also, in every case we are considering a solid solution in which RaX is a trace component in MX, so that $\lambda_{MX} \simeq N_{MX} \simeq 1$. Accordingly, the expression for Kex may be simplified to

$$Kex = D \cdot \lambda_{RaX}. \quad (6)$$

Because the activity of RaX in the solid solution is $a_{RaX} = \lambda_{RaX} \cdot N_{RaX}$, but also $a_{RaX} = K_H \cdot N_{RaX}$, where K_H is the Henry Law constant, then also $\lambda_{RaX} = K_H$. Multiplying $-RT$ times the natural log of expression (6) leads to

$$\Delta G^0_{ex} = -RT \ln Kex$$

$$= -RT \ln D - RT \ln \lambda_{RaX}. \quad (7)$$

The first and second terms on the right may be designated $\Delta G^0_{ex}(D)$ and $\Delta G^0_{ex}(\lambda)$ so that

$$\Delta G^0_{ex} = \Delta G^0_{ex}(D) + \Delta G^0_{ex}(\lambda). \quad (8)$$

If empirical data for the temperature variation of D_a are available, and if a plot of log D *versus* $1/T$ yields a straight line, then through the integrated van't Hoff equation we find

$$\Delta H^0_{ex}(D), \text{cal/mol} = 4.576 \left[\log\left(\frac{D_2}{D_1}\right)\right]\left(\frac{T_2 T_1}{T_2 - T_1}\right). \quad (9)$$

By analogy to the treatment of Gibbs free energy

$$\Delta H^0_{ex} = \Delta H^0_{ex}(D) + \Delta H^0_{ex}(\lambda) \quad (10)$$

where ΔH^0_{ex} is the standard enthalpy of the exchange reaction, and $\Delta H^0_{ex}(\lambda)$ the enthalpy contribution due to [illegible] ion. It can readily be shown [illegible]

$$\Delta H^0_{ex}(\lambda) = 4.576 \left[\log\left(\frac{\lambda_{RaX(2)}}{\lambda_{RaX(1)}}\right)\right]\left(\frac{T_2 T_1}{T_2 - T_1}\right) \quad (11)$$

or stated differently

$$\log \lambda_{RaX(2)} = \log \lambda_{RaX(1)} - \frac{\Delta H^0_{ex}(\lambda)}{4.576}\left(\frac{1}{T_2} - \frac{1}{T_1}\right). \quad (12)$$

Plotted in Fig. 1 are $\Delta G^0_{ex}(D)$ values against ΔG^0_{ex} values for 14 trace Ra-major divalent ion salts. The D values used to compute $\Delta G^0_{ex}(D)$ are from DOERNER and HOSKINS (1925), GOLDSCHMIDT (1940), and WEIGEL (1977). The ΔG^0_{ex} values have been computed using free energy data from Table 1, WAGMAN *et al.* (1982), and LANGMUIR (unpub. data). The plot shows a strong correlation between the two variables, with increased selectivity of host salts for Ra exhibited as ΔG^0_{ex} becomes more negative. Obviously, for D values greater than unity, ($\Delta G^0_{ex}(D) < 0$), Ra is favored over the major cation in the solid solution, and conversely for D values less than unit ($\Delta G^0_{ex}(D) > 0$). Figure 1 shows a strong correlation ($r^2 = 0.95$), with the equation of the line equal to

$$\Delta G^0_{ex}(D) = 0.492 \Delta G^0_{ex}. \quad (13)$$

The effect of temperature on D values, based chiefly on data from GOLDSCHMIDT (1940), is plotted in Fig. 2. The figure shows that D values decrease with increasing temperature, consistent except for $Ba(C_2H_3O_2)_2$ and $Sr(NO_3)_2 \cdot 4H_2O$, with a decreasing selectivity difference between the ions at higher temperatures. The plot also shows that D varies linearly or nearly so with $1/T$. This indicates that in most cases $\Delta H^0_{ex}(D)$ for the exchange reaction is constant from 0 to 100°C. $\Delta H^0_{ex}(D)$ values for the nine solid solutions based on Fig. 2 and the van't Hoff equation, are listed in Table 3, along with other thermodynamic properties of the solid solutions at 25°C, computed

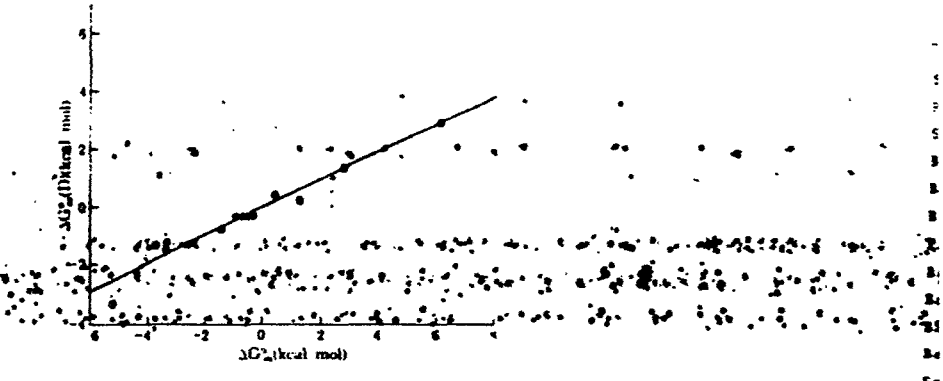

FIG. 1. Plot of $\Delta G^0_{ex}(D)$ *versus* ΔG^0_{ex} for trace radium solid solution in some major divalent metal salts at 25°C. The line through the data is constrained to pass through the point $\Delta G^0_{ex}(D) = \Delta G^0_{ex} = 0$.

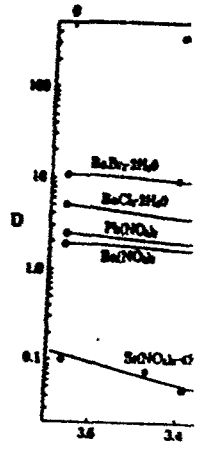

FIG. 2. Empirical
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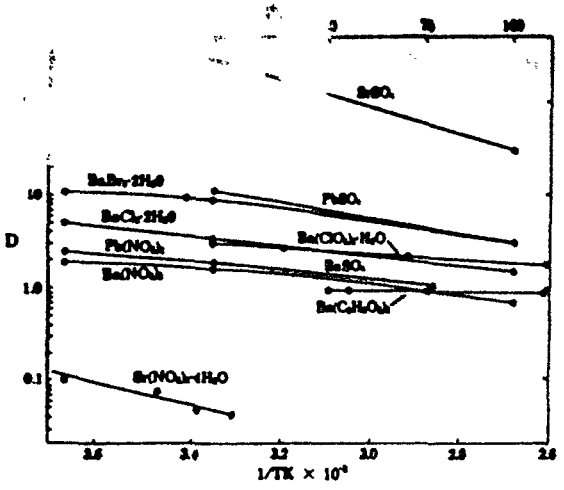

FIG. 2. Empirical distribution coefficient (D) values for trace radium solid solution in some major divalent metal salts as a function of temperature.

as described above. A plot of $\Delta H^0_{ex}(D)$ *versus* ΔH^0_{ex} for the six solid solutions in Fig. 2 is given in Fig. 3. The equation of the line through the data is

$$\Delta H^0_{ex}(D) = 0.642\Delta H^0_{ex} \qquad (14)$$

($r^2 = 0.91$). Equations (13) and (14) have been used to estimate missing thermodynamic data in Tables 3 and 4.

Of particular interest geochemically are the solubilities of trace Ra in Ca, Sr, Ba and Pb sulfate and carbonate minerals as a function of temperature. The effect of increasing temperature on D and λ_{RaX} values between 0 and 100°C is shown in Table 4. The decrease in D and λ_{RaX} values with temperature corresponds to a major reduction in the selectivity of host minerals for trace Ra. Somewhat surprisingly, trace Ra is more selectively enriched in celestite and anglesite than in barite. None of the carbonate minerals prefer Ra over their major cat... table shows that λ_{RaSO_4} and λ_{RaCO_3} ... witherite, respectively, are near unity ... so these Ra-Ba salts behave as ideal sol...

The solubility of trace Ra in rock-f... such as gypsum, anhydrite, calcite an... either not known or only approximately known. If one assumes that Ra solubility in anhydrite follows the same general relations already described for Ra solubility in other salts, then from Eqn. (13) we can compute D = 800 at 25°C. Examination of D values given by GOLDSCHMIDT (1940) shows that in every case D is greater for the anhydrous salt than hydrous salt at the same temperature. If D = 800 for anhydrite is correct, then D for gypsum should be less than this, although how much is uncertain. GOLDSCHMIDT (1940) measured an approximate selectivity of gypsum for Ra at 25°C and obtained $D \approx 0.02$. The model-predicted D value for anhydrite is larger than any measured D value in Table 3. However, the trend in D values for the sulfates with radius of the host cation is clear from the data. Thus, in the sequence of decreasing cation radius from Ra to Ba, Pb and Sr, corresponding D values increase from 1.0 to 1.8, 11 and 280. This trend indicates an increase in the solubility of Ra in host sulfate minerals with an increase in the difference between the ionic radii of Ra and the host cation. The same behavior is apparent for the carbonate solid solutions, although the magnitude of the effect is far less pronounced than for the sulfates. Such behavior is clearly at variance with conventional wisdom regarding the effect of ionic radii differences between cations on their binary solid solution behavior.

Considered from a thermodynamic point of view, however, there is logic to the trends. Among the alkaline earth sulfates, $RaSO_4$ has a *Ksp* of −10.26, followed by *Ksp* values of −9.97, −6.64 and −4.36 for $BaSO_4$, $SrSO_4$, and $CaSO_4$ (LANGMUIR and MEL-

TABLE 3. Ther...ic properties of trace Ra-major salt solid ... ...ed in the text. Enthalpies and free energies ... kilocalories per mole. Parentheses enclose values estimated from equations (13) or (14), or derived from such estimates.

	ΔH^0_{ex}	$\Delta H^0_{ex}(D)$	ΔG^0_{ex}	$\Delta G^0_{ex}(D)$	D	λ_{RaX}
$SrSO_4$(celestite)	−9.93	−6.58	−5.16	−3.34	280	215
$PbSO_4$(anglesite)	−7.25	−3.83	−3.37	−1.42	11	26.8
$Sr(IO_3)_2$	−7.55	(−4.85)	−3.36	−1.36	10	29.0
$BaBr_2 \cdot 2H_2O$	−5.9	−3.24	−3.60	−1.30	9	37.9
$BaCl_2 \cdot 2H_2O$	−3.43	−2.50	−1.36	−.74	3.5	2.17
$Ba(ClO_3)_2 \cdot H_2O$	(−2.35)	−1.51	(−1.36)	−.67	3.1	(3.2)
$Pb(IO_3)_2$	−3.3	−1.51	−.96	−.38	1.9	2.66
$BaSO_4$(barite)	−3.2	−2.03	−.41	−.35	1.8	1.11
$Ba(IO_3)_2$	−2.3	(−1.48)	−.72	−.31	1.7	1.98
$Ba(IO_3)_2$	−2.9	−2.44	−.30	−.28	1.6	1.86
$Ba(C_2H_3O_2)_2$	(−.50)	−.32	(.05)	.024	.96	(1.13)
$SrCO_3$(strontianite)	−3.81	(−2.45)	1.3	.25	.66	.17
$BaCO_3$(wit...	−2.43	(−1.56)	.39	.41	.5	1.04
$Sr(IO_3)$	...08)	−5.19	2.80	1.36	.1	.089
$PbCO_3$(	14.8	(−9.50)	6.14	2.98	.067	.00047

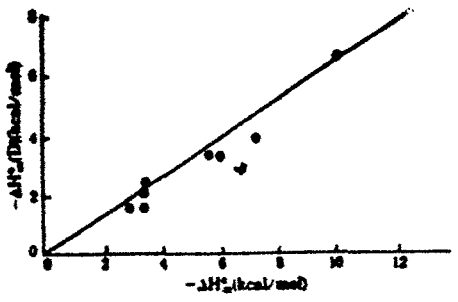

FIG. 3. Plot of $\Delta H^\circ_m(D)$ *versus* ΔH°_m for trace radium solid solution in some major divalent metal salts at 25°C. The line through the data is constrained to pass through the point $\Delta H^\circ_m(D) = \Delta H^\circ_m = 0$.

CHIOR, 1985). $RaSO_4$ is obviously the *least* soluble sulfate: nearly six orders of magnitude less so than anhydrite. The stability constants indicate that bonding between Ra and SO_4 is much stronger, than between Ca and SO_4. One could then argue that given competition between the cations in a sulfate lattice, Ra would be favored over Ca. This effect should increase as the difference in stability constants between Ra and the host cation increases.

Among the alkaline earth carbonates, however, $RaCO_3$ is the *most* soluble, with $Ksp = -8.3$, followed by aragonite, calcite, witherite and strontianite, with Ksp values of -8.34, 8.48, (PLUMMER and BUSENBERG, 1982), and -8.58, and -9.27 (see footnote *RaCO₃(c)* and Table 1). In this case the trend in D values is opposite, probably for the same reason as given for the sulfates. Model-predicted D values for calcite and aragonite are 0.82 and 0.96, respectively. $D = 0.5$ for witherite indicates further exclusion of Ra, as the host carbonate becomes even more insoluble than $RaCO_3$. $D = 0.66$ for strontianite is inconsistent with the trend in D with Ksp, but probably within the uncertainties in the D values.

These observations suggest that at trace concentrations of Ra, the solid solution behavior of the sulfates and carbonates is more dependent on [illegible] thermodynamic properties of the Ra and host cation salts, than on differences in the cationic radii. The D values obtained by GOLDSCHMIDT (1940) were measured at N_{RaX} values between 10^{-5} and 10^{-11}. Radium concentrations in natural waters rarely exceed 10^{-12} m (cf. LANGMUIR and MELCHIOR, 1985). Combined with concentration data for Ca, Sr, Ba, and Pb, and using Eqn. (1), it seems unlikely that N_{RaX} will exceed 10^{-5} in natural water/rock systems. At such low N_{RaX} concentrations, crystal strain caused by Ra substitution is probably negligible. Under these conditions, simple thermodynamic principles apparently control solid solution behavior.

For a trace Ra solid solution to play an important role in Ra ground water transport, the host mineral must be close to saturation with respect to the water. That this condition exists ca[illegible]

[illegible] ground water chemical analysis into a computer program such as WATEQF (PLUMMER *et al.* 197[illegible] for ionic strengths less than about 0.1 molal or higher ionic strengths into a computer program [illegible] calculation of ion activities *via* the ion-interaction approach of Pitzer (*cf.* HARVIE and WEARE, 1980; LANGMUIR and MELCHIOR, 1985). Once saturation with respect to a host mineral is proven, then

$$N_{RaX} = D_{RaX} \cdot \frac{[Ra^{2+}]}{[M^{2+}]} \qquad (15)$$

so that N_{RaX} in the host mineral may be computed from the ion activity ratio in the water. Note that the ion activity ratio has been substituted for the molal ratio in Eqn. (15). Most empirical D values have been measured in sufficiently dilute solutions so that these ratios are roughly equal. [At high ionic strengths in strongly complexing solutions they may not be, so that to be rigorous, we will henceforth deal with the activity ratio only.]

To determine the relative importance of trace Ra solid solutions, we not only must know the thermodynamic properties of these solutions, but also their abundances in water-rock systems. If the rock is composed of several host minerals of divalent cations, then the total Ra in solid solution in a given rock mass is

$$\text{Ra } (\mu g/g \text{ rock}) = 226 \sum D_{RaX} \times \left(\frac{[Ra^{2+}] \text{ (Wt } MX \text{ } (\mu g/g \text{ rock}))}{[M^{2+}] \text{ (GFW } MX \text{ (g/mol))}} \right). \qquad (16)$$

As Eqn. (16) indicates, for a given Ra concentration the importance of a particular solid solution as a Ra sink is directly proportional to the abundance of the host mineral and the value of D, and inversely proportional to the activity of M^{2+} in solution. Unfortunately, there are no published data that allow us to test this equation. AMES and RAI (1978) tabulate the Ra content of several major rock types, and suggest that the average Ra content of limestone is 0.42×10^{-6} μg/g rock. With Eqn. (16) we may estimate Ra = 0.054×10^{-6} μg/g rock in fresh marine limestone. That this value is less than measured probably reflects that the Ra in limestone is almost entirely Ra-226 formed by the decay of U-238 already

TABLE 4. Distribution coefficients and rational activity coefficients for trace Ra in some sulfate and carbonate minerals at 0 and 100°C. Values in parentheses are estimates. See text.

Mineral	D(25°C)	D(100°C)	λ(25°C)	λ(100°C)
$CaSO_4$ (anhydrite)	(800)	(40)	(29.8)	(5.6)
$SrSO_4$ (celestite)	280	30	215	69
$PbSO_4$ (anglesite)	11	3	26.8	8.4
$BaSO_4$ (barite)	1.8	.90	1.11	.75
$CaCO_3$ (aragonite)	(.96)	(.95)	(3.09)	(1.84)
$CaCO_3$ (calcite)	(.82)	(.77)	(.81)	(.79)
$SrCO_3$ (strontianite)	.66	(.29)	.17	(.11)
$BaCO_3$ (witherite)	.5	(.29)	1.04	(.77)
$PbCO_3$ (cerussite)	.067	(.027)	.00047	(.000077)

present in the limestone. (The average U in carbonate rocks is 2.2 μg/g, according to MASON and MOORE, 1982). Equation (16) only applies to the formation of a homogeneous solid solution incorporating Ra from a water of constant composition without significant radioactive decay, or with continuous reequilibration. Such conditions are probably approached in some instances of nuclear waste disposal, but may be uncharacteristic of radium geochemistry in most natural hydrogeologic environments. (The half-life of Ra-226 is 1622 years).

CHURCH (1979) notes that the Ra-226/Ba content of modern marine barites and pore waters is practically constant with depth in some Pacific cores at 2.4×10^{-4} μg/g. This fact, and a relatively constant Ra-228/Ra-226 ratio in these barites indicates that radium-barium exchange between the water and barite takes place within a few years. This suggests that such barites are rapidly forming a homogeneous Ra-in-barite solid solution. However, the empirical D value of 0.18 derived from analyses of Ra and Ba in the water and barite is inexplicably about ten times less than theoretically predicted for 3°C, based on this paper.

A second calculation provides further insight into the relative importance of the Ra-solid solutions listed in Tables 3 and 4. Assuming that each host mineral is at saturation with seawater, the Ra content of the rock has been computed assuming weight percents of the host minerals present. The results are given in Table 5. Anhydrite (and possibly gypsum) may be significant sinks for Ra. Limestone (and probably dolomite) are unimportant; however, at the 1% level, barite, and especially anglesite are more important than the carbonates by about six orders of magnitude. At 0.03 wt% of the rock, too small an amount to be identified by conventional means, anglesite can hold as much Ra as barite at the 1% level.

RADIOACTIVITY-CONCENTRATION RELATIONSHIPS

Radium analyses are generally reported in terms of the radioactivity of a particular Ra isotope, whereas such reactions as adsorption, precipitation, and complexation are written in terms of molar or molal concentrations. Radium isotope concentrations in water are usually given in picoCuries (1 pCi = 10^{-12} Ci) or decays per second (1 pCi = 0.037 dps). The general expression relating decay (d) rate to molar concentration (M) is

$$M\,(\text{Mol/l}) = 10^{-25.05} \cdot d\,(\text{pCi/l}) \times T\,(\text{sec}) \quad (17)$$

where T is the half-life of the isotope in seconds (LANGMUIR and HERMAN, 1980). The important isotopes of Ra and their half-lives are listed below (AMES and RAI, 1978).

Isotope	*Half life*	*Series*
Ra-223	11.43 d	U-235
Ra-224	3.64 d	Th-232
Ra-226	1622 y	U-238
Ra-228	5.77 y	Th-232

In the case of Ra-226, the conversion factor from pCi/l to picograms per liter is unity. The corresponding conversion from pCi/l to M (Mol/l) is

$$\text{Mol/l (Ra-226)} = 10^{-14.34} \cdot d\,(\text{pCi/l}). \quad (18)$$

The short-lived isotopes Ra-223 and Ra-224 are unlikely to be significantly involved in solution-mineral equilibria, which have low-temperature reaction rates most often in weeks to years. However, all the Ra isotopes must participate in complexation and adsorption-desorption reactions. The latter go to completion within seconds to a few hours unless diffusion controlled.

Another point, rarely considered, is that the extent of reaction of a particular radionuclide in a geochemical process such as adsorption or precipitation, is proportional to the ratio of the isotope's molar concentration to the total concentration of the element. This fact is irrelevant to the geochemistry of Ra-226, the predominant isotope, which greatly exceeds 99% of total Ra, but must be considered in reactions involving the other Ra isotopes.

Rigorous application of the thermodynamic data presented in this paper to radium behavior in water-rock systems requires that we have rock chemical and isotopic data, as well as measured concentrations of Ra and related aqueous species in the water. Such rock data is practically nonexistent. Numerous recent papers have reported Ra concentrations in surface and ground waters. Introducing the thermodynamic properties of radium into aqueous-reaction computer codes such as WATEQF (PLUMMER *et al.*, 1976) allows us to determine the reaction state of a water with respect to radium. Application of such an approach to the published literature on Ra in ground water will be presented in a following paper.

TABLE 5. Hypothetical Ra contents of some rocks composed of minerals assumed at equilibrium with sea water at 25°C.

Host Mineral	Wt% of host mineral in the rock	Molal concentration of host mineral cation in sea water[a]	Ra(μg/g) in rock[b]
anhydrite	100	1.03×10^{-2}	39×10^{-6}
limestone (calcite)	100	1.03×10^{-2}	$<0.054\times10^{-6}$
celestite	1	9.1×10^{-5}	11×10^{-6}
barite	1	1.5×10^{-9}	3500×10^{-6}
anglesite	1	2×10^{-10}	$123{,}000\times10^{-6}$

[a] Ra = 3×10^{-16}m. Concentrations from Henderson (1982).

[b] Assuming a homogeneous solid solution, and no net depletion or addition of Ra-226 after solid solution formation.

CONCLUSIONS AND DISCUSS[illegible]

We have critically appraised the available thermodynamic data for aqueous radium species, pure solids and solid solutions of geochemical importance, and presented an internally consistent tabulation of preferred thermodynamic values. These have been estimated for the aqueous species, and derived from empirical data or estimated for pure Ra solids and solid solutions. A model has been developed that permits prediction of the extent of trace Ra solid solution and its temperature variation, given only the standard state Gibbs free energies and enthalpies of the ions and the pure Ra and host divalent salts at 25°C and 1 bar.

Although empirical data support the solid solution model, there is a lack of experimental measurements of radium solid solution in major rock-forming sulfate and carbonate minerals, for example, with which to test the model. There is also a need for data on the Ra content of major and minor rock-forming minerals, including studies of the Ra distribution (zoning, etc.) in such minerals. When possible and appropriate, the mineralogical data should be obtained along with Ra and other isotopic and chemical analytical data for coexisting waters. The extent of such information already published will be examined by RIESE and LANGMUIR (in preparation).

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Geo... formation of ferroselite and selenium beha... vicinity of oxidizing sulfide and uranium deposits

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Abstract—The geochemistry of Se is largely controlled by that of iron, with which Se is closely alliliated in both oxidizing and reducing environments. In aerated waters the Se(IV) oxyanions, $HSeO_3^-$ and SeO_3^{2-}, are strongly adsorbed by hydrated surfaces of ferric oxides over the pH range 2–8; above pH 8 adsorption decreases to complete desorption at pH 11. This adsorption immobilizes Se(IV) in neutral-to-acid waters and increases the range of oxidation potential over which Se(IV) is stable. During experimental aeration of aqueous Fe-S-Se systems, the stability field of Se(IV) is attained, and elemental Se is slowly oxidized to this higher valence; oxidation potentials of the Se(VI) stability field were never reached, however, even by continued aeration of an alkaline system. Under reducing conditions, elemental Se either is incorporated within pyrite or forms the mineral ferroselite ($FeSe_2$).

Selenium geochemistry is summarized on an Eh-pH diagram, synthesized from equilibrium calculations, experimental work, and reported geologic occurrences. A stability field for ferroselite, constructed for a Gibbs free-energy value of −23.2 kcal/mole, is in accord both with its geologic occurrence and behavior and with conditions under which ferroselite has been synthesized. Traces on this diagram of Eh-pH variation show the behavior of selenium during oxidation of associated iron-sulfide minerals. Such considerations also demonstrate the manner in which selenium migrates, is deposited, and is increasingly concentrated in roll-type sandstone uranium deposits, as well as the relative positions of the several forms of selenium within the deposit.

INTRODUCTION

SINCE the studies of selenium by GOLDSCHMIDT and his coworkers (1933, 1935) and the almost coincident discovery that acute and chronic livestock poisoning in the western Great Plains of the United States was caused by selenium assimilated by forage crops from the soil [see ROSENFELD and BEATH (1964) for historical summary], there has been continual study of the geologic occurrence and geochemistry of selenium. Important works include summary books (TRELEASE and BEATH, 1949; ANDERSON *et al.*, 1961; ROSENFELD and BEATH, 1964; SINDEEVA, 1964; MUTH, 1967; LEUTWEIN, 1972), annotated bibliographies (LUTTRELL, 1959; GENT, 1976), and detailed geochemical studies (LAKIN and TRITES, 1956; COLEMAN and DELEVAUX, 1957; DAVIDSON and POWERS, 1959; DAVIDSON, 1960, 1963; TISCHENDORF and UNGETHÜM, 1964; D'YACHKOVA, 1965; D'YACHKOVA and KHODAKOVSKIY, 1968; GEERING *et al.*, 1968; HINGSTON *et al.*, 1968; WARREN, 1968; BUR'YANOVA, 1969).

At the surface of the Earth selenium occurs in diagenetic pyrite of fine-grained sediments (HOWARD, 1969)—for example, certain Upper Cretaceous formations of the western interior United States—and, in oxygenated aqueous environments, with hydrous iron oxides (GOLDSCHMIDT and STROCK, 1935; LAKIN and DAVIDSON, 1967; HOWARD, 1972). Incorporation of selenium into sulfides is due to the similarity in chemical properties of elemental selenium to sulfur and of ionic selenide to sulfide (GOLDSCHMIDT and HEFTER, 1933); its association with hydrous iron oxides is accomplished through strong adsorption of the selenite ions ($HSeO_3^-$ and SeO_3^{2-}) upon the hydroxylated surfaces of the iron oxides (PLOTNIKOV, 1964; HINGSTON *et al.*, 1968; HOWARD, 1972). Pyrite and hydrous iron oxides are abundant and ubiquitous, and these minerals are thus important in controlling the geochemical behavior and occurrence of selenium both in reducing environments and in more oxidizing milieux.

Selenium is concentrated also in high-temperature sulfide ore deposits and in uranium deposits in sandstones (COLEMAN and DELEVAUX, 1957; DAVIDSON, 1960, 1963; GOLDSCHMIDT and HEFTNER, 1933; LAKIN and DAVIDSON, 1967; ROSENFELD and BEATH, 1964; SINDEEVA, 1964; FARAMAZYAN and ZAR'YAN, 1964; CHITAYEVA, 1965; D'YACHKOVA and KODAKOVSKIY, 1968; BUR'YANOVA, 1969). The selenium of these deposits is contained within the sulfide minerals and is also common as native selenium and the selenide minerals: ferroselite ($FeSe_2$), clausthalite (PbSe), stilleite (ZnSe), cadmoselite (CdSe), berzelianite (Cu_2Se), eucairite (AgCuSe), and others (see BUR'YANOVA, 1969; SINDEEVA, 1964; TISCHENDORF and UNGETHÜM, 1964).

GOLDSCHMIDT and his coworkers (1933, 1935) interpreted the selenium cycle on the basis of the known chemistry of that element, analyses of many different types of geologic materials, and a few chemical experiments with selenium and iron hydroxide. Their con-

[illegible] we [illegible] essentially the following: (1) in magma[illegible] [illegible]ity [illegible]lenium is incorporated in sulfide [illegible] [illegible] volcanic sulfur; (2) selenium is separ[illegible]ed from su[illegible]r during weathering by oxidation to elemental selenium or to the selenite ion, SeO_3^{2-}, while sulfur is oxidized to a soluble, mobile SO_4^{2-} ion; (3) of the sedimentary rocks, shales and particularly iron and manganese ores are enriched in selenium; and (4) the SeO_3^{2-} is coprecipitated or strongly adsorbed by freshly precipitated ferric hydroxide, thus explaining its enrichment in sedimentary iron-oxide beds. Subsequent interpretations of selenium geochemistry are based upon the selenium content of various types of geologic materials and are generally similar to those of Goldschmidt, with elaboration and refinement made possible with the accrual of analytical data (BYERS *et al.*, 1938; LAKIN, 1961; LAKIN and DAVIDSON, 1967; ROSENFELD and BLATH, 1964; SINDEEVA, 1964).

It is the purpose of this paper to consider the manner of occurrence and the behavior of selenium during oxidation of selenium-bearing iron sulfide minerals and during formation of roll-type uranium deposits in sandstone. The interpretations are based on results of simple experiments and equilibrium calculations. Geochemical behavior of selenium in aerated natural waters, during diagenesis of sediments, and in volcanic activity will be described in subsequent papers.

THERMODYNAMIC CONSIDERATIONS

Eh–pH diagrams for selenium have been drawn previously (KRAUSKOPF, 1955; LAKIN, 1961; POURBAIX, 1963), but a more useful Eh–pH diagram than that of only the chemical species of selenium is a plot of predominant geochemical species: dissolved ions, minerals, or adsorbed ions. The association of selenium with iron sulfides and hydrous oxides and the commonly abundant occurrence of either pyrite or hydrous iron oxides in various near-surface environments lead to modified selenium Eh–pH diagrams which include these iron species and show the relationship of selenium to them. The most recent thermodynamic data available (GARRELS and CHRIST, 1965; KRAUSKOPF, 1967; MILLS, 1975; STULL and PROPHET, 1971; WAGMAN *et al.*, 1968, 1969) were used for the construction of diagrams from reactions which, although not experimentally determined, are balanced equations of Eh–pH relationships among species which are thermodynamically stable within the ranges of oxidation potential and pH [illegible] for each reaction. These [illegible] and per[illegible] oxidation potential–pH rel[illegible] with ASIS/NAPS.*

Effect of adsorption on stability of selenium species

If iron oxide is present in the system, specific adsorption of selenium oxyanions takes place by ion exchange with surface *aquo* (—Fe—OH_2), *hydroxo* (—Fe—OH), and *ol* ($^{-Fe}_{-Fe}$>OH) groups of the hydrous iron oxides and of hematite (Fe_2O_3), which, in the presence of water, readily develops a hydrous surface film with adsorptive properties of goethite (FeOOH) (PARKS, 1965, 1967). Experimental work (CHAU and RILEY, 1965; ISHIBASHI *et al.*, 1967; HINGSTON *et al.*, 1968; HOWARD, 1969, 1972) indicates that adsorption on hydrous ferric oxides removes from 95 to 99% of the Se(IV) oxyanion from solutions of pH 8 and below; the proportion of adsorbed selenium seems to depend upon the surface characteristics of adsorbing ferric oxide.

The net effect of lowered Se(IV) concentrations† is to broaden the range of oxidation potential over which Se(IV) can persist as the predominant and stable species (Fig. 1). Higher oxidation potentials are required to oxidize adsorbed Se(IV) to Se(VI), and, in the presence of ferric hydroxide, elemental Se can be oxidized at lower potentials. Figure 1 also illustrates the almost quantitative adsorption of the Se(IV) oxyanions at pH 8 to essentially complete desorption at pH 11 (HINGSTON *et al.*, 1968; HOWARD, 1972). Low

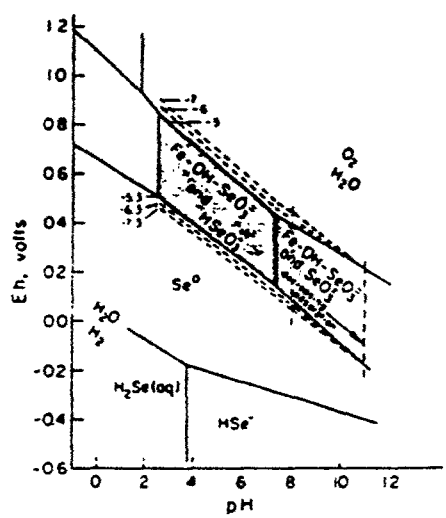

Fig. 1. The effect of adsorption of SeO_3^{2-} upon hydrous ferric oxide (represented by formula Fe—OH—SeO_3^{2-}) on Se(IV) stability fields. Dashed lines show resulting shift of oxidation potentials for Se(IV)–Se(VI) and Se(IV)–Se(0) couples; numbers are logarithms of Se(IV) concentration: 10^{-5} and $10^{-5.3}$ M, if not adsorbed; 10^{-6} and $10^{-6.3}$ M, if 90% adsorbed; and 10^{-7} and $10^{-7.3}$ M, if 99% adsorbed. Large shaded area depicts observed Eh–pH measurements of natural waters and of geologically important organisms (BAAS BECKING *et al.*, 1960). $\Sigma(Se) = 2 \times 10^{-5}$ M, representing the range of selenium concentrations in natural waters, 10^{-3}–10^{-9} M.

* Order NAPS Document 03098 from ASIS/NAPS c/o Microfiche Publications, 440 Park Avenue, New York, NY 10016, remitting $3.00 for the microfiche or $5.00 for photocopies. Cheques should be made payable to "Microfiche Publications".

† In the wide range of ionic strengths of the several environments considered, the ionic activities of selenium species may vary by at least an order of magnitude from their ionic concentrations. For the geologic purposes of this paper, however, ionic concentrations will be considered equivalent to ionic activities.

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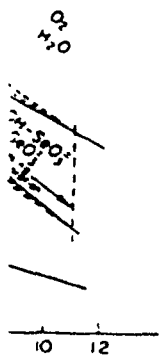
HOWARD, 1972). Low



$SeO_3^{=}$ upon hydrous
Fe—OH—$SeO_3^{=}$) on
now resulting shift of
VI) and Se(IV)–Se(0)
Se(IV) concentration:
10^{-6} and $10^{-6.3}$ M,
^{3} M, if 99% adsorbed.
Eh–pH measurements
important organisms
2×10^{-6} M, repre-
ntrations in natural
M.

pH favors [illegible] olution, as H_2SeO_3 [illegible] ous ferric oxide dissolves [illegible] ing conditions—the pH [illegible] upon the crystalline [illegible] —and the selenium on [illegible]

Ferric-hydroxide adsorption, not the formation of an insoluble selenite, is responsible for controlling the selenite concentration in natural waters. Selenium and iron concentrations of natural waters are far below the amounts to be expected from equilibrium dissociation, at any pH, of either a basic ferric selenite, $Fe_2(OH)_4SeO_3$ (BYERS *et al.*, 1938), or another very slightly soluble selenite, $Fe(SeO_3)_3$ (CHUKHLANTSEV and TOMASHEVSKY, 1957; BUKETOV, 1965).

Geochemical stability of iron-selenide compounds

The Eh pH diagram of selenium may be further developed by consideration of the low-temperature selenide minerals. The mineral ferroselite ($FeSe_2$) is the stable compound of iron and selenium and occurs with iron sulfides of very high selenium content in uranium deposits in sandstones of the western United States (COLEMAN and DELEVAUX, 1957; COLEMAN, 1959; GRANGER, 1966; HARSHMAN, 1966) and, in the U.S.S.R., with sulfide and uranium mineralization in sandstones (BUR'YANOVA and KOMKOV, 1955; BUR'YANOVA, 1961, 1969; KASHIRTSEVA, 1964); another iron selenide, FeSe, occurs as the mineral achavalite. Equilibrium relationships between these iron selenides and iron sulfides are developed herein to assist in interpreting paragenesis of low-temperature pyrite–ferroselite–iron oxide–elemental selenium associations. Eh–pH stability relationships have previously been determined for clausthalite (PbSe) (CHENDORF and UNGENTHUM, 1964) and for some selenides of Fe, Zn and Cd (BUR'YANOVA, 1969) in order to interpret conditions of formation of these minerals and to compare their geologic stabilities in low-temperature ore deposits.

The rare occurrence of achavalite (FeSe), even in mineral associations of high selenium content, can be understood through examination of Fig. 2. Formation of FeSe by reduction is unlikely because the equilibrium oxidation potentials for reactions (2) and (3) lie below that at which water is reduced (Fig. 2A and 2B), except at lower concentrations of H_2S (Fig. 2C). Yet the stoichiometric excess of sulfur in the system which produces pyrite in low-temperature selenium-bearing mineral associations limits the stability range of FeSe to oxidation potentials at which pyrite is itself oxidized, a very small FeSe stability field [Fig. 2A and 2B, reactions (5), (6), and (7)]; FeSe can thus form by alkaline oxidation of FeS–Se^0 or FeS–HSe^- mixtures. Initial formation of a hydrous iron oxide in the oxidation of selenium-bearing iron sulfide would permit formation of FeSe, but, since hematite (Fe_2O_3) is actually stable at an oxidation potential below that of the FeS–FeSe couple (Fig. 2A), FeSe should eventually oxidize to Fe_2O_3 and to elemental

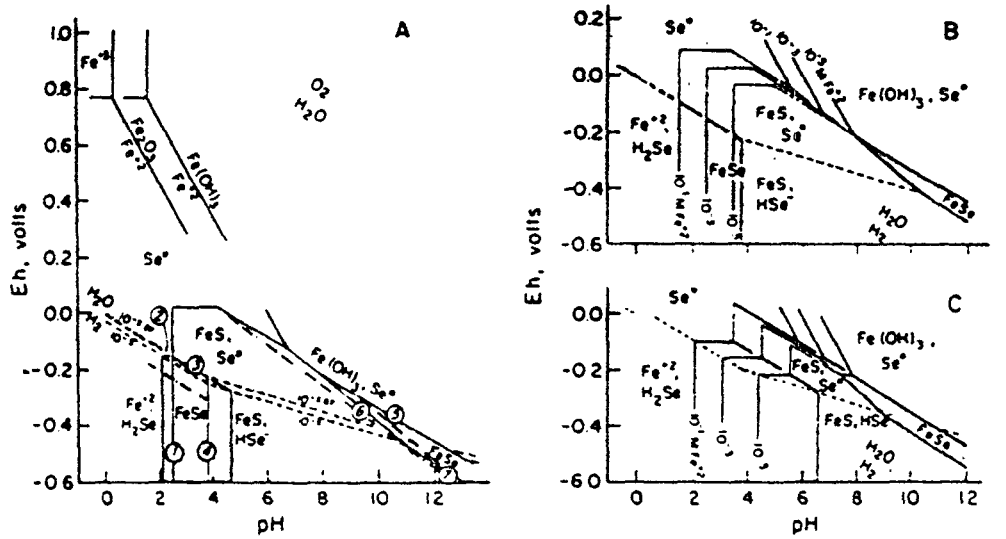


Fig. 2. Eh–pH relations of iron compounds which may form initially in an aqueous system of sulfur and selenium. The left-hand Fe–Se stability field is derived from half-cell reactions (1)–(4); equation numbers appear on representative boundary lines; reactions are in the Appendix; and the right-hand FeSe field is determined by reactions (5)–(7). A. ΣS is 10^{-1} M; (Fe^{+2}), 10^{-3} M, and ΣSe, 10^{-3} and $10^{-3.8}$ M. FeSe and FeS coexist only when the (H_2Se)/(H_2S) ratio exceeds $10^{-2.8}$, producing the smaller field within the left-hand FeSe stability field. This field expands with an increasing (H_2Se)/(H_2S) ratio (illustrated at 10^{-3} M H_2Se) but disappears at any lower concentration ratio. Dashed lines represent the H_2Se–Se^0 and HSe^-–Se^0 couples at 10^{-3} and $10^{-3.8}$ M. Dash-dot lines are oxidation and reduction boundaries of FeS_2 (pyrite), showing that pyrite is more stable than FeS. Double-dash, double-dot line is the FeS–Fe_2O_3 (hematite) oxidation boundary. B. Effect of concentration of dissolved iron. ΣS, 10^{-1} M; ΣSe, $10^{-3.8}$ M. C. Effect of lower concentrations of dissolved sulfur species. ΣS, 10^{-5} M; ΣSe, 10^{-5} M.

Se without requiring further increase in oxidation potential.

Recently published thermodynamic data (MILLS, 1975) facilitate calculation of the Gibbs free energy of formation for ferroselite (Table 1) according to the relationship

$$\Delta G^{\circ}_{f,FeSe_2} = \Delta H^{\circ}_{f,298} - T\Delta S^{\circ}_{298}. \qquad (8)$$

where $\Delta H^{\circ}_{f,298}$ and ΔS°_{298} are the standard heat of formation (enthalpy) and formation-reaction entropy differences, respectively, for $FeSe_2$ at 298.15 K. Of two estimated heat of formation values, -21.5 ± 3 kcal/mole and -25.0 ± 3 kcal/mole (MILLS, 1975), Mills had adopted the latter, which was calculated from dissociation-pressure data. Standard entropy of ferroselite (20.75 cal/mole/K) was determined from heat-capacity measurements (GRONVOLD and WESTRUM, 1962). Another value for the free energy of formation of ferroselite, -34.06 kcal/mole, had been estimated earlier (LETNIKOV, 1965) from theoretical consideration of similarities of other thermodynamic properties of many chemical compounds of mineralogic importance.

The stability relations of ferroselite are plotted in Fig. 3 for each of these $\Delta G^{\circ}_{f,FeSe_2}$ values (Table 1); the free-energy value of -23.2 kcal/mole (MILLS, 1975), however, is used for subsequent interpretations of selenium geochemistry (Fig. 7). The geochemical behavior of ferroselite and elemental selenium observed in sandstone-type uranium deposits, as well as the geochemical character of iron sulfide oxidation, lend support to a ferroselite free-energy value of about -23 kcal/mole, rather than the earlier estimated -34 kcal mole value; this evidence and its implications are discussed in subsequent sections of the paper.

Two stability fields for ferroselite, separated by the pyrite field, appear in Fig. 3A because, as determined from equilibrium consideration of the reaction

$$FeSe_2 + 2S^{\circ} \rightleftharpoons FeS_2 + 2Se^{\circ}, \qquad (20)$$

ferroselite is not stable with respect to pyrite when excess sulfur is present. Under these conditions, elemental [illegible] pyrite and is probabl[illegible] since up to 3% by we[illegible] lid solution in pyrite at the estimated formation temperature and pressure of the Colorado Plateau ores, 138°C and 800 atm (COLEMAN and DELEVAUX, 1957). Selenium exceeding this amount may occur as native selenium, or as ferroselite (COLEMAN, 1959) if excess ferrous iron is available.

The right-hand ferroselite stability field (Fig. 3A and 3B) is not large, yet it occupies a geochemically significant position, astraddle the boundary between pyrite and its immediate oxidation product, hydrous ferric oxide (Fig. 3A). The size and shape of the field are only slightly affected by concentration of selenium species [reactions (12) and (13)]. Eventual conversion of ferric hydroxide to the more stable hematite causes ferroselite to be oxidized at a lower redox potential; the ferroselite stability field is thus decreased in size (Fig. 3B).

The formation of ferroselite under naturally occurring reducing conditions, represented by the left-hand stability field (Fig. 3A), requires either that the value of $\Delta G^{\circ}_{f,FeSe_2}$ be more negative than the estimated -23 to -24 kcal/mole or that the concentration ratio of dissolved H_2Se to H_2S in the system be in excess of about $10^{-2.6}$. Otherwise, elemental Se within, or associated with, pyrite will be reduced directly to H_2Se or HSe^-. The selenium content of pyrite in some uranium deposits indicates that the $(H_2Se)/(H_2S)$ ratio may have indeed been great enough to form ferroselite from selenium-bearing pyrite or selenium-pyrite associations; for example, the Se/S ratio, by weight, of pyrite with 3% by weight selenium in solid solution is $10^{-1.63}$. With no further knowledge about low-temperature distribution of selenium between pyrite and an aqueous solution, however, this value can only suggest that the (H_2Se) concentration was large enough to permit reduction of elemental selenium to ferroselite.

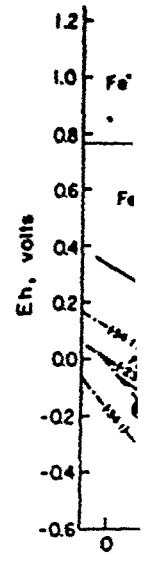
OXIDATION OF IRON SULFIDE

Chemical weathering of iron sulfides by oxygenated

Table 1. Values of free energy of formation of ferroselite calculated from reported heat of formation and entropy data

$\Delta G^{\circ}_{f,\ FeSe_2}$, kcal/mole	$\Delta H^{\circ}_{f,\ 298}$, kcal/mole	S°, cal/mole/°K	ΔS°, cal/mole/°K
-23.20	-25.0 ± 3*	20.75**	-6.05
-19.70	-21.5 ± 3*	20.75**	-6.05
-34.06	-36.56†	-	-8.4†

* MILLS (1975).
** GRONVOLD and WESTRUM (1962).
† LETNIKOV (1965).



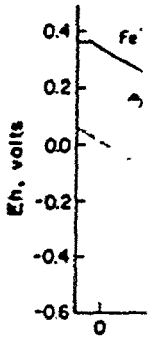


Fig. 3. Eh-pH st
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ΣSe ≥ 10^{-5} M.
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right-hand ferrose
(13) are depend
10^{-5} M). For ΔG
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(left-hand stabilit
exceeds $10^{-2.6}$
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$\Delta G^{\circ}_{f,FeSe_2}$ of −34
$(H_2Se)/(H_2S)$ ratio
trated is for (
HSe^-–H_2S field
to H_2Se and FeS
or greater, for wh
to and below the
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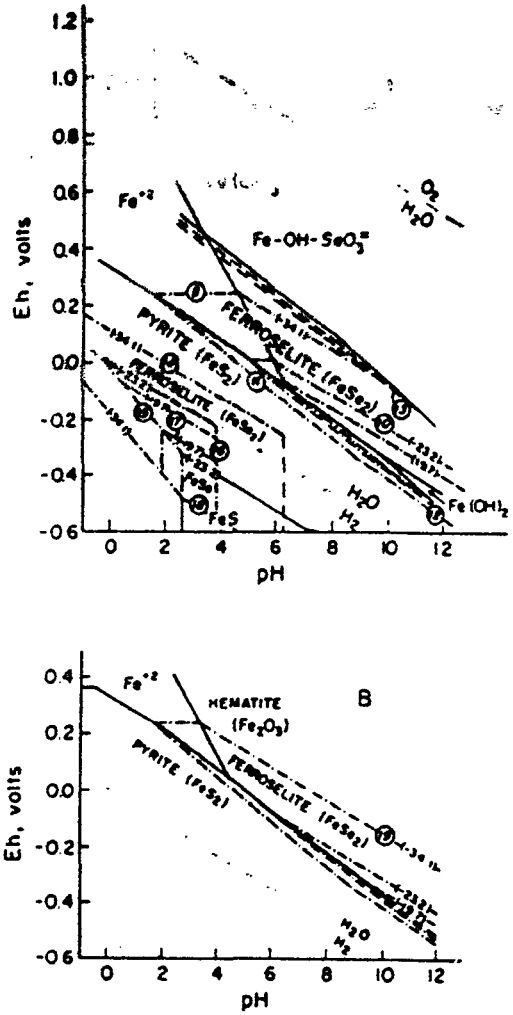

Fig. 3. Eh pH stability relations of pyrite, ferroselite, and iron oxide. $\Sigma S = 10^{-1}$ M, $(Fe^{+2}) = 10^{-5}$ M, and $\Sigma Se \geq 10^{-5}$ M. A. Stability boundaries (dash-dot lines, numbered for reactions; see Appendix) of ferroselite, calculated for several values of $\Delta G^0_{f,FeSe_2}$ (indicated on boundary lines; see text), and of the iron selenide, FeSe. For the right-hand ferroselite stability field, only reactions (12) and (13) are dependent upon Se concentration (shown at 10^{-5} M). For $\Delta G^0_{f,FeSe_2}$ values of −19.7 and −23.2 kcal/mole, ferroselite is stable with respect to pyrite and H_2Se (left-hand stability field) only when the $(H_2Se)/(H_2S)$ ratio exceeds $10^{-2.64}$ and $10^{-1.36}$, respectively. Stability fields are shown at these ratios ($10^{-3.64}$ and $10^{-2.36}$ M H_2Se); at lower concentrations this ferroselite field disappears. For $\Delta G^0_{f,FeSe_2}$ of −34.1 kcal/mole, ferroselite is stable at an $(H_2Se)/(H_2S)$ ratio of $10^{-3.64}$ or greater; the field illustrated is for $(H_2Se) = 10^{-5}$ M, extending into the $HSe^- - H_2S$ field (pH > 3.81). FeSe is stable with respect to H_2Se and FeS only at $(H_2Se)/(H_2S)$ ratio of $10^{-3.87}$ or greater, for which its stability field is shown adjacent to and below the −23.2 and −19.7 $FeSe_2$ fields. Dashed lines show displacement of Se(IV) reduction due to $SeO_3^{=}$ adsorption (Fig. 1). B. Effect of formation of hematite on the ferroselite stability field.

waters establishes conditions of increased Eh and, in the absence of neutralizing carbonates or readily soluble silicates, very low pH (SATO, 1960). Reduced forms of selenium in diagenetic pyrite in sediments, in hydrothermal pyrite of sulfide ore bodies, and in sandstone-type uranium deposits will be oxidized in response to the changing chemical conditions. The experiments with air oxidation of Fe-S-Se systems in water which are described below simulate the oxidation of ferrous sulfides and illustrate the consequent selenium behavior.

Experimental oxidation of ferrous iron (HUBER and GARRELS, 1953; SATO, 1960) has demonstrated two distinct courses of change in Eh and pH, one which is controlled by hydrolysis of the ferric iron produced during oxidation and paralleling the $Fe(OH)_3$–Fe^{+2} equilibrium boundary (Fig. 4, Trace A) and another in which alkaline conditions are maintained by a carbonate buffer (Fig. 4, Trace B). Further, measurements of Eh and pH of natural mine waters, experimental air oxidation of iron and manganese solutions, and theoretical considerations of chemical and mineral controls on the oxidation potential indicate that the maximum oxidation potential which can be attained by air oxidation of metal ions in aqueous media is that of the reversible O_2–H_2O_2 couple.

$$O_2 + 2H^+ + 2e^- \rightleftharpoons H_2O_2 \qquad (21)$$

(SATO, 1960; Fig. 4), catalyzed in surface and groundwater environments by the iron- and manganese-oxide products of aeration. The oxidation experiments of this study (Table 2, Experiments I, II, V, and VII) demonstrated the same apparent controls by the O_2–H_2O_2 decomposition, by the $Fe(OH)_3$–Fe^{+2} equilibrium, and by a $CaCO_3$ (or NH_4OH) buffer.

Apparatus and instrumentation

The experimental apparatus consisted of an air-tight plastic cell (250 ml) with glass, platinum-inlay, and saturated-calomel electrodes; thermometer; burettes for addition of acid or base; gas-bubbling tube; and outlet tube connected to a water trap. Electrochemical output was monitored by strip-chart recorders through Beckman Zeromatic pH meters, and the solution was continuously agitated with a magnetic stirrer. The compositions and results of each experiment, prepared from various reagents in 200 ml of distilled water, are summarized in Table 2 and Fig. 4.

Selenium was determined by X-ray fluorescence (XRF) using a vacuum X-ray spectrograph (Philips Electronics Instruments) with a tungsten target tube and Ni-foil filter to mask W L_β radiation (HOWARD, 1969). Selenium precipitates on MF-Millipore® filters were mounted in Mylar film on plastic sample holders (Spex Industries, Inc.) for X-ray analysis.

Analytical procedures

Oxyselenium anions were desorbed from ferric hydrous oxides by shaking with 0.5 N ammonium hydroxide–ammonium acetate; selenium in the 3-μm filtrate was reduced to the elemental state by either sulfur dioxide–hydroxylamine hydrochloride treatment or stannous chloride (HILLEBRAND *et al.*, 1953; JOHNSON, 1958; ROSENFELD and BEATH, 1964) and collected on a 0.45-μm membrane filter for quantitative XRF determination (CHAN, 1963). Dissolved selenium forms present in aqueous phases of experimental systems were similarly reduced after removal of solid materials by centrifugation and filtration. Elemental selenium was extracted from solid phases of experimental systems with carbon disulfide; evaporation of this

Table 2. Experimental air oxidation and pH variation of [illegible]

riment	System composition	Proced[illegible]	lts
I	Fe-S-Se-$CaCO_3$: (500 ppm Fe^{+3}, 10 ppm $SeO_3^=$, 580 ppm $S^=$, excess $CaCO_3$).	Reduction of Fe and Se and precipitation of FeS with Na_2S; addition of $CaCO_3$; air bubbling. Duration, 10½ hours.	Oxidation of FeS to $Fe(OH)_3$ and some Se^0 to $SeO_3^=$.
II	Fe-quartz-feldspar: (0.01 M Fe^{+3}; excess ground quartz and feldspar).	Reduction of Fe with H_2 gas; increase of alkalinity and precipitation of ferrous hydroxide (?) with NaOH; air bubbling. Duration, 17 hours.	Oxidation of $Fe(OH)_3$ to $Fe(OH)_3$.
III	$Fe(OH)_3$-$SeO_3^=$: (3.45 mg $Fe(OH)_3$/ml; 20 ppm $SeO_3^=$.	Adjustment of pH with NaOH and HCl.	See Fig. 5.
V	Fe-S-Se-$CaCO_3$: (same as for Experiment I).	Same as for Experiment I. Duration, 365 hours. Aliquots withdrawn for Se analysis (Table 3).	Same as for Experiment I; see Table 3.
VI	Fe-S-Se-$CaCO_3$: (Experiment V).	Adjustment of pH with HCl.	See Fig. 5.
VII	Fe-S: (1000 ppm Fe^{+3}; 0.1 M H_2S (satd.)).	Reduction of Fe with H_2S gas; addition of NH_4OH and precipitation of FeS; air bubbling. Duration, 2½ days.	Oxidation of FeS to $Fe(OH)_3$.
VIII	$Fe(OH)_3$-SeO_3: (10 ppm $SeO_3^=$, added to $Fe(OH)_3$ slurry of Experiment VII).	Adjustment of pH with HCl. Aliquots withdrawn for Se analysis (Table 4 and Fig. 6).	See Table 4 and Fig. 5.

* A more detailed tabulation of experimental composition, procedure, and results is available with the previously cited NAPS document.

extract under high-purity nitrogen left a precipitate of red amorphous selenium, to be dissolved with concentrated sulfuric or nitric acid, diluted, and reduced to elemental selenium for X-ray determination. Precision of XRF analysis for precipitated elemental selenium (predominantly the standard counting error) is very low for a few tenths of a microgram of selenium, but improves to 15%, and better for amounts of 1 μg or greater (HOWARD, 1969, 1975).

Results of experiments

Selenium added as Se(IV) to the systems (Experiments I, II, and V; Fig. 4) was reduced to elemental selenium as the oxidation potentials were lowered but was not again oxidized to Se(IV) by the air passed through the suspension, although the systems rapidly attained their maximum oxidation potentials—which were similar to those of natural surface waters and which lay within the $SeO_3^=$ stability field—and remained at these high potentials during the longest portion of the experiment. Bubbling of air through an Fe-S-Se-$CaCO_3$ system for a period of 365 hr (15 days) failed to oxidize the elemental selenium to its $SeO_3^=$ form (Experiment V; Table 3); similarly, elemental sulfur formed from oxidized FeS was not appreciably oxidized to sulfate. [This very high oxidation potential, the same as that achieved by SATO (1960) in 14 hr of air bubbling, may be due to a slowing of the rate of the O_2–H_2O_2 decomposition reaction whenever the oxidized form of the catalytic element—in this instance ferric iron—is in a solid form (SATO, 1960); perhaps continued aging of the $Fe(OH)_3$ precipitate slows the reaction rate even further, permitting higher oxidation potentials to be attained.] More time and possibly bacterial activity are needed for selenium oxidation. The higher Eh and pH conditions of the Se(VI) stability field were never reached in the experimental oxidation of a reduced system by air. Perhaps, therefore, air oxidation cannot produce $SeO_4^=$ during natural weathering of selenium and iron-sulfide mineral associations.

Experiment VIII provides an estimation of the extent of adsorption of $SeO_3^=$ on the $Fe(OH)_3$ product of FeS oxidation with increase in acidity of the medium. Sodium selenite was added to the air-oxidized system (Experiment VII, Table 2), and, after successive pH adjustments and 12-hr equilibration periods, aliquots of slurry were analyzed for soluble $SeO_3^=$, adsorbed $SeO_3^=$, $SeO_4^=$, and elemental selenium (Table 4 and Fig. 6). The dominant species found in each aliquot was in accord with the expected form of selenium (Fig. 5 and Table 4); no $SeO_4^=$ was detected. The amounts determined of each form of selenium roughly correspond to those to be expected, theoretically, for the Eh-pH course of Experiment VIII

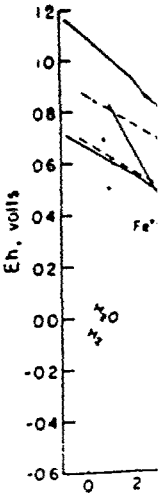

Fig. 4. Traces of exper
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The Eh variations
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Even if the ferrous-

S-Se systems*

Results

ition of FeS to $Fe(OH)_3$ and some Se^0 to $SeO_3^{=}$.

Oxidation of $Fe(OH)_3$ to $Fe(OH)_3$.

See Fig. 5.

Same as for Experiment I; see Table 3.

See Fig. 5.

Oxidation of FeS to $Fe(OH)_3$.

See Table 4 and Fig. 5.

able with the previously

the rate of the O_2-H_2O_2 the oxidized form of the ferric iron—is in a solid ued aging of the $Fe(OH)_3$ even further, permitting attained.] More time and eeded for selenium oxi- conditions of the Se(VI) in the experimental oxi- r. Perhaps, therefore, air during natural weather- mineral associations.

estimation of the extent $Fe(OH)_3$ product of FeS of the medium. Sodium lized system (Experiment ve pH adjustments and oots of slurry were ana- $SeO_3^{=}$, $SeO_4^{=}$, and ele- 6). The dominant species ecord with the expected able 4); no $SeO_4^{=}$ was ined of each form of those to be expected. rse Experiment VIII

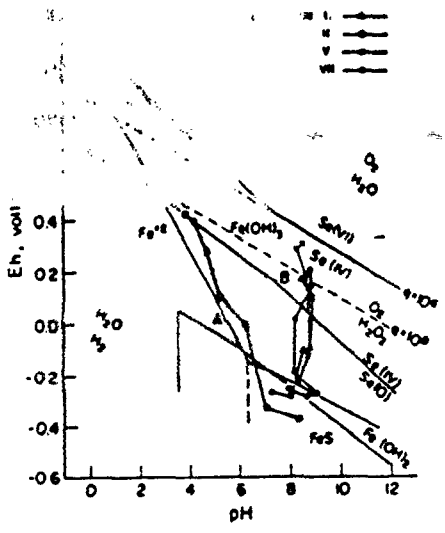


Fig. 4. Traces of experimental air oxidation of ferrous-iron solutions. Experiments I, II, V and VII (Table 2). I and V: Fe-S-Se-$CaCO_3$ system; II: Fe-quartz-feldspar system; and VII: Fe-S system. Stability fields of iron and selenium species formed during the experiments are plotted for reference: $(Fe^{++}) = 10^{-2}$ M, $\Sigma S = 10^{-2}$ M, and $\Sigma Se = 10^{-5}$ M. Also, the Fe^{++}-$Fe(OH)_2$ boundary is extended through the FeS stability field (vertical dashed line). Traces A and B (Sato, 1960) illustrate air oxidation of 0.01 M ferrous-iron solutions. The O_2-H_2O_2 couple is shown for P_{O_2}:(H_2O_2) ratios, q, of 1 and 10^n (Sato, 1960).

(Fig. 6), although the amounts of free $SeO_3^{=}$ seem much too large at pH 8, 6, and 4.

The Eh variations that occur with these experimental pH adjustments (Fig. 5) are not fully understood. Coating of the platinum electrode with ferric oxide should cause the oxidation potential to approximate the Nernst potential

$$Eh = E^0 - 0.177\,pH - 0.059 \log (Fe^{++}). \quad (22)$$

where the value of the standard electrode potential, E^0, depends upon the particular iron oxide in a ferric oxide-ferrous ion reaction such as

$$Fe(OH)_3 + 3H^+ + e^- \rightleftharpoons Fe^{++} + 3H_2O. \quad (23)$$

Even if the ferrous-ferric reaction should be too slow to be observed in the course of the experiment [illegible] should not be the case (Doyle, 1968)—and [illegible] oxidation-reduction couple exerts a pH-depend[illegible] the Eh should vary according to

$$Eh = E^0_{H^+,H_2} - 0.003\,(P_{H_2}) - 0.059\,pH, \quad (24)$$

the oxidation potential of the H^+-H_2 equilibri[illegible] measured Eh-pH slopes (Fig. 5) are neither [illegible] -0.059 V per pH unit. The oxidation potential did finally rise to higher Eh values (Experiments VI and VIII, Fig. 5), with a slope between the final and the initial points of about -0.059 pH. Perhaps slow equilibration of ferric hydroxide to the added acid, by some one-to-one H^+-e^- transfer reaction, caused the observed Eh-pH variations.

In summary, the experimental oxidation of aqueous Fe-S-Se systems suggests the following conclusions about the behavior of the selenium during natural oxidation of seleniferous iron sulfide:

(1) The higher-valence-state stability fields of selenium—at least Se(IV)—can be attained by air oxidation of a reduced aqueous Fe-S-Se system, either acid or alkaline, but elemental selenium is only slowly oxidized to $SeO_3^{=}$. Lowering of the Eh-pH conditions into the elemental-selenium field, however, easily and rapidly reduces oxidized selenium.

(2) With oxidation of selenium in iron-sulfide systems, buffered at pH 8–9 by $CaCO_3$, some selenium should become mobile, because the $SeO_3^{=}$ ions are not adsorbed strongly at the higher pH, at least pH 9–10. Adsorption at lower pH was not adequately demonstrated by these particular experiments, but it has been demonstrated elsewhere (Hingston *et al.*, 1968; Howard, 1972). Oxidation under acid conditions should produce $HSeO_3^-$, which will be strongly adsorbed by $Fe(OH)_3$ at low pH and immobilized.

(3) The stability field of Se(VI) may not be attained by air oxidation of sulfides, so that formation of the selenate ($SeO_4^{=}$) species, even under alkaline conditions, should not take place under natural conditions of weathering.

DISCUSSION

The geochemistry of selenium is summarized by the Eh-pH diagram of Fig. 7, which is based on the ex-

Table 3. Amounts of selenium in 20.0-ml aliquots of slurry withdrawn during air oxidation of aqueous Fe-S-Se-$CaCO_3$ system, Experiment V. Aliquots were centrifuged and the supernatant filtered through Millipore® 3-μm filters. The adsorbed $SeO_3^{=}$ and the elemental Se^0 were removed from the $Fe(OH)_3$ precipitate by successive extractions with NH_4OH-NH_4OAC and CS_2, respectively. The 20.0-ml aliquots should contain 200 μg selenium

Time elapsed during oxidation, hrs.: mins.	pH	Eh, mv.	Identity of suspended solid	Selenium, μg			
				>3-μ ppt.	3-μ filtrate	ads. $SeO_3^{=}$	elem. Se^0
7:20	8.53	175	$Fe(OH)_3$-S^0	0.7	0.7	0.6	> 53
50:55	8.33	280	$Fe(OH)_3$-S^0	4.3	0.9	0.2	>135
364:55	8.43	305	$Fe(OH)_3$-S^0	1.7	0.8	0.2	>148

Table 4. Amounts of selenium in 20.0-ml a[illegible] slurry (Experiment VIII) withdrawn durin[illegible] tion of aqueous FeS system previously o[illegible] (Experiment VII). Separation of the seleni[illegible] to that of Experiment V (Table 3)

pH	Eh, mv.	Selenium, μg[a]		
		dissolved $SeO_3^=$ (0.45-μ filtrate)	adsorbed $SeO_3^=$ (NH_4OH-NH_4OAc extracted)	elemental Se° (CS_2 extracted)
9.87	192	82.2	0.7	8.4[c]
8.87	221	77.9	13.5	5.2[c]
6.17	253	14.4	[b]	[b]
3.96	273	13.6	0.3	107.4
2.07	611	0.1	1.2	157.5
2.16	567	0.3	1.2	171.3

[a] Total 200 μg in each aliquot was never recovered, indicating need for improvement of separation techniques.
[b] Extraction was not successful.
[c] Some extracted material lost after the evaporation of CS_2.

perimental work and theoretical computations presented herein and elsewhere (HOWARD, 1972) and upon the geologic considerations which follow. Of major interest are the low-temperature oxidizing and reducing environments in the vicinity of ore bodies which contain iron sulfides. Adsorbed $SeO_3^=$, selenium-bearing pyrite, and ferroselite are important geochemical forms of selenium in these environments.

Ferroselite in sandstone-type uranium deposits occurs near the interface between altered sandstone (which contains goethite, limonite, and hematite) and either pyritic uranium ore or unoxidized barren sandstone containing pyrite with low selenium content (GRANGER, 1966; HARSHMAN, 1966; GRANGER and WARREN, 1969). Associations both of ferroselite-pyrite (and marcasite) and of goethite-hematite-ferroselite are seen, implying that selenium and ferrous iron, released in the destruction of pyrite by oxidizing solutions, have combined to form the minute stellate crystals of ferroselite (GRANGER, 1966). Ferroselite, then, is stable in an environment more oxidizing than is pyrite. If the Gibbs free energy of ferroselite were not more negative than about −10 kcal/mole, there would not be an $FeSe_2$ stability field between the pyrite and ferric hydroxide fields (Figs. 3 and 7). Stability of ferroselite at pH below 8 (produced by oxidation of pyrite and subsequent hydrolysis of ferric iron) further requires that its free energy of formation be more negative than −15 kcal/mole.

Ferroselite has been synthesized at pH ranging

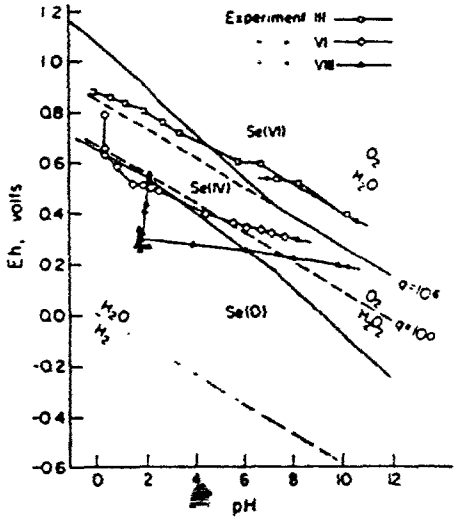


Fig. 5. Eh variation with experimental adjustment of the system pH. Experiments III, VI, and VIII (Table 2). Arrows show direction of pH change. Stability fields of selenium (10^{-5} M) are plotted for reference.

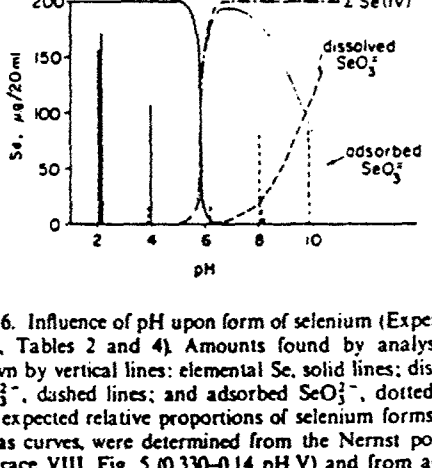
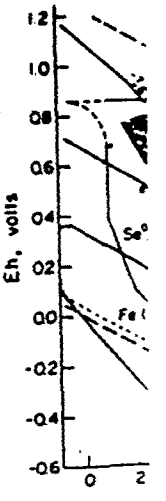


Fig. 6. Influence of pH upon form of selenium (Experiment VIII, Tables 2 and 4). Amounts found by analysis are shown by vertical lines: elemental Se, solid lines; dissolved $SeO_3^=$, dashed lines; and adsorbed $SeO_3^=$, dotted lines. The expected relative proportions of selenium forms, plotted as curves, were determined from the Nernst potential of Trace VIII, Fig. 5 (0.330–0.14 pH V) and from adsorption studies with selenite and hydrous ferric oxide (HINGSTON *et al.*, 1968; HOWARD, 1972).



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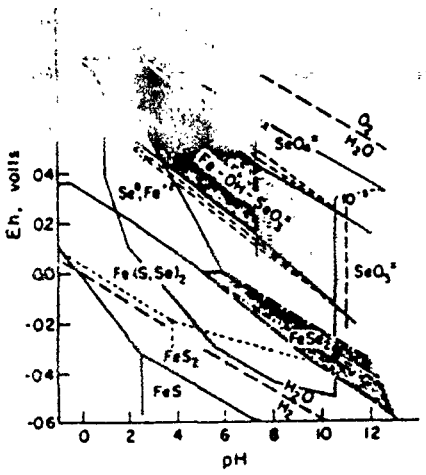

Fig. 7. Eh–pH diagram of predominant Se species in earth-surface aqueous environments. $FeSe_2$ (ferroselite) field calculated for ΔG^0 of −23.2 kcal/mole. Double-dash, double-dot line within the ferroselite field is $FeSe_2$-Fe_2O_3-Se^0 boundary (reaction 19, Fig. 3B); short-dash line within the pyrite field represents the Se^0–H_2Se and Se^0–HSe^- couples. Dashed lines parallel to the Se(0)–Se(IV) and Se(IV)–Se(VI) boundaries show displacement of these couples by adsorption on ferric hydroxide; vertical dashed lines bound a "transition" zone of decreasing adsorption with increasing alkalinity (Fig. 1). (Fe^{3+}) is 10^{-3} M; ΣS, 10^{-1} M; and ΣSe, 10^{-5} M.

from 7 to 9 and at temperatures of 80°C (WARREN, 1968), simulating the ore solutions which formed the roll-type uranium deposits (GRANGER and WARREN, 1969). No ferroselite was produced at pH 6 or below (WARREN, 1968). The synthesis involved reaction of solid FeS with a solution prepared by reaction of 1 M sodium sulfite with elemental selenium, purported to be an equilibrium mixture of sodium sulfite and sodium selenosulfate, Na_2SeO_3. Although the oxidation potential of these ferroselite syntheses is not reported, the near-neutral to alkaline conditions of its formation are in accord with the theoretical stability field of ferroselite (Figs. 3 and 7).

A ferroselite stability field constructed at $\Delta F^0_{f,FeSe_2}$ of −23.2 kcal/mole (Table 1; MILLS, 1975) is larger than that for the free-energy value of −15 kcal/mole inferred from its field occurrence (Fig. 3). It extends to pH 5, lower than that at which ferroselite could be synthesized (WARREN, 1968), but perhaps the oxidation potential of the synthesis experiments lay outside the ferroselite domain at pH 6 and below. If the free energy of ferroselite were to be more negative than −23.2 kcal/mole [as, for example, that of BURYANOVA (1969)], the range of geochemical conditions under which ferroselite can form would be expanded even further, including a stability domain at acid, very reducing conditions (Fig. 3). No field evidence suggesting that ferroselite forms at Eh–pH conditions more reducing than the pyrite stability field has been reported, however, and such acidic reducing conditions are unlikely in natural waters (F... *et al.*, 1960; SATO, 1960).

Oxidation of selenium-bearing sulfides

The Eh–pH conditions in the vicinity of ... ing sulfide body should, according to ... results, vary along one of two courses (Fig. 4): increasing oxidation of the ferrous iron of pyrite and consequent ferric-iron hydrolysis makes the medium increasingly acid, and the changing Eh and pH will follow the $Fe(OH)_3$–Fe^{3+} equilibrium. If, however, calcite or reactive silicates are present to neutralize the acid, the oxidation potential will rise, but the waters will remain alkaline or neutral. These paths can be transposed to Fig. 7 from Fig. 4 for reference.

Oxidation of seleniferous pyrite will release selenium from the pyrite structure. At low potentials the selenium may combine with ferrous iron to form ferroselite, such as that associated with some sandstone uranium deposits of the western interior United States. Further oxidation will eventually form elemental selenium, which may persist to oxidation potentials well above the upper oxidation limit of pyrite (Fig. 7), associated with limonite and jarosite. Experimental oxidation to SeO_3^{2-} takes place only very slowly, leaving most of the selenium in the native state, and elemental selenium has been found in several natural limonite materials of weathered sedimentary rocks (SAVEL'EV, 1963; HOWARD, 1969). As the Se(0)–Se(IV) couple is attained, and selenium is oxidized to $HSeO_3^-$ under acid conditions, it should be adsorbed on the limonite as demonstrated by numerous adsorption experiments with hydrous ferric oxides and ferric-oxide-bearing rock materials (BYERS *et al.*, 1938; OLSON, 1939; OLSON and JENSEN, 1940; PLOTNIKOV, 1958, 1960, 1964; HINGSTON *et al.*, 1968; CARY *et al.*, 1967; HOWARD, 1969, 1972) and experimental extractions of selenite from limonitic materials (GEERING *et al.*, 1968; HOWARD, 1969).

Whether selenium can be oxidized by aerated waters to the extent necessary to form the mobile SeO_4^{2-} ion is still uncertain. Selenate has been reported as a soluble constituent of soils, identified on the basis of its chemical behavior (that is, it is not reduced by SO_2 in sulfuric acid solutions) (ROSENFELD and BEATH, 1964; CARY *et al.*, 1967), and LAKIN (1961) has suggested that, in an alkaline environment, SeO_3^{2-} is oxidized to the Se(VI) state, SeO_4^{2-}, which neither is strongly adsorbed nor forms insoluble compounds and is, therefore, a mobile ion. Catalytic decomposition of the oxidation by-product, H_2O_2, however, seemingly prevents attainment of oxidation potentials high enough to form SeO_4^{2-} during aeration of natural waters (SATO, 1960). Even with removal of H_2O_2 and reduced ionic species in migrating waters and subsequent replenishment by oxygenated water, the remaining ferric-hydroxide oxidation products will catalyze the decomposition of H_2O_2 produced in subsequent oxidation, again inhibiting the oxidation process. Oxidation experiments

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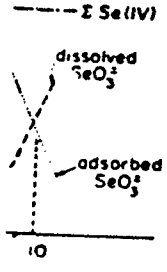

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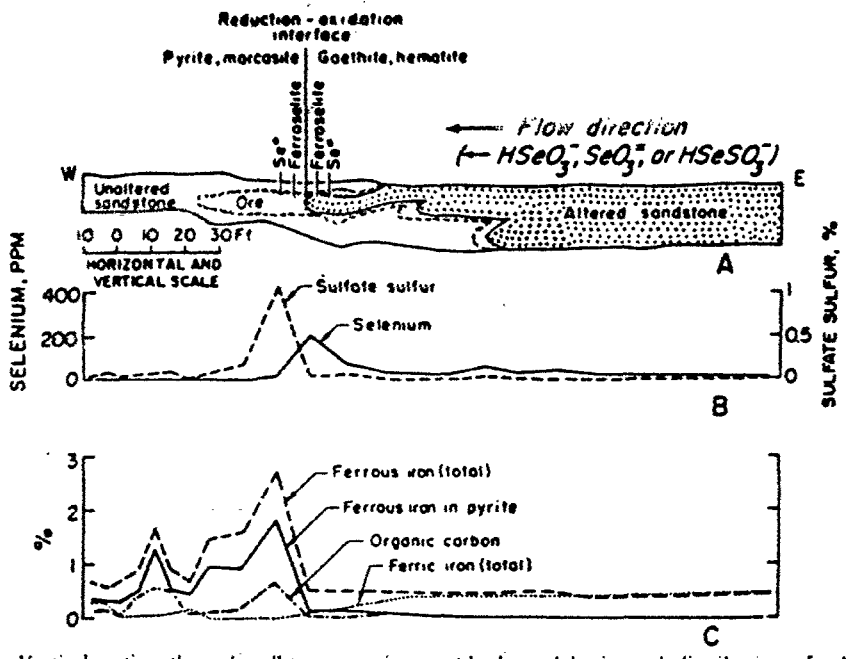


Fig. 8. Vertical section through roll-type uranium ore body and horizontal distribution of selected geochemical species through the tongue of altered sandstone and ore and into the unaltered sandstone. Arrow shows direction in which ore solution moved. [Modified from HARSHMAN (1966).]

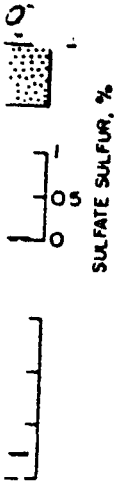
with clausthalite (PbSe), selenium-containing galena (PbS), and $SeO_3^{=}$–ferric hydroxide systems have also reportedly failed to put selenium into solution as the $SeO_4^{=}$ ion (D'YACHKOVA, 1965; KULIKOVA, 1966). Mobility of selenium as a dissolved ion does not require oxidation to $SeO_4^{=}$, however: selenite, which does not form an insoluble ferric selenite but is adsorbed on hydrous ferric oxide at pH below 8, is increasingly desorbed from pH 8 to 11, is not adsorbed at all at pH above 11, and becomes, therefore, free for transportation in alkaline waters.

Such should be the behavior of selenium during oxidation of its pyrite host, whether in sulfide ore bodies or in diagenetic pyrite. Acid conditions should prevail in the weathering zone of large pyrite bodies, with subsequent accumulation of Se^0 and $SeO_3^{=}$ in the limonite gossan. Oxidation of selenium-bearing sedimentary pyrite grains (and organic material), if neutralized by calcium carbonate of the sediments, and, more slowly, by reaction with the silicates, should release $SeO_3^{=}$ to migrate until adsorbed by limonite in waters made more acid, perhaps by atmospheric carbon dioxide. The localized environment of a diagenetic pyrite nodule undergoing oxidation, however, might remain acid, perhaps affected by its limestone host rock only around the periphery of the nodule. Selenium should remain in the nodule as adsorbed $SeO_3^{=}$ or elemental selenium; high selenium contents are indeed reported for goethite pseudomorphs after pyrite nodules in certain limestones (WILLIAMS and BYERS, 1934; HOWARD, 1969).

Selenium behavior in the vicinity of uranium ore deposits

The roll-type uranium ore bodies of Wyoming and Texas and tongue-like ores in the Colorado Plateau are concentrations of uranium and associated metals (e.g. iron, molybdenum, vanadium, selenium) in gently dipping, permeable sandstone units which are confined between units of much lower permeability. These bodies, elongated parallel to the plane of stratification, are crescent-shaped in vertical cross-section (Fig. 8). The up-dip and concave side of the ore body forms a sharp interface with sandstone altered by oxidation; down dip the sandstone is unaltered by groundwaters, iron is in the ferrous state in silicates and in diagenetic pyrite, and abundant carbonaceous plant materials occur throughout, all attesting to the prevalence of reducing conditions prior to formation of the roll deposits. These deposits probably formed as oxidizing meteoric solutions moved through the host sandstone, dissolving pyrite and other readily oxidized minerals (GRANGER and WARREN, 1969, 1974). The solution gradually lost its oxidizing potential through these reactions and passed into the reducing environment of the host rock, depositing reduced iron, selenium, and uranium minerals. These percolating ground waters have continually brought into solution and subsequently deposited the minerals at the migrating interface between the oxidized and reduced environments, increasingly concentrating those elements which are immobile under reducing conditions (GRUNER, 1956). Selenium is concentrated (Fig. 8) as elemental selenium in oxidized sandstone near the deposit, as ferroselite in both goethite–hematite and pyrite–marcasite associations at the oxidized–reduced interface, and as ferroselite and native selenium with the pyrite–marcasite and uraninite–coffinite assemblages of the ore body (GRANGER, 1966; HARSHMAN, 1966; GRANGER and WARREN,

TABULAR ORE DEPOSITS



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tially and temporally over a wide range, have been delineated from Eh–pH measurements of oxidizing mine waters, experimental oxidation systems, and stability field of minerals which are sensitive to changes in the oxidation potential (SATO, 1960). Changes induced toward either more oxidizing or more reducing conditions should follow paths of Eh–pH change, according to the buffering capacity of the environment, similar to those depicted in Fig. 4. Oxidation potentials within the front result from the relative amounts, in the mixing fluids, of active oxidizing species introduced by the ore solution and of reducing species already present in the host rock and its contained fluids or produced by oxidation–reduction reactions which take place within the mixing solutions and fluid–host medium. Oxidizing reactions use up reducing agents of the host rock (pyrite, ferrous clays, carbonaceous material) and produce, either by bacterial activity or in biologically sterile reactions, both oxidized and reduced chemical species. The ultimate oxidized species—SO_4^{2-}, ferric hydroxide, CO_2—are essentially inert and do not elevate the oxidation potential of the solution (GRANGER and WARREN, 1969). The reduced species—such as Fe^{2+}, HS^-, H_2S, $S_2O_3^{2-}$—are reactive, however, so that oxidation actually maintains a reducing environment. Only complete oxidation or removal of all reducing agents by the migrating fluid and introduction of more oxidizing agents will raise the oxidation potential.

Selenium, in low concentration in the unaltered, reduced rock (HARSHMAN, 1966, 1974), should occur as either ferroselite, or, more likely, substituting for sulfur within the pyrite (COLEMAN and DELLEVAUZ, 1957). As the ore solution intrudes the non-mineralized host rock and conditions become increasingly more oxidizing, pyrite should be destroyed and ferroselite be formed from the released ferrous iron and selenium (Fig. 7), or perhaps the delicate stellate crystals of ferroselite observed in these deposits (GRANGER, 1966) are exsolution forms in pyrite preserved after oxidation. More intense oxidation and consequent rise in oxidation potential should destroy the ferroselite, producing ferric oxide and elemental selenium. Subsequent encroachment of ore solutions of even higher oxidation potential will oxidize the elemental selenium to a selenite form, SeO_3^{2-} or $HSeO_3^-$. Some, perhaps most, SeO_3^{2-} ions will move with the alkaline oxidizing fluid, leaving behind hydrous ferric oxides with some selenite absorbed. As this SeO_3^{2-}-bearing solution moves on into the reducing environment of the host rock, its Eh will be lowered both by H_2S generated by sulfate-reducing bacteria in the host rock and from dissociation of [illegible] species (for example, SO_3^{2-} and S[illegible] intermediate products of pyrite oxidation (GRANGER and WARREN, 1969). Such dissociation produces S^0 and HS^-, which lower the Eh of the solution, and inert SO_4^{2-}, which exerts no control on the oxidation potential (GRANGER and WARREN, 1969). Selenite is reduced at the lowered Eh to elemental selenium and precipitated at the margin of the oxidized host rock with the ferric oxides formed from pyrite, the oxygen-acceptor in the reduction of SeO_3^{2-}. Other chemical species which require lower Eh for their reduction, such as those of uranium, vanadium (GARRELS and CHRIST, 1965), molybdenum, and iron, will move to the more reducing environment beyond the zone of selenium accumulation and be deposited (KASHIRTSEVA and TROSTYANSKIY, 1970). The solution, depleted of its metals and oxidizing capability, passes on into the reduced rock.

Elemental selenium will accumulate until the reducing agents in the rock either are oxidized or coated protectively with oxidized material. The ore fluid which subsequently enters this zone can then maintain its moderately elevated Eh and can bear SeO_3^{2-} (and other oxygenated metal ions) without reduction beyond and into the region of lower oxidation potential. This SeO_3^{2-} is reduced to form ferroselite and ferric oxides coevally by reaction with free ferrous iron and pyrite. Ferroselite formation is represented summarily for thermodynamic consideration (Figs. 3 and 7) by the reactions

$$Fe^{2+} + 2Se^0 + 2e^- \rightleftharpoons FeSe_2, \qquad (9)$$

and

$$FeS_2 + 2Se^0 + 8H_2O \rightleftharpoons FeSe_2 + 2SO_4^{2-} + 16H^+ + 12e^-. \qquad (11)$$

although these reactions may not depict actual reaction mechanisms. Selenium may, [illegible] solutions with limited oxygen supply and moderately low Eh, form the selenosulfate ion, $SeSO_3^{2-}$, by reaction of elemental selenium with sulfite (WARREN, 1968), an intermediate product of sulfur redox reactions. Such a metastable selenium–sulfur ion might thus effect movement of selenium into the region of very low Eh within the ore deposit (GRANGER and WARREN, 1969).

Reduction of SeO_3^{2-} and formation of ferroselite continues until oxygen acceptors are consumed. Selenite ions can then be carried through the elemental selenium–ferric oxide and the ferroselite–ferric oxide zones, passing into the ore zone, a region of lower oxidation potential in which reduced forms of several metals have already been deposited and in which the active reducing agents H_2S and HS^-, produced either by biologically sterile dissociation of oxy-sulfur products (GRANGER and WARREN, 1969) or by bacterial sulfate reduction, are accumulating. Ferroselite forms in this zone in association with iron

sulfides and reduced uranium minerals. At very low oxidation potentials, selenium is incorporated into the iron-sulfide mineral structures, forming highly seleniferous pyrite or marcasite (COLEMAN and DELEVAUX, 1957).

Continued introduction of oxidizing ore solution oxidizes and mobilizes elemental selenium from the upflow side of the metal deposit and moves it into an environment of lower potential to be reduced and deposited. As the higher oxidation potentials encroach upon the deposit the following successions of oxidative reactions occur: elemental selenium to SeO_3^{2-}; ferroselite to elemental selenium and, subsequently, to SeO_3^{2-}; seleniferous pyrite to ferroselite and ferric oxides, then to elemental selenium, later to SeO_3^{2-}. Similarly, other minerals of the deposit are oxidized, moved, reduced, and deposited. Early mineral accumulations which are very low in tenor become, through successive activity of the oxidizing solution, deposits of much higher concentrations (GRUNER, 1956; KASHIRTSEVA, 1964; GRANGER and WARREN, 1969). Selenium lags behind in the migration of other minerals of the ore body as it requires conditions more oxidizing to be dissolved and will be deposited as elemental selenium and ferroselite upon encountering a redox potential less reducing than that necessary to form pyrite and the uranium minerals.

Acknowledgements—My thanks and appreciation go to Prof. K. B. KRAUSKOPF, Stanford University, for his interest, encouragement, and guidance whenever necessary in my geochemical studies. I am also grateful for my reviewers' helpful criticism. Especially useful was reference to thermodynamic data for ferroselite (MILLS, 1975), supplied by C. G. WARREN; as a result the thermodynamic treatment now stands on much firmer ground, rather than on the hypothetical and assumed free-energy values of the first version (also in HOWARD, 1969). Funds from the Department of Geology and the School of Earth Sciences at Stanford University, which made the experimental and analytical work possible, are acknowledged with appreciation.

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REFERENCE # 27

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

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The mobility of thorium in natural waters at low temperatures

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Abstract—Thermodynamic properties of 32 dissolved thorium species and 9 thorium-bearing solid phases have been collected from the literature, critically evaluated and estimated where necessary for 25°C and 1 atm pressure. Although the data are incomplete, especially for thorium minerals and organic complexes, some tentative conclusions can be drawn. Dissolved thorium is almost invariably complexed in natural waters. For example, based on ligand concentrations typical of ground water (ΣCl^- = 10 ppm, ΣF^- = 0.3 ppm, ΣSO_4 = 100 ppm, and ΣPO_4 = 0.1 ppm), the predominant thorium species are $Th(SO_4)_2^0$, ThF_2^{2+}, and $Th(HPO_4)_2^0$ below pH ≈ 4.5; $Th(HPO_4)_3^{2-}$ from about pH 4.5 to 7.5; and $Th(OH)_4^0$ above pH 7.5. Based on stability constants for thorium citrate, oxalate and EDTA complexes, it seems likely that organic complexes predominate over inorganic complexes of thorium in organic-rich stream waters, swamp waters, soil horizons, and waterlogged recent sediments. The thorium dissolved in seawater is probably present in organic complexes and as $Th(OH)_4^0$. The tendency for thorium to form strong complexes enhances its potential for transport in natural waters by many orders of magnitude below pH 7 in the case of inorganic complexing, and below about pH 8 when organic complexing is important. The existence of complexes in addition to those formed with hydroxyl, is apparent from the fact that measured dissolved thorium in fresh surface waters (pH values generally 5–8) usually ranges from about 0.01 to 1 ppb and in surface seawater (pH = 8.1) is about 0.00064 ppb. This may be contrasted with the computed solubility of thorianite in pure water which is only 0.00001 ppb Th as $Th(OH)_4^0$ above pH 5. Although complexing increases the solubility of thorium-bearing heavy minerals below pH 8, maximum thorium concentrations in natural waters are probably limited in general by the paucity and slow solution rate of these minerals and by sorption processes, rather than by mineral–solution equilibria.

INTRODUCTION

THE THERMODYNAMIC properties of dissolved thorium species and thorium minerals can be used to compute solution-mineral equilibria relations. These theoretical calculations tell much about the possible conditions for and extent of thorium mobility. Such information helps us to understand controls on thorium concentrations in ground water, and to predict the risk of thorium release in leachates from mining activity and radioactive wastes.

Thorium is found in nature only as a tetravalent cation. The element usually occurs in geologic materials as a trace constituent in solid solution in phosphate, oxide and silicate minerals, and sorbed onto clays and other soil colloids (HANSEN, 1970; BONDIETTI, 1974). It occurs as a major species only in a few rare minerals such as thorianite (ThO_2), and thorite ($ThSiO_4$). The former mineral is isomorphous with uraninite, the latter with zircon. For this reason a large part of naturally occurring thorium is found incorporated in the zircon structure. The chief source of thorium is monazite (Ce, La, Y, Th) PO_4 which usually contains 3–9% and up to 20% ThO_2. Along with zircon, monazite is concentrated with other resistant heavy minerals in stream and beach sands (RANKAMA and SAHAMA, 1958). Igneous UO_2 can form a complete solid solution with ThO_2 (ROGERS and ADAMS, 1969). Most Th host minerals are highly refractory to weathering and thorium has long been considered a very insoluble and immobile element in natural waters.

Data on dissolved thorium concentrations in natural waters is generally of poor quality or nonexistent. Few researchers have distinguished carefully or at all between the thorium in true solution, and that associated with suspended matter. For this reason it must usually be assumed that reported thorium concentrations are the maximum possible amounts dissolved.

MOORE and SACKETT (1964) measured 0.00064 ± 0.0002 ppb Th in two centrifuged Atlantic Ocean surface water samples. Because this is among the lowest seawater values reported (see ROGERS and ADAMS, 1969), and because the salinity and cations present in seawater tend to flocculate colloidal materials, this value should closely approximate the dissolved thorium present. SOMAYAJULU and GOLDBERG (1966)

concentrations in deep waters in the two oceans which were sometimes higher and sometimes lower than their surface ocean values.

KAMATH *et al.* (1964) obtained 1.1–2.7 ppb Th in five surface waters from non-uraniferous areas in India. The samples were passed through a 10 μm filter before chemical analysis. MIYAKE *et al.* (1964) found 0.0087–0.045 ppb Th in ten Japanese river waters. Samples were passed through a 5 μm filter before analysis. Based on a sampling of (filtered?) waters from five lakes and eleven streams in California, Nevada and Utah, THURBER (1965) reported 0.08–0.4 ppb Th with a few values <0.03 ppb.

DEMENTYEV and SYROMYATNIKOV (1965) measured Th in some spring and well waters in granite, weathered mantle and alluvium on granite. For 6, clear (unfiltered) ground waters, they obtained 0.2–0.9 ppb Th, whereas, 2 anomalous waters showed 7 and 40 ppb. Both OSMOND (1964) and KAMATH *et al.* (1964) studied thorium in ground waters of different temperatures. Osmond presumably analyzed unfiltered waters from carbonate rocks. Kamath and his coworkers passed their samples through a 10 μm filter before analysis. Both studies reported Th concentrations increasing with ground water temperature. Osmond obtained 0.1 to 2 ppb Th in 4 waters having temperatures from about 25 to 91°C, respectively. KAMATH *et al.* noted that Th concentrations increased from 0.27 to 0.74 ppb in three spring waters with temperatures from 47 to 56°C, respectively.

In four surface and ground waters from areas near uranium mining, KAMATH *et al.* (1964) found 1.9–5.4 ppb Th. Based on the Russian literature, DROZDOVSKAYA and MEL'NIK (1968) concluded that as much as 0.1–10 ppb Th can occur in 'ground and mine waters'. Even higher Th concentrations (up to 38 ppm) have been recorded in seeps and ground waters associated with uranium mining and milling in the U.S.A. and Canada (see KAUFMAN *et al.*, 1976; MOFFETT and TELLIER, 1978). These situations are described in detail later in this paper.

Admittedly, much or most of the thorium reported in the above studies must be in suspended matter, not in true solution. Nevertheless, even the surface seawater value measured by MOORE and SACKETT (1964) exceeds the solubility of thorianite which is 0.00001 ppb Th as $Th(OH)_4^0$ above pH 5. The available data therefore suggest that the concentration of Th in natural waters and therefore its mobility, is greatly increased by thorium complex formation.

The behavior of thorium in aqueous systems has been summarized by AMES and RAI (1978) and RAI and SERNE (1978). They have published solubility vs pH diagrams for thorianite, $Th(OH)_4$, ThF_4 and thorium phosphate solids. However, their diagrams are

This report contains a collection and critical evaluation of the thermodynamic data for 9 solid and 32 dissolved thorium species including organic complexes. These data are then used to evaluate the distribution of thorium aqueous species and the solubility of thorianite at various ligand concentrations chosen to simulate those found in natural waters. The importance of thorium complexes to thorium mobility, thus far a matter of relative ignorance, has been estimated from these calculations. The report also includes a brief discussion of the role of sorption in thorium mobility.

THE CHOICE OF ORGANIC LIGANDS

The selection of inorganic ligands and corresponding thorium complexes for consideration was relatively straightforward in that thermodynamic data for these ligands and complexes was accessible. Also, typical concentrations of inorganic ligands in natural waters are well known. In contrast, both the identity and concentrations of organic ligands in such waters are poorly known.

The bulk of the organic material dissolved in natural waters has been described as humic substances. According to REUTER and PERDUE (1977) most of this material resembles the fulvic acids present in soils. A representative concentration of humic substances in surface waters may be about 10 mg/l (REUTER and PERDUE, *ibid.*), whereas the average concentration of humic substances in shallow ground waters may be nearer to 1 mg/l. Higher amounts are likely in most soil waters (100 mg/l, cf. MCKEAGUE *et al.*, 1976). The acidic functional groups present in natural fulvic acids (carboxyl and phenolic hydroxyl groups) vary in both strength and relative abundance (SCHNITZER and KHAN, 1978). Consequently, stabilities of metal fulvic complexes vary with solution composition and with pH. This makes the use of such stability data impractical in model calculations. For this reason we have selected citrate ($C_6H_5O_7^{3-}$), oxalate ($C_2O_4^{2-}$) and EDTA ($C_{10}H_{12}O_8N_2^{4-}$) to exemplify the probable role of thorium–organic complexes in natural waters.

The occurrence of oxalate and citrate in soils and some natural waters supports our choice of these ligands. Oxalate is present in many plants and is released upon organic decomposition (LEAVENS, 1960). LIND and HEM (1975) reported oxalic and citric acids as two of the principal organic acids in forest soils and litter. GRAUSTEIN *et al.* (1977) identified whewellite and weddellite, calcium salts of oxalic acid, as common phases in the litter layer of soils. The same observers measured 900 ppb of dissolved oxalate at

Fig. 1. Entro

20 cm depth [illegible] Oregon [illegible] that oxalic acid was the [illegible] organic acid in solution at [illegible] layer. LAKIN (1979) noted that plant root exudates (as exemplified by those from wheat) contain oxalic and citric acids among others. He also showed that pine tree root exudates contain oxalic acid. It is likely, therefore, that citrate and oxalate are not uncommon in natural waters, although their concentrations will usually be much lower than those of humic substances.

EDTA was included in our study more as a 'type' ligand than as a specific constituent in natural waters. EDTA was chosen as an example of a multidentate organic chelating agent which forms an extremely strong complex with thorium. In fact, one EDTA group can completely satisfy the coordination requirements of the Th^{4+} ion. Communications with MALCOLM (1980) and WEBER (1980) suggest that EDTA may be equivalent in complexing ability to some aqueous humic species. Also, the present and proposed use of EDTA in cleansers and decontaminants in laboratory research and in large-scale decontamination operations involving radionuclides at nuclear facilities (cf. AYRES, 1970; MEANS *et al.*, 1978) makes its consideration here the more appropriate.

The wastes from clean-up operations at such facilities are treated and disposed of in a variety of ways, but quite often end up in near-surface tanks or trenches at radioactive burial sites (CERRE and MESTRE, 1970). There, agents including EDTA can [illegible] for long periods in solution. MEANS *et al.* (1978) observed migration of ^{60}Co and other radionuclides, including thorium, from pits and trenches at the Oak Ridge National Laboratory burial site. The mobile species were identified as dissolved complexes of organic ligands, particularly EDTA. These authors found an EDTA concentration of about 98 ppb in well waters near disposal trenches at Oak Ridge.

THE THERMOCHEMICAL DATA

The thermodynamic data for thorium minerals and solutes at 25°C and 1 atm total pressure are given in Table 1. Table 2 lists thermodynamic data for non-thorium minerals and solutes used to derive the data in Table 1. Footnotes to the tables explain the data sources and methods of calculation. Such data was unavailable for citric acid or EDTA, or for their thorium complexes. However, stability constants for these species were available and are given in Table 3. The data in the tables are considered internally consistent.

A number of Russian authors have proposed that thorium carbonate complexes are important in alkaline waters (cf. SHCHERBINA and ABAKIROV, 1967). No thermodynamic data exist for such species, which in any case are unlikely to ever be significant. Thus, at alkaline pHs, thorium occurs chiefly as the strong neutral $Th(OH)_4^0$ complex which will have little tendency to associate with carbonate ion.

In Fig. 1 are plotted entropies (S° values) of thorium

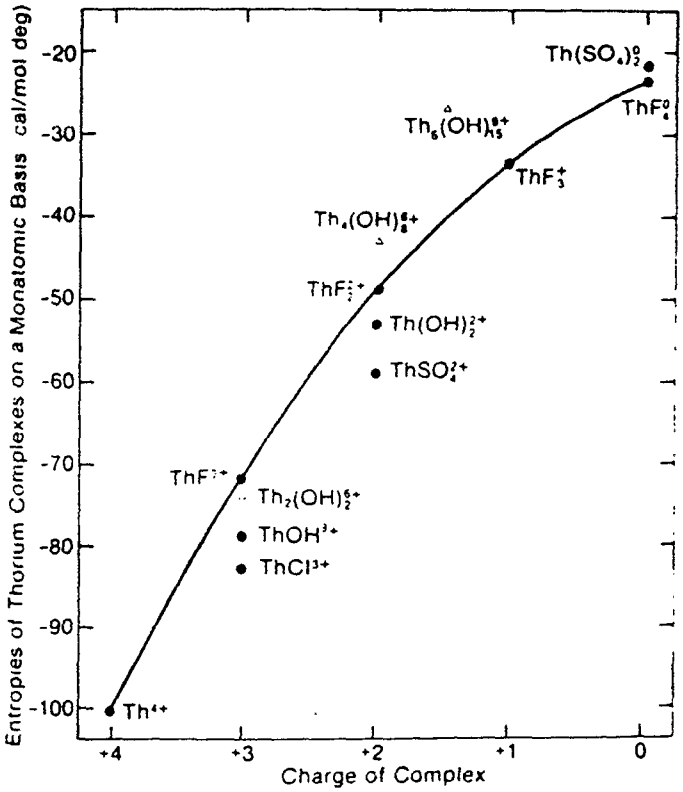

Fig. 1. Entropy vs valence for thorium ion and some thorium complexes on a monatomic basis.

Table 1.
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Mineral or aqueous species	ΔH_f° (kcal/mol)	ΔG_f° (kcal/mol)	S° (cal/mol deg)	Source
α-Th(c)	0	0	12.76	Fuger and Oetting (1976)
Th^{4+}	−183.8	−168.4	−101	Fuger and Oetting (1976)
$ThOH^{3+}$	(−246.2)	−220.7	−79*	Fuger and Oetting (1976)
$Th(OH)_2^{2+}$	(−306.5)	−272.3	−53*	Fuger and Oetting (1976)
$Th(OH)_3^+$	(−368.4)	(−322.5)	(−36)	See footnotes
$Th(OH)_4^0$	(−438.4)	−373.5	(−24)	See footnotes
$Th_2(OH)_2^{6+}$	(−489.4)	−441.8	−147*	Baes and Mesmer (1976)
$Th_4(OH)_8^{8+}$	(−1224)	−1098.3	−173*	Baes and Mesmer (1976)
$Th_6(OH)_{15}^{9+}$	(−2019)	−1810.6	−160*	Baes and Mesmer (1976)
$Th(OH)_4$	(−449.5)	−408.0	(34)	See footnotes
ThO_2(c)	—	−273.2	—	See footnotes
ThO_2(c) thorianite	−293.12	−279.35	15.59	CODATA (1977), Wagman *et al.* (1977)
$ThSiO_4$(c) thorite (huttonite)	—	—	(25.5)	See footnotes
ThF^{3+}	−265.15	−246.70	−72	Wagman *et al.* (1977)
ThF_2^{2+}	−346.1	−322.52	−49	Wagman *et al.* (1977)
ThF_3^+	−427.1	−396.2	−34	Wagman *et al.* (1977)
ThF_4^0	−508.1	−468.2	−24	Wagman *et al.* (1977)
ThF_4(c)	−501.4	−478.9	33.95	Wagman *et al.* (1977)
$ThF_4 \cdot 2.5H_2O$(c)	(−682.2)	(−624.7)	(56.0)	Wagman *et al.* (1977)
$ThCl^{3+}$	−223.7	−201.3	−83	Wagman *et al.* (1977)
$ThCl_2^{2+}$	—	−232.3	—	Wagman *et al.* (1977)
$ThCl_3^+$	—	−264.8	—	Wagman *et al.* (1977)
$ThCl_4^0$	—	−295.6	—	Wagman *et al.* (1977)
$ThCl_4$(c)	−283.6	−261.6	(45.5)	Wagman *et al.* (1977)
$ThSO_4^{2+}$	−397.2	−353.8	−59	Wagman *et al.* (1977)
$Th(SO_4)_2^0$	−611.0	−537.6	−22	Wagman *et al.* (1977)
$Th(SO_4)_3^{2-}$	—	−716.6	—	Wagman *et al.* (1977)
$Th(SO_4)_4^{4-}$	—	−891.8	—	Wagman *et al.* (1977)
$ThH_3PO_4^{4+}$	—	−444.1*	—	See footnotes
$ThH_2PO_4^{3+}$	—	−444.9	—	Wagman *et al.* (1977)
$Th(H_2PO_4)_2^{2+}$	—	−720.9	—	Wagman *et al.* (1977)
$ThHPO_4^{2+}$	(−450.3)	−443.5*	(−60)	See footnotes
$Th(HPO_4)_2^0$	(−762.3)	−720.2*	(−24)	See footnotes
$Th(HPO_4)_3^{2-}$	—	−992.1*	—	See footnotes
$Th(HPO_4)_2 \cdot 4H_2O$(c)	(−1070)	−952.5*	(89)	See footnotes
$ThC_2O_4^{2+}$	—	−342.2	—	Wagman *et al.* (1977)
$Th(C_2O_4)_2^0$	—	−515.9	—	Wagman *et al.* (1977)
$Th(C_2O_4)_3^{2-}$	—	−686.8	—	Wagman *et al.* (1977)

α-Th(c): S° supported by Rand (1975), CODATA (1977), and Wagman *et al.* (1977). Th^{4+}: Properties determined by Fuger and Oetting (1976), adopted by Wagman *et al.* (1977). $ThOH^{3+}$ and $Th(OH)_2^{2+}$: S° values based on potentiometric measurements in 1 M $NaClO_4$ (Baes and Mesmer, 1976). $Th(OH)_3^+$: ΔG_f° based on estimated K value (Baes and Mesmer, 1976). S° estimated from Fig. 2. $Th(OH)_4^0$: ΔG_f° based on K from Baes and Mesmer (1976). S° estimated from Fig. 2. $Th_2(OH)_2^{6+}$, $Th_4(OH)_8^{8+}$ and $Th_6(OH)_{15}^{9+}$: S° values based on potentiometric measurements in 1 M $NaClO_4$ (Baes and Mesmer, 1976). $Th(OH)_4$: ΔG_f° based on solubility of 'active' or 'hydrous' ThO_2 given by Baes and Mesmer (1976), assuming $\Delta G_f^\circ = 0$ for: ThO_2 (active) + $2H_2O$ = $Th(OH)_4$. S° estimated using Latimer's method with component entropies from Naumov *et al.* (1974). ThO_2(c): $\Delta G_f^\circ = -273.2$ based on solubility given by Baes and Mesmer (1976). $ThSiO_4$(c): Huttonite is apparently the stable polymorph at all temperatures (Rogers and Adams, 1969). S° is estimated as the sum of values for ThO_2(c) and SiO_2(c) quartz. $ThH_3PO_4^{4+}$: ΔG_f° computed from $K = 10^{1.89}$ measured at $I = 2$ for: $Th^{4+} + H_3PO_4^0 = ThH_3PO_4^{4+}$ (Katz and Seaborg, 1957). $ThHPO_4^{2+}$ through $Th(HPO_4)_3^{2-}$: ΔG_f° values based on stability constants measured at $I = 0.35$ (Moskvin *et al.*, 1967). S° values estimated from Fig. 2. $Th(HPO_4)_2 \cdot 4H_2O$(c): ΔG_f° based on solubility measured by Moskvin *et al.* (1967) at $I = 0.35$. S° estimated by Latimer's method with component entropies: S° (Th) = 15.9, S° (HPO_4) = 15 and S° (H_2O) = 10.7.

complexes vs their charge, where the entropy values are reasonably well known based on calorimetric or potentiometric measurements. This plot was used to estimate entropies of other monomeric complexes of the same valence. S° values for the OH polymers are also plotted for comparison purposes in Fig. 1, where S° (plotted) = S° polymer/x; [x is the number of thorium atoms in the polymer, and the charge of complex (plotted) = charge of polymer/x].

Table 3 lists the cumulative formation constants of thorium complexes with their formation reactions written

$$Th^{4+} + nL^{z-} = ThL_n^{4-nz}.$$

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the dimer $Th_2(OH)_2^{6+}$
species given by Wagr
deg respectively, in g
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Data are unavailab
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permits us to com
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$[ThO_2(c)] = 10^{-49}$
reported in Baes an
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Table 2. Thermodynamic [illegible] 1 atm total pressure. Values estimated [illegible]

Mineral or aqueous species	ΔH_f° (kcal/mol)	ΔG_f° (kcal/mol)	S° (cal/mol deg)	Source
H_2(g)	0	0	31.207	CODATA (1976)
O_2(g)	0	0	49.005	CODATA (1976)
H_2O(l)	−68.315	−56.687	16.71	CODATA (1976)
OH^-	−54.977	−37.604	−2.560	CODATA (1976)
HF^0	−76.97	−71.68	22.09	PARKER *et al.* (1976)
F^-	−80.15	−67.34	−3.15	PARKER *et al.* (1976)
Cl^-	−39.933	−31.379	13.56	CODATA (1976)
PO_4^{3-}	−305.3	−243.5	−53	WAGMAN *et al.* (1968)
HPO_4^{2-}	−308.83	−260.34	−8.0	WAGMAN *et al.* (1968)
$H_2PO_4^-$	−309.82	−270.17	21.6	See footnotes
$H_3PO_4^0$	−307.92	−273.10	37.8	WAGMAN *et al.* (1968)
SiO_2(c) quartz	−217.66	−204.66	9.91	CODATA (1976)
SiO_2(am)	−215.33	−202.91	11.8	See footnotes
$H_4SiO_4^0$	−348.30	−312.58	45.1	See footnotes
$H_3SiO_4^-$	−342.18	−299.18	20.7	BUSEY and MESMER (1977)
$H_2SiO_4^{2-}$	—	−281.31	—	BAES and MESMER (1976)
SO_4^{2-}	−217.40	−177.95	4.50	CODATA (1977)
HSO_4^-	−212.16	−180.67	31.2	See footnotes
$H_2C_2O_4^0$	−194.7	−168.6	44.4	See footnotes
$HC_2O_4^-$	−195.6	−166.93	35.7	WAGMAN *et al.* (1968)
$C_2O_4^{2-}$	−197.2	−161.1	10.9	WAGMAN *et al.* (1968)

$H_2PO_4^-$: WAGMAN *et al.* (1968) give $\Delta G_f^\circ = -260.17$ kcal/mol, which is apparently a misprint. The tabulated value is consistent with well established stability constant data and with the tabulated ΔH_f° and S° values. SiO_2(am): ΔG_f° based on the stability of amorphous silica from 0–250°C, written $SiO_2(am) + 2H_2O = H_4SiO_4^0$, for which log $[H_4SiO_4^0]$ molar $= -0.259 - 731/T(K)$ (FOURNIER, 1976). KILDAY and PROSEN (1973) measured $\Delta H_r^\circ = 2.22 \pm 0.07$ kcal/mol for SiO_2(quartz) = SiO_2(am) from which $\Delta H_f^\circ = -215.33$ and combined with ΔG_f° from FOURNIER (1976), $S^\circ = 11.8$ cal/mol deg. The temperature function of FOURNIER (1976) leads to $S^\circ = 10.5$ cal/mol deg. $H_4SiO_4^0$: Data based on log$[H_4SiO_4^0]$ molar $= 0.394 - 1310/T(K)$ from 25–250°C for quartz solubility written SiO_2(quartz) + $2H_2O = H_4SiO_4^0$ (MOREY *et al.*, 1962). HSO_4^-: ΔH_f°, ΔG_f° and S° adjusted relative to values for SO_4^{2-} assuming properties for the reaction $H^+ + SO_4^{2-} = HSO_4^-$ unchanged from properties computed using values given by WAGMAN *et al.* (1968). $H_2C_2O_4^0$: MARTELL and SMITH (1977) list log $K = 1.252$ and $\Delta H_r^\circ = 0.9 \pm 0.1$ kcal/mol for $H^+ + HC_2O_4^- = H_2C_2O_4^0$. The data for $H_2C_2O_4^0$ are computed from this information and tabulated results for $HC_2O_4^-$ and $C_2O_4^{2-}$. The properties of $H_2C_2O_4^0$ listed by Wagman *et al.* are in error.

In this expression L is the ligand of valence z and n is the number of ligand groups in the complex. In some cases, for comparison purposes, more than a single source and constant are listed in Table 3. Sources of the data chosen for inclusion in Table 1 are indicated in the 'Source' column of that table. The stability constants and entropies of the Th-OH complexes given by BAES and MESMER (1976) have been adapted here. These authors provide a more complete description of the Th-OH system than do WAGMAN *et al.* (1977), who give only data for $ThOH^{3+}$, $Th(OH)_2^{2+}$ and the dimer $Th_2(OH)_2^{6+}$. Entropies of the first two fo these species given by Wagman *et al.* are −82 and −52 cal mol deg respectively, in good agreement with the tabulated values.

Data are unavailable for complexes between Th^{4+} and $H_4SiO_4^0$ or $H_3SiO_4^-$, however, such complexes are likely to be important in acid, silica-rich waters. No empirical thermodynamic values are available for thorite.

Writing the solubility of ThO_2(thorianite) as

$$ThO_2 + 2H_2O = Th^{4+} + 4OH^-$$

permits us to compare the stabilities of ThO_2 and $Th(OH)_4$. Thus, K_{sp} $[Th(OH)_4] = 10^{-46.6}$; and K_{sp} $[ThO_2(c)] = 10^{-49.7}$ based on solubility measurements reported in BAES and MESMER (1976) and $10^{-54.2}$ computed from the CODATA (1977) ΔG_f° value for thorianite. The disparity between these last 2 values is disturbing. However, the full range of K_{sp} values of 7.6 log units separating the amorphous and crystalline Th oxides and hydroxides is perfectly possible for a quadravalent cation such as Th^{4+}. Approximate solubilites of $Th(OH)_4$ and ThO_2(c) as a function of temperature to near 300°C are reported by ROBINS (1967).

DISSOLVED THORIUM SPECIES

Cumulative formation constants of the complexes vs ligand number are plotted in Fig. 2. In general, the stronger the 1:1 complex, the more likely that an important 1:2 and 1:3 complex will also exist. Weak 1:1 complexes as are formed with Cl^-, NO_3^-, and $H_3PO_4^0$ indicate that higher order complexes will also be unimportant. Strong complexes are formed with $H_2PO_4^-$, SO_4^{2-} and F^-. The strongest common inorganic complexes are formed with OH^- and HPO_4^{2-}. The organic species, oxalate, citrate and especially EDTA, form strong complexes with thorium.

Application of the stability constant data shows that thorium in natural waters is usually complexed with sulfate, fluoride, phosphate, hydroxide and organic anions. These complexes greatly increase the solubility of thorium minerals and the mobility of thorium in surface, soil and ground waters. To

...relative formation constants ... parentheses denote estimated values. Where more than one ... complex is shown, an asterisk indicates the value chosen for calculation in ... Table ...

Complex	Log K	I	Source
$ThOH^{3+}$	10.8*	0	Baes and Mesmer (1976)
	10.2	0	Wagman *et al.* (1977)
$Th(OH)_2^{2+}$	21.07*	0	Baes and Mesmer (1976)
	21.23	0	Wagman *et al.* (1977)
$Th(OH)_3^+$	(30.3)	0	Baes and Mesmer (1976)
$Th(OH)_4^0$	40.1	0	Baes and Mesmer (1976)
ThF^{3+}	8.44	0	Bauman (1970)
	8.03*	0	Wagman *et al.* (1977)
ThF_2^{2+}	15.06	0	Bauman (1970)
	14.25*	0	Wagman *et al.* (1977)
ThF_3^+	19.81	0	Bauman (1970)
	18.93*	0	Wagman *et al.* (1977)
ThF_4^0	23.17	0	Bauman (1970)
	22.31*	0	Wagman *et al.* (1977)
$ThCl^{3+}$	1.35	0	See footnotes
	1.09*	0	Wagman *et al.* (1977)
$ThCl_2^{2+}$	0.80	0	Wagman *et al.* (1977)
$ThCl_3^+$	1.65	0	Wagman *et al.* (1977)
$ThCl_4^0$	1.26	0	Wagman *et al.* (1977)
$ThHPO_4^{2+}$	10.8	0.35	Moskvin *et al.* (1967)
$Th(HPO_4)_2^0$	22.8	0.35	Moskvin *et al.* (1967)
$Th(HPO_4)_3^{2-}$	31.3	0.35	Moskvin *et al.* (1967)
$ThH_2PO_4^{3+}$	4.52	0	Wagman *et al.* (1977)
$Th(H_2PO_4)_2^{2+}$	8.88	0	Wagman *et al.* (1977)
$ThH_3PO_4^{4+}$	1.91	2	Katz and Seaborg (1957)
$ThSO_4^{2+}$	(6.17)	0	See footnotes
	5.45*	0	Wagman *et al.* (1977)
$Th(SO_4)_2^0$	(9.59)	0	See footnotes
	9.73*	0	Wagman *et al.* (1977)
$Th(SO_4)_3^{2-}$	(10.34)	0	See footnotes
	10.50*	0	Wagman *et al.* (1977)
$Th(SO_4)_4^{4-}$	(8.27)	0	See footnotes
	8.48*	0	Wagman *et al.* (1977)
$ThNO_3^{3+}$	0.94	0	Wagman *et al.* (1977)
$Th(NO_3)_2^{2+}$	1.97	0	Wagman *et al.* (1977)
$ThC_2O_4^{2+}$	9.30	0	Wagman *et al.* (1977)
$Th(C_2O_4)_2^0$	18.54	0	Wagman *et al.* (1977)
$Th(C_2O_4)_3^{2-}$	25.73	0	Wagman *et al.* (1977)
$ThC_6H_5O_7^+$	13.00	0.5	See footnotes
$Th(C_6H_5O_7)_2^{2-}$	20.97	0.5	See footnotes
$ThEDTA^0$	25.30	0.1	See footnotes
$ThHEDTA^+$	17.02	0.1	See footnotes

$ThCl^{3+}$: At $I = 0.5$ Katz and Seaborg (1957) give $K_1 = 2.24$ for $Th^{4+} + Cl^- = ThCl^{3+}$. Correction to $I = 0$, assuming the same activity coefficient behavior as observed for $ThOH^{3+}$ in perchlorate media (Ahrland *et al.*, 1973), gives $K_1 = 10^{1.35}$. $ThSO_4^{2+}$ through $Th(SO_4)_4^{4-}$: Allen and McDowell (1963) measured log $K_3 = 0.75$ and log $K_4 = -2.07$ for the successive stability constants of $Th(SO_4)_3^{2-}$ and $Th(SO_4)_4^{4-}$ respectively at $I = 0$. Ahrland *et al.* (1973) give log $K_2 = 2.42$ for $I = 2$. Rough correction to $I = 0$ gives log $K_2 = 3.42$. These data lead to stepwise differences of log $(K_3 K_4) = 2.82$ and log $(K_2 K_3) = 2.67$. Assuming the average of 2.75 applies to log (K_1/K_2) leads to log $K_1 = 6.17$ at $I = 0$. Values based on these calculations are shown in parentheses in Table 3. Th-citrate: Nebel and Urban (1966) as reported in Sillen and Martell (1971). Th-EDTA and Th-HEDTA: Bottari and Anderegg (1967), as reported in Sillen and Martell (1971).

properly judge the relative importance of these complexes, we must compare their amounts in solutions that contain typical concentrations of the complexing ligands.

The thermochemical data in Tables 1–3 have been used to construct the diagrams in Figs 2–11. Mathematical methods needed to develop the percentage distribution of complexes in Figs 3–8 and the mineral solubility diagrams in Figs 9–11 are described by Butler (1964). Creation of the more complicated diagrams was accomplished by programming the calculations on an IBM 370/168 computer. The diagrams

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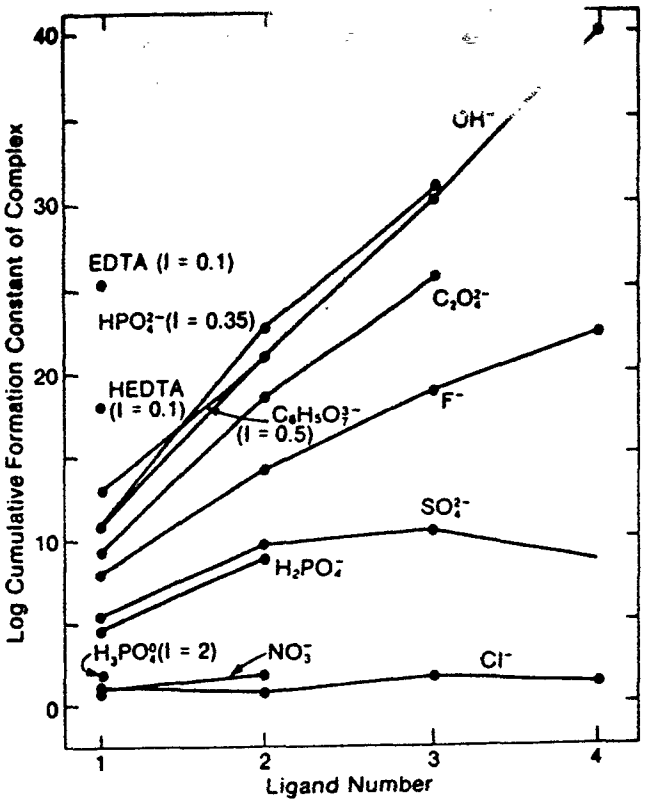

Fig. 2. Cumulative formation constants of monomeric Th^{4+} complexes at 25°C plotted against their ligand numbers. Constants are for zero ionic strength except where indicated.

are presented in terms of Th species concentrations, assuming ionic strengths and activity coefficients defined by the total concentrations specified for each plot.

Distribution of aqueous species

The distribution of aqueous thorium species for different water compositions was calculated to establish the relative importance of the various complexes in typical natural waters. Since the degree of thorium complexation is independent of its total concentration when a complexing ligand is in large excess over thorium, these distribution diagrams apply to a range of thorium concentrations depending upon which ligand is of interest. The calculations were made for 0.01 ppb total thorium, a concentration much smaller than that for any of the anions.

Figure 3 shows the range of predominance of dissolved thorium species in pure water. Free Th^{4+} ion dominates at pH's below 3. From about pH 3 to 4.5,

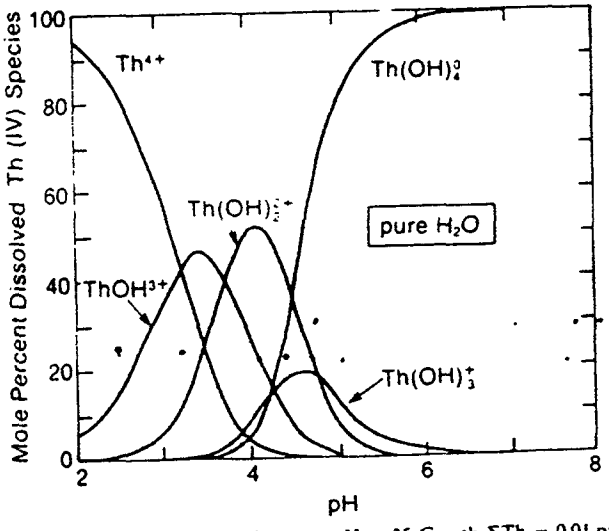

Fig. 3. Distribution of thorium–hydroxy complexes vs pH at 25 C with ΣTh = 0.01 ppb in pure water.

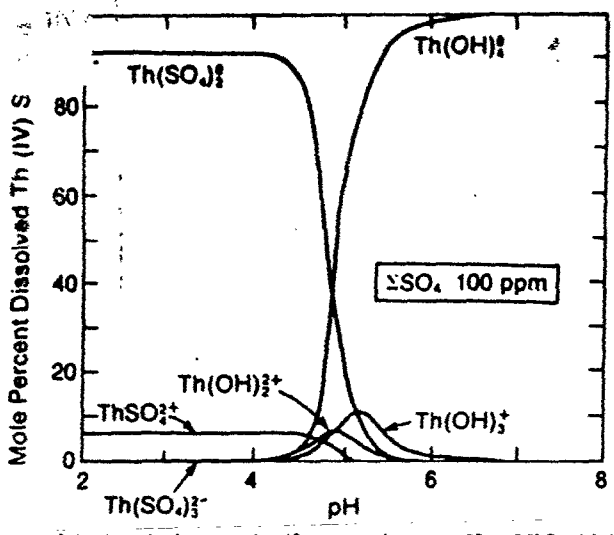

Fig. 4. Distribution of thorium–hydroxy and sulfate complexes vs pH at 25°C with ΣTh = 0.01 ppb and ΣSO_4 = 100 ppm.

the 1:1 and 1:2 hydroxy complexes predominate. Above pH 4.5, $Th(OH)_4^0$ is the major species. Figures 4–6 show the distribution of species in solutions of common inorganic ligands, sulfate, fluoride and phosphate, respectively. The anion concentrations used in each case are typical of those in natural waters. In a solution of 100 ppm total sulfate, $Th(SO_4)_2^0$ is vastly more important than other sulfate complexes or free Th^{4+} ion. Above pH 5, $Th(OH)_4^0$ is the most important aqueous species. Total fluoride equal to 0.3 ppm makes ThF_2^{2+} the major fluoride complex, although the 1:3 and 1:1 complexes are also significant. $Th(OH)_4^0$ dominates the pH region above about 5.5. $ThH_2PO_4^{2+}$, $Th(HPO_4)_2^0$, $Th(HPO_4)_3^{2-}$, and $Th(OH)_4^0$ each in turn predominate as pH increases in a 0.1 ppm total phosphate solution.

Combining these anion concentrations to create a typical groundwater and calculating the corresponding distribution of thorium species in such a solution results in Fig. 7. $Th(SO_4)_2^0$, ThF_2^{2+}, $Th(HPO_4)_2^0$, $Th(HPO_4)_3^{2-}$, and $Th(OH)_4^0$ are each in turn the most abundant aqueous species as pH increases.

Similar distribution calculations made for each of the organic ligands considered individually showed generally that the thorium–organic complexes predominate over Th–OH complexes below about pH 7. Figure 8 is a percent dissolved total thorium vs pH diagram calculated for a water with all the anions previously considered as present. The $ThEDTA^0$ complex clearly dominates among the aqueous species up to approximately pH 8.

Solubility of thorianite

Solubility diagrams were generated assuming equilibrium with thorianite. A more abundant mineral such as monazite, with thorium in solid solution,

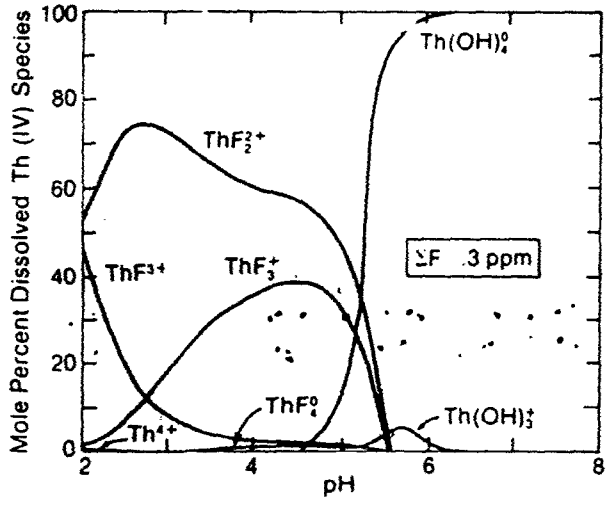

Fig. 5. Distribution of thorium-hydroxy and fluoride complexes vs pH at 25 C with ΣTh = 0.01 ppb and ΣF = 0.3 ppm.

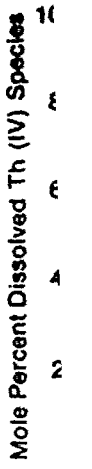

Fig. 6. Distribution

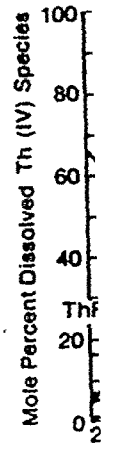

Fig. 7. Distributior

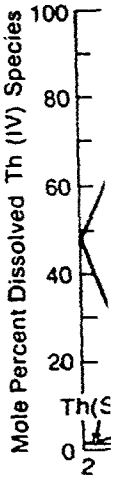

Fig. 8. Distribution

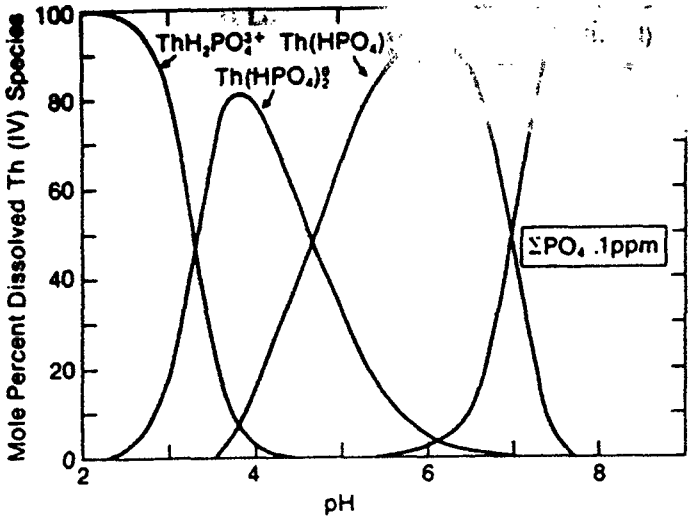

Fig. 6. Distribution of thorium-hydroxy and phosphate complexes vs pH at 25°C with ΣTh = 0.01 ppb and ΣPO_4 = 0.1 ppm.

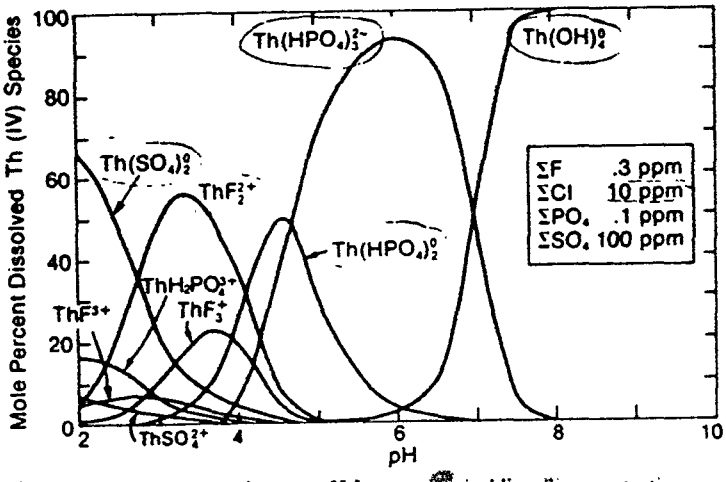

Fig. 7. Distribution of thorium complexes vs pH for some typical ligand concentrations in ground water at 25°C with ΣTh = 0.01 ppb.

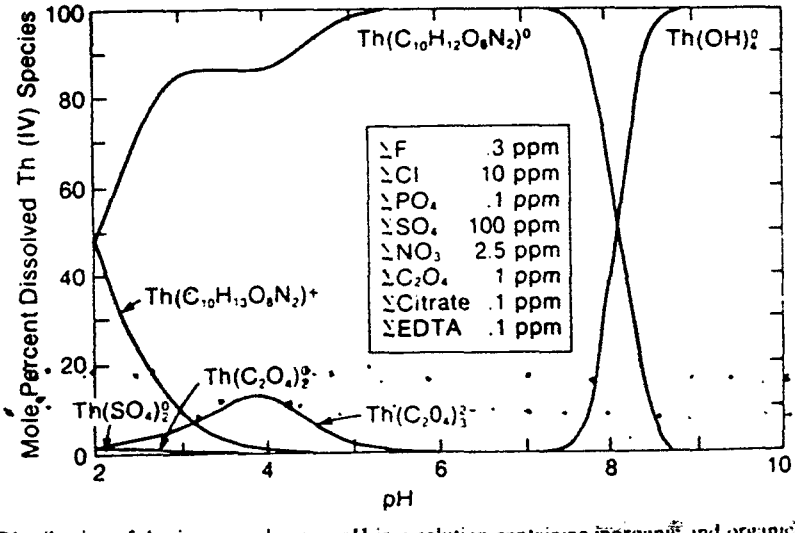

Fig. 8. Distribution of thorium complexes vs pH in a solution containing inorganic and organic species at the concentrations indicated and 25 C with ΣTh = 0.01 ppb

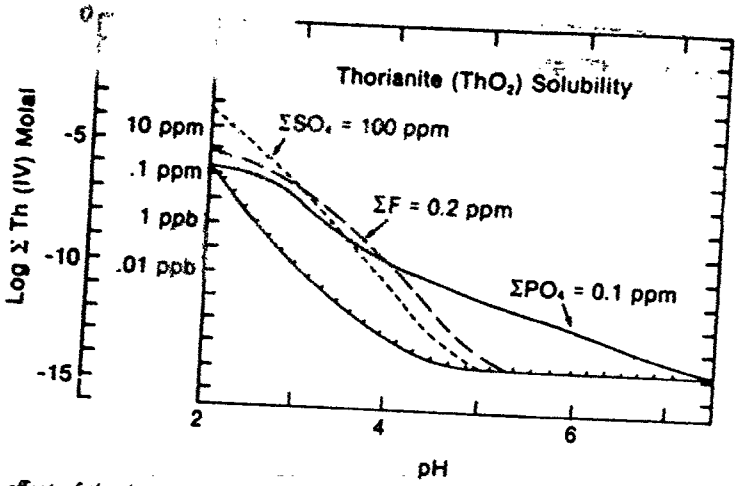

Fig. 9. The effect of thorium–sulfate, fluoride and phosphate complexing on the solubility of thorianite, ThO_2(c), as a function of pH at 25°C. The cross-hatched curve denotes the solubility of thorianite in pure water. The curves indicating thorianite solubility as affected by complexing have been constructed assuming each ligand present in the absence of the others.

could not be considered because of a lack of thermodynamic data.

The individual effects of Cl^- and NO_3^- ions on thorianite solubility are negligible. Even in sea water (pH 8.1) with Cl = 19,000 ppm, Th–Cl^- complexing is insignificant relative to hydroxyl complexing. For nitrate concentrations up to 1000 ppm, Th–NO_3^- complexes never approach 1% of total Th–OH^- complexes. Sulfate increases thorianite solubility below pH 5, as shown in Fig. 9. Dissolved thorium is increased by three orders of magnitude at pH 3 in the presence of 100 ppm total sulfate alone in solution. However, except in acid mine water and raffinates, and acid sulfate soils and H_2SO_4 leachates from hydrothermal uranium ores, increases in ThO_2 solubility due to sulfate complexing would generally be unimportant. Even in seawater with SO_4 = 2650 ppm, sulphate complexes are insignificant relative to hydroxyl complexes. Fluoride also increases ThO_2 solubility in the low pH range (Fig. 9) and does so significantly more than does sulfate alone at the same concentration. Thus, 2 ppm total fluoride can increase dissolved thorium from 10^{-4} ppb to 10 ppb at pH 4. Phosphate can increase thorianite solubility up to pH 7 (Fig. 9). For example, at pH 4, 0.1 ppm total phosphate increases ThO_2 solubility by a thousandfold.

In general, organic ligands greatly enhance the solubility of thorianite at pH's below 7. As shown in Fig. 10, 1 ppm total oxalate increases ThO_2 solubility by 10^7 times at pH 4. Only 1 ppb total EDTA (not shown in Fig. 10) similarly increases thorianite solubility by nearly 10^6 times at pH 5. Corresponding calculations for citrate show it to be a less important complexer than oxalate or EDTA. The final solubility diagram in Fig. 11 despicts the effect of the combined

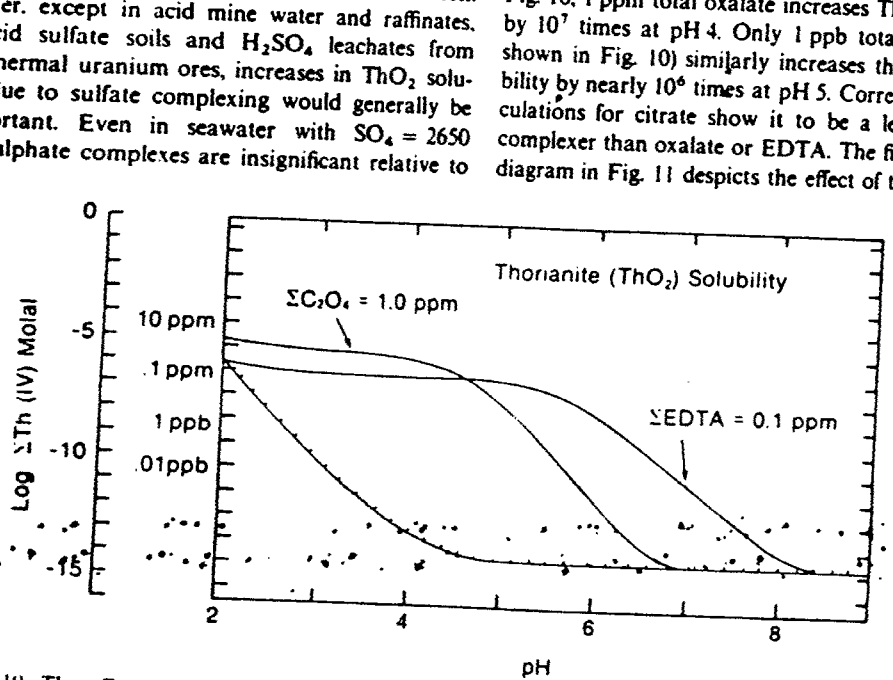

Fig. 10. The effect of thorium-oxalate vs thorium EDTA complexing on the solubility of thorianite, ThO_2(c), as a function of pH at 25 C. The cross-hatched curve denotes the solubility of thorianite in pure water. The curves indicating thorianite solubility as affected by complexing have been constructed assuming each ligand present in the absence of the other.

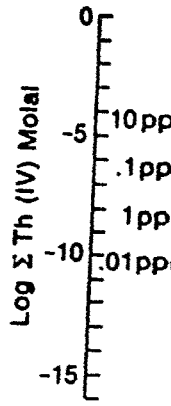

Fig. 11. The effect of thori
solution of ΣCl = 10 ppm.
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solution compositions. ThO_2
organic ligands present is incr
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pH 8, whereas inorganic ligand
effect solubility only below pH 7.

Qualitative calculations by A
suggest that in the presence of
thorium phosphate solids may
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such a conclusion is tenuous.

SORPTION OF TH

Most studies of thorium–sorpti
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of such work has involved measur
tion coefficient, K_d, defined as th
centration on the solid weight of
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chemistry (cf. DAHLMAN *et al.*, 19
(1979, pp. 2-30) summarize some c
ciencies in such work. Nevertheless
mation on the sorption behavior c
obtained.

The adsorption of thorium onto
organic matter increases with inc
practically complete at pH 6.5 (BON
bition of adsorption and a tendenc
tion is favored when strongly cc
ligands such as fulvic or citric ac
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tion of thorium–organic complex

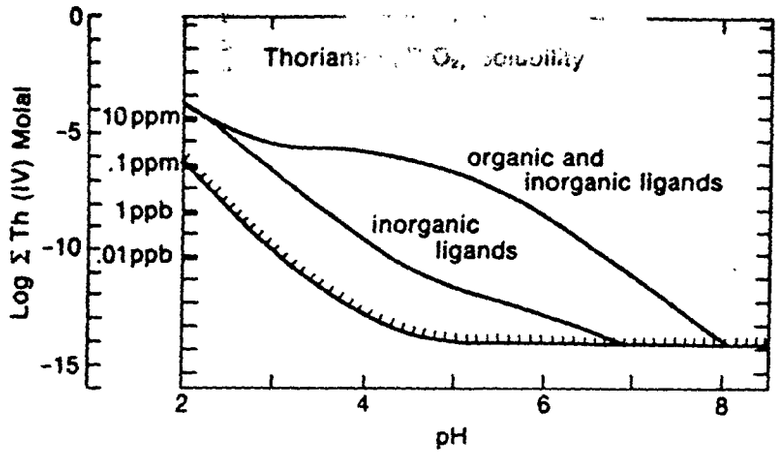

Fig. 11. The effect of thorium complexing on the solubility of thorianite. $ThO_2(c)$ vs pH at 25°C in a solution of ΣCl = 10 ppm, ΣNO_3 = 2.5 ppm, ΣSO_4 = 100 ppm, ΣF = 0.3 ppm, ΣPO_4 = 0.1 ppm, Σoxalate = 1 ppm, Σcitrate = 0.1 ppm and ΣEDTA = 0.1 ppm.

solution compositions. ThO_2 solubility with the organic ligands present is increased five orders of magnitude above the purely inorganic solubility at pH 5. The range of increased solubility extends up to pH 8, whereas inorganic ligands alone significantly effect solubility only below pH 7.

Qualitative calculations by AMES and RAI (1978) suggest that in the presence of calcium phosphates, thorium phosphate solids may be even less soluble than thorianite above pH 6. However, because their results were obtained without considering complexes such a conclusion is tenuous.

SORPTION OF THORIUM

Most studies of thorium-sorption onto natural materials have at best led to qualitative results. The bulk of such work has involved measurement of a distribution coefficient, K_d, defined as the radionuclide concentration on the solid/weight of solid, divided by the radionuclide concentration in solution solution volume. Such values have rarely been determined with adequate consideration of the detailed mineralogy and surface chemistry of sorbent phases, or of the solution, including its speciation and reaction chemistry (cf. DAHLMAN *et al.*, 1976). AMES and RAI (1979, pp. 2–30) summarize some of the common deficiencies in such work. Nevertheless, some useful information on the sorption behavior of thorium has been obtained.

The adsorption of thorium onto clays, oxides and organic matter increases with increasing pH and is practically complete at pH 6.5 (BONDIETTI, 1974). Inhibition of adsorption and a tendency towards desorption is favored when strongly complexing organic ligands such as fulvic or citric acids, or EDTA are present (BONDIETTI, *ibid.*). In neutral to acid waters, thorium adsorption is less complete onto clays than onto solid humic substances. Conversely, the formation of thorium–organic complexes leads to more complete desorption of thorium from clay than from organic matter.

Because thorium ion is largely hydrolyzed at pHs above 3.2, it is evident that the hydroxy complexes are involved in the sorption process and that aquothorium ion (Th^{4+}) is not as readily adsorbed. This will in part reflect the fact that Th^{4+} must compete with protons for exchange sites (cf. DAVIS and LECKIE, 1979). VYDRA and GALBA (1967) found that only minor sorption of thorium onto silica gel occurred at pH's below 2, but that sorption increased with pH to maximum values at about pH 5.5. Employing a mixed quartz-illite soil as sorbent, RANCON (1973) measured a K_d value of 5 ml.g at pH 2, but K_d rose to 5×10^5 ml/g at pH 6. With a quartz-illite-calcite-organic matter soil, Rancon found that K_d decreased from 10^6 ml/g at pH 8 to 100 ml g at pH 10. This reduction in sorption with increased pH was attributed to dissolution of soil humic acids and the formation of thorium–organic complexes.

Unfortunately, the published research on thorium adsorption to date has been insufficiently detailed to allow more than qualitative application of such results to complex natural systems. Distribution coefficients have no accurate predictive value outside the laboratory systems employed for their measurement. Future research should instead be directed towards measurement of thermodynamically meaningful adsorption constants, which require a relatively complete knowledge of the activities of dissolved species including complexes, and of the surface properties of sorbent phases (cf. DAVIS and LECKIE, 1979; LANGMUIR and OZSVATH, 1980).

RELATIONSHIP BETWEEN THE MOLAR CONCENTRATION OF THORIUM AND ITS RADIOACTIVITY

The radioactive isotopic concentration of a given element in water is usually determined from the

water ... in pico-Curies (10^{-12} ...) ... the radioactivity measured ... ion per liter, the pico-C... nverted to decays per se... 037 dps. From the radioactive decay law, the expression $T = (\ln 2)/\lambda$ is derived, where T is the half-life of the radionuclide in seconds and λ is the probability that the nuclide will decay within a given time. By definition: Disintegration rate (D) = λN, where N is the number of radioactive atoms present. Then: $N = D(\text{dps})/\lambda(\text{sec}^{-1})$. Substituting $(\ln 2)/T$ for λ, and dividing the preceding expression by Avogadro's number (6.022×10^{23} atoms/mol) to convert atoms per liter to moles per liter (M), leads to a general equation relating radioactivity to concentration for any radionuclide:

$$\text{M(mol/l)} = 10^{-25.05} D(\text{pCi/l}) \times T(\text{sec})$$

The predominant thorium isotope (near 100% of total Th) is ^{232}Th, with a half-life of 4.4×10^{17} sec. The isotope ^{230}Th has a half-life of 2.5×10^{12} secs. Half-lives of the other thorium isotopes are given by ROSLER and LANGE (1972). The total thorium concentration based on a ^{232}Th isotope analysis is given by

$$^{232}\text{Th (mol/l)} = 10^{-7.41} D(\text{pCi/l}).$$

Similarly, the molar concentration of ^{230}Th based on a ^{230}Th isotope analysis is given by

$$^{230}\text{Th (mol/l)} = 10^{-12.65} D(\text{pCi/l}).$$

In order to predict the reaction chemistry of thorium it is necessary to compute total dissolved thorium from an isotopic anslysis of ^{232}Th. ^{230}Th is the most important thorium isotope in the decay series beginning with ^{238}U and the most important thorium isotope in terms of its radioactivity in uranium mill tailings (ANON., 1976) and in many ground waters affected by uranium mining, milling and tailings disposal (KAUFMAN *et al.*, 1976; MOFFETT and TELLIER, 1978). The effect of reaction chemistry on ^{230}Th mobility can be estimated from its molar concentration ratio relative to ^{232}Th. Without a ^{232}Th analysis, however, the solution–reaction chemistry of ^{230}Th can only be qualitatively predicted.

MOORE and SWAMI (1972) suggest that the natural radioactivity ratio of ^{230}Th to ^{232}Th is about 0.8 in river waters and river sediments. This corresponds to a molar concentration ratio of about 4.6×10^{-6} l. In ground waters, seepages and injection well waters from the uraniferous Grants Mineral Belt in New Mexico (KAUFMAN *et al.*, 1976) the ^{230}Th ^{232}Th radioactivity ratio averaged 431 and ranged from 0.96 to 1607 in 6 waters for which analyses of both isotopes were above detection. Clearly the radioactivity due to ^{230}Th usually predominantes in such waters. In these same waters the concentration ratio of these isotopes averaged 2.5×10^{-3} and ranged from 5.8×10^{-6} to 9.1×10^{-3}, indicating the predominance of ^{232}Th on a concentration basis. Unfortunately, chemical and isotopic analyses of ground waters and related hydrologic, geologic and ... ogic data are not complete enough in this or in other published studies to allow quantitative prediction of the roles of thorium complexing, solution–mineral equilibria, or thorium adsorption on thorium mobility in these natural systems.

CONCLUSIONS AND DISCUSSION

Theoretical calculations based on critically assessed thermodynamic data indicate that thorium complexing can increase the mobility of dissolved thorium by many orders of magnitude below pH 8 relative to the solubility of thorium-bearing minerals in pure water as exemplified by the solubility of thorianite (ThO_2) above pH 5, which is only 10^{-5} ppb Th as $Th(OH)_4^0$. The important inorganic complexes of thorium with increasing pH are $Th(SO_4)_2^0$, ThF_3^{2+}, $Th(HPO_4)_2^0$, $Th(HPO_4)_3^{2-}$ and $Th(OH)_4^0$ respectively. Organic complexes as exemplified by those formed with citrate, oxalate and EDTA must greatly predominate over inorganic thorium complexes in organic-rich waters including many soil waters.

Studies by BONDIETTI (1974) and others show that adsorption of dissolved thorium increases markedly with pH above pH 2, with maximum amounts of thorium adsorption (95–100%) onto clays, oxyhydroxides and organic matter atttained at pH values above 5.5–6.5. Adsorption is more complete onto humic organic solids than onto clays. Organic ligands such as citrate and EDTA that form strong thorium complexes, inhibit adsorption and can lead to partial desorption of thorium (RANCON, 1973; BONDIETTI, 1974).

Thorium is concentrated in natural sediments largely either in detrital resistate minerals such as monazite, rutile and thorianite, or adsorbed onto natural, colloidal-sized materials. The tendency of thorium to be strongly adsorbed by clays and oxyhydroxides explains its anomalously high mean concentrations in bauxites (49 ppm), bentonites (24 ppm) and pelagic clays (30 ppm), and its range in marine manganese nodules (24–124 ppm). Thorium in bauxites is apparently both sorbed and in resistate minerals. These values may be compared to thorium concentrations generally less than 13 ppm in shales, and less than 5–7 ppm in arkoses and graywackes. (Preceding data are from ROGERS and ADAMS, 1969.)

Although thorium complexing in natural waters increases the solubility of thorium-bearing minerals and can lead to desorption of thorium, thorium concentrations in natural waters (pH 5–9) rarely exceed 1 ppb. This is equivalent to a radioactivity of 0.1 pCi/l as ^{232}Th, and assuming a natural activity ratio of 0.8 for ^{230}Th/^{232}Th (MOORE and SWAMI, 1972) to 0.08 pCi/l as ^{230}Th. This low total thorium concentration must reflect a combination of slow solution rates, paucity and insolubility of thorium-bearing minerals, and strong adsorption of thorium by natural materials in this pH range.

... isorption and ... -called 'low ... andoned ura... Lake, Onto... o, may explai... ^{230}Th activities in the g... detection (MOFFETT and Te... class' ground waters bene... ^{232}Th concentrations we... (4200 pCi/l) and ^{230}Th co... ground water up to 0.0028... ably the thorium in th... present chiefly as sulfate c... case of ^{232}Th by acid lea... minerals. The U.S. Environ... (ANON., 1976) has reported... tions (sulfuric acid leach, ... land Uranium Mill i... 22,000 pCi/l of ^{230}Th (1.1... values reflect the greater ... ditions of ^{230}Th formed fro... ^{238}U. This may be contraste... 110 pCi/l (0.0057 ppb) in ... solutions discharged from t... (ANON., 1976). The alkalin... the milling process tend to ... and the solubility of thoriu... ium adsorption onto clays, ... fine-sized materials in tailin...

The thermochemical dat... considered in this paper hel... of thorium and its isotope... ments and wastes. Howev... natural systems have inevita... chemical, mineralogic, geo... data to permit an unambig... prediction of thorium beha... prediction is solubility data... bearing minerals such as... uranothorite. Finally, more... studies should be perfor... adsorption is measured as a... complexation, activities of... their complexes, and other... with an understanding of th... ties of the sorbent phases.

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ABRLAND S., LILJENZIN J. O. ... tion chemistry (of the actin... *organic Chemistry*, Vol. 5, ... 465 635. Pergamon Press.

Thorium adsorption and the insolubility of thor... minerals in so-called 'low acid class' ground w... beneath an abandoned uranium tailings area at E... Lake, Ontario, may explain the fact that ^{232}Th and ^{230}Th activities in the ground water were below detection (MOFFETT and TELLIER, 1978). In 'high acid class' ground waters beneath the tailings, however, ^{232}Th concentrations were as high as 38 mg/l (4200 pCi/l) and ^{230}Th concentrations in the same ground water up to 0.0028 mg/l (52,000 pCi/l). Probably the thorium in these ground waters was present chiefly as sulfate complexes, released in the case of ^{232}Th by acid leaching of thorium-bearing minerals. The U.S. Environmental Protection Agency (ANON., 1976) has reported that waste milling solutions (sulfuric acid leach, pH 1.5–2) from the Highland Uranium Mill in Wyoming contained 22,000 pCi/l of ^{230}Th (1.1 ppb). These high ^{230}Th values reflect the greater mobility under acid conditions of ^{230}Th formed from the radioactive decay of ^{238}U. This may be contrasted with a ^{230}Th activity of 110 pCi/l (0.0057 ppb) in alkaline (pH = 10) leach solutions discharged from the Humeca Uranium Mill (ANON., 1976). The alkaline pH values employed in the milling process tend to minimize both complexing and the solubility of thorium minerals and favor thorium adsorption onto clays, oxyhydroxides and other fine-sized materials in tailings from the mill.

The thermochemical data and adsorption results considered in this paper help to explain the behavior of thorium and its isotopes in natural waters, sediments and wastes. However, published studies of natural systems have inevitably lacked sufficient geochemical, mineralogic, geologic and or hydrologic data to permit an unambiguous explanation for, or prediction of, thorium behavior. Also needed for such prediction is solubility data for important thorium-bearing minerals such as monazite, thorite and uranothorite. Finally, more sophisticated adsorption studies should be performed in which thorium adsorption is measured as a function of pH, thorium complexation, activities of competing cations and their complexes, and other solution properties, and with an understanding of the detailed surface properties of the sorbent phases.

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REFERENCE # 28

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

ARSENIC

Agency for Toxic Substances and Disease Registry
U.S. Public Health Service

2. HEALTH EFFECTS SUMMARY

2.1 INTRODUCTION

This section summarizes and graphs data on the health effects concerning exposure to arsenic. The purpose of this section is to present levels of significant exposure for arsenic based on key toxicological studies, epidemiological investigations, and environmental exposure data. The information presented in this section is critically evaluated and discussed in Sect. 4, Toxicological Data, and Sect. 7, Potential for Human Exposure.

This Health Effects Summary section comprises two major parts. Levels of Significant Exposure (Sect. 2.2) presents brief narratives and graphics for key studies in a manner that provides public health officials, physicians, and other interested individuals and groups with (1) an overall perspective of the toxicology of arsenic and (2) a summarized depiction of significant exposure levels associated with various adverse health effects. This section also includes information on the levels of arsenic that have been monitored in human fluids and tissues and information about levels of arsenic found in environmental media and their association with human exposures.

The significance of the exposure levels shown on the graphs may differ depending on the user's perspective. For example, physicians concerned with the interpretation of overt clinical findings in exposed persons or with the identification of persons with the potential to develop such disease may be interested in levels of exposure associated with frank effects (Frank Effect Level, FEL). Public health officials and project managers concerned with response actions at Superfund sites may want information on levels of exposure associated with more subtle effects in humans or animals (Lowest-Observed-Adverse-Effect Level, LOAEL) or exposure levels below which no adverse effects (No-Observed-Adverse-Effect Level, NOAEL) have been observed. Estimates of levels posing minimal risk to humans (Minimal Risk Levels) are of interest to health professionals and citizens alike.

Adequacy of Database (Sect. 2.3) highlights the availability of key studies on exposure to arsenic in the scientific literature and displays these data in three-dimensional graphs consistent with the format in Sect. 2.2. The purpose of this section is to suggest where there might be insufficient information to establish levels of significant human exposure. These areas will be considered by the Agency for Toxic Substances and Disease Registry (ATSDR), EPA, and the National Toxicology Program (NTP) of the U.S. Public Health Service in order to develop a research agenda for arsenic.

2.2 LEVELS OF SIGNIFICANT HUMAN EXPOSURE

To help public health professionals address the needs of persons living or working near hazardous waste sites, the toxicology data summarized in this section are organized first by route of exposure--inhalation, ingestion, and dermal--and then by toxicological end points that are categorized into six general areas--lethality, systemic/target organ toxicity, developmental toxicity, reproductive toxicity, genetic toxicity, and carcinogenicity. The data are discussed in terms of three exposure periods--acute, intermediate, and chronic.

Two kinds of graphs are used to depict the data. The first type is a "thermometer" graph. It provides a graphical summary of the human and animal toxicological end points (and levels of exposure) for each exposure route for which data are available. The ordering of effects does not reflect the exposure duration or species of animal tested. The second kind of graph shows Levels of Significant Exposure (LSE) for each route and exposure duration. The points on the graph showing NOAELs and LOAELs reflect the actual doses (levels of exposure) used in the key studies. Where appropriate, adjustments for exposure duration or intermittent exposure protocol were made.

Adjustments reflecting the uncertainty of extrapolating animal data to man, intraspecies variations, and differences between experimental vs actual human exposure conditions were considered when estimates of levels posing minimal risks to human health were made for noncancer end points. These minimal risk levels were derived for the most sensitive noncancer end point for each exposure duration by applying uncertainty factors. These levels are shown on the graphs as a broken line starting from the actual dose (level of exposure) and ending with a concave-curved line at its terminus. Although methods have been established to derive these minimal risk levels (Barnes et al. 1987), shortcomings exist in the techniques that reduce the confidence in the projected estimates. Also shown on the graphs under the cancer end point are low-level risks (10^{-4} to 10^{-7}) reported by EPA. In addition, the actual dose (level of exposure) associated with the tumor incidence is plotted.

2.2.1 Key Studies

Investigation and analysis of the toxicity of arsenic are complicated by the finding that different chemical forms of arsenic are not equally toxic. In particular, methylated derivatives and more complex organic derivatives such as "fish arsenic" (arsenobetaine) are considerably less toxic than inorganic arsenic. For example, oral LD_{50} values in animals range from 10 to 300 mg/kg for inorganic arsenic compounds, while LD50 values for the monomethyl and dimethyl derivatives of arsenic acid range from 600 to 2600 mg/kg. Arsenobetaine is even less toxic, producing no clear symptoms at doses of 10,000 mg/kg. For this reason, this section will focus on studies that address the toxicity of inorganic arsenic. A summary of available toxicity data on the most important organic arsenic compounds is presented in Sect. 4.3.

Among inorganic arsenic compounds, those that are easily soluble in water tend to have more acute toxicity than the less soluble ones, and arsenic(III) compounds are generally observed to be more toxic than arsenic(V) compounds. While it is possible to investigate the

[illegible] dividual arsenic compounds in animals, inf[illegible] [illegible]e[illegible]ce and chemical form is often not available [illegible] exposure must be expressed in terms of total [illegible]

[illegible] additional difficulty is raised by the observation that most studies indicate that animals are less sensitive to the toxic effects of arsenic than are humans. For example, reported lethal doses in animals (10 to 300 mg/kg) are significantly higher than lethal doses reported in humans (0.6 to 2 mg/kg). Similarly, chronic oral exposure of humans to inorganic arsenic at doses of 50 to 100 μg/kg/day is frequently associated with neurological or hematological signs of arsenic toxicity, but no characteristic neurological or hematological signs of arsenism were detected in young monkeys exposed to 3700 μg/kg/day of arsenate for one year (Heywood and Sortwell 1979), in dogs exposed to 3700 μg/kg/day of arsenite or arsenate for two years (Byron et al. 1967), or in rats given intraperitoneal injections of As_2O_3 at an average dose of 700 μg/kg/day for 18 months (Schaumberg 1980). Moreover, while there is good evidence that arsenic is carcinogenic in humans by both the oral and inhalation routes, evidence of arsenic-induced carcinogenicity in animals is mostly negative. For these reasons, dose-response data from animals are not judged to be reliable for determining levels of significant human exposure and will not be considered except in the absence of any human data.

2.2.1.1 Oral

Many reports describe the symptoms and course of inorganic arsenic poisoning in humans, but only a few of these studies provide sufficient information on exposure levels to permit accurate estimates of the ingested dose. These studies are summarized in Table 2.1, and the data from this table are displayed graphically in Figs. 2.1 and 2.2. While no one study by itself provides a full description of the dose-response relationships, taken together, these studies do provide an adequate basis for estimating NOAEL values for the principal end points of arsenic toxicity in humans.

Lethality. Reports by Armstrong et al. (1984) and Hamamoto (1955) indicate that acute or subacute lethality may occur at doses of around 600 μg/kg/day or higher. Lethality has not been associated with doses of 100 μg/kg/day or less.

Systemic/target organ toxicity. Although some humans can ingest up to 150 μg/kg/day without apparent ill-effects (Bencko 1987), a number of studies indicate that, in more sensitive individuals, doses as low as 20 to 60 μg/kg/day (roughly 1 to 4 mg/day in an adult) may produce one or more of the characteristic signs of arsenic toxicity, including gastro-intestinal irritation, anemia, neuropathy, skin lesions, vascular lesions, and hepatic or renal injury (Tay and Seah 1975, Mizuta et al. 1956, Silver and Wainman 1952, Huang et al. 1985, Borgono et al. 1980, Tseng et al. 1968). The severity of symptoms in affected individuals generally tends to increase as a function of exposure duration (Tseng 1977), although in some individuals, effects may occur after relatively brief exposure periods (e.g., see Mizuta et al. 1956). In most cases of subchronic or chronic exposure, many or all of the signs of arsenic

Table 2.1. Summary of key studies on oral toxicity of arsenic in humans

Chemical form	Exposure: Source	Dose (μg/kg/d)[a]	Duration	Noncarcinogenic signs of toxicity observed: Lethality	GI distress	Hematologic abnormalities	Neuritis/ neuropathy	Skin lesions	Hepatic/ renal	CVS lesions	Carcinogenic effects: Skin cancer	Other tumors	Study group	References
?[b]	Water (100 mg/L)	400–3000	1–2 weeks	+(2/8)	+(7/8)	+(3/8)	+(3/8)						Family of 8	Armstrong et al. 1984
As_2O_3	Milk powder (15–35 mg/kg)	700	33 days	+(1%)				+	+				12,000 infants	Hamamoto 1955
?	Water (0.6 mg/L)	60–140	Chronic		+		+	+		+	+		Residents of Antofagasta, Chile	Zaldivar 1974
As(III)	Fowler's Solution	50–100	Subchronic					+(40%)			+(21/262)		262 Adults	Fierz 1965
	[illegible] mg/L)	60–80	2–12 years					+(12%)					27,000 children	Borgano and Greiber 1972
[illegible]rsenic	[illegible]sis	55	Subchronic		+(23%)	+(23%)	+(51%)	+(97%)	+(19%)		+(6/74)	+(4/74)	74 adults	Tay and Seah 1975
	Sea-Source	50	2–20 days		+(70%)	+(15%)	+(3%)	+(20%)	+(60%)	+(80%)			220 adults	Mizuta et al. 1956
As(III)	Fowler's [illegible]	50	13–28 months		+		+	+	+				1 patient (asthma)	Silver and Wainman 1952
	Water [illegible] mg/L)	40	12 years		+(12%)		+(36%)	+(45%)					336 workers in plant	Huang et al. 1985
	Water [illegible] mg/L)	30–40	Chronic					+(29%)					1000 school children	Borgano et al. 1980
?	Water (0.4–0.6 mg/L)	20–30	Chronic					+(18%)		+(0.9%)	+(428/40,421)		40,000 Taiwanese	Tseng et al. 1968
?	Water (0.3–1.1 mg/L)	20	Chronic								+(SMR = 534–652)[c]	+(SMR = 170–2009)	140,000 Taiwanese	Chen et al. 1985
?	Water (0.3–1.1 mg/L)	20	Chronic									+(AOR = 2.7–3.9)[d]	279 cases and 368 controls	Chen et al. 1986
?	Water (0.4 mg/L)	20	Chronic					+(18%)			+(4/296)		300 residents of Mexican village	Cebrian et al. 1983
?	Water (0.001–0.4 mg/L)	10	Chronic		NS[e]		NS	NS					Groups of 15 to 52 in 6 U.S. cities	Valentine et al. 1985
?	Water (0.2 mg/L)	6	Chronic		–	NS	NS	NS			NS		250 Mormons	Southwick et al. 1981
?	Water (0.2 mg/L)	6	Chronic				NS	NS			NS		211 Alaskans	Harrington et al. 1978
?	Water (0–0.02 mg/L)	0.7	Chronic					NS		NS	NS		7500 Taiwanese	Tseng et al. 1968
?	Water (0.005 mg/L)	0.2	Chronic					NS					300 residents of Mexican village	Cebrian et al. 1983

[a] If not reported otherwise by author or by EPA 1987b, calculated by assuming 2 L/day of water for a 70-kg adult or 1 L/day for a 10-kg child.
[b] Chemical form unknown, but presumed to be inorganic arsenic.
[c] SMR = standardized mortality ratio.
[d] AOR = adjusted odds ratio.
[e] NS = not significantly different from control or expected.

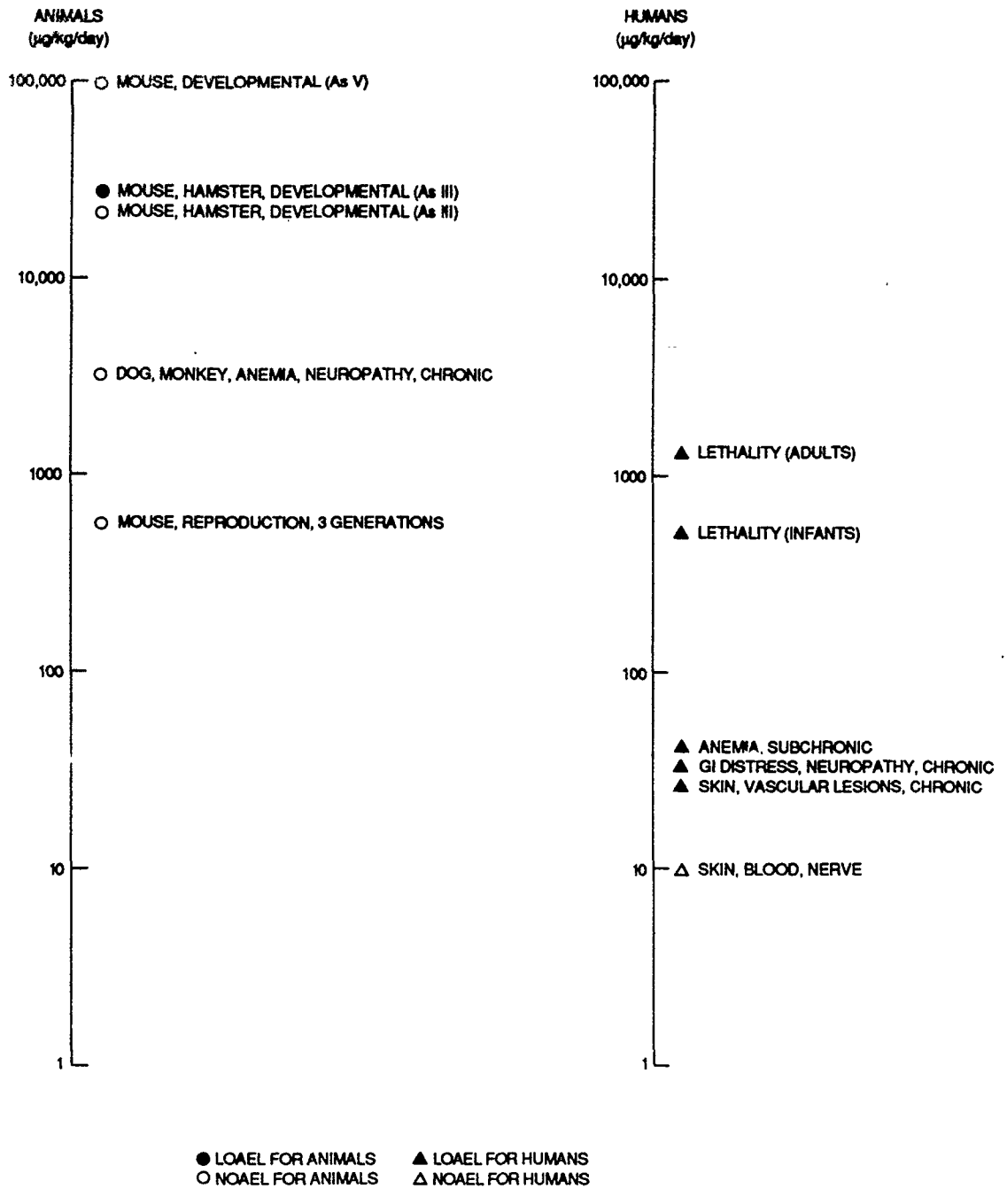


Fig. 2.1. Effects of inorganic arsenic—oral exposure.

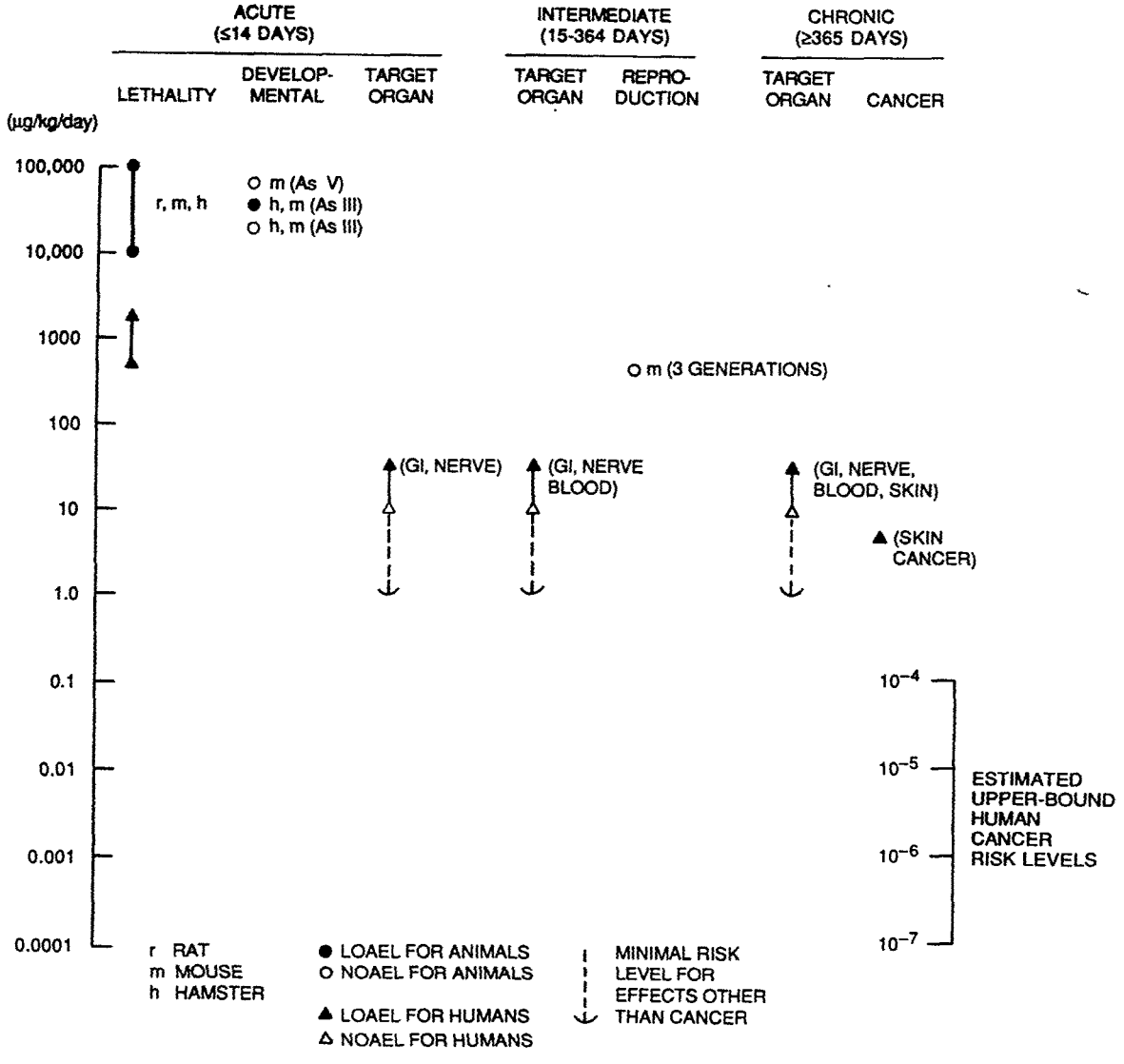


Fig. 2.2. Levels of significant exposure for inorganic arsenic—oral.

toxicity are detect[illegible]d[illegible]ting that the dose-response relationships for t[illegible]sy[illegible]e[illegible] end points are fairly similar. If any one effect is m[illegible]sitive i[illegible]s probably the appearance of the characteristic pigm[illegible]n[illegible]d hyperkeratotic lesions. Although it is difficult to [illegible]f[illegible]t level with certainty, doses of around 10 μg/kg/day (about 0.7 mg/day in an adult) are not generally expected to cause measurable signs of arsenic intoxication (e.g., Valentine et al. 1985, Southwick et al. 1981).

Developmental toxicity. Studies in animals have revealed that very high oral doses of sodium arsenate (in excess of 100 mg/kg) may be teratogenic and fetotoxic, while oral doses of 60 to 100 mg/kg/day have no significant effect (Hood et al. 1977, 1978). Sodium arsenite appears to be somewhat more toxic, causing increased malformations and prenatal mortality in mice and hamsters dosed by gavage at levels of 25 to 40 mg/kg/day (Baxley et al. 1981, Hood and Harrison 1982, Willhite and Ferm 1984). These researchers observed no effect at 20 mg/kg/day. It should be noted that these dose levels may cause maternal lethality in exposed animals and are considerably higher than levels which may cause lethality in humans (0.6 mg/kg/day). On this basis, it seems likely that developmental end points are not of primary concern at exposure levels lower than those which cause maternal toxicity.

Reproductive toxicity. The effects of arsenic exposure on reproductive parameters have not been well studied. Limited data in mice suggest that ingestion of water containing 5 mg/L of arsenite (about 0.7 mg/kg/day) for three generations does not significantly impair reproductive success (Schroeder and Mitchner 1971).

Genotoxicity. The genotoxicity of various inorganic arsenic compounds has been investigated in a number of prokaryotic and eukaryotic test systems. Although data are not entirely consistent, the weight of evidence indicates that arsenic is clastogenic (i.e., causes chromosomal breaks and aberrations) and induces sister chromatid exchange (SCE) in cultured mammalian cells (Jacobson-Kram and Montalbano 1985). Trivalent arsenic compounds ($NaAsO_2$, As_2O_3, $AsCl_3$, and $NaAsO_2$) tend to be more potent in causing chromosomal aberrations than pentavalent compounds (Na_2HAsO_4, H_3AsO_4, and As_2O_5) (Nakamuro and Sayato 1981). Several studies have reported increased frequencies of SCEs and chromosome aberrations in lymphocytes from exposed humans, but these studies have limitations and must be interpreted with caution (EPA 1984a). Despite these cytogenetic effects, arsenic appears to be either inactive or extremely weak for the induction of specific gene mutations in vivo.

Carcinogenicity. The study of Tseng et al. (1968) generally provides the best available description of the dose-response relationship for skin cancer. In this study, individuals were classified into one of three exposure groups on the basis of the concentration of arsenic in their drinking water: low = 0 to 0.29 mg/L; medium = 0.3 to 0.59 mg/L; high = 0.6 mg/L or more. EPA (1987a) estimated that the average daily intake of arsenic by these groups was 10.8, 29.9, and 50.9 μg/kg/day for males and 6, 8, 18.8, and 32.0 μg/kg/day for females, respectively. As shown in Fig. 2.3, skin cancer prevalence rates in these groups were proportional to arsenic exposure level. This study is

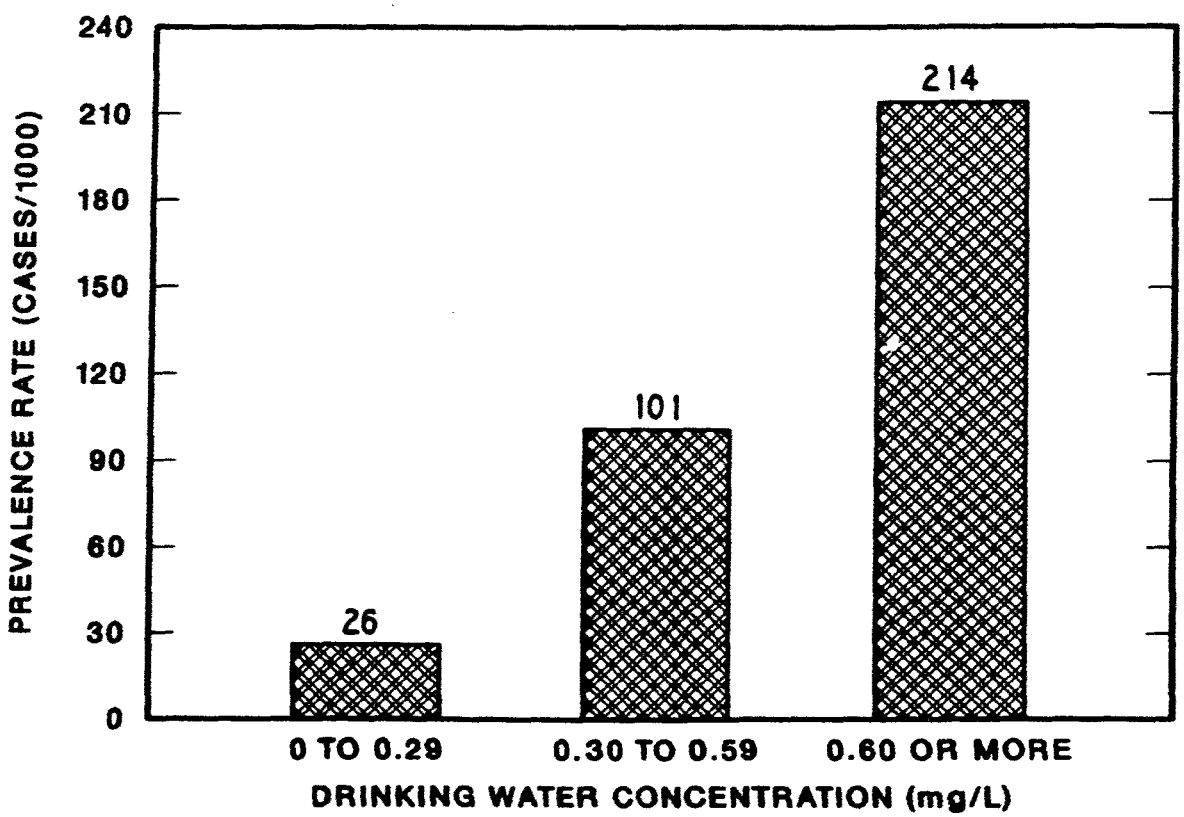


Fig. 2.3. Dose-response relationship for arsenic-induced skin cancer in humans. *Source:* Adapted from Tseng et al. 1968.

a number of other studies (see Table 2.1) that associate increased frequency of skin cancer and/or internal cancer in individuals exposed to water containing 0.3 mg/L or more. Failure to detect increases at lower doses (e.g., Harrington et al. 1978, Goldgar et al. 1981) may be due to a lack of statistical power in the studies (Andelman and Barnett 1983), or it could suggest that arsenic-induced cancers have a threshold dose. Although toxicokinetic data regarding arsenic methylation (see Sect. 4.2.2 on toxicokinetics) provide some support for this concept, the EPA has judged that the evidence is not adequate at present to conclude that arsenic-induced cancer has a nonzero threshold (EPA 1987b).

Based on the data of Tseng, EPA (1984a) originally calculated that a dose of 1 μg/kg/day corresponded to a skin cancer risk of 1.58×10^{-2}. More recently, EPA (1987b) has refined these calculations, having estimated that a dose of 1 μg/kg/day corresponds to a risk of 1.5×10^{-3}.

As with any cancer risk calculation, there is considerable uncertainty in this value, especially when extrapolated to very low exposure levels. In addition, there are a number of limitations to the Tseng study that may introduce uncertainty concerning the applicability of this risk estimate to the U.S. population. These uncertainties include (1) possible exposure of the Taiwanese subjects to arsenic from sources other than drinking water, (2) an above-average death rate in the exposed population from Blackfoot disease, (3) differences in diet between the Taiwanese and U.S. populations, (4) exposure to other chemicals besides arsenic, (5) lack of blinding in the researchers who collected data on exposure levels and symptoms in the study populations, and (6) use of prevalence rates to estimate cumulative cancer incidence rates (EPA 1987b). Although these uncertainties may cast some doubt on the precise quantitative value calculated for the oral cancer potency factor for arsenic, they do not challenge the conclusion that arsenic ingestion does increase the risk of skin cancer.

None of the available studies provide adequate dose-response data to calculate the risk of internal cancers following exposure to arsenic (EPA 1987b).

2.2.1.2 Inhalation

Most information on human exposure to arsenic dusts and fumes is derived from occupational settings such as smelters and chemical plants. It should be noted that significant oral and dermal exposures are likely under these conditions, and that exposure to other metals and chemicals is also common. Table 2.2 summarizes available reports on health effects in humans exposed to airborne arsenic. Studies with quantitative estimates of exposure are shown graphically in Figs. 2.4 and 2.5.

Lethality. Inhalation exposure is not usually associated normally with acute lethality in animals or humans. Webb et al. (1986) reported that the maximally tolerated nonlethal dose of As_2O_3 given by intratracheal instillation to rats was 17 mg/kg. If a rat inhales about 1 m^3/kg/day (Guyton 1947), and approximately 40% of the airborne arsenic is deposited in the lung (Holland et al. 1959), this would correspond to an air concentration of over 40 mg/m^3.

Table 2.2. Summary of key human studies on exposure to airborne arsenic

Study group	Airborne exposure data	Results		References
Copper smelter workers	High variable; very high (over 50 mg/m^3) in some locations	Dermatitis, mostly on exposed areas of skin; more common in work areas of high exposure		Holmqvist 1951
1276 smelter workers	Up to 7 mg/m^3	Rhinopharyngolaryngitis, tracheobronchitis		Lundgren 1954
348 smelter workers	0.2[a]	One possible case of systemic effects; no hyperpigmentation; primary observation was dermatitis, conjunctivitis, pharyngitis		Pinto and McGill 1953
Sodium arsenite factory		**Hyperkeratoses**	**Pigmentation**	Perry et al. 1948
Chem workers	0.4–1.0 mg/m^3	9/31 (29%)	28/31 (90%)	
Maint./packers	0.06–0.16 mg/m^3	1/32 (3%)	12/32 (37%)	
Controls	Not reported	2/56 (4%)	10/56 (18%)	
Children near gold smelter	None	Dermatoses, mostly on face and neck		Birmingham et al. 1965
11 smelter workers	None	Preclinical neurological effects detected by EMG; correlation with arsenic levels in hair and urine		Landau et al. 1977
Women working in or living near smelter	None	Increased spontaneous abortion rate, decreased birth weight		Nordstrom et al. 1978a,b,c,d
8000 white male smelter workers	3000–36,000 μg/m^3-years	Exposure-dependent increase in lung cancer mortality (overall SMR = 285)		Lee-Feldstein 1983
1800 male smelter workers	250–16,000 μg/m^3-years	Exposure-dependent increase in lung cancer mortality (high dose SMR = 548)		Higgins et al. 1982
2800 male smelter workers	90–4000 μg/m^3-years[b]	Exposure-dependent increase in lung cancer mortality (overall SMR = 189)		Enterline and Marsh (1982)
1900 pesticide plant workers	40–19,500 μg/m^3-years	Exposure-dependent increase in lung cancer mortality (high dose SMR = 694)		Ott et al. (1974)
2802 male smelter workers	<750–45,000 μg/m^3-years	Exposure-dependent increase (nonlinear) in lung cancer mortality (high dose SMR = 477)		Enterline et al. 1987

[a]ACGIH (1986); based on urinary arsenic levels.
[b]Estimated from urinary arsenic levels.

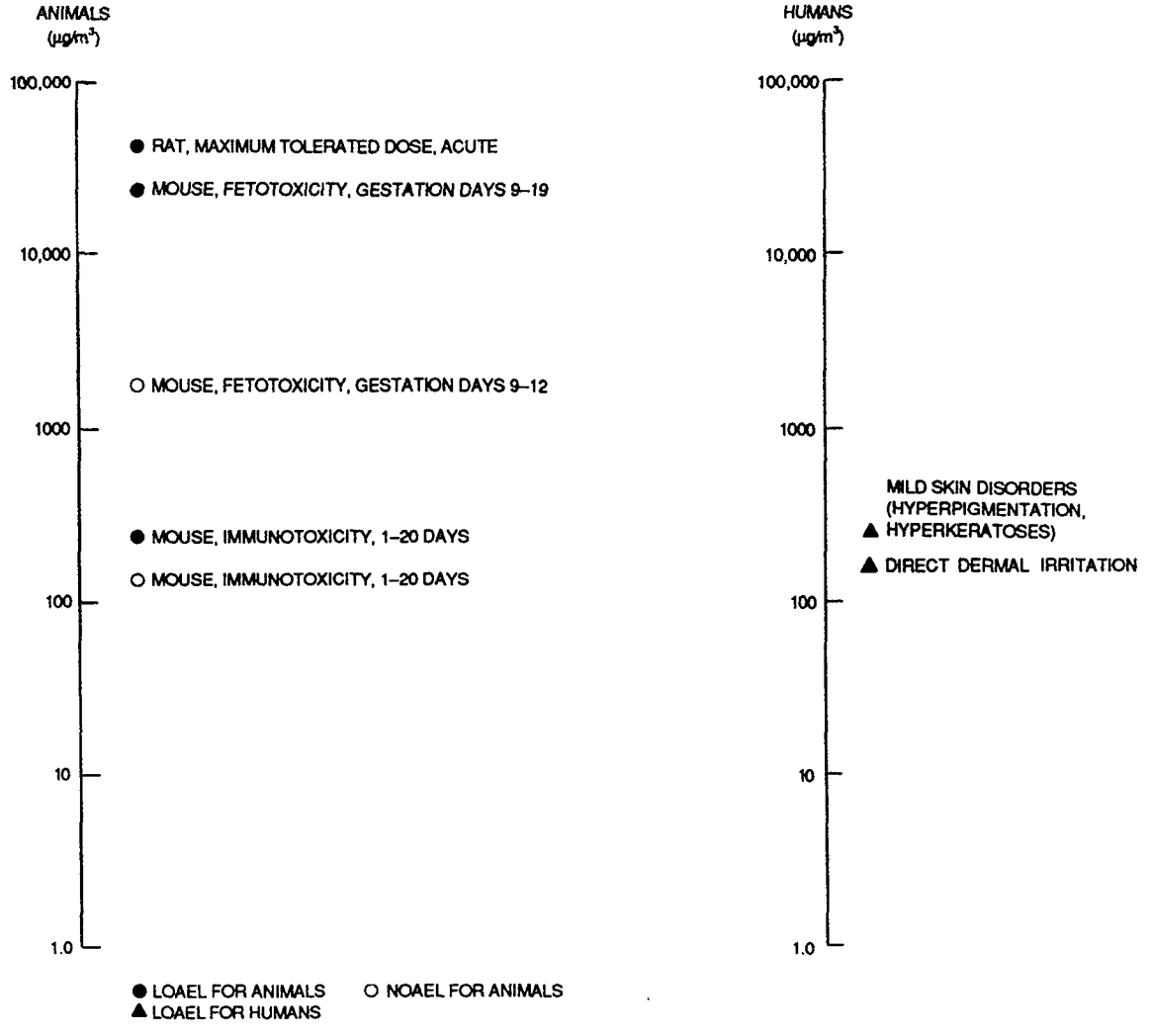


Fig. 2.4. Effects of inorganic arsenic—inhalation exposure.

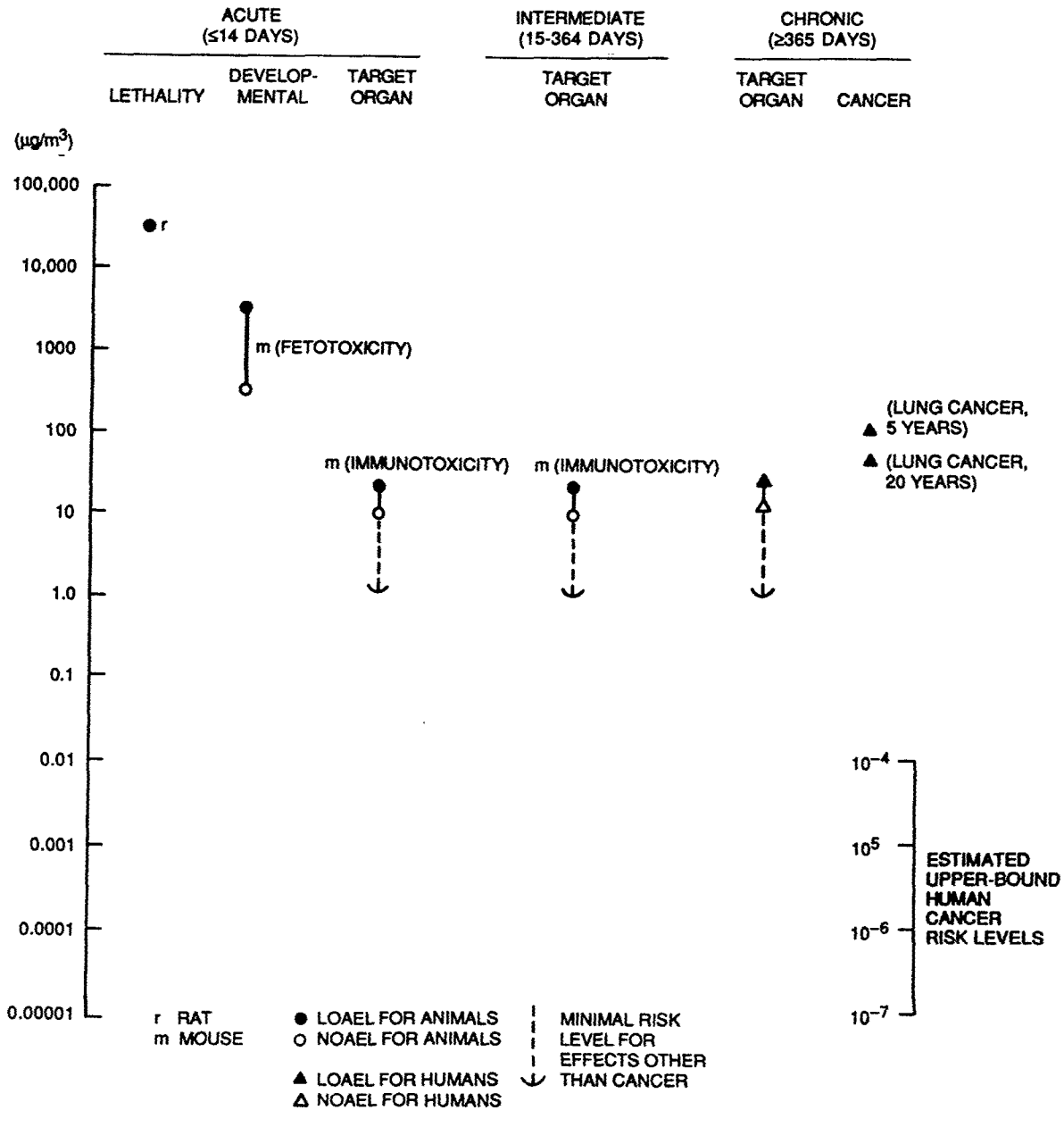


Fig. 2.5. Levels of significant exposure for inorganic arsenic—inhalation.

Systemic/target organ effects. There is a general agreement among studies of occupationally exposed workers that signs of systemic toxicity (nausea, neuropathy and hyperkeratoses) are infrequent and generally mild. Rather, the primary noncarcinogenic health risk associated with exposure to airborne arsenic is irritation of the skin and mucous membranes (dermatitis, conjunctivitis, pharyngitis, and rhinitis) (Pinto and McGill 1953, Vallee et al. 1960, Stokinger 1981, ACGIH 1986).

Very few studies provide quantitative information on the concentrations of arsenic in air that may cause dermatitis or systemic effects. The data of Holmqvist (1951) and Lundgren (1954) reveal dermal and mucosal irritation in workers who have been exposed to high levels of arsenic in air, but they do not identify a threshold for these effects. Perry et al. (1948) reported that chemical workers exposed to about 0.4 to 1.0 mg/m^3 inorganic arsenic in air manifested gross pigmentation and an elevated frequency of hyperkeratinization, whereas maintenance workers and packagers with a lower level of exposure (estimated to be about 0.06 to 0.16 mg/m^3 of air) displayed only a slight tendency toward mild hyperpigmentation. Pinto and McGill (1953) reported that dermatitis was common in smelter workers whose urinary arsenic levels exceeded 0.4 mg/L, a value which probably corresponds to an airborne exposure level of about 0.1 to 0.2 mg/m^3 (Pinto et al. 1976, ACGIH 1986). No cases of hyperpigmentation or hyperkeratoses were observed in these workers. Based on these limited observations, it appears that chronic exposure to concentrations of 0.4 mg/m^3 or higher in workplace air may result in characteristic systemic effects in skin, and that exposure to levels of 0.1 to 0.2 mg/m^3 may cause direct dermal irritation. Levels below 0.1 mg/m^3 do not appear likely to cause significant noncarcinogenic effects. Because these data are derived from the workplace where exposure is for 8 h/day 240 days/year, these values must be divided by a factor of 4.56 to yield values appropriate for continuous exposure (EPA 1984a).

Aranyi et al. (1985) have investigated the effect of inhalation exposure on pulmonary antibacterial defenses in mice. Animals were exposed to aerosols containing As_2O_3, 3 h/day for 1 to 20 days. Concentrations of 270 $\mu g/m^3$ arsenic or higher resulted in significantly increased mortality following infection with active pneumonia-causing bacteria, while concentrations of 125 $\mu g/m^3$ or lower had no significant effect. This action of arsenic did not appear to be cumulative, since the same response was seen following 20 days of exposure as after 1 day of exposure.

Developmental toxicity. There are very few reports dealing with developmental effects of arsenic by the inhalation route. Limited data suggest that women who work in or live nearby smelters may have higher than normal abortion rates and lower than normal birth weights. Nordstrom et al. (1978c) reported that the prevalence rate of congenital birth defects was about the same (3.0%) in Swedish women working in a smelter as in women living in the same area but not working in the smelter. However, there was a decrease in the average birth weight and an increase in the incidence of spontaneous abortions in the female workers, with the highest rate (17%) in women who had been employed during their pregnancy (Nordstrom et al. 1978a,b). The incidence of

spontaneous abortion in women living near the plant was also higher than average, although many of the women who lived nearby also worked in the smelter (Nordstrom et al. 1978d). These observations should be interpreted with caution, because these studies were designed to evaluate the effects of smelter pollutants in general. This prevents making conclusive statements about the specific effects of arsenic from these findings. Nagymajtenyi et al. (1985) reported that inhalation exposure of pregnant mice to 28.5 mg/m^3 of As_2O_3 (4 h/day on days 9 to 12 of gestation) caused fetotoxic effects, while concentrations of 2.9 or 0.26 mg/m^3 caused no changes except for a slight decrease in fetal weight (9.9% and 3.1%, respectively).

Reproductive toxicity. No information was located on the reproductive effects of inhalation exposure to arsenic in animals or humans.

Genotoxicity. As described above for oral exposure, the weight of evidence indicates that arsenic induces SCEs and chromosome aberrations, but does not induce detectable gene mutations.

Carcinogenicity. Many studies report above-average lung cancer rates in groups of people with above-average exposure to airborne arsenic, but only a few contain adequate quantitative data on exposure levels and durations to permit derivation of dose-response relationships. EPA (1981, 1984a) has reviewed the available data and calculated dose-response curves for cohorts exposed at the Anaconda smelter in Montana (Lee and Fraumeni 1969; Lee-Feldstein 1983; Higgins et al. 1982; Brown and Chu 1983a,b), the ASARCO smelter in Tacoma, Washington (Enterline and Marsh 1982, Pinto et al. 1977), and a pesticide plant (Ott et al. 1974). In most cases, cumulative exposure (the time-weighted average of air concentration times years of exposure expressed as $\mu g/m^3$-years) was taken to be the most appropriate index of exposure, although in some cases (e.g., Enterline and Marsh 1982, Welch et al. 1982), exposure duration did not appear to be as important as exposure level. The calculations of exposure are quite complex in some cases, and the interested reader is referred to the EPA documents (1981, 1984a) for a detailed description. Figure 2.6 shows one typical data set (Lee-Feldstein 1983), which illustrates the approximately linear increase in relative risk (the frequency of lung cancer in the exposed group divided by the frequency of lung cancer in the control group) as a function of increasing exposure. Relative risk was significantly increased even at the lowest cumulative doses (290 $\mu g/m^3$ for an average of 20 years or 580 $\mu g/m^3$ for an average of 5.3 years) (EPA 1987a). Adjusted for intermittent worker exposure (8 h/day, 240 days/year), these concentrations correspond to continuous exposure levels of 64 and 127 $\mu g/m^3$, respectively. Based on these analyses, EPA (1984a) concluded that the most reliable estimates of the dose-response curve were provided by the reports of Lee-Feldstein (1983), Higgins et al. (1982), Brown and Chu (1983a,b), and Enterline and Marsh (1982). Table 2.3 presents the estimates of unit risk (the increased risk of lung cancer associated with lifetime exposure to 1 $\mu g/m3$) derived from these studies. By calculating the geometric mean of these estimates, EPA (1984a) derived an overall unit risk of 4.3×10^{-3}.

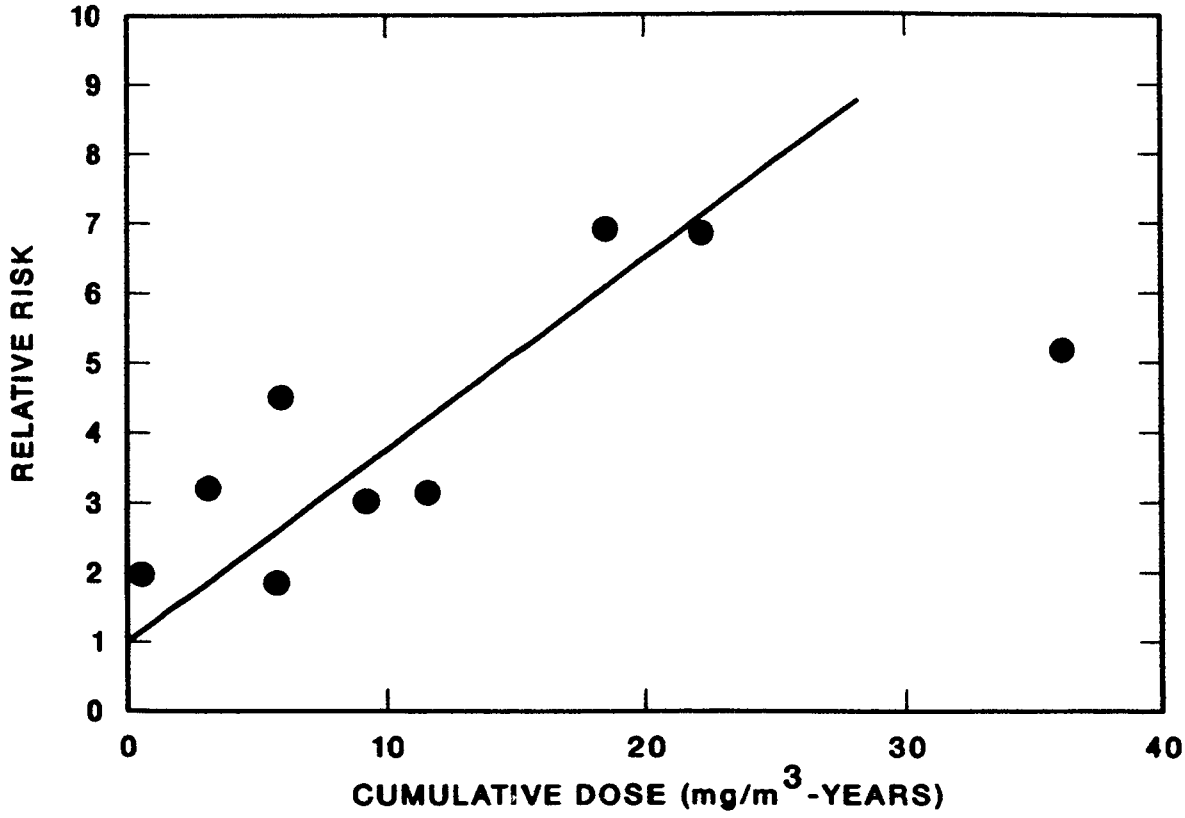


Fig. 2.6. Dose-response relationship for lung cancer in occupationally exposed workers. *Source:* Adapted from Lee-Feldstein 1983.

Table 2.3. Summary of lung cancer risk estimates

Study	Unit risk[a]
Lee-Feldstein 1983	2.8×10^{-3}
Higgins et al. 1982	4.9×10^{-3}
Brown and Chu 1983a,b	1.2×10^{-3}
Enterline and Marsh 1982	7.2×10^{-3}

[a]Unit risk is the increased risk of cancer associated with lifetime exposure to 1 $\mu g/m^3$.

Adapted from EPA 1984a.

The Occu[illegible]d Health Administration (OSHA) also conducted a d[illegible]sment for lung cancer from inhalation of arsenic (OSHA [illegible]). A[illegible]ew of the epidemiological data of Lee and Fraumeni (19[illegible]1977), Ott et al. (1974), Hill and Fanning (194[illegible]n 1983), Enterline and Marsh (1982), Higgins et al. (1[illegible], [illegible]et al. (1979) and Lubin et al. (1981), OSHA concluded that the risk of lung cancer from a working lifetime of exposure to inorganic arsenic at an exposure level of 10 $\mu g/m^3$ ranged from 2.2 to 29 excess deaths per 1000 exposed employees, with the preferred estimate being 8 deaths/1000 employees.

More recently, Enterline et al. (1987) reexamined the dose-response relationship between inhalation exposure to arsenic and risk of lung cancer, using historical records of airborne arsenic levels in the smelters, along with records of urinary arsenic levels in exposed workers. The researchers concluded that arsenic is a more potent lung carcinogen then previously believed, with a dose-response relationship concaved downward at exposure levels below 10,000 $\mu g/m^3$/year. In contrast, the relationship between lung cancer and urinary arsenic levels was linear, suggesting that bioavailability and lung absorption of arsenic tend to be proportionately greater at low exposure levels than at high exposure levels.

2.2.1.3 Dermal

As discussed above (see Table 2.2), many reports indicate that dermal exposure to inorganic arsenic compounds leads to dermatitis. However, none of these reports provide quantitative information on dose-duration relationships. No reports indicating that dermal exposure is associated with increased risk of cancer were located.

2.2.2 Biological Monitoring as a Measure of Exposure and Effects

Arsenic levels in blood, urine, hair, and nails have all been investigated and used as biological indicators of exposure to arsenic. A discussion of the utility and the limitations of each of the indicators for human biomonitoring is provided below.

2.2.2.1 Blood arsenic

Most arsenic is cleared from blood within a few hours (Tam et al. 1979, Vahter 1983), so measurements of blood arsenic reflect exposures only within the very recent past. Typical values in nonexposed individuals range from 1 to 5 $\mu g/L$ (Heydorn 1970, Valentine et al. 1979, Hindmarsh and McCurdy 1986). Consumption of medicines containing arsenic is associated with blood values of 100 to 250 $\mu g/L$, while levels in acutely toxic and fatal cases may be 1000 $\mu g/L$ or higher (Driesback 1980). However, blood levels do not appear to be reliable indicators of chronic exposure to low levels of arsenic. For example, Valentine et al. (1979, 1981) measured the concentration of arsenic in whole blood of residents in several U.S. communities where arsenic levels in water ranged from 0.6 to 393 $\mu g/L$. They found that in groups with water levels ranging from 6 to 123 $\mu g/L$, average blood levels did not increase in proportion to increased exposure. Consequently, measurement of blood arsenic is not generally considered to be a reliable means of monitoring human populations for arsenic exposure.

2.2.2.2 Urinary arsenic

Because absorbed arsenic is rapidly and efficiently excreted in urine [mostly as monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA)], analysis of urinary arsenic levels is useful as an indicator of recent exposure. Normal urinary levels generally range from 2 to 100 μg/L, with values of 20 to 50 μg/L being typical (Pinto et al. 1977, Wagner et al. 1979, Foa et al. 1984). Values of 150 μg/L or higher are common in industrially exposed populations (Pinto et al. 1976, 1977; Enterline and Marsh 1982; Beckett et al. 1986) and in populations exposed to elevated arsenic levels in drinking water (Southwick et al. 1981, Valentine et al. 1981, Harrington et al. 1978). Some workers have found that urinary arsenic levels are linearly related to airborne concentrations (Pinto et al. 1977, Vahter et al. 1986), but Borgono et al. (1980) did not find urinary levels to be well correlated with clinical signs of arsenic toxicity. Elevated levels of arsenic in urine may occur following ingestion of the nontoxic forms of arsenic present in fish or seafood (Hindmarsh and McCurdy 1986), illustrating that increased total urinary arsenic levels may not necessarily reflect exposures of toxicological significance. Chemical analyses which distinguish between inorganic arsenic, MMA, DMA, and arsenobetaine in the urine help to solve this difficulty (Foa et al. 1984, Lovell and Farmer 1985).

2.2.2.3 Hair and nails

Arsenic tends to accumulate in hair and nails, and measurement of levels in these tissues may be a useful indicator of chronic arsenic exposure. Normal levels in nails are 0.5 ppm or less, whereas typical levels in hair range from 0.02 to 1.0 ppm (Gordon 1985, Takagi et al. 1986). These values may increase from several-fold to over 100-fold following chronic arsenic exposure (Landau et al. 1977, Valentine et al. 1979, Southwick et al. 1981, Valentine et al. 1985, Bencko et al. 1986). The greatest problem with the use of these tissues is that both hair and nails appear to adsorb and strongly retain arsenic from external sources as well as from internal deposition. Thus, elevated levels in hair or nails may not be definite evidence that a significant dose of arsenic has been absorbed, and could lead to an overestimation of potential health risks.

2.2.2.4 Electromyography

Since peripheral neuropathy is one of the characteristic results of chronic arsenic intoxication, electromyographic measurement of nerve conduction velocity and amplitude has been evaluated as a means of detecting preclinical signs of neuropathy in exposed individuals. While electromyographic abnormalities have been detected in some exposed populations (Hindmarsh et al. 1977, Landau et al. 1977, Valentine et al. 1981), no significant effects were detected in other populations with moderately elevated exposure in drinking water (Southwick et al. 1981, Kreiss et al. 1983). Thus, this approach does not appear to be sufficiently sensitive to be useful as a biological [illegible] exposure (Hindmarsh and McCurdy 1986).

2.2 Environmental Levels as Indicators of Exposure and Effects

2.2.1 Levels found in the environment

Arsenic is very widely distributed in the environment. Levels in water typically range from 0.2 to 10 μg/L, with more than 90% of U.S. drinking water systems having values lower than 50 μg/L. Most epidemiological studies indicate that water levels of 400 μg/L or higher may lead to signs of arsenic toxicity in the population, whereas water concentrations of 100 μg/L are not usually observed to produce significant noncarcinogenic effects.

Typical concentrations of arsenic in ambient air range from 2 to 10 ng/m^3, with over 99% falling below 80 ng/m^3 (Akland 1983). These levels are not usually associated with any systemic effects, although they may represent a small increase in the risk of lung cancer.

For most humans, the diet normally represents the largest source of arsenic exposure (typically about 25 to 50 μg/day) (EPA 1982b). Levels in different types of food typically vary between 0.01 and 0.10 ppm, with higher levels in rice (0.4 ppm), chicken (0.5 ppm), and fish or shellfish (20 ppm). As previously noted, the organic form of arsenic in seafood is rapidly excreted in urine and is not of toxicological concern.

2.2.3.2 Human exposure potential

Because arsenic is nearly ubiquitous in air, food, water, and soil, all humans are routinely exposed at low levels via these routes. Outside the occupational setting, the greatest potential for exposure of significant health concern is through ingestion of contaminated water. This could result from natural mineral deposits, wells contaminated with arsenical pesticides, or groundwater contaminated by a nearby waste site. Typically, groundwater will contain a mixture of arsenate and arsenite, depending on pH and oxidation potential, usually with arsenate predominating. Another pathway that may be of concern in some cases is ingestion of contaminated soil. All persons ingest low levels of soil (around 10 mg/day); however, small children may ingest 200 mg/day or more (Calabrese et al. 1987). Significant inhalation exposure is likely to occur only around industrial sites, such as copper smelters or pesticide factories.

2.3 ADEQUACY OF DATABASE

2.3.1 Introduction

Section 110 (3) of SARA directs the Administrator of ATSDR to prepare a toxicological profile for each of the 100 most significant hazardous substances found at facilities on the CERCLA National Priorities List. Each profile must include the following content:

> "(A) An examination, summary, and interpretation of available toxicological information and epidemiologic evaluations on a hazardous substance in order to ascertain the levels of significant human exposure for the substance and the associated acute, subacute, and chronic health effects.

(B) A determination of whether adequate information on the health effects of each substance is available or in the process of development to determine levels of exposure which present a significant risk to human health of acute, subacute, and chronic health effects.

(C) Where appropriate, an identification of toxicological testing needed to identify the types or levels of exposure that may present significant risk of adverse health effects in humans."

This section identifies gaps in current knowledge relevant to developing levels of significant exposure for arsenic. Such gaps are identified for certain health effect "end points" (lethality, systemic/target organ toxicity, developmental toxicity, reproductive toxicity, and carcinogenicity) reviewed in Sect. 2.2 of this profile in developing levels of significant exposure for arsenic, and for other areas such as human biological monitoring and mechanisms of toxicity. The present section briefly summarizes the availability of existing human and animal data, identifies data gaps, and summarizes research in progress that may fill such gaps.

Specific research programs for obtaining data needed to develop levels of significant exposure for arsenic will be developed by ATSDR, NTP, and EPA in the future.

2.3.2 Health Effect End Points

2.3.2.1 Introduction and graphic summary

The availability of data for health effects in humans and animals is depicted on bar graphs in Figs. 2.7 and 2.8, respectively.

The bars of full height indicate that there are data to meet at least one of the following criteria:

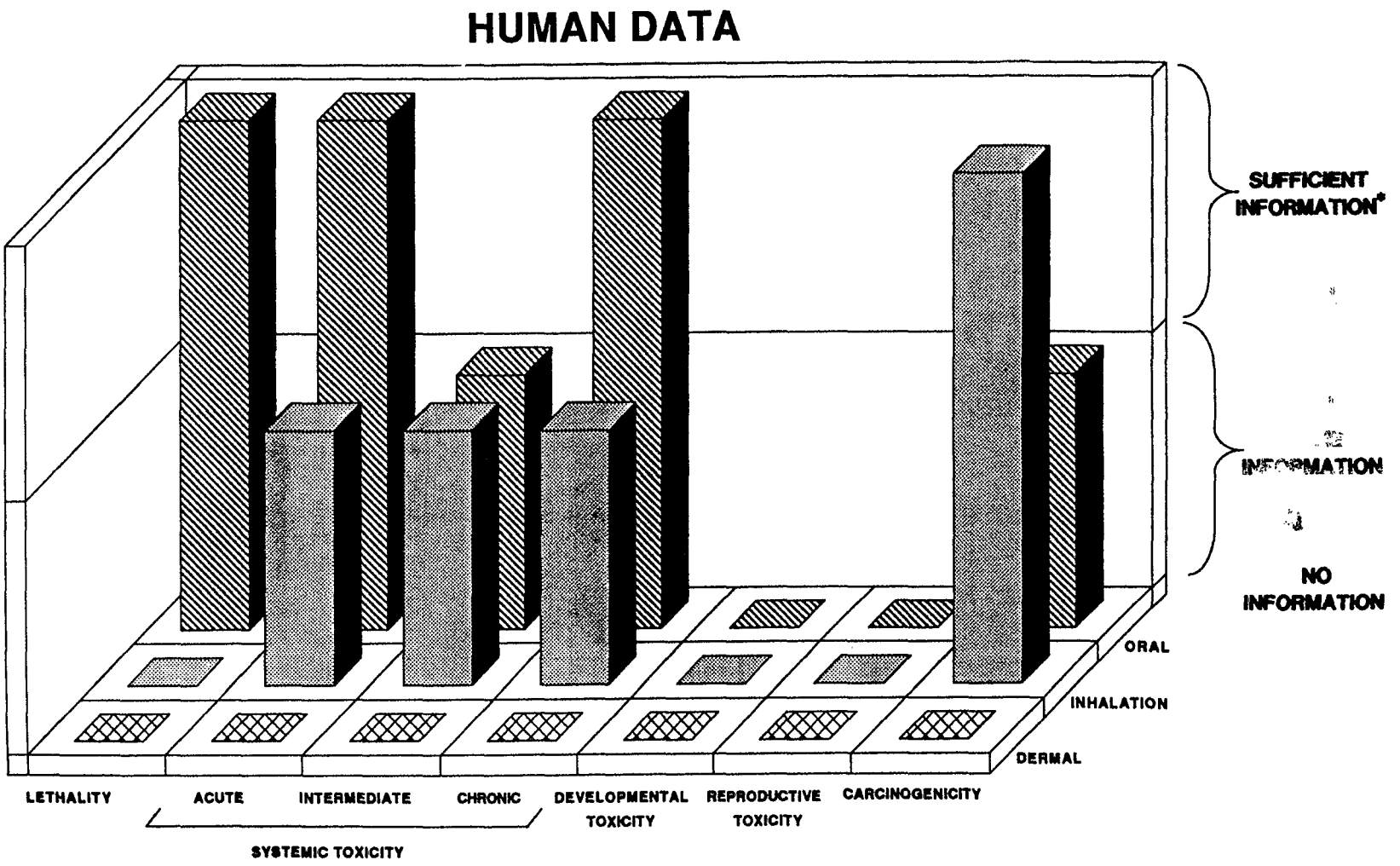
1. For noncancer health end points, one or more studies are available that meet current scientific standards and are sufficient to defi... a range of toxicity from no effect levels (NOAELs) to levels that cause effects (LOAELs or FELs).

2. For human carcinogenicity, a substance is classified as either a "known human carcinogen" or "probable human carcinogen" by both EPA and the International Agency for Research on Cancer (IARC) (qualitative), and the data are sufficient to derive a cancer potency factor (quantitative).

3. For animal carcinogenicity, a substance causes a statistically significant number of tumors in at least one species, and the data are sufficient to derive a cancer potency factor.

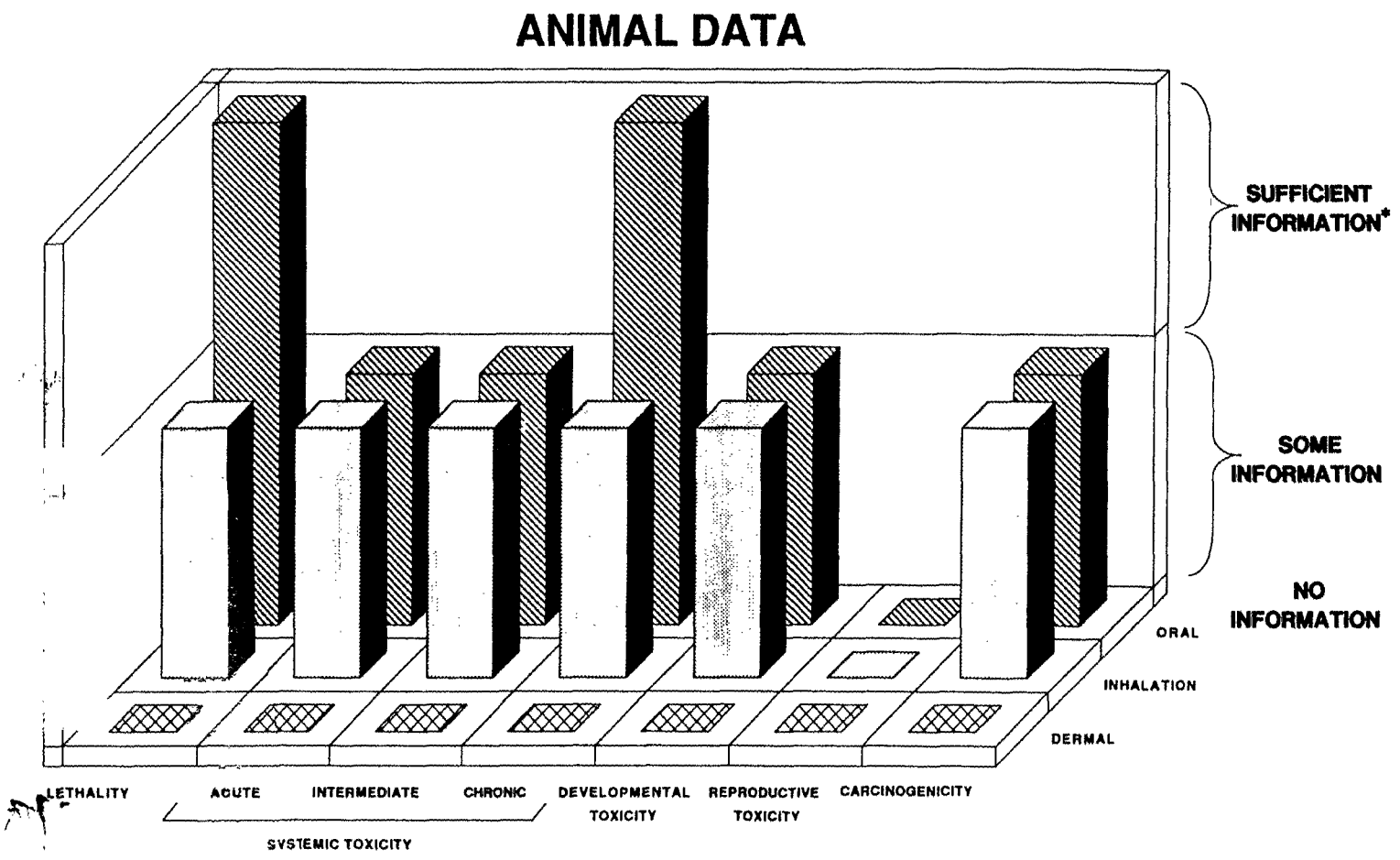
4. There are studies which show that the chemical does not cause this health effect via this exposure route.

Bars of half height indicate that "some" information for the end point exists, but does not meet any of these criteria.



*Sufficient information exists to meet at least one of the criteria for cancer or noncancer end points.

Fig. 2.7. Availability of information on health effects of arsenic (human data).



*Sufficient information exists to meet at least one of the criteria for cancer or noncancer end points.

Fig. 2.8. Availability of information on health effects of arsenic (animal data).

The absence of a column indicates that no information exists for that end point and route. In some cases, information for one route of exposure may not be applicable for developing levels of significant human exposure, even if it is available, and this is indicated by a fully shaded cell on the graph.

2.3.2.2 Description of highlights of graphs

Because arsenic occurs naturally in groundwater and because arsenic has been used for many years as a poison, a therapeutic agent, and an industrial material, there is a broad database available on the human health effects of arsenic exposure. Most quantitative information available is for oral exposure, although risk of lung cancer from inhalation exposure has been well studied. Reproductive and developmental effects have not been adequately studied in humans, although limited data from animal studies suggest this is not an effect of major concern. Little quantitative information exists on risks from dermal exposure. While dermal irritation may be significant, systemic effects following dermal exposure are rare.

Arsenic toxicity in animals has been reasonably well studied by the oral route, but only limited data are available for inhalation toxicity in animals. As previously noted, animals appear to be considerably less sensitive to arsenic than humans, and several of the most characteristic effects of arsenic toxicity in humans (neuropathy, skin lesions, and anemia) have not been observed in animal models at doses where humans would be affected. Thus, animal data are of limited utility in estimating significant levels of human exposure.

2.3.2.3 Summary of relevant ongoing research

Table 2.4 summarizes ongoing research projects related to arsenic that are presently funded by the National Institutes of Health (NIH). These projects may be expected to produce valuable new information on the toxicokinetics, mechanism of action, and dose-response relationships for arsenic. Significant research on arsenic is also being conducted in Taiwan and Mexico.

2.3.3 Other Information Needed for Human Health Assessment

2.3.3.1 Pharmacokinetics and mechanism of action

There is good evidence in animal and human studies that inorganic arsenic is metabolized by methylation. Additional research is needed to further clarify the relationship between absorbed dose, methylation capacity, and levels of inorganic arsenic in blood and tissues. In addition, a more thorough evaluation of the toxicity of the metabolites (MMA, DMA) and transitory intermediates (e.g., arsenoxy radicals) is needed. A detailed understanding of these relationships will help in the selection of appropriate no-effect values for noncarcinogenic effects, and may also influence the evaluation of mutagenic and carcinogenic risk from arsenic. Of special importance is the need for studying differences in methylating capacity between individuals and for distinguishing "methylators" from "nonmethylators" (Table 2.4).

Table 2.4. Summary of ongoing research[a]

Principal investigator	Institutional affiliation	Description of research	Data gap
Carter, D. E.	University of Arizona	Investigate pulmonary toxicity (lung fibrosis) of gallium arsinide (GaAs), a semiconductor with growing industrial use	Toxicity of this arsenic compound has not been studied
Fowler, B. E.	NIEHS, NIH	Investigate molecular mechanisms which regulate intracellular availability of metals	Arsenic toxicokinetics
Landolph, J. R.	University of Southern California	Molecular biology of transformation of mouse fibroblasts in vitro by arsenic and other metals	Mechanism of arsenic-induced carcinogenicity
Landrigan, P. J.	Mount Sinai, New York	Epidemiological studies of environmental toxicants, including arsenic	Dose-response data for arsenic-induced effects in humans
Menzel, D. B.	Duke University	Absorbtion and clearance of metals, including arsenic, adsorbed to airborne particulates such as flyash	Inhalation toxicokinetics; role of particulate size and composition
Robins, J. M.	Harvard University	Improved statistical means for controlling the "healthy worker" effect in epidemiological studies; applied to mortality data for 8000 arsenic workers	Better ability to detect cause-effect relations in exposed humans
Rossman, T. G.	New York University	Mutagenisis of metals; improved techniques for detecting mutations in bacterial, viral, and eukaryotic systems	Clarification of the co-mutagenic activity of arsenic, and dependence on solubility
Snyder, C. A.	New York University	Respiratory carcinogenicity of As_2O_3 in rodents	Dose-response curve for lung cancer
Upton, A. C.	New York University	Inhalation carcinogenicity of arsenic in rats	Dose-response curve for lung cancer

[a]Adapted from NIH CRISP database.

2.3.3.2 Monitoring of human biological samples

A number of biomonitoring options are available for estimating short-term and long-term arsenic exposure levels in humans. Arsenic levels in blood, urine, hair, and nails all tend to increase with increasing exposure, but there is a wide range in "normal" levels, and values in people with moderate levels of exposure are sometimes not distinguishable from typical "background" levels. In addition, in the low to moderate exposure range of chief concern, there is not a strong correlation between arsenic levels in these fluids or tissues and the onset of arsenic-induced toxicity. Thus, these biomarkers are of limited utility in judging the health risk to populations with low to intermediate levels of arsenic exposure.

This difficulty is not primarily related to analytical methodology, but to intra-human variability in toxicokinetics and sensitivity. Additional research on other potential biomarkers of exposure (skin or tissue levels, levels in cells, enzyme activity, adducts with proteins or other molecules, etc.) might lead to a more sensitive and predictive indicator.

2.3.3.3 Environmental considerations

The environmental fate of arsenic is very complex, involving processes such as oxidation, reduction, organification, volatilization, solubilization, and adsorption. While these processes are understood in general terms (EPA 1984a), there are presently inadequate data to allow quantitative modeling of arsenic fate in the environment. Development of rate constants and identification of the key variables in rate processes would permit a more sophisticated analysis of arsenic fate than is presently possible.

6.3 ENVIRONMENTAL FATE

6.3.1 Atmosphere

Arsenic released to the atmosphere as a gas vapor or adsorbed to particulate matter may be transported to other media via wet or dry deposition, making the atmosphere an important route of arsenic transfer to other media. Trivalent arsenic may undergo oxidation in the air, and arsenic in the atmosphere is usually a mixture of the trivalent and pentavalent forms (EPA 1984a).

Most arsenic in air is adsorbed to particulate matter, especially small diameter particles (e.g., less than 2 μm in diameter) (Coles et al. 1979, as cited in EPA 1982b). The residence time of particulate-bound arsenic in the air depends on particle size, but a typical value is about 9 days (Walsh et al. 1979, as cited in EPA 1982b). Arsenic may persist longer under conditions of limited atmospheric mixing or low precipitation.

Photolysis is not considered an important fate process for arsenic compounds (Callahan et al. 1979).

6.3.2 Surface Water

Arsenic in surface water can undergo a complex pattern of transformations, including oxidation-reduction reactions, ligand exchange, biotransformation, precipitation, and adsorption (Callahan et al. 1979). This complexity results in extremely mobile behavior in aquatic systems, with much of the arsenic entering rivers and eventually transported to oceans (Callahan et al. 1979). Rate constants for these various reactions are not readily available, but the factors most strongly influencing intramedium fate processes in surface water include Eh, pH, metal sulfide and sulfide ion concentrations, iron concentration, presence of phosphorus minerals, temperature, salinity, and distribution and composition of biota (Callahan et al. 1979).

Sorption onto clays, iron oxides, manganese compounds, and organic material is an important fate of arsenic in surface water (Callahan et al. 1979, EPA 1982b), and sediment serves as a reservoir for much of the arsenic entering surface waters. Sediment-bound arsenic (arsenate/arsenite), which has been methylated by aerobic and anaerobic microorganisms, may be released back to the water column (EPA 1982b).

6.3.3 Groundwater

Soluble forms of arsenic interact with soil and travel with the groundwater mass with which they are associated. Shifts in oxidation state may occur in either direction, depending on the particular physical and chemical characteristics of the soil and groundwater.

Volatilization of methylated forms from groundwater is possible. Nonporous soil and heavy vegetation cover are expected to impede volatilization, and oxidation may transform volatile forms into nonvolatile species that will adsorb to clay, organic matter, and iron and aluminum complexes.

6.3.4 Soil

Arsenic occurs in soil predominantly in an insoluble adsorbed form (EPA 1982b). Clay with high anion exchange capacity (e.g., high kaolinite content) is particularly effective at adsorbing arsenate via anion exchange. Complexation and chelation by organic material, iron, or calcium are also important processes fixing arsenic in insoluble form (Cooper et al. 1932, as cited in EPA 1982b).

Red and yellow podzols, latosols, arid and limestone soils, and subsoils high in clay and iron oxides have greater holding capacity for arsenic than other types of soil (Hiltbold et al. 1974, as cited in EPA 1982b). A rise in pH in high iron soil, a drop in pH in lime soil, or a change in redox potential may lead to resolubilization of fixed arsenic.

Leaching of arsenic is usually important only in the top 30 cm of soil (EPA 1982b). Leaching carries arsenic deeper in sandy soils than in clay or loam soils, although EPA (1982b) reports that no leached arsenic could be detected below 90 cm in any of the studies.

While arsenate dominates in aerobic soils, arsenite is the predominant form in slightly reduced soils (e.g., temporarily flooded soil), and arsine, methylated arsenic, and elemental arsenic predominate in very reduced conditions (e.g., swamps and bogs) (EPA 1982b).

6.3.5 Biota

As noted above, arsenic in water and soil may be reduced and methylated by fungi, yeasts, algae, and bacteria, and these forms may volatilize and escape into the air (Wood 1974). The rate of volatilization may vary considerably, depending on soil conditions (oxygenated or anaerobic). The pH value of the soil and microbes present also influence the rate of volatilization. For example, a report by the PAX company (1973) estimated that 50% of an applied dose might volatilize in one year, while Woolson (1976) reported only 1 to 2% volatilization over a period of several months.

Bioconcentration of arsenic occurs in aquatic organisms, primarily in algae and lower invertebrates. Biomagnification in aquatic food chains does not appear to be significant (EPA 1982b, Callahan et al. 1979), although some fish and invertebrates contain high levels of arsenic compounds which are relatively inert toxicologically (EPA 1984a).

Plants may accumulate arsenic via root uptake from soil solution, and certain species may accumulate substantial levels (EPA 1982b). In addition to species differences, the amount of arsenic taken up depends on soil arsenic concentration, soil characteristics, and other factors.

REFERENCE # 29

NAVAJO SUPERFUND OFFICE

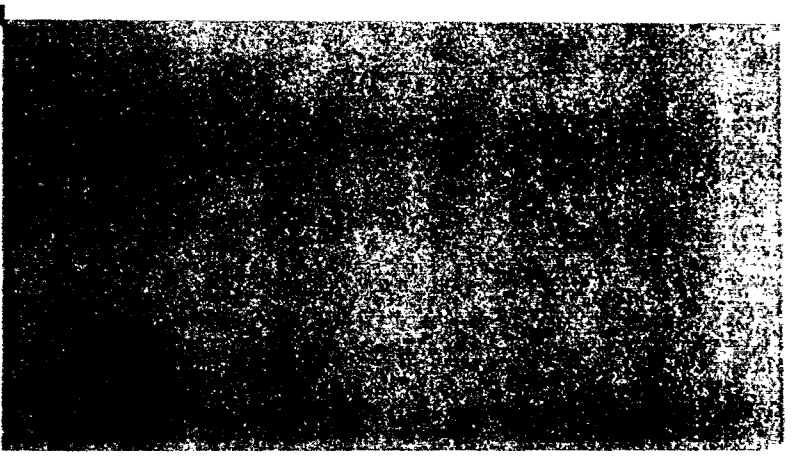
BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

RECEIVED
Navajo Superfund
Office

CHROMIUM

Agency for Toxic Substances and Disease Registry
U.S. Public Health Service



2. HEALTH EFFECTS SUMMARY

2.1 INTRODUCTION

This section summarizes and graphs data on the health effects concerning exposure to chromium. The purpose of this section is to present levels of significant exposure for chromium based on key toxicological studies, epidemiological investigations, and environmental exposure data. The information presented in this section is critically evaluated and discussed in Sect. 4, Toxicological Data, and Sect. 7, Potential for Human Exposure.

This Health Effects Summary section comprises two major parts. Levels of Significant Exposure (Sect. 2.2) presents brief narratives and graphics for key studies in a manner that provides public health officials, physicians, and other interested individuals and groups with (1) an overall perspective of the toxicology of chromium and (2) a summarized depiction of significant exposure levels associated with various adverse health effects. This section also includes information on the levels of chromium that have been monitored in human fluids and tissues and information about levels of chromium found in environmental media and their association with human exposures.

The significance of the exposure levels shown on the graphs may differ depending on the user's perspective. For example, physicians concerned with the interpretation of overt clinical findings in exposed persons or with the identification of persons with the potential to develop such disease may be interested in levels of exposure associated with frank effects (Frank Effect Level, FEL). Public health officials and project managers concerned with response actions at Superfund sites may want information on levels of exposure associated with more subtle effects in humans or animals (Lowest-Observed-Adverse-Effect Level, LOAEL) or exposure levels below which no adverse effects (No-Observed-Adverse-Effect Level, NOAEL) have been observed. Estimates of levels posing minimal risk to humans (Minimal Risk Levels) are of interest to health professionals and citizens alike.

Adequacy of Database (Sect. 2.3) highlights the availability of key studies on exposure to chromium in the scientific literature and displays these data in three-dimensional graphs consistent with the format in Sect. 2.2. The purpose of this section is to suggest where there might be insufficient information to establish levels of significant human exposure. These areas will be considered by the Agency for Toxic Substances and Disease Registry (ATSDR), EPA, and the National Toxicology Program (NTP) of the U.S. Public Health Service in order to develop a research agenda for chromium.

2.2 LEVELS OF SIGNIFICANT EXPOSURE

To help public health professionals address the needs of persons living or working near hazardous waste sites, the toxicology data summarized in this section are organized first by route of exposure--inhalation, ingestion, and dermal--and then by toxicological end points that are categorized into six general areas--lethality, systemic/target organ toxicity, developmental toxicity, reproductive toxicity, genetic toxicity, and carcinogenicity. The data are discussed in terms of three exposure periods--acute, intermediate, and chronic.

Two kinds of graphs are used to depict the data. The first type is a "thermometer" graph. It provides a graphical summary of the human and animal toxicological end points (and levels of exposure) for each exposure route for which data are available. The ordering of effects does not reflect the exposure duration or species of animal tested. The second kind of graph shows Levels of Significant Exposure (LSE) for each route and exposure duration. The points on the graph showing NOAELs and LOAELs reflect the actual doses (levels of exposure) used in the key studies. No adjustments for exposure duration or intermittent exposure protocol were made.

Adjustments reflecting the uncertainty of extrapolating animal data to man, intraspecies variations, and differences between experimental versus actual human exposure conditions were considered when estimates of levels posing minimal risk to human health were made for noncancer end points. These minimal risk levels were derived for the most sensitive noncancer end point for each exposure duration by applying uncertainty factors. These levels are shown on the graphs as a broken line starting from the actual dose (level of exposure) and ending with a concave-curved line at its terminus. Although methods have been established to derive these minimal risk levels (Barnes et al. 1987), shortcomings exist in the techniques that reduce the confidence in the projected estimates. Also shown on the graphs under the cancer end point are low-level risks (10^{-4} to 10^{-7}) reported by EPA. In addition, the actual dose (level of exposure) associated with the tumor incidence is plotted.

2.2.1 Key Studies and Graphical Presentations

2.2.1.1 Inhalation

As indicated in Figs. 2.1 and 2.2, respiratory tract effects, including irritation of the nasal mucosa, transient decreases in lung function, and induction of lung cancer, seem to be the key end points for inhalation exposure to chromium. These effects can occur in humans occupationally exposed to chromium(VI) compounds. Nasal irritation has also been observed in humans who inhaled chromium(VI) aerosols for short periods in an experimental study.

Lethality. For four soluble chromium(VI) compounds, 4-h rat LC_{50} values range from 33 to 65 mg/m^3 c[illegible] al. 1986). The 33-mg/m^3 level is plotted on Figs. [illegible] ute exposure.

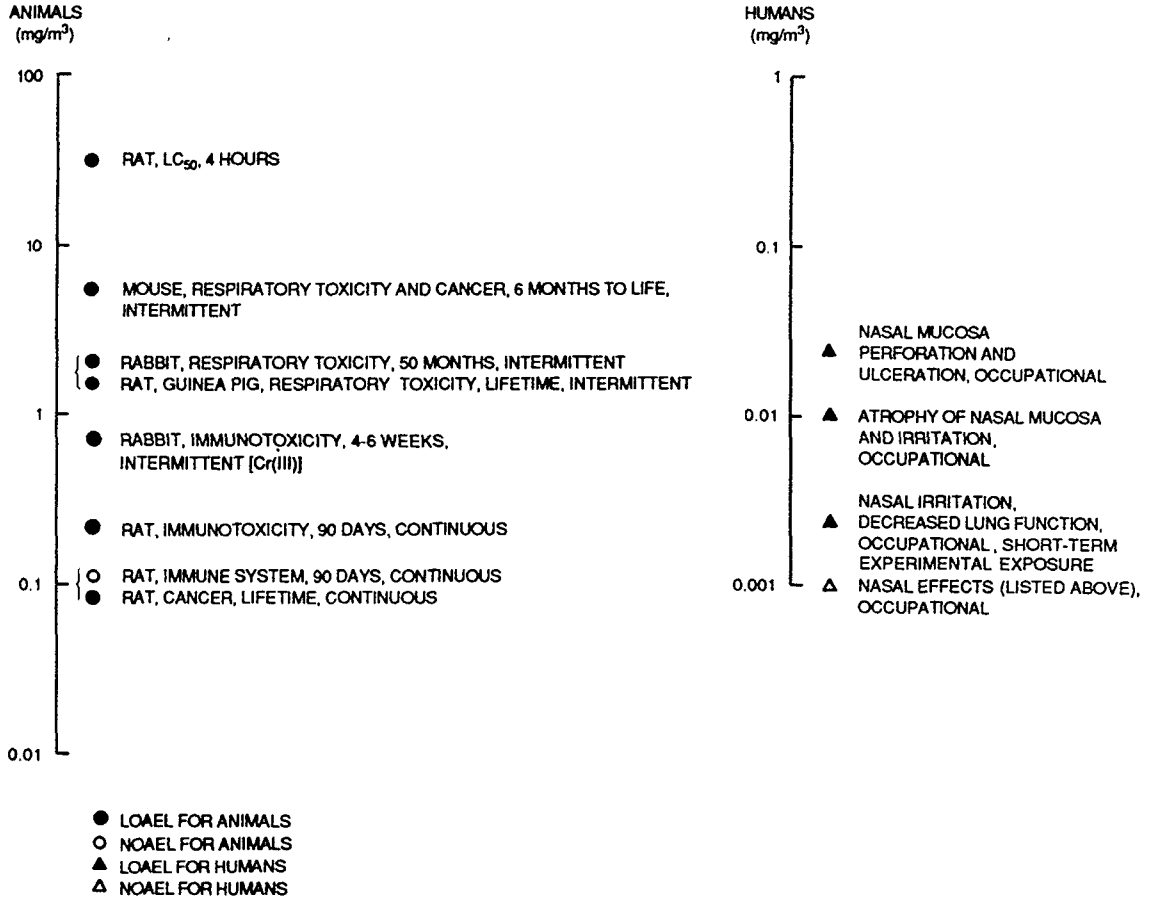


Fig. 2.1. Effects of chromium—inhalation exposure [primarily chromium(VI) unless otherwise specified].

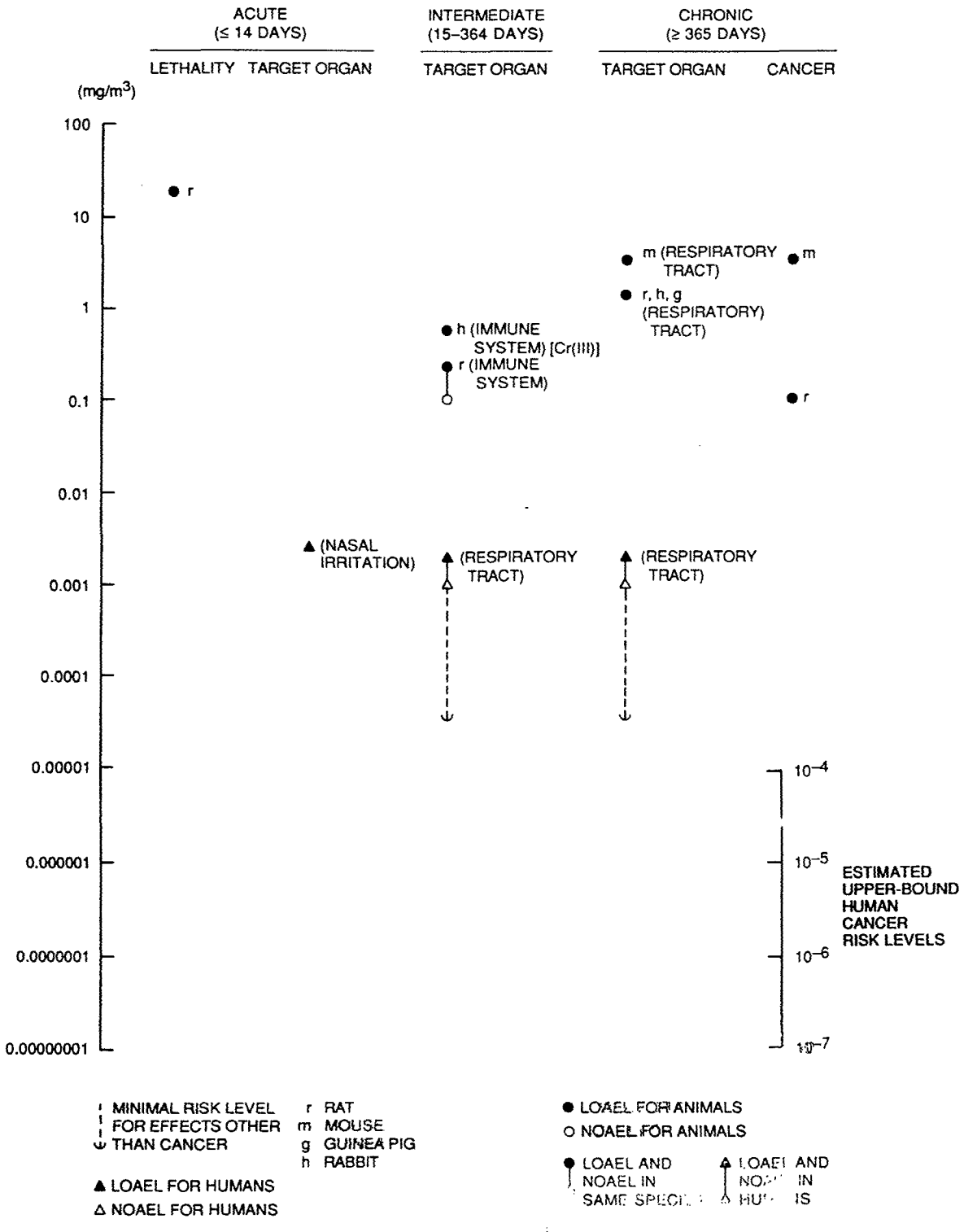


Fig. 2.2. Levels of significant exposure for chromium inhalation [primarily chromium(VI) unless otherwise specified].

Systemic/target organ toxicity. Exposure of normal individuals to chromium(VI) aerosols for short periods of time produced nasal irritation at concentrations of 0.01-0.024 mg/m^3 with the most sensitive individual responding at 0.0025-0.004 mg/m^3 (Kuperman 1964) (LOAEL plotted on Figs. 2.1 and 2.2). In animals respiratory distress and irritation have been reported in 4/50 studies (Gad et al. 1986), but without any indication of exposure-response relationships.

The respiratory tract is a target of intermediate and chronic inhalation exposure to chromium(VI). Many cases of nasal mucosal ulceration and nasal septal perforation have been reported in persons occupationally exposed to chromium(VI). Lindberg and Hedenstierna (1983) reported that subjective and objective evidence of adverse nasal effects were found at mean exposure levels of 0.002-0.20 mg/m^3 chromium(VI), but not at <0.001 mg/m^3 chromium(VI). The effects noted at ≤0.002 mg/m^3 were a smeary and crusty septal mucosa in 11/19 workers and atrophied mucosa in 4/19. Severity of effect correlated better with highest (peak) exposure levels than with mean exposure levels. Nasal mucosal ulceration and septal perforation occurred in individuals exposed at peak levels of 0.02-0.046 mg/m^3 chromium(VI), nasal mucosal atrophy and irritation occurred at peak exposures of 0.0025-0.011 mg/m^3, and no significant nasal effects were seen at peak exposures of 0.0002-0.0012 mg/m^3. The effects observed in this study may not have been a result of exposure levels actually measured, but may have been a result of earlier exposure under unknown conditions. Despite this limitation, the study provides useful data to indicate concentrations of chromium that may result in effects and concentrations that cause minimal or no effects. This study indicates that effects on the nasal mucosa (irritation, atrophy) may occur at chromium(VI) concentrations at 0.002 mg/m^3 and greater. That a concentration of about 0.002 mg/m^3 (LOAEL on Figs. 2.1 and 2.2) is an effect level is supported by the experimental exposure study by Kuperman (1964), which reported nasal irritation in sensitive individuals at a chromium(VI) concentration of 0.0025-0.004 mg/m^3. Because the nasal effects observed in the Lindberg and Hedenstierna (1983) study at concentrations <0.0002 mg/m^3 were mild and no effects were observed at concentrations <0.001 mg/m^3 or peak concentrations of 0.0002-0.0012 mg/m^3, a concentration of 0.001 mg/m^3 is considered a NOAEL for nasal effects.

In addition, slight effects on lung function have been observed in workers exposed to chromium(VI). Lindberg and Hedenstierna (1983) found that workers exposed to mean concentrations of 0.002-0.020 mg/m^3 chromium(VI) for a median duration of 2.5 years had slight, transient decreases in forced vital capacity (FVC), forced expired volume in 1 s (FEV1), and forced mid-expiratory flow (FEF25-75) during the workday. No permanent changes were seen in this group (after 2 days without exposure) in comparison with unexposed controls. Workers exposed to <0.002 mg/m^3 chromium(VI) showed no effect on lung function. The chromium(VI) concentrations at which minor lung function changes were observed (0.002-0.02 mg/m^3) and those at which no changes were observed (<0.002 mg/m^3) are similar to those for nasal irritation, so the NOAEL of 0.001 mg/m^3 chromium(VI) for nasal mucosal irritation should also prevent changes in lung function. Because occupational exposures involve both intermediate and chronic durations, the LOAEL and NOAEL from the

Lindberg and Hedenstierna (1983) study are plotted on Fig. 2.1 for effects in humans and on Fig. 2.2 under intermediate and chronic exposure for respiratory tract toxicity and serve as the basis of the minimal risk levels for both intermediate and chronic inhalation exposure to chromium(VI).

In animals, immune system reactions were depressed in rats exposed to 0.2 mg/m^3 chromium(VI) virtually continuously for 90 days (LOAEL, intermediate exposure on Figs. 2.1 and 2.2), while the immune system was stimulated at concentrations ≤0.1 mg/m^3 chromium(VI) (NOAEL, intermediate exposure on Figs. 2.1 and 2.2) (Glaser et al. 1985). Johansson et al. (1986) found changes in macrophages from rabbits exposed 6 h/day, 5 days/week for 4-6 weeks to chromium(VI) (Na_2CrO_4) or chromium(III) [$Cr(NO_3)_3$] at chromium concentrations of 0.9 and 0.6 mg/m^3, respectively. A decrease in phagocytic activity was observed in macrophages from chromium(III)- but not chromium(VI)-exposed rabbits. Therefore, the 0.6 mg/m^3 concentration can be considered a LOAEL for chromium(III) exposure and is presented on Figs. 2.1 and 2.2 for intermediate exposure.

Respiratory tract effects, including nasal mucosa perforation and granulomata of the lungs, were observed in rabbits exposed for 50 months and in rats and guinea pigs exposed for their lifetime to chromium(VI) as mixed chromate dust at 3-4 mg/m^3 CrO_3 [1.6-2.1 mg/m^3 chromium(VI)] 5 h/day, 4 days/week (LOAEL for several species, chronic exposure on Figs. 2.1 and 2.2) (Steffee and Baetjer 1965). Nettesheim et al. (1971) observed necrosis, atrophy and hyperplasia of the bronchial epithelium, and alveolar proteinosis in mice exposed to chromium(VI) as calcium chromate dust at 13 mg/m^3 $CaCrO_4$ [4.3 mg/m^3 chromium(VI)], 5 h/day, 5 days/week for 6 months to life (LOAEL for mice, chronic exposure on Figs. 2.1 and 2.2).

Developmental toxicity. Pertinent data regarding developmental toxicity of inhalation exposure to chromium were not located in the available literature. Parenteral administration of chromium(III) or chromium(VI) resulted in adverse developmental effects in animals.

Reproductive toxicity. Pertinent data regarding the reproductive toxicity of inhalation exposure to chromium were not located in the available literature. Parenteral administration of chromium(III) or chromium(VI) resulted in adverse reproductive effects in animals.

Genotoxicity. Studies of chromosome effects in lymphocytes of workers exposed to chromium(VI) have given mixed results. Bigaliev et al. (1977) reported an increase in chromosomal aberrations in lymphocytes of workers exposed to soluble chromium(VI) compounds. Studies of chromosomal aberrations (Sarto et al. 1982) or sister chromatid exchange (SCE) (Stella et al. 1982, Nagaya 1986) in chromium-plating workers [exposed to soluble chromium(VI)] showed significant increases in these chromosomal effects only in young workers (Sarto et al. 1982, Stella et al. 1982).

In vivo assays of the genotoxicity of chromium(VI) in nonhuman systems have given positive results for somatic mutations in *Drosophila melanogaster* (Rasmuson 19[illegible] the mouse (Knudson 1980), a dominant lethal assay in [illegible] (Rasc[illegible] et al. 1982), a study of

"Discrepancies of [illegible] measured [illegible] Study of the San Juan Basin, Northwest New Mexico"

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Socorro, New Mexico 87801

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This report is preliminary and has not been edited or reviewed for conformity to New Mexico Bureau of Mines standards.

chromosome ab[illegible] (Newton and Lilly 1986), and a micronucleus assay in mice (Wild 1978). The only in vivo assay of the genotoxicity of chromium(VI) in nonhuman systems, a micronucleus assay in mice, gave [illegible] (Wild 1978).

In vitro [illegible] mutations, chromosome effects, and cell transformation [illegible] y given positive results for chromium(VI) (Bianchi and [illegible], 1984a). Positive results have been obtained for chromium(III) only in cells with phagocytic activity or at very high concentrations of chromium (Bianchi and Levis 1985).

In general, the genotoxicity data support the carcinogenicity results in animal studies: chromium(VI) is a more active genotoxin than chromium(III). The positive dominant lethal study taken together with positive results in human somatic cells raises concern that chromium(VI) may be a potential human germ-cell mutagen.

Carcinogenicity. Case studies and epidemiological studies indicate that occupational exposure to chromium compounds is associated with respiratory cancer. Although these studies do not clearly implicate specific compounds, they do implicate chromium(VI), and the results of animal testing also implicate chromium(VI). The key epidemiological study used for quantitative risk assessment is by Mancuso (1975), who found a dose-related increase in lung cancer death rates in chromate production workers exposed to chromium at 1-8 mg/m^3-year total chromium. Using these data and a dose-response model which is linear at low doses, EPA (1984a, 1986c) has derived a unit risk estimate of 1.2×10^{-2} for exposure to air containing 1 $\mu g/m^3$ chromium(VI) [or potency of 1.2×10^{-2} $(\mu g/m^3)^{-1}$]. The exposure levels associated with increased lifetime upperbound cancer risks of 1×10^{-4} to 1×10^{-7} are 8.3×10^{-6} to 8.3×10^{-9} mg/m^3 and are indicated in Fig. 2.2.

Chronic inhalation studies of chromium(VI) in animals provide sufficient evidence that certain chromium(VI) compounds are carcinogenic to animals. Nettesheim et al. (1971) reported a statistically significant increase in lung tumors in mice exposed to calcium chromate at 13 mg/m^3 [4.3 mg/m^3 chromium(VI)] 5 h/day, 5 days/week for life. In a review of the study, the International Agency for Research on Cancer (IARC 1980) stated that an excess tumor incidence was not observed. Glaser et al. (1986) found lung tumors in 3/19 rats exposed to sodium dichromate at 0.1 mg/m^3 chromium(VI) virtually continuously for 18 months (followed by 12 months of observation) versus 0/37 in controls. Statistical analysis at Syracuse Research Corporation indicates that the tumor incidence is statistically significant ($P = 0.03$, Fisher Exact test). The concentrations of chromium(VI) resulting in a carcinogenic effect in mice and rats are plotted on Fig. 2.2.

Studies in which chromium compounds were instilled or implanted into the lungs or injected into sites other than the lungs have given positive results for some chromium(VI) compounds and negative results for chromium(III) compounds and chromium metal.

After reviewing all available data, the EPA Carcinogen Assessment Group (CAG) (EPA 1984a) stated that the level of evidence for combined animal and human data would place hexavalent chromium [chromium(VI)]

compounds into Group A, meaning that there is decisive evidence for the carcinogenicity of those compounds in humans. The EPA (1986c) applies the classification of Group A to inhaled chromium(VI) (see Sect. 9.2.3 on data analysis in Regulatory and Advisory Status).

2.2.1.2 Oral

For adults, the estimated safe and adequate daily dietary recommendation of chromium, considered to be an essential nutrient, is 50-200 μg/day (0.0007-0.003 mg/kg/day) (Danford and Anderson 1985).

As indicated in Figs. 2.3, 2.4, 2.5, and 2.6, effects observed after chromium(VI) and chromium(III) oral exposure have not been well defined. The safe and adequate level for human nutrition is shown on Figs. 2.5 and 2.6 for ingestion of chromium(III).

Lethality. Oral rat LD_{50} values for soluble chromium(VI) compounds (sodium chromate; sodium, potassium, and ammonium dichromate) of 16.7-22.5 mg/kg chromium(VI) have been reported (Gad et al. 1986). The lowest LD_{50} of 16.7 mg/kg chromium(VI) is indicated on Figs. 2.3 and 2.4 for acute exposure. Smyth et al. (1969) demonstrated rat oral LD_{50}s for chromium(III) compounds of 3.25 g/kg of chromic nitrate (nonahydrate) [$Cr(NO_3)_3 \cdot 9H_2O$] [422 mg/kg chromium(III)] and 11.26 g/kg of chromic acetate (monohydrate) [$Cr(CH_3COO)_3 \cdot H_2O$] [2,369 mg/kg chromium(III)]. Both doses are indicated on Fig. 2.5 and the lower dose is plotted on Fig. 2.6 for acute lethality for chromium(III).

Although some data on the lethality of chromium(VI) to humans are available (Langard and Norseth 1986, NIOSH 1979), the data are inadequate to characterize a lethal dose for humans.

Systemic/target organ toxicity. Diaz-Mayans et al. (1986) observed hypoactivity in rats provided with sodium chromate(VI) in their drinking water for 28 days at a dose of 0.7 g/L chromium (98 mg/kg/day, LOAEL, acute and intermediate exposure on Figs. 2.3 and 2.4). The decrease in activity was noted after 7 days of treatment. No effects on activity were noted at 0.07 g/L (9.8 mg/kg/day, NOAEL) throughout the 28-day treatment period. Doses were calculated from drinking water concentrations using EPA (1986a) methods. Minimal risk levels for acute and intermediate oral exposure were not derived from the NOAEL, because adequate data are not available for other possibly more sensitive end points.

Chronic oral studies of chromium compounds in rats, mice, and dogs have not identified any adverse effects on toxicological end points including body and organ weights, clinical chemistry values, hematological values, and histological appearance of tissue. The highest NOAEL for chromium(VI), 25 ppm in drinking water, equivalent to 2.4 mg/kg/day chromium (EPA 1980, 1984b; EPA 1986c) in rats, was identified by MacKenzie et al. (1958). In this study, rats were dosed with potassium chromate in the drinking water for 1 year and examined for body weights, clinical blood chemistry, and gross and microscopic pathology. The 2.4-mg/kg/day dose is plotted on Figs. 2.3 and 2.4 and is the basis for the minimal risk level for chronic oral exposure to chromium(VI) as calculated by EPA (1986c).

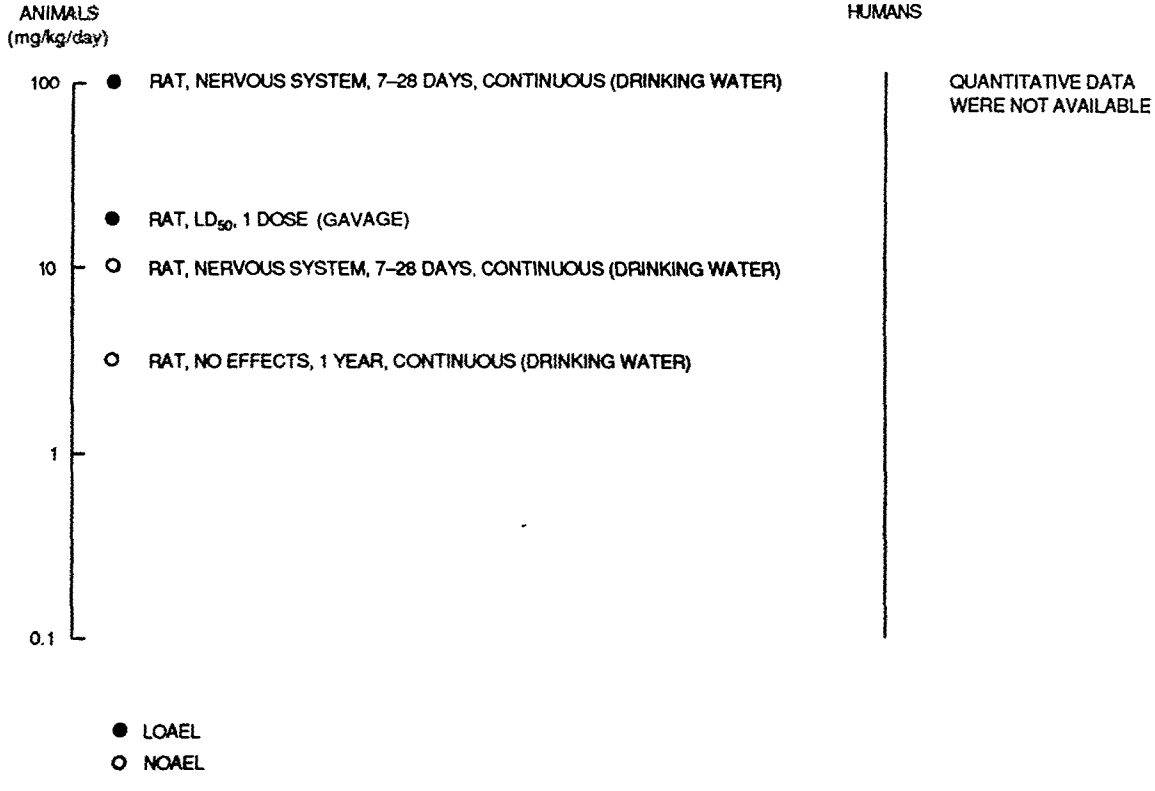


Fig. 2.3. Effects of chromium(VI)—oral exposure.

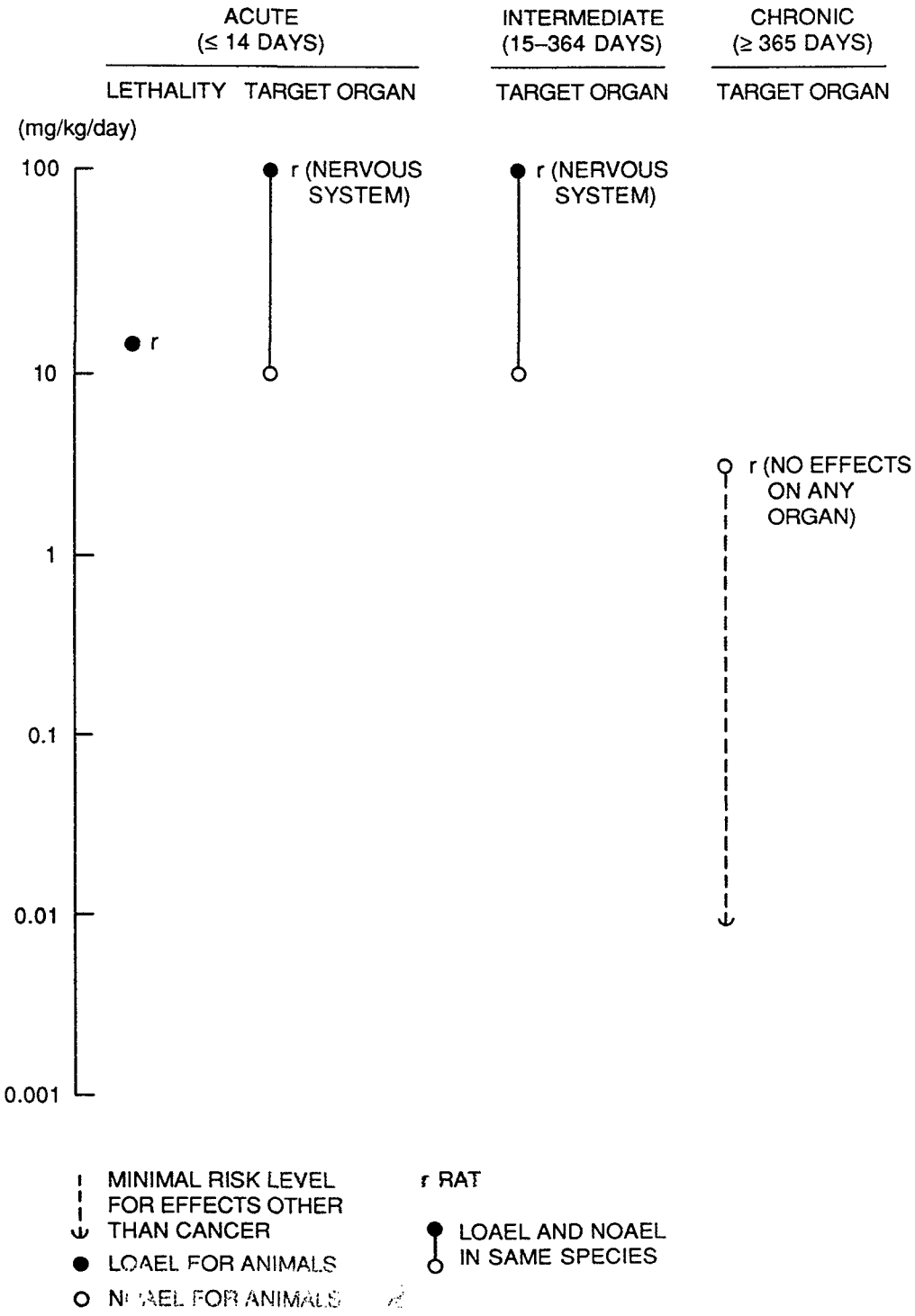


Fig. 2.4. Levels of significant exposure for chromium(VI)—oral.

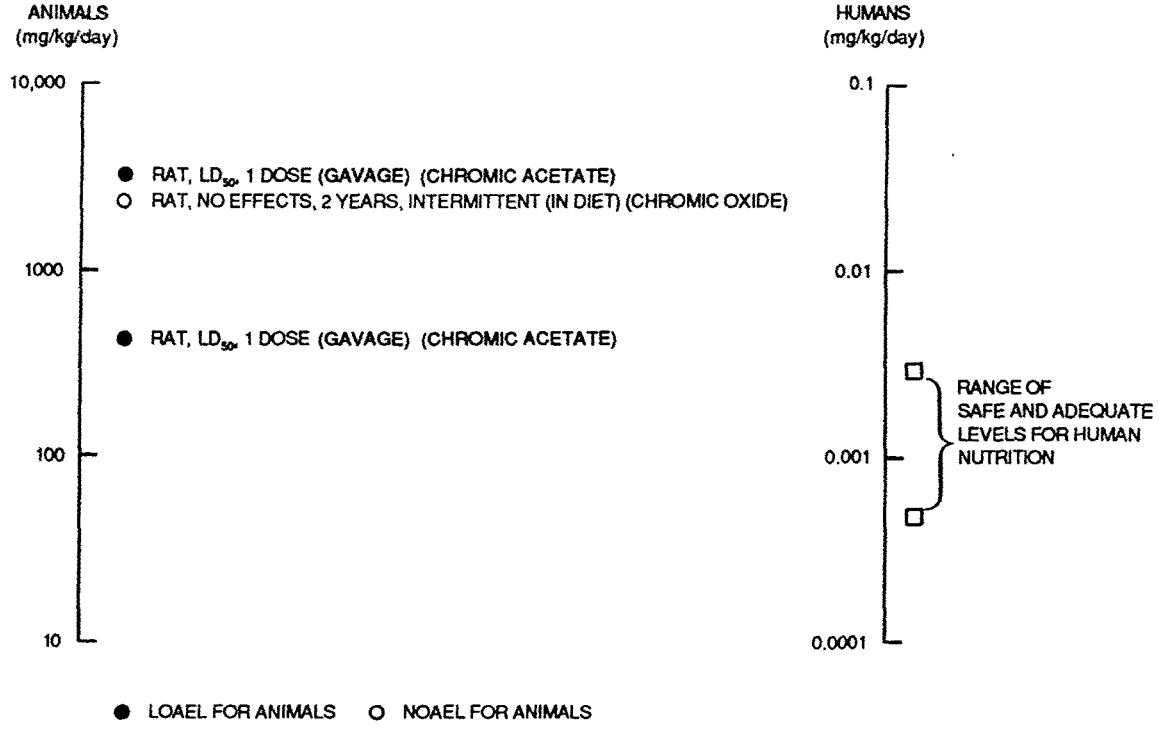


Fig. 2.5. Effects of chromium(III)—oral exposure.

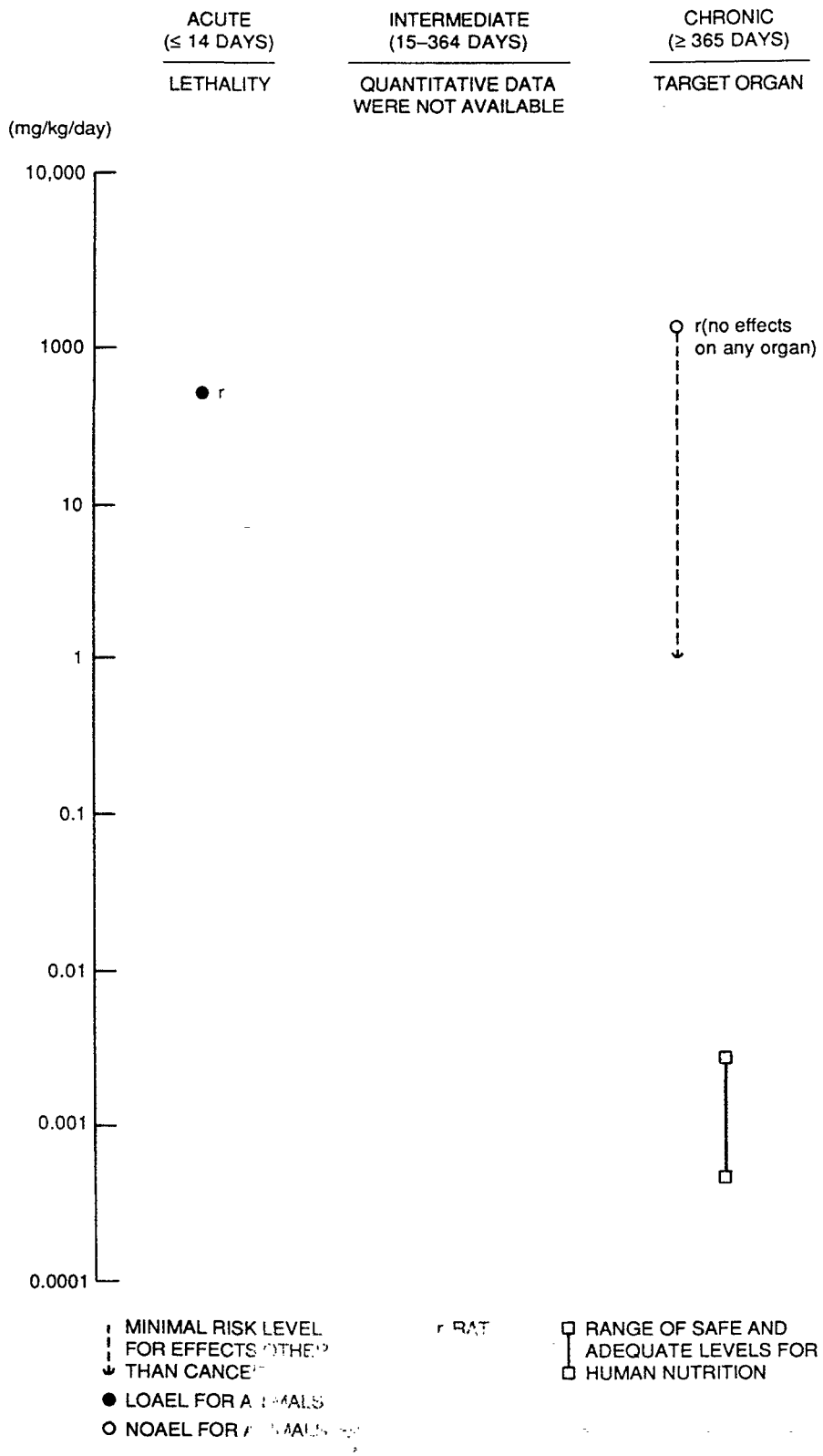


Fig. 2.6. Levels of significant exposure for chromium(III)—oral.

Ivankovic and Preussmann (1975) found that rats tolerated a dosage of 1,468 mg/kg/day chromium(III) for 2 years (as chromic oxide in bread at 5% with no effects on survival, body weight, blood and urine chemistry values, or gross and microscopic appearance of organs and tissues. This dosage, calculated by EPA (1985d) (Sect. 2.3 Data Analysis for Regulatory and Advisory Status) from data provided by the investigators, is higher than the oral LD50 found for the chromium(III) tested as chromic nitrate but not higher than chromium(III) tested as chromic acetate. The discrepancy in dose may be due to the use of different compounds and different methods of administration. In the LD50 study (Smyth et al. 1969), the compounds were given by gavage in one bolus dose, while in the long-term study, rats consumed smaller amounts (as chromic oxide) with food throughout the dosing days. The dosage of 1,468 mg/kg/day chromium(III) is plotted as a NOAEL on Figs. 2.5 and 2.6 and is the basis of the minimal risk level for chronic oral exposure to chromium(III) as calculated by EPA (1985d).

Developmental toxicity. Pertinent data regarding developmental toxicity of oral exposure to chromium were not located in the available literature. Parenteral administration of chromium(III) or chromium(VI) to animals produced adverse developmental effects.

Reproductive toxicity. The study by Gross and Heller (1946) provides some data that indicate that oral chromium(VI) may result in reproductive toxicity. Because data concerning the length of the study, the number of rats used, and the method of sterility ascertainment were not available, the study is not adequate for use in the determination of levels of significant exposure. Similarly, the study by Ivankovic and Preussmann (1975) on chromium(III), in which only a few rats were mated and no reproductive effects were observed, is not adequate for assessment of reproductive toxicity. Parenteral administration of chromium(III) or chromium(VI) to animals resulted in adverse reproductive effects.

Genotoxicity. See Sect. 2.2.1.1, genotoxicity subsection in Health Effects Summary, for a summary of the available data.

Carcinogenicity. Chronic oral administration of chromium(III) compounds to rats and mice (Schroeder et al. 1964, Schroeder et al. 1965, Ivankovic and Preussman 1975, Borneff et al. 1968) has not resulted in significantly increased tumor incidences. Oral studies of chromium(VI) compounds are not of adequate duration for evaluation of carcinogenic potential in animals. Signs of toxicity included dermal edema, erythema, necrosis, eschar formation and corrosion, and diarrhea and hypoactivity. The cause of death was not specified.

2.2.1.3 Dermal

The only dose-response dermal data are rabbit LD50 values for chromium(VI) compounds determined by Gad et al. (1986). These values ranged from 1,000 mg/kg for sodium dichromate (397 mg/kg chromium) to 1,640 mg/kg for ammonium dichromate (677 mg/kg chromium) (Fig. 2.7). The lower value is displayed on Fig. 2.8. Necrosis of the skin, kidney damage, and death have been reported in humans following acute dermal exposure to high levels of chromium(VI) compounds (Brieger 1920, Major 1922, Fritz et al. 1959). Skin sensitivity (dermatitis with eczema) is

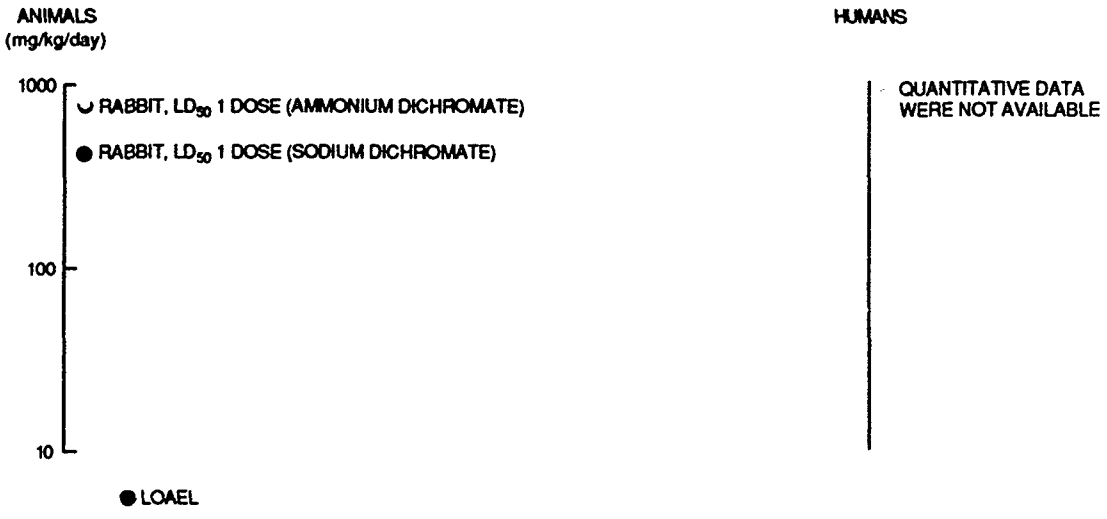


Fig. 2.7. Effects of chromium(VI)—dermal exposure.

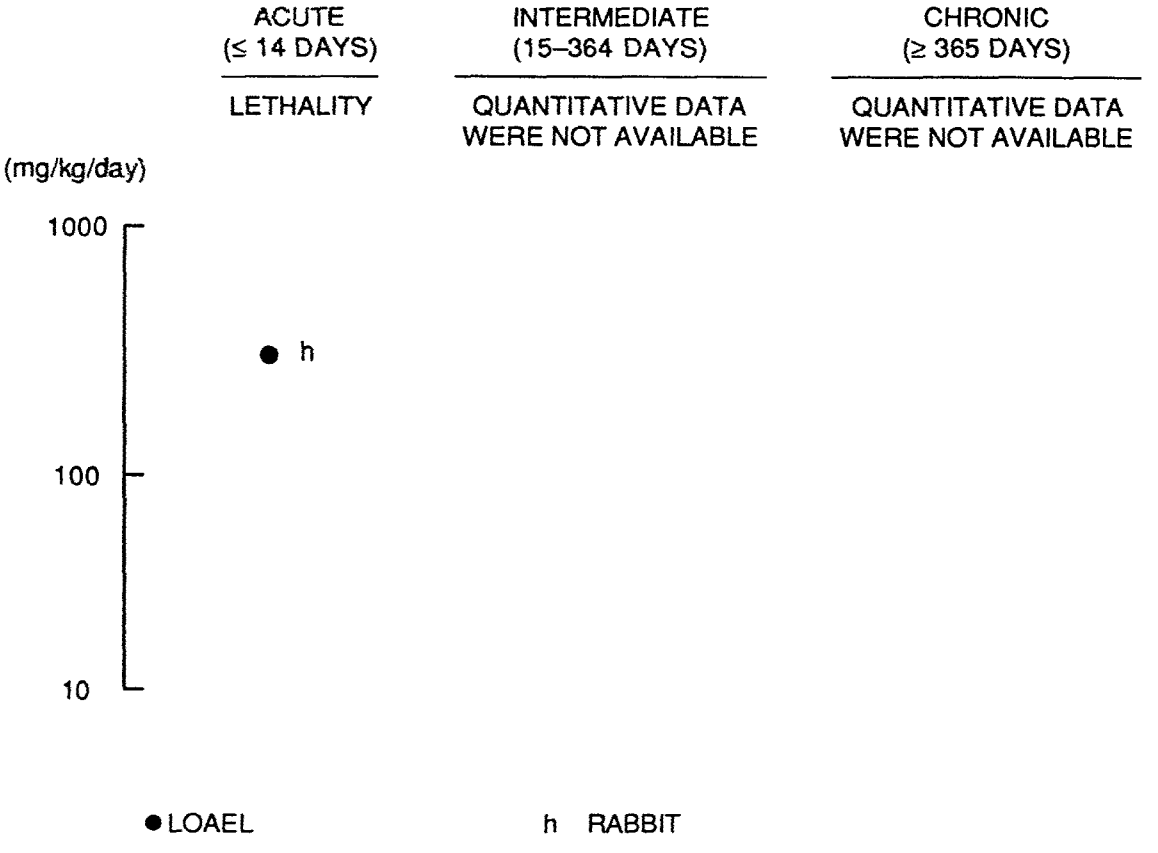


Fig. 2.8. Levels of significant exposure for chromium(VI)—dermal.

the most common effect in humans following exposure to chromium compounds [especially chromium(VI) compounds] at concentrations below those resulting in irritation. Skin sensitivity is more common among men as a result of occupational exposure to chromium(VI) compounds. The types of workers in which the effect has been reported includes printers, cement workers, metal factory workers, painters, and leather tanners. Doses of chromium resulting in sensitization were not available.

2.2.2 Biological Monitoring as a Measure of Exposure and Effects

Normal chromium levels in human fluid and tissues should be interpreted with caution. Low sensitivities of most commonly used methods and the ubiquitous presence of chromium in laboratories make detection of low levels of chromium in blood and urine difficult. Normal endogenous levels listed by Danford and Anderson (1985) are: tissues, 0.02-0.04 μg/g; serum/plasma, <0.05 ng/mL (not in equilibrium with body stores); 24-h urine, <0.05 μg/day (correlates with dietary intake >40 μg chromium, but not <40 μg chromium); and hair, 50-1,000 ppm (measurement methodology not reliable). See Versieck (1985) for additional information concerning the evaluation of data for chromium in biological samples.

Biological monitoring of human fluids and tissues has not been used to associate chromium levels with specific effects, other than a positive association between urine chromium levels and chromosome aberrations in peripheral lymphocytes of workers exposed to soluble chromium(VI) compounds (Sect. 4.3.5 on genotoxicity in the Toxicological Data section). Biological monitoring has been used to relate serum and urine chromium levels to occupational exposure levels. Gylseth et al. (1977) studied five welders exposed to chromium(VI) and observed a statistically significant ($r = 0.95$, $P < 0.001$) relationship between total chromium exposure and urinary chromium concentrations at the end of the workday. The investigators state that urinary chromium concentrations of 40-50 μg/L immediately after work would reflect exposure to levels corresponding to the American Conference of Governmental Industrial Hygienists (ACGIH 1986) Threshold Limit Value (TLV) of 0.05 mg/m^3 chromium for soluble chromium(VI) compounds (a concentration associated with nasal perforations in some studies). The investigators caution that individual variations in habits make it difficult to state an exact biological threshold, but that urinary concentrations of 40-50 μg/L should be used to indicate the need for air monitoring in the workplace.

Mutti et al. (1985) examined end-of-shift chromium levels and related them to chromium(VI) and/or chromium(III) exposure. Their results indicated that urinary chromium levels correlated with exposure to soluble chromium(VI) but not insoluble chromates or chromium(III) compounds. Figure 2.9 shows the relationship between workroom air concentrations of water-soluble chromium(VI) compounds and daily increase in urinary chromium (pre-exposure values subtracted from end-of-shift values). A urinary increase of 12.2 μg/g creatinine or a total concentration of 25 μg/g creatinine corresponded to an air concentration of 50 μg/m^3 chromium(VI) from welding fumes.

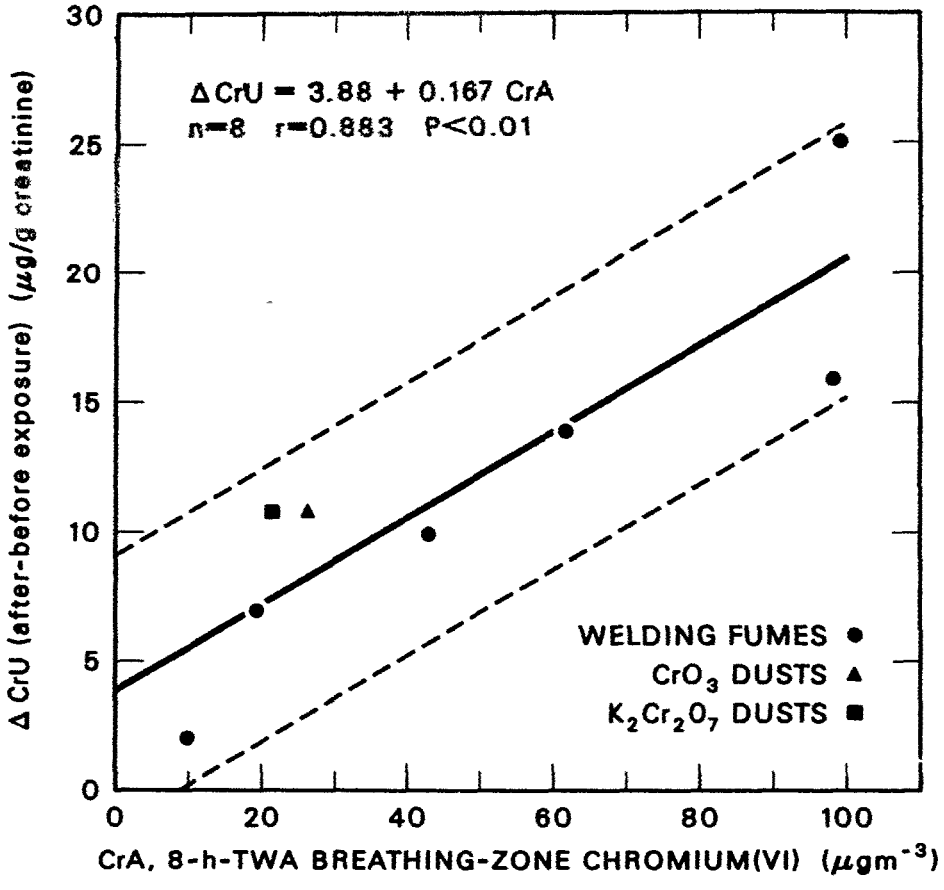


Fig. 2.9. Relationship between water-soluble chromium(VI) concentration in the workroom air (CrA) and daily increase in urinary chromium levels (CrU) (pre-exposure values were subtracted from end-of-shift values). *Source:* Mutti et al. (1985).

In an examination of the distribution of chromium in serum, red blood cells (RBC), and urine in workers exposed to chromium(III) and chromium(VI), Cavalleri and Minoia (1985) also concluded that the determination of chromium in the urine at the end of the workday is a good indicator of exposure to chromium(VI) but not chromium(III). Following exposure to chromium(III), a significant ($P < 0.01$) increase in serum chromium was observed compared to controls and individuals exposed to chromium(VI). RBC chromium was significantly higher ($P < 0.001$) in chromium(VI)-exposed individuals compared to controls and chromium(III)-exposed groups.

Randall and Gibson (1987) found that serum and urine concentrations of chromium were significantly elevated in a group of 72 tannery workers as compared with a group of 52 control subjects at the end of the workweek on Friday and before exposure began on Monday. Serum and urine chromium levels did not correlate with length of employment in the tanning industry, but did correlate with work area of the tannery, with workers who handled wet hides in the chrome tan and wringing departments having the highest chromium levels in these body fluids. The tanning compounds contained chromium primarily as chromium(III). The time-weighted average (TWA) level of total chromium in tannery air was 1.7 $\mu g/m^3$ and did not vary significantly among the various tanneries involved in the study or among various work areas of each tannery. Chromium(VI) could not be detected in tannery air. The investigators concluded that significant absorption of chromium(III) had occurred and that serum and urine levels of chromium may be useful indices of chromium exposure. The finding of higher serum and urine chromium levels in workers having the greatest opportunity for skin contact with the tanning compounds indicates that dermal absorption may have contributed to the results, but the investigators did not address this issue.

In an attempt to determine a urine concentration of chromium to screen for levels of occupational exposure to chromic acid that may cause nasal ulcerations and impairment of lung function, Lindberg and Vesterberg (1983a) studied exposure levels and postshift urinary chromium in 91 workers exposed to chromic acid in the chrome-plating industry. After excluding workers with obvious contamination of the skin, the authors found a correlation between air chromium concentration and urinary chromium concentration ($r = 0.71$) and determined that a urinary chromium level of ≤100 nmol/L (5.2 $\mu g/L$) would reflect TWA exposure to ≤2 $\mu g/m^3$ chromium(VI) from chromic acid. (Inclusion of workers with skin contamination weakened the association between air chromium and urinary chromium concentrations, presumably because of dermal absorption.) A related study (Lindberg and Hedenstierna 1983) had determined that exposure to chromic acid at TWA levels below 2 $\mu g/m^3$ chromium(VI) did not produce severe damage to the nasal septum or affect lung function.

Lewalter et al. (1985) stated that following exposure to soluble chromium(VI) compounds, the chromium is reduced in the plasma to form chromium protein complexes, which can be eliminated by the kidneys. In contrast, exposure to soluble chromium(III) compounds mainly in the form of hydrate complexes, does not result in the formation of chromium protein complexes. The inability of "native" chromium(III) to form

excretable chromium protein complexes may account for the lack of correlation between chromium(III) exposure and urinary chromium levels.

Korallus (1986) further questioned the use of RBC chromium levels as an indication of chromium(VI) exposure. When chromium(VI) plasma levels exceed the plasma reduction capacity (PRC), chromium(VI) enters erythrocytes, is reduced, and becomes bound to hemoglobin. The bond persists for the lifetime of the erythrocytes (120 days), so that a single determination allows a longitudinal evaluation of exposure for an extended period in the past. Low chromium concentrations in the erythrocytes indicate that the amount of chromium(VI) uptake did not exceed the PRC. The capacity of human plasma to reduce chromium(VI) to chromium(III) varies, with slow and fast reducers recognized. It is not clear what is responsible for individual differences in PRC, although the difference in magnitude of PRC has been shown to correlate with the levels of ascorbic acid in plasma. The relationship between blood and urine chromium levels and air CrO_3 concentrations in slow and fast reducers at the end of a 5-day shift at a dichromate plant is shown in Fig. 2.10. The figure indicates that individuals who reduce chromium(VI) slowly have much higher blood chromium levels, while fast reducers have higher urinary chromium levels.

The occupational data indicate a correlation between urine and blood chromium levels at relatively high air chromium(VI) concentrations. Because of variable background urine and blood chromium levels, a correlation between exposure at low concentrations found in the environment and urine and blood chromium levels is not possible.

2.2.3 Environmental Levels as Indicators of Exposure and Effects

2.2.3.1 Levels found in the environment

Except for the correlation of occupational exposure and blood and urine chromium levels, no data are available that correlate environmental levels of chromium and adverse effects.

2.2.3.2 Human exposure potential

Absorption studies of chromium compounds in humans and animals indicate that chromium(VI) compounds are more readily absorbed from all routes of exposure than are chromium(III) compounds (Sect. 4.2.1 on absorption in the Toxicological Data section). This is consistent with the water solubilities of these compounds. Ogawa (1976) found that the absorption of orally administered chromium increased in rats fasted for 48 h. The soluble organic complex GTF, which contains chromium(III), is more readily absorbed from the gastrointestinal tract than is inorganic chromium (Mertz, 1969).

In addition, the bioavailabilty of chromium from soil has been studied. Factors that may increase the mobility of chromium in soils include the speculated conversion of chromium(III) to chromium(VI), increases in pH, and the complexation of chromium(III) with organic matter to form water-soluble complexes. Hexavalent chromium is relatively stable and mobile in sandy soils or soils that contain low concentrations of organic matter. Although chromium is found primarily

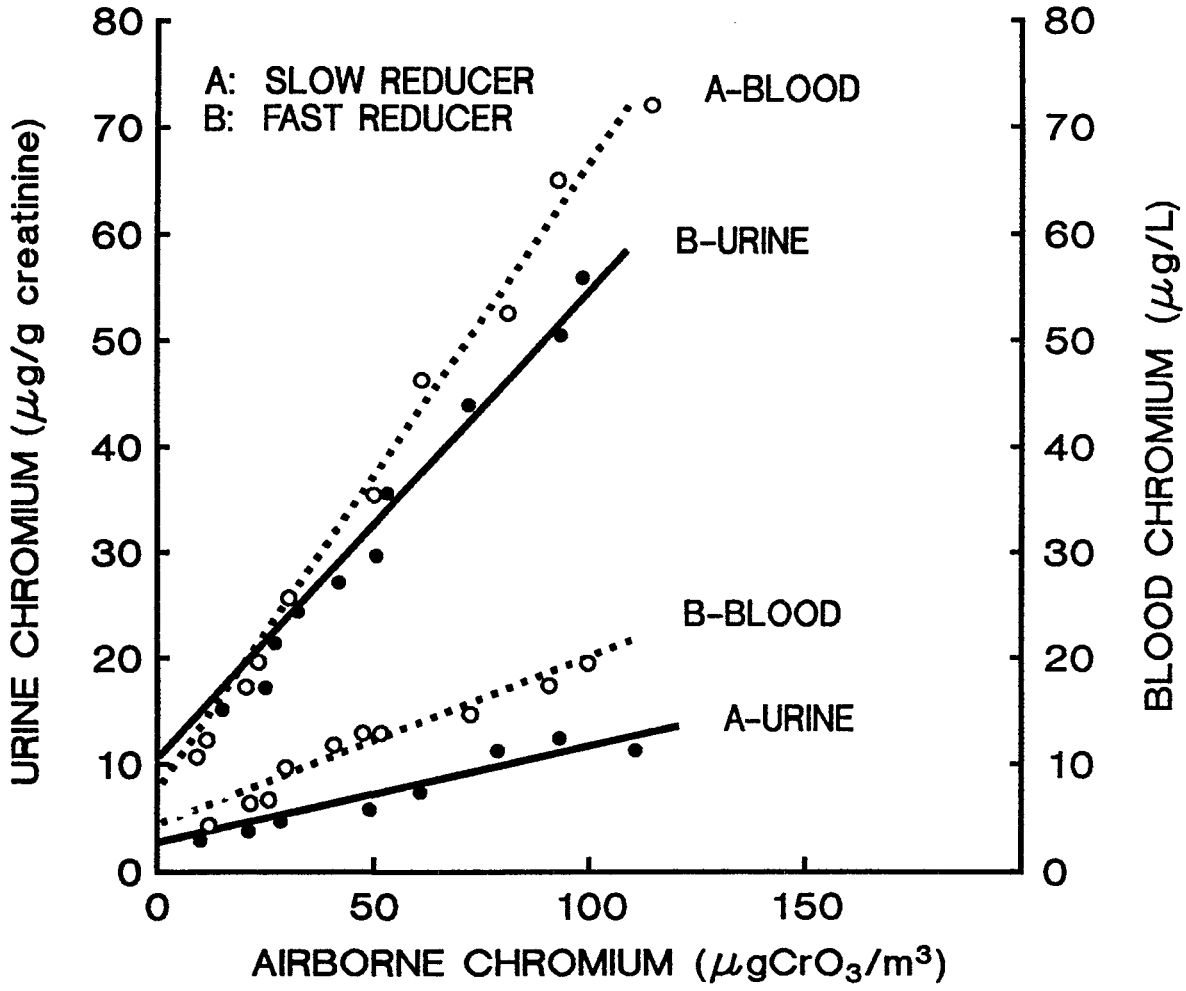


Fig. 2.10. Linear relationship between the airborne hydrosoluble chromium concentration and the chromium concentration in blood and urine at the end of a 5-day shift in workers of a dichromate plant. *Source:* Korallus 1986.

chromium(III) in nature, Carey (1982) has speculated that leaching rocks under extreme conditions or the elevated temperatures produced during brush fires in the presence of MnO_2, present in some soil, may oxidize chromium(III) to chromium(VI). Increasing pH will help solubilize chromium(VI) from soils. Part of the chromium(VI) in soil will be reduced, and some may leach into groundwater and be available for plant uptake. This distribution will depend on soil pH, organic matter content, presence of reducing agent, and the texture of soil. Formation of soluble organic complexes of chromium(III) will also increase its mobility in soils. The complexes are probably formed more readily as chromium(VI) is reduced to chromium(III) by organic matter in soil than by interaction of already present chromium(III) with organic matters present in soils (Carey 1982). No information is available regarding the effect of pH on these complexes formed in soils. Similarly, very little is known about the effect of increased organic carbon content on the mobility of the complexes. In certain soils, increases in organic carbon content may increase the mobility of the complexes as a result of enhanced complexation, while in other soils increases in organic matter may decrease the mobility because of increased sorption.

2.3 ADEQUACY OF DATABASE

2.3.1 Introduction

Section 110 (3) of SARA directs the Administrator of ATSDR to prepare a toxicological profile for each of the 100 most significant hazardous substances found at facilities on the CERCLA National Priorities List. Each profile must include the following content:

"(A) An examination, summary, and interpretation of available toxicological information and epidemiologic evaluations on a hazardous substance in order to ascertain the levels of significant human exposure for the substance and the associated acute, subacute, and chronic health effects.

(B) A determination of whether adequate information on the health effects of each substance is available or in the process of development to determine levels of exposure which present a significant risk to human health of acute, subacute, and chronic health effects.

(C) Where appropriate, an identification of toxicological testing needed to identify the types or levels of exposure that may present significant risk of adverse health effects in humans."

This section identifies gaps in current knowledge relevant to developing levels of significant exposure for chromium. Such gaps are identified for certain health effects end points (lethality, systemic/target organ toxicity, developmental toxicity, reproductive toxicity, and carcinogenicity) reviewed in Sect. 2.2 of this profile in developing levels of significant exposure for chromium and for other areas such as human biological monitoring and mechanisms of toxicity. The present section briefly summarizes the availability of existing human and animal data, identifies data gaps, and summarizes research in progress that may fill such gaps.

Specific research programs for obtaining data needed to develop levels of significant exposure for chromium will be developed by ATSDR, NTP, and EPA in the future.

2.3.2 Health Effect End Points

2.3.2.1 Introduction and graphic summary

The availability of data for health effects in humans and animals is depicted on bar graphs in Figs. 2.11, 2.12, and 2.13.

The bars of full height indicate that there are data to meet at least one of the following criteria:

1. For noncancer health end points, one or more studies are available that meet current scientific standards and are sufficient to define a range of toxicity from no effect levels (NOAELs) to levels that cause effects (LOAELs or FELs).
2. For human carcinogenicity, a substance is classified as either a "known human carcinogen" or "probable human carcinogen" by both EPA and IARC (qualitative), and the data are sufficient to derive a cancer potency factor (quantitative).
3. For animal carcinogenicity, a substance causes a statistically significant number of tumors in at least one species, and the data are sufficient to derive a cancer potency factor.
4. There are studies which show that the chemical does not cause this health effect via this exposure route.

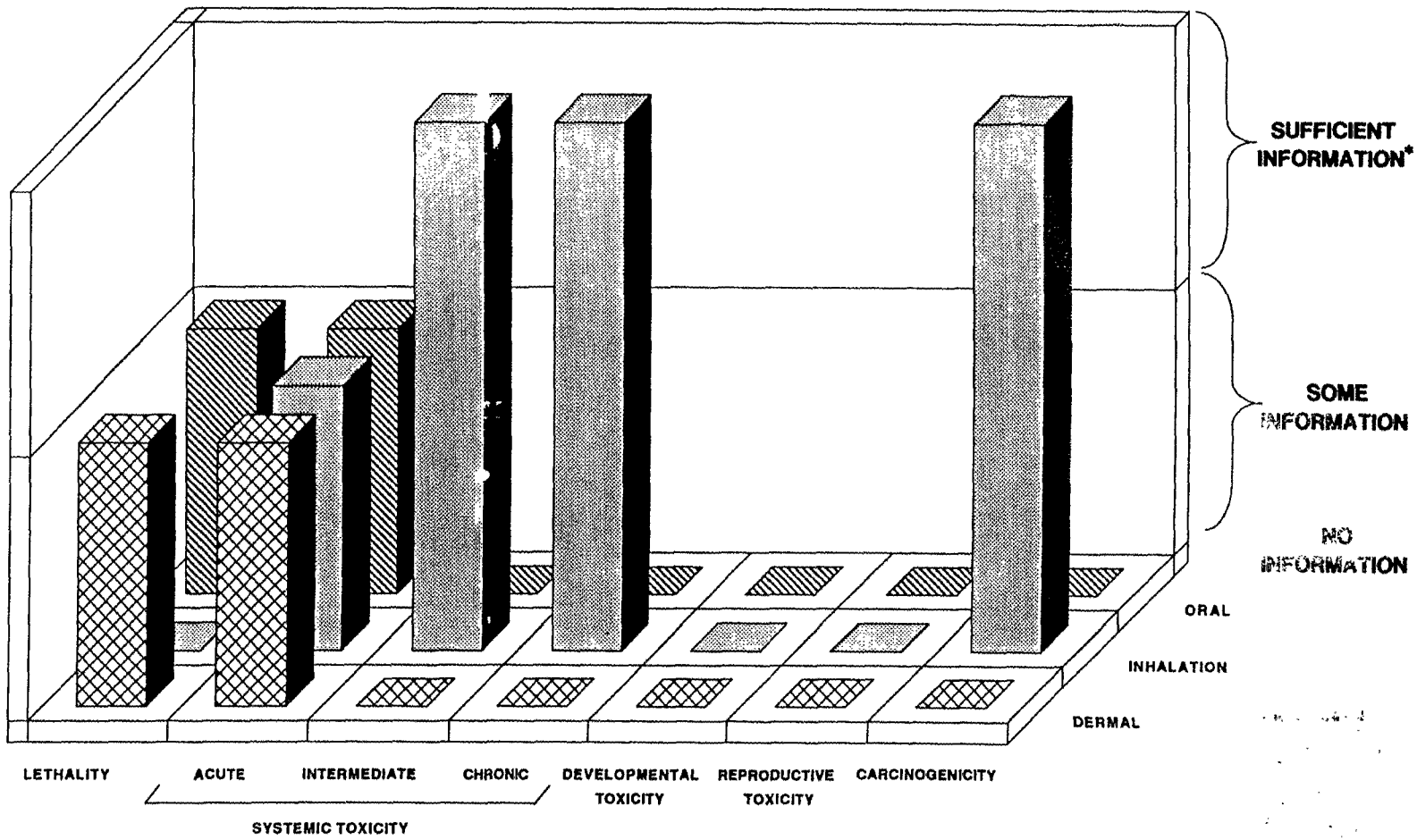
Bars of half height indicate that "some" information for the end point exists, but does not meet any of these criteria.

The absence of a column indicates that no information exists for that end point and route.

2.3.2.2 Description of highlights of graphs

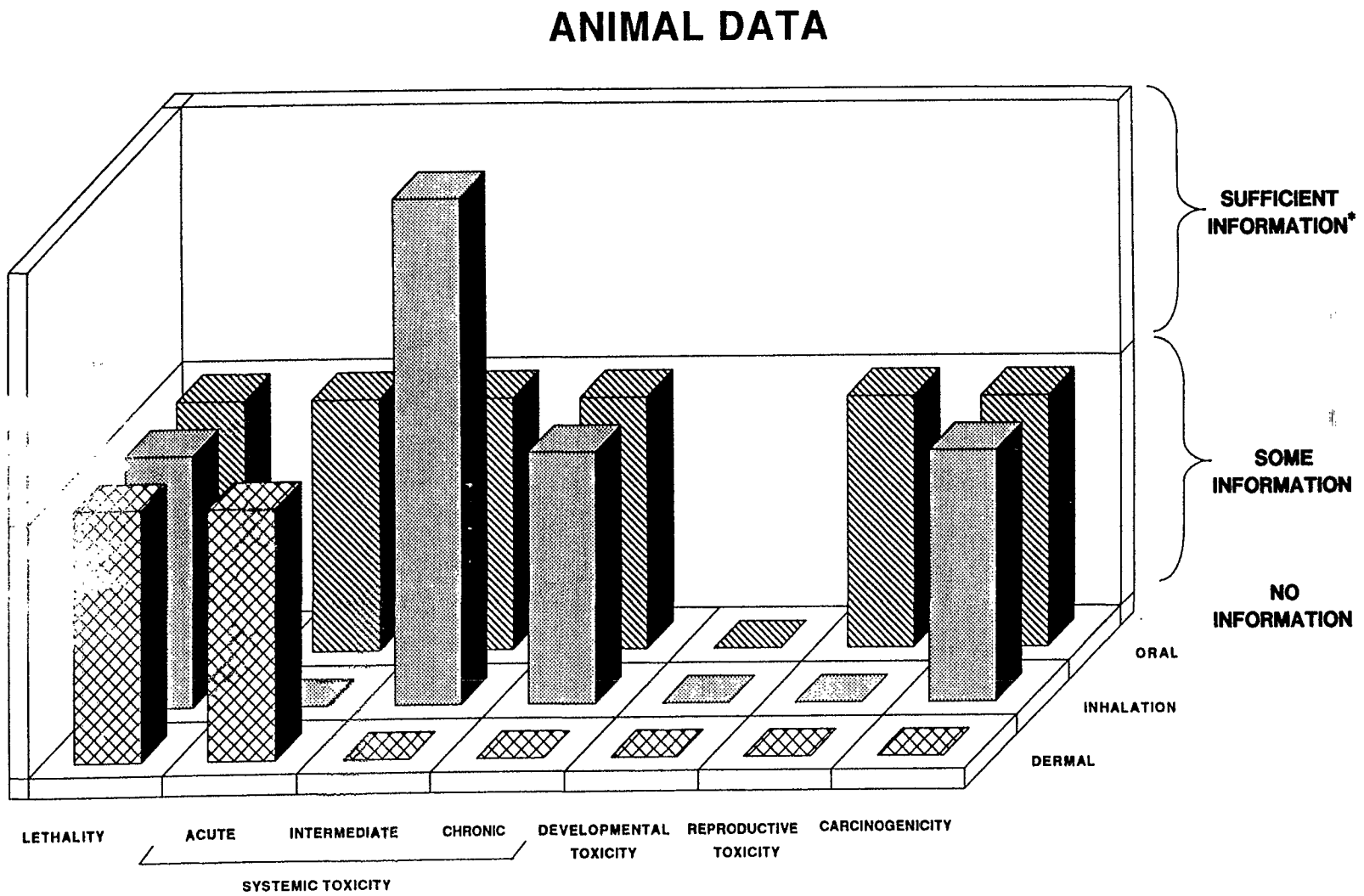
As indicated in Fig. 2.11, very few human effect/route/duration data are available. Adequate data are available from occupational exposure studies showing nasal mucosal and lung function effects attributed to chromium(VI). Because these effects can occur following intermediate or long-term exposure, the data are considered for both exposure durations. Numerous epidemiological studies associate occupational chromium exposure with respiratory cancer and constitute adequate evidence of carcinogenicity. Although the studies do not clearly implicate specific chromium compounds, they do implicate chromium(VI). The EPA (1984b, 1986c) concludes that chromium(VI) is the form responsible for the carcinogenic effect because of the evidence in humans and the results of animal studies, including implantation and injection studies.

Acute oral and dermal exposure of humans to chromium(VI) compounds has resulted in liver and kidney effects and death. Chromium(VI) compounds are powerful skin irritants, and at lower concentrations may are sensitizers. Following acute inhalation exposure, chromium(VI)



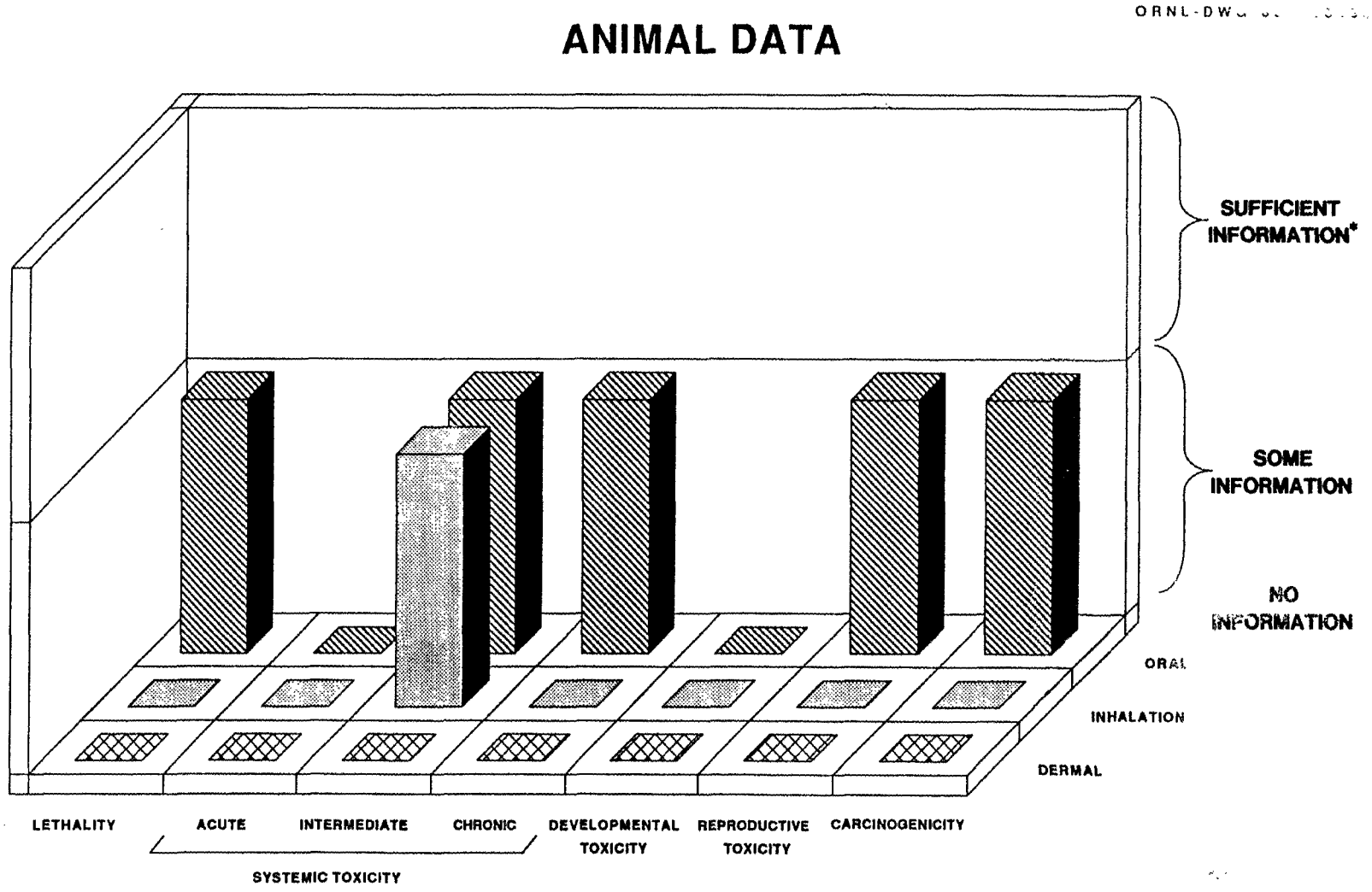
*Sufficient information exists to meet at least one of the criteria for cancer or noncancer end points.

Fig. 2.11. Availability of information on health effects of chromium(VI) and (III) (human data).



*Sufficient information exists to meet at least one of the criteria for cancer or noncancer end points.

Fig. 2.12. Availability of information on health effects of chromium(VI) (animal data).



*Sufficient information exists to meet at least one of the criteria for cancer or noncancer end points.

Fig. 2.13. Availability of information on health effects of chromium(III) (animal data).

compounds are respiratory tract irritants. Because adequate dose-response data for lethality and acute exposure to chromium compounds are not available, the bars for systemic toxicity for inhalation, oral, and dermal exposure and for lethality following oral and dermal exposure indicate that some data exist.

Figures 2.12 and 2.13 indicate that there are many gaps in the animal effect/route/duration data. Except for dermal LD_{50} values for chromium(VI) compounds, dermal data are lacking. Inhalation studies indicate effects on the respiratory tract and immune system, but NOAELs are not clearly defined. Although LOAELs and NOAELs for nervous system toxicity were available for acute and intermediate oral exposure to chromium(VI), other perhaps more sensitive end points for systemic toxicity were not examined. Thus the bars for systemic toxicity due to acute and intermediate oral exposure to chromium(VI) in Fig. 2.12 indicate that only some data exist. As shown in Fig. 2.13, some data are available for intermediate oral exposure to chromium(III) compounds. Developmental and reproductive toxicity studies conducted by parenteral routes have shown adverse effects with both chromium(III) and chromium(VI), but no adequate experiments have been conducted by inhalation, oral, or dermal routes. Results of inhalation cancer studies with chromium(VI) are suggestive but not definitive. Chronic oral studies of chromium(VI) and (III) toxicity do not identify effect levels for systemic toxicity and are not entirely adequate for investigating carcinogenicity.

2.3.2.3 Summary of relevant ongoing research

IARC (1987a) provides an extensive listing of ongoing research in cancer epidemiology. Included on this list are numerous ongoing studies of chromium-exposed populations. Primary investigators and populations under study in representative studies include studies of stainless steel welders in Denmark (S. K. Hansen) and in Sweden (B. Sjogren), studies of auto workers in France (S. Schraub) and the United States (A. H. Okun), a study of plating workers in Japan (K. Tsuchiya), a study of persons exposed to chromium(VI) compounds in chemical plants in Rumania (M. Eftimescu), a study of workers in the dichromate-producing industry in England (J. M. Davis), and a study of workers exposed to lead chromate paints in the United States (J. Walker).

EPA is sponsoring a study on the feasibility of determining the relative contributions of chromium(III) and chromium(VI) to total chromium exposure in Allied Chemical workers in Baltimore, Maryland, in order to study the relative carcinogenic potential of chromium(III) vs chromium(VI) (Gibb 1987; EPA 1986d, 1987c). The ongoing research will also attempt to refine the dose-response for carcinogenicity of chromium(VI) with the intention of replacing the Mancuso (1975) epidemiological study as the basis of the potency factor for chromium(VI).

The Metal Oxides and Ceramic Colors Committee of the Dry Color Manufacturers' Association (DCMA) is currently collecting toxicological data on chromium pigments (Robinson 1988). The data will be forwarded to ATSDR when it is available

2.3.3 Other Information Needed for Human Health Assessment

2.3.3.1 Pharmacokinetics and Mechanisms of Action

Chromium (III), an essential nutrient, plays a role in glucose, fat, and protein metabolism by potentiating insulin action. Because the potentiation of insulin action results in an improvement in glucose tolerance, the form of chromium(III) that is biologically active is called glucose tolerance factor (GTF). The structure of GTF has not been characterized fully, but GTF is known to consist of chromium(III) complexed with nicotinic acid, and possibly glycine, glutamic acid, and cysteine (Anderson 1981, Mertz 1975). Estimated safe and adequate daily dietary recommendations of chromium for adults are 50-200 μg/day based on the absence of signs of chromium deficiency in the U.S. population consuming 60 μg/day (Danford and Anderson 1985).

It is not yet clear which valence state of chromium is the ultimate carcinogen. In vitro studies of genotoxicity have found that chromium(VI) but not chromium(III) is genotoxic to intact cells, while chromium(III) but not chromium(VI) can react with isolated nuclei and purified DNA. After reviewing all the available data, Norseth (1986) states that genotoxic action of chromium(VI) in cells and animals may be dependent on the reduction of chromium(VI) inside the cell to generate reactive chromium species that form complexes with DNA. The reactive intermediate may be chromium(V) (Jennette 1982, Norseth 1986, Anderson 1981). Until the mechanism of action of chromium is clarified, Norseth (1986) believes that all chromium compounds [soluble, slightly soluble, and insoluble chromium(VI) compounds; particles of slightly soluble chromium(VI) and soluble chromium(III); and soluble chromium(III) bound to ligands] should be regarded as having a potential carcinogenic effect, with the differences in activity related to their biological availability.

Petrilli and DeFlora (1987) and Levy et al. (1987) disagree with Norseth (1987). Petrilli and DeFlora (1987) suggest that because some forms of chromium compounds are essential and because there are mechanisms that limit the bioavailability and attenuate the potential effects of chromium compounds in vivo, "chromium should not be regarded as a 'universal' carcinogen." Levy et al. (1987) believe that there is sufficient experimental evidence suggesting that chromium(III) compounds are not carcinogenic and good evidence to indicate that a limited number of chromium(VI) compounds (sparingly soluble) "represent a real carcinogenic risk to man."

The pharmacokinetics of chromium at the whole-animal level is relatively well studied. More work should be completed on how chromium compounds cross cell membranes so that toxicity of individual chromium compounds could be predicted by chemical properties.

There are several studies in the areas of chromium essentiality and absorption in progress. R. A. Anderson of Agricultural Research Service is conducting a study sponsored by the U.S. Department of Agriculture to more clearly define the nutritional and biochemical roles of chromium in humans (NTIS 1987). H. M. Goff of the University of Iowa is working on the chemical structure and biological activity of GTF under the sponsorship of the U.S. Department of Agriculture, Competitive Research

Grant Office. Gastrointestinal tract absorption of chromium is under study by P. E. Johnson at Agricultural Research Service and by F. X. Pi-Sunyer at St. Luke's Roosevelt Hospital Center; both of these studies are also sponsored by the U.S. Department of Agriculture (NTIS 1987).

2.3.3.2 Monitoring of human biological samples

Measurements of chromium in urine and blood are useful methods for monitoring human occupational exposure to chromium compounds. Serum levels reflect exposures to chromium(III), chromium(VI), and chromium metal, while urine and RBC chromium levels reflect exposure to chromium(VI). In contrast to monitoring human biological samples for occupational exposure, the monitoring of human biological samples for low-level environmental exposure may not be useful because serum chromium levels change only in cases of extreme exposure or deficiency.

The measurement of low levels of chromium in blood and urine is difficult; using "normal" levels of chromium to assess deficiency is not yet possible (Danford and Anderson 1985).

No ongoing studies concerning monitoring of human biological samples were located, although the monitoring of human body fluids to assess mobilization of chromium from orthopedic prostheses appears to be a subject of current research and publication (Sunderman et al. 1987).

2.3.3.3 Environmental considerations

There is no major gap in the understanding of the different routes of exposure of chromium into human bodies from environmental media (Sect. 7 on Potential for Human Exposure).

In one ongoing study by C. Blincoe of the University of Nevada, the bioavailability of chromium from various foods is being studied under the sponsorship of the U.S. Department of Agriculture (NTIS 1987).

Although limited data regarding the physical fate processes of chromium in different environmental media and its transport from one media to another are available, data on its chemical fate are almost nonexistent (Sect. 6.3, Releases to the Environment). Even the nature of chemical species present in a medium is not known with certainty. Therefore, significant uncertainties are expected in the estimated data on its fate and transport. In an ongoing research program conducted by North Texas State University under the sponsorship of the Industrial Health Foundation, the fate of both chromium(III) and chromium(VI) in aquatic surface and subsurface conditions is being studied. The effect of E_h (electrode potential or redox potential) and pH on the fate of chromium(III) and chromium(VI) is being studied in this yet unpublished study (Loewengast 1988).

Limited speculative data exist on the interactions of chromium in the environment (Sect. 6.3, Releases to the Environment). As a result, data gaps exist in this area.

6. ENVIRONMENTAL FATE

6.1 OVERVIEW

Chromium occurs naturally in the earth's crust. Continental dust is the main source of natural chromium present in the environment; however, chromium is released to the environment in much larger amounts as a result of human activities. Of the total atmospheric chromium emissions in the United States, approximately 64.1% is due to chromium(III) from coal and oil combustion and steel production, and 31.6% is due to chromium(VI) from chemical manufacture, primary metal production, chrome plating, and cooling towers. Wastewaters from electroplating, leather tanning, and textile industries release relatively large amounts of chromium in surface waters. Solid wastes produced during roasting and leaching processes of chromate manufacture, when disposed of improperly in landfill sites, can be sources of chromium emission. Copying machine toner powder waste, when disposed of without containment, can be a source of chromium emission. Chromium released to the environment from combustion processes and metallurgical industries is probably present mainly as Cr_2O_3. On the other hand, chromium released to the environment from chromate manufacturing and user sites largely contains bioavailable chromium(VI). Chromium is primarily removed from the atmosphere by fallout and precipitation. The residence time of chromium in the atmosphere is expected to be <10 days. The residence times of chromium in water and soil may be several years.

6.2 RELEASES TO THE ENVIRONMENT

Chromium is released into the atmosphere mainly by stationary point sources. Stationary point sources that release chromium in the atmosphere are industrial, commercial, and residential fuel combustion, primarily the combustion of natural gas, oil, and coal. Other important stationary point sources of chromium emission to the atmosphere are metal industries. It has been estimated that ~12,000 to 18,000 tons of chromium was emitted in the atmosphere from U.S. sources in 1970. These older estimates indicated that emission from the metal industry ranges from 35 to 86% of the total and emission from fuel combustion ranges from 11 to 65% of the total. More recent estimates (1976 and 1980) of atmospheric chromium emission in the Los Angeles, California, and Houston, Texas, areas indicated that emission from stationary fuel combustion ranges from 46 to 47% of the total and emission from the metal industry ranges from 26 to 45% of the total. The primary stationary nonpoint source of chromium emission in the atmosphere is fugitive emission from road dusts. Other potentially small sources of atmospheric chromium emission are cement-producing plants (cement contains chromium), the wearing of asbestos brake linings containing chromium, incineration of municipal refuse and sewage sludge, and

emission from chromium-based automotive catalytic converters. Emissions from cooling towers that use chromate chemicals as rust inhibitors are also sources of atmospheric chromium (Cass and McRae 1986, EPA 1984a, Fishbein 1981). The estimated atmospheric chromium emission factors for almost all sources are given in an EPA report (EPA 1984c). Given the chromium consumption or production volumes for each of these sources, it is possible to estimate the total atmospheric chromium emission from these individual sources. A recent EPA report (EPA 1987) estimates that ~2,840 metric tons of total chromium is emitted per year in the atmosphere in the United States. Table 6.1 shows the sources, estimates of yearly emissions, and percentage of hexavalent chromium in the total atmospheric chromium emissions in the United States as reported by EPA (1987a). Another potential source of chromium emission is the very fine powders used as toners in copying machines. The powders may be emitted in offices during copying machine maintenance and servicing or during disposal without containment both in offices and garbage dumps. It is reported that toner powder may contain more than 0.1% total chromium and about 0.003% chromium(VI). The reported average particle size of the toner powders of 10 μm indicates that at least part of these particles are respirable (Bond 1987).

Surface waters and groundwaters contaminated with wastewaters from electroplating operations, leather tanning, and textile manufacturing or through deposition of airborne chromium may also be nonpoint sources of chromium exposure. Similarly, solid wastes resulting from the roasting and leaching steps of chromate manufacture or from municipal incineration, when disposed of improperly in landfill sites, may be sources of nonpoint chromium exposure (EPA 1984a).

6.3 ENVIRONMENTAL FATE

Chromium is primarily removed from the atmosphere by fallout and precipitation. Atmospheric chromium removed by physical processes predominantly enters surface water or soil; however, prior to their removal, chromium particles of aerodynamic diameter <20 μm may remain airborne for long periods and may be transported long distances. Roughly half of the total chromium in the ferrochrome smelter dust may be bioavailable. About 40% of the bioavailable part may exist as chromium(VI), mostly in the form of $Cr_2O_7^{-2}$ or CrO_4^{-2}. About 75% of the total chromium(VI) particles have diameters <10 μm. The remainder of chromium particles are primarily present as insoluble Cr_2O_3 particles of diameter >10 μm. There is no evidence in the literature to indicate that chromium particles are transported from the troposphere to the stratosphere. This is not surprising since, by analogy with the residence time of atmospheric copper, the residence time of atmospheric chromium is expected to be <10 days (Nriagu 1979, EPA 1984a, Pacyna and Ottar 1985, Cox et al. 1985). In the atmosphere, chromium(VI) may be reduced to chromium(III) at a significant rate by vanadium (V^{2+}, V^{3+}, and VO_2^+), Fe^{2+}, HSO_3^-, and As^{3+} (EPA [illegible]).

Because there are no known chromium compounds that can volatilize from water, transport of chromium from land to the atmosphere is not likely other than by transport by windblown sea sprays. Most of the chromium(III) is eventually expected to precipitate in sediments. Small amounts of chromium(III) may remain in solution as soluble complexes.

Table [illegible] nates of U.S. atmospheric chromium emissions

Source category	Number of sources	Estimated chromium emissions (metric tons/year)	Estimated chromium(VI) (%)
Combustion of coal and oil	Many	1,723	0.2
Chromium chemical manufacturing	2	18	67
Chemical manufacturing cooling towers	2,039	43	100
Petroleum refining cooling towers	475	32	100
Speciality/steel production	18	103	2.2
Primary metal cooling towers	224	8	100
Chrome plating	4,000	700	≃100
Comfort cooling towers	38,000	7.2–206	100
Textile manufacturing cooling towers	51	0.1	100
Refractory production	10	24	1.3
Ferrochromium production	2	16	5.4
Sewage sludge incineration	133	13	<0.1
Tobacco cooling towers	16	0.2	100
Utility industry cooling towers	6	1.0	100
Chrome ore refining	6	4.8	<0.1
Tire and rubber cooling towers	40	0.2	100
Glass manufacturing cooling towers	3	0.01	100
Cement production	145	3	0.2
Municipal refuse incineration	95	2.5	0.3
NATIONWIDE TOTAL		2,700–2,900	

Source: EPA 1987a.

Chromium(VI) will predominantly be present in soluble form. These soluble forms of chromium may be stable enough to undergo intramedia transport; however, chromium(VI) will eventually be reduced to chromium(III) by organic matters present in water. It has been estimated that the residence time of chromium in lake water is in the range of 4.6 to 18 years. The oxidation of chromium(III) to chromium(VI) by solid MnO_2 in water remained unaffected by dissolved oxygen, and the process was very slow in slightly acidic (pH 6) and basic solutions (pH 11) because of the low solubility of the $Cr(OH)_3$ that is formed at these pHs (Eary and Rai 1987). Therefore, this oxidation process would not be significant in most natural water where the pH range is usually between 6 and 9. Similar oxidation of chromium(III) to chromium(VI) in the atmosphere is unlikely (EPA 1987a).

It was reported that only small amounts of chromium(III) in leachates from some coal fly ash disposal sites having pH <6 would be converted to chromium(VI) by reaction with solid MnO_2 because of the short residence time in soil. The converted chromium(VI) in the leachate would encounter reducing conditions in the underlying soil where chromium(VI) would be reduced to chromium(III) and possibly precipitate as $Cr(OH)_2$ (Eary and Rai 1987). The oxidation of chromium(III) to chromium(VI) during chlorination of water was highest in the pH range 5.5 to 6.0. However, the process would occur rarely during chlorination of drinking water because of low concentrations of chromium(III) in these waters and the presence of naturally occurring organics that may protect chromium(III) from oxidation, either by forming strong complexes with chromium(III) or by acting as a reducing agent to free available chlorine. In chromium(III)-contaminated wastewaters having pH ranges of 5 to 7, chlorination may readily convert chromium(III) to chromium(VI) in the absence of chromium(III) complexing and free chlorine reducing agents (EPA 1988a). The bioconcentration factor for chromium(VI) in rainbow trout (*Salmo gairdneri*) is ~1. In bottom-feeder species, such as the oyster (*Crassostrea virginica*), blue mussel (*Mytilus edulis*), and soft shell clam (*Mya arenaria*), the BCF values for chromium(III) and chromium(VI) may range from 86 to 192 (EPA 1980, 1984a; Schmidt and Andren 1984; Fishbein 1981).

Chromium probably occurs as insoluble $Cr_2O_3 \cdot nH_2O$ in soil, since the organic matter in soil is expected to convert soluble chromate [chromium(VI] to insoluble Cr_2O_3. Chromium in soil may be transported to the atmosphere in the form of aerosol, while runoff and leaching may transport chromium from soil to surface waters and groundwaters. Runoff could remove both soluble and bulk precipitate with final deposition on either a different land area or a water body. Flooding of soils and the subsequent anaerobic decomposition of plant matters may increase mobilization of chromium in soils due to formation of soluble complexes. The half-life of chromium in soils may be several years (EPA 1984a, 1985c).

REFERENCE # 30

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

New Mexico Bureau of Mines & Mineral Resources

Open-File Report 90

Descriptions of Sections Measured for Hydrogeologic Study of the San Juan Basin, Northwest New Mexico

William J. Stone, Hydrogeologist

June 1979

MK3E - 2, HAYSTACK MOUNTAIN (Bluewater 7½' Quad.). West- and east-facing slopes of mesa; S½, SW¼, sec. 11 to C, W½, sec. 13, T13N, R11W and NW¼, sec. 18, T13N, R10W, McKinley County; measured by Robert C. Brod, 6 July 1977.

Unit	Lithology	Thickness: m(ft)
	DAKOTA SANDSTONE	
21	SANDSTONE--like unit 19 below; SHALE lenses up to 2 dcm thick in lower 4 m; caps mesa, top has pitted surface.	33.5 (110.6)
20	CARBONACEOUS SHALE AND COAL--like unit 18 below.	1.7 (5.6)
19	SANDSTONE--light brown (5 YR 6/4) weathered, light brown (5 YR 5/6) fresh; beds thin - medium, regular, even with thin, planar, discontinuous, parallel laminae; small- and large-scale, tangential, low-angle, solitary, trough cross bedding; grains fine, well sorted, subangular - subrounded; composed mainly of quartz, trace of silt matrix, not calcareous; contact with above sharp.	1.9 (6.3)
	MORRISON FORMATION BRUSHY BASIN MEMBER	
18	CARBONACEOUS SHALE AND COAL--color not recorded, iron stained, organic debris in partings.	4.0 (13.2)
17	SHALE--light greenish gray (5 GY 8/1) mottled with pale yellowish orange (10 YR 8/6) weathered and fresh; clay rich.	4.4 (14.5)
16	SILTSTONE, SANDSTONE, AND SHALE--color not recorded; beds medium, regular, even mostly massive, some thin, wavy, discontinuous, convergent laminae; sand grains fine, subrounded; composed of quartz and unidentified red and green grains, silt matrix, not calcareous; SHALE like unit 15 below occurs as 1 dcm-thick lens near middle; contact with above sharp.	4.8 (15.8)
15	SHALE--grayish yellow green (5 GY 7/2) weathered and fresh, red lenses at base; mostly covered; contact with above sharp.	13.3 (43.9)

MORRISON FORMATION
WESTWATER CANYON MEMBER

14	CONGLOMERATIC SANDSTONE--pale red (10 R 6/2) weathered, pale reddish brown (10 R 5/4) fresh; beds medium, irregular, uneven with medium, curved, discontinuous, parallel laminae; large-scale, tangential, mostly low-angle (a few high-angle), solitary, trough cross bedding; grains silt - gravel (up to 2 cm in diameter), very poorly sorted, subrounded - subangular; composed mainly of quartz with about 7% feldspar, silt and clay matrix, calcareous; gravel consists of chert, quartz, and feldspar, occurs throughout but especially abundant in lower 5 m; clay blebs up to 1 dcm long (rip-up) throughout; contact with above sharp.	12.8 (42.2)
13	SHALE--dark reddish brown (10 R 3/4), light brownish gray (5 YR 6/1) and yellowish gray (5 Y 7/2) weathered and fresh; contact with above sharp.	6.1 (20.1)
12	SANDSTONE--like unit 10 below; contact with above sharp.	19.2 (63.4)
11	SANDSTONE--like unit 10 below; contact with above gradational.	4.8 (15.8)
10	SANDSTONE--pale red (10 R 6/2) weathered, pale reddish brown (10 R 5/4) fresh; beds thin - medium, irregular, uneven with thin, planar and curved, discontinuous, convergent laminae; small-scale, tangential, low-angle, solitary, wedge-planar(?) cross bedding; grains fine - coarse, poorly sorted, rounded; composed mainly of quartz, silt and clay matrix, calcareous, some iron cement.	4.8 (15.8)

MORRISON FORMATION
RECAPTURE MEMBER

9	SANDY SILTSTONE--light greenish gray (5 GY 8/1) weathered and fresh; beds thin, irregular, uneven with thin, curved, discontinuous, convergent laminae; large-scale, tangentila, low-angle, solitary, wedge-planar cross bedding; grains silt - fine sand, very poorly sorted, subangular; composed of quartz, silt matrix, calcareous; lenses (up to 3 m thick) of dark reddish	54.4 (179.5)

brown (10 R 3/4) SHALE near upper and lower contacts; very friable, poorly exposed; contact with above gradational.

COW SPRINGS SANDSTONE

8	SANDSTONE--moderate orange pink (10 R 7/4) - pale red (10 R 6/2) weathered, moderate reddish orange (10 R 6/6) fresh; beds thin - medium, irregular, uneven with medium (a few thin), wavy, dis ontinuous, convergent laminae; grains fine, moderately sorted, subangular; composed mainly of quartz, not calcareous, iron cemented(?).	6.4 (21.1)

BLUFF SANDSTONE

7	SANDSTONE--moderate orange pink (5 YR 8/4) weathered, moderate reddish orange (10 R 6/6) fresh; beds medium - thick, regular, even with thin - medium, planar, discontinuous, mostly parallel laminae; small- and large-scale, tangential, high- and low-scale, grouped, tabular-planar cross bedding; grains silt - fine sand, poorly sorted, angular; composed mainly of quartz with 5 - 10% unidentified black grains; silt and minor clay matrix, not calcareous; contact with above difficult, gradational(?).	42.2 (139.3)

SUMMERVILLE FORMATION

6	INTERBEDDED SANDSTONE AND SILTSTONE--SANDSTONE grayish orange pink (10 R 8/2) weathered, white (N9) - very light gray (N8) fresh; beds thick - very thick, regular, uneven with thin, planar and curved, discontinuous, parallel laminae; small- and large-scale, tangential, low-angle, grouped, tabular-planar (some wedge-planar?) cross bedding; grains fine, well sorted, subangular; composed mainly of quartz and minor unidenfified black grains, clay matrix, not calcareous; SILTSTONE dark reddish brown (10 R 3/4) weathered and fresh; beds medium with vague internal structures; well indurated but not calcareous, possibly cemented by iron or silica(?); contact with above sharp.	34.6 (114.2)

5	COVERED INTERVAL	25.3 (83.5)

TODILTO LIMESTONE

4	LIMESTONE--very light gray (N8) weathered, medium light gray (N6) fresh; beds thin, regular, uneven (thicken toward top) with very thin - thin, planar, discontinuous, parallel laminae; small-scale, tangential, low-angle, solitary, trough cross bedding; microcrystalline; grayish red (5 R 4/2) SHALE occurs in lower 1 dcm, as interbeds with LIMESTONE, these decrease in abundance toward top but present throughout; dip at top of this unit is 3°, N45° - 50°E; Abney set accordingly for units above.	4.1 (13.5)

ENTRADA SANDSTONE
UPPER SANDSTONE MEMBER

3	SILTSTONE--moderate orange pink (5 YR 8/4) weathered and fresh; beds thin(?), irregular, uneven with thin, curved, discontinuous, convergent laminae; small-scale, tangential, low-angle, solitary, tabular-planar cross bedding, poorly exposed; grains silt - fine sand, poorly sorted, subangular; composed of quartz, no matrix(?), calcareous; contact with above sharp.	5.0 (16.5)
2	SANDSTONE--moderate orange pink (10 R 7/4) weathered and fresh; beds medium - very thick, irregular, uneven with thin, curved, continuous, parallel laminae; conspicuous large-scale, tangential, high-angle, grouped, trough cross bedding; grains mostly fine, poorly sorted, subrounded - rounded (some medium - coarse, well sorted, subangular sand scattered throughout most beds); composed mainly of quartz with trace of unidentified black grains and clay, clay and minor silt matrix, calcareous; contact with above sharp.	38.4 (126.7)

ENTRADA SANDSTONE
MIDDLE SILTSTONE MEMBER

1	SILTSTONE--moderate reddish orange (10 R 6/6) weathered, moderate reddish	3.0 (9.9)

brown (10 R 4/6) fresh; beds thick, irregular, uneven, mostly massive, some lenses with thin laminae locally; grains silt and minor fine sand, poorly sorted, angular; composed mainly of quartz, calcareous; small (< 1 cm in diameter) white blebs throughout, same lithology as surrounding rock; small (< .5 cm) crystalline nodules (gypsum?) common, especially in lower half; incomplete exposure; contact with above sharp; dips of 3° N70^{O} - 85°E measured in Entrada; Abney set accordingly; tried to measure in a N77^{O}E direction.

Total section thickness = 324.7 (1071.4)

Base is base of exposed middle Entrada, west of Haystack Mountain. Measured units 1 through 4 in sec . 11, T13N, R11W, units 5 through 8 in sec. 13, T13N, R11W, and remainder in sec. 18, T13N, R10W.

REFERENCE # 31

NAVAJO SUPERFUND OFFICE

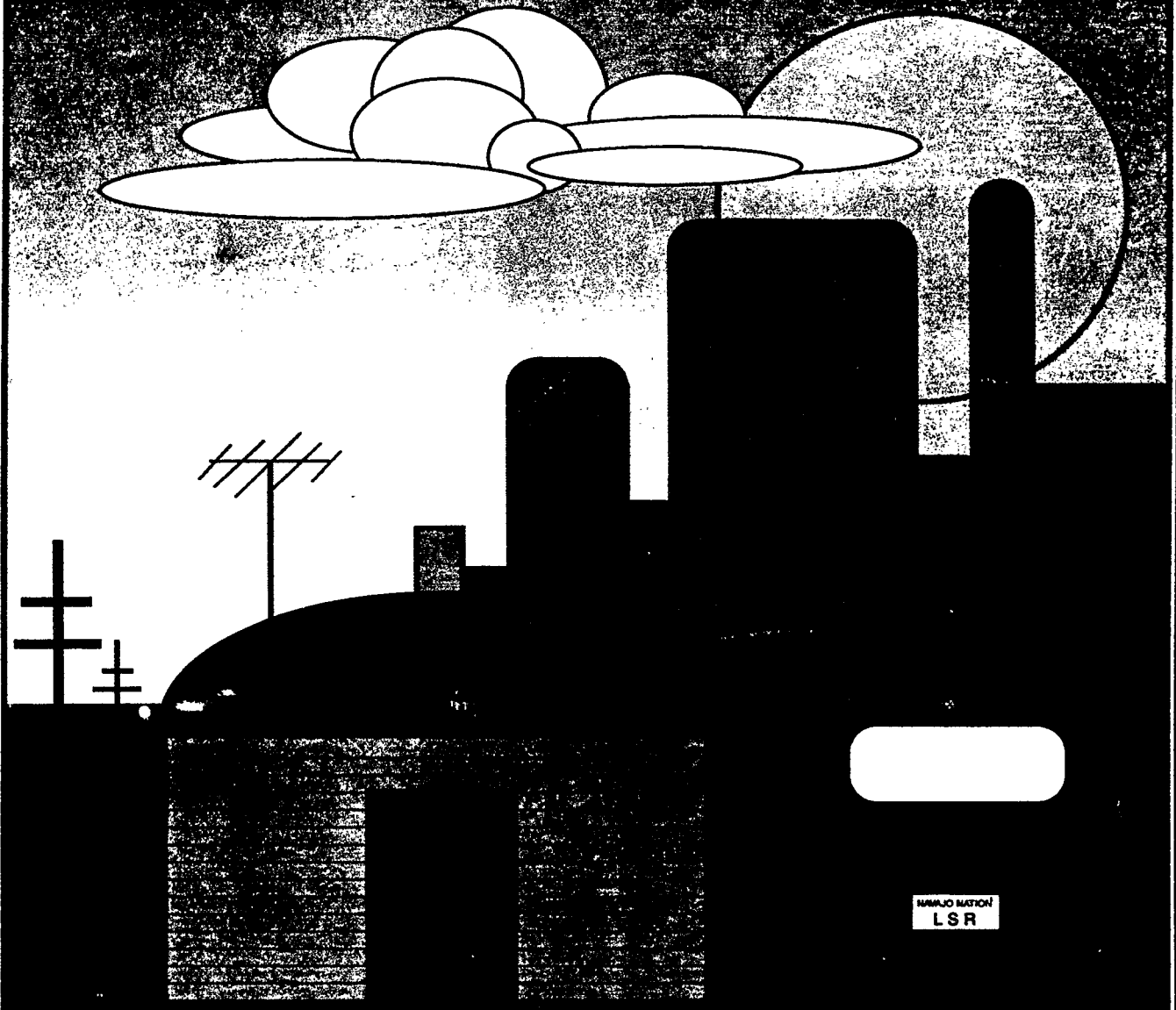
BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

NAVAJO NATION

FAX 88

$5.00



A Statistical Abstract

September 1988

SUMMARY OF 1980 CENSUS NAVAJO RESERVATION DATA ON SELECTED SUBJECTS

MEMBERSHIP

96.7% of Indian persons on the reservation were enrolled members of the Tribe.

LONG-TERM RESIDENCY

81.9% of Indian persons 1 year old and older on the reservation had always lived on the reservation, never off-reservation.

MEDIAN AGE

18.7 Years

INCOME (Per Capita)

1970 Census	1980 Census
$776	$2,414

INCOME (Median Family)

1970 Census	1980 Census
$3,084	$9,079

POVERTY STATUS (% Persons)

1970 Census	1980 Census
64.5	49.7

POVERTY STATUS (% Families)

1970 Census	1980 Census
62.1	47.3

25.8% of Indian households on reservation received food stamps in 1979.
38.0% of Indian persons 15 & older received financial assistance in 1979.

FAMILY CHARACTERISTICS

5.14 Persons per family
73.9% of Indian families on the reservaton had 1 or more minor children,
40.5% had 1 or more children under 6 years of age.
24.3% of Indian families had female heads, with no husbands present.

EDUCATION

50.9% of those 5-19 years old were enrolled in school.
24.3% of those 16-19 years old were not enrolled and not HS graduates.
37.4% of those 25 years & older completed less than 5 years of school;
34.1% were high school graduates.

HEALTH CARE

83.6% of Indian persons received health care in previous year.
87.5% of these persons revceived health care at IHS facilities.
05.9% paid for their own care.
03.0% had private health insurance.
00.9% received medicaid or medicare benefits.
39.8% were able to get a health facility within 30 minutes.
28.4% required 30-60 minutes to reach a health care facility.
31.8% required more than 1 hour to reach a health care facility.

SUMMARY OF 1980 CENSUS NAVAJO RESERVATION DATA ON SELECTED SUBJECTS (Continued)

LABOR FORCE

58.3% of Indian persons 16 years & older were in labor force in 1979.
49.9% of labor force pop had a job for pay or were in business or farming.
23.9% of labor force pop received unemployment comp during 1979.
28.2% of labor force pop were unemployed 15 or more weeks in 1979.
16.0% of Indian families on reservation had on workers in 1979.
29.6% of Indian persons 16 years & older on reservation never worked.

HOUSING

53.8% of Indian homes lacked complete plumbing for exclusive use.
50.6% of Indian homes were without piped water.
43.8% of Indian homes had water source more than 100 yards away.
49.5% of Indian homes had an oddhouse or privy.
76.8% of Indian homes lacked central heating systems.
45.8% of Indian homes lacked electrical lighting.
46.9% of Indian homes had no refrigerators.
79.4% of Indian homes had no telephones.
65.0% of Indian homes had more than 1 occupant per room.

EMPLOYMENT BY INDUSTRY (16 years & older working pop in 1980)

38.1% Services Industry.
18.0% Public Administration
08.9% Construction
07.5% Manufacturing
07.5% Transportation, Communications, & Utilities
07.3% Mining
06.8% Retail Trade

OCCUPATIONS (of working pop in 1980)

24.7% Technical, Sales, & Admin Support
20.2% Service
19.4% Operators, Fabricators, & Laborers
14.3% Precision Production, Craft, and Repair
13.0% Managerial and Professional Specialities
05.6% Traditional Indian (Weaving, Jewelry, Healing, etc.)

SOURCE: Abtracts from 1980 Census; Division of Community Development

REFERENCE # 33

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

Uncontrolled Hazardous Waste Site Ranking System

A Users Manual

(HW-10)

Originally Published in
the July 16, 1982, *Federal Register*

United States
Environmental Protection
Agency

1984

REFERENCE # 34

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

CONTACT REPORT

Meeting: ( ) Telephone: ( ) Other: (X)
DERIVED MATERIAL

CONTACT LOCATION: NAVAJO SUPERFUND OFFICE

ADDRESS: 53 CREST DRIVE, ST. MICHAELS, AZ 86511

PERSON CONTACTED
AND TITLE : PATRICK ANTONIO, STAFF HYDROGEOLOGIST, NSO

PHONE: (602) 871 - 7332

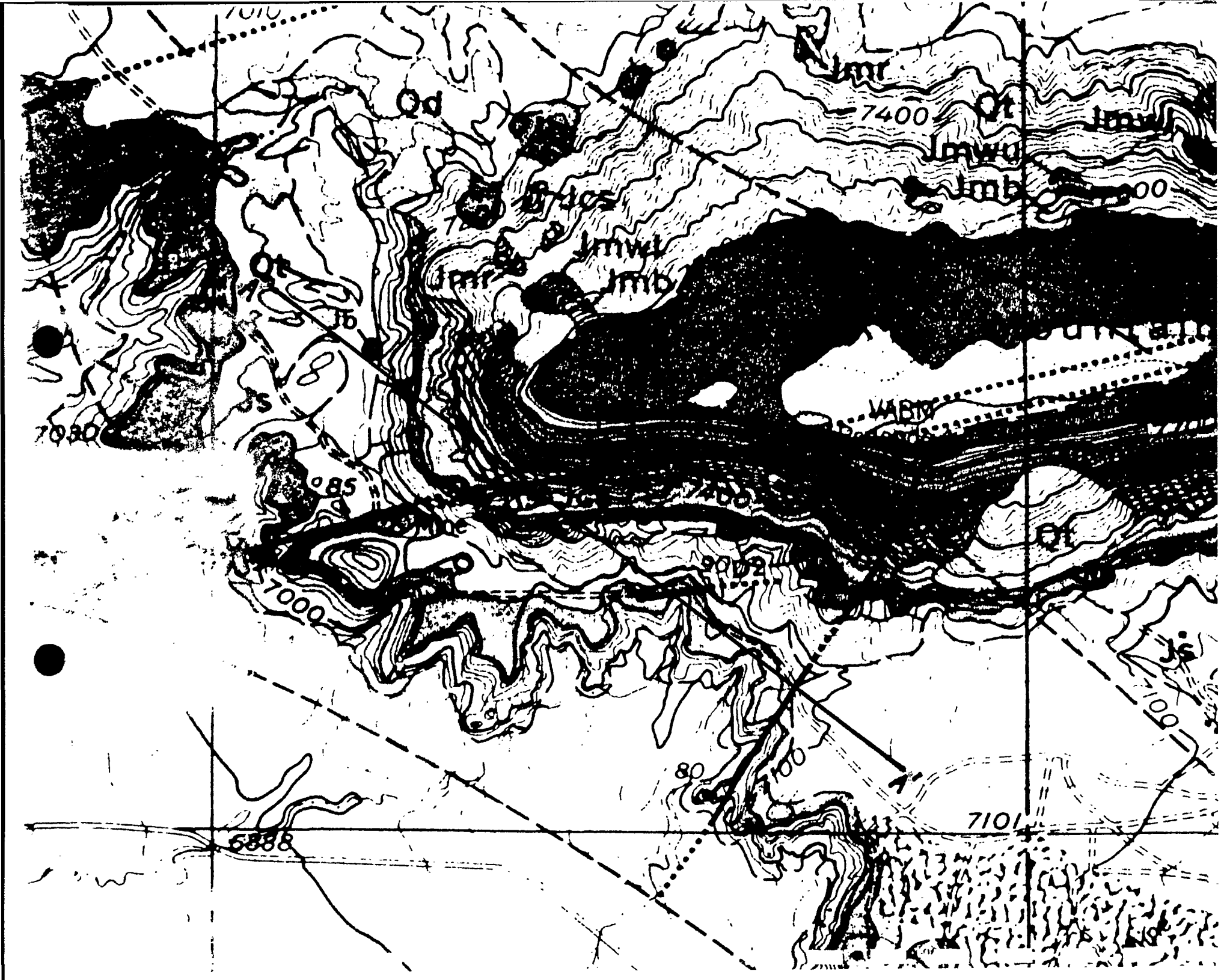
FROM (Contacting
Party) : PATRICK MOLLOY, HEALTH PHYSICIST, NSO

DATE : MAY 29,1990

SUBJECT: INFLUENCE OF FAULTS IN THE HAYSTACK AREA ON GROUNDWATER HYDROGEOLOGY

CONTACT SUMMARY REPORT:

SEE ATTACHED FACSIMILES



Jmr
7400
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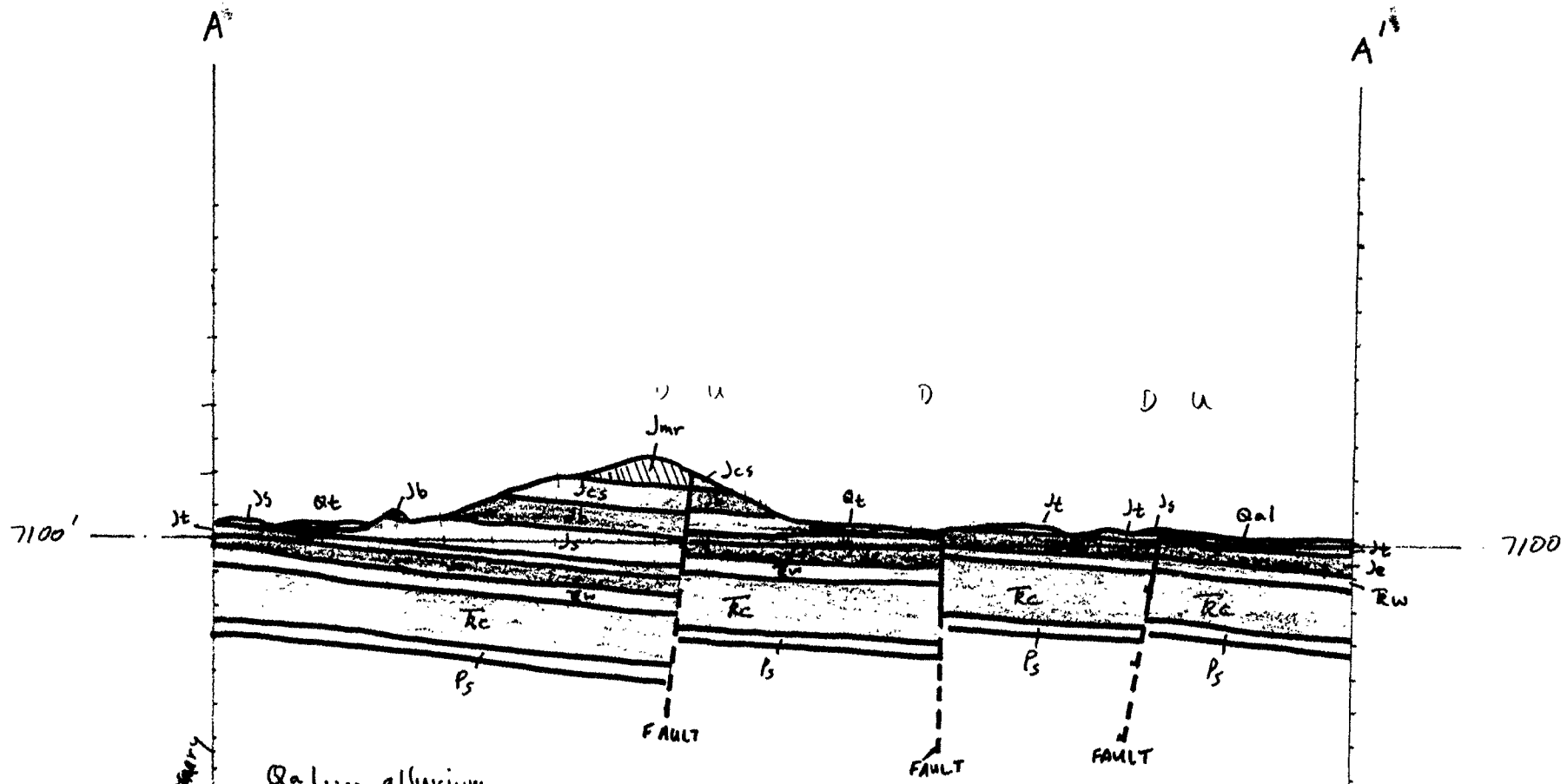

Quaternary
Qal..... alluvium
Qt..... talus/landslide blocks

Jurassic
Jmr.... Morrison Recapture mbr.
Jcs.... Cow Springs SS
Jb..... Bluff SS
Js..... Summerville fm.
Jt..... Todilto LS
Je..... Entrada SS aquifer

Triassic
Rw..... Wingate SS
Rc..... Chinle fm aquifer

Permian
Ps..... San Andres LS aquifer

Potential regional ground water flow direction

INFLUENCE OF FAULTS ON GROUND WATER

Faulting of sedimentary rocks can create vary complex hydrogeologic systems, in which determination of the location of recharge and discharge zones and flow systems is confounded.

Fault zones can act as either barriers to ground water flow or as ground water conduits, depending on the nature of the material in the fault zone----space within the fault surfaces.

If the fault zone consists of finely ground rock and clay, the material may have a very low hydraulic conductivity----meaning water will have difficulty moving through the fault zone.

In consolidated rocks (sandstones, limestones, etc.), faults are more often ground water conduits. Broken and brecciated rock in the fault zone may have a high porosity and hydraulic conductivity ----meaning water will move freely through the fault zone.

The presence of faulting may have no significant effect on hydrogeology. Faults with a very small movement will ususally have the same hydraulic characteristics as the parent rock. Brecciated fault zones are potential conduits for movement of hydrothermal solutions, and faults can become mineralized possibly sealing the fault and losing the original high conductivity.

OPINION (for Tom Morrissey): Since the stratigraphy is composed of mostly of sedimentary limestone and sandstone formations, no drastic influences (barriers) on ground flow is expected. The only item of note is that recharge from infiltration through above formations or from surface outcrops may be slightly hindered upon contact with a fault, espeically if the rocks on each side of the fault are of different formations. Extra time will be needed for ground water t_ flow through a less permeable formation or for ground water to lower to a more suitable permeable formation.

If there is sufficient artesian pressure in the aquifer and the fault zone has favorable conductivity, ground water may rise up through the fault and emerge as a spring or seep at surface level. Just the opposite, faults can also transmit contamination to lower, previously uncontaminated aquifers.

A fault would have more of an influence if a well was drawing right near a fault zone.

Barbara Reed 6/25/90
6/25
→ 6H-MA

THE NAVAJO NATION

LEONARD HASKIE
INTERIM PRESIDENT
NAVAJO NATION

IRVING BILLY
INTERIM VICE PRESIDENT
NAVAJO NATION

June 11,1990

Mr. Mark Satterwhite
Indian Superfund Coordinator
US-EPA,Region-VI
1445 Ross Avenue
Dallas, Texas 75202-2733

Dear Mr. Satterwhite:

Find enclosed Addenda to the Preliminary Assessment Package for the Navajo-Brown Vandever Uranium Mine.

Additional information, pertinent to the site and Bioaccumulation of Radiospecies has become available(Reference#37). More reliable calculations regarding the area Radon burden have been produced(mine spoils calculations Addenda). Dr. Gaurav Rajen(Senior Environmental Engineer) and Patrick Molloy worked on the calculations. References#35 and #36 are included in support of the calculations. Reference#38 pertains to Radon levels obtained during an Indian Health Service Radon survey in the area of residences approximately two miles from the site. It is intended that the levels be considered as background parameters for the area.

If you have any questions regarding this material, please contact me, Dr. Rajen or Patrick Molloy at (602) 871-7329 or -7332. Thank you.

Sincerely,

Gaurav Rajen, for Clara Bia
Clara Bia
Executive Director
Navajo Superfund Office

Enclosures

CB/pm

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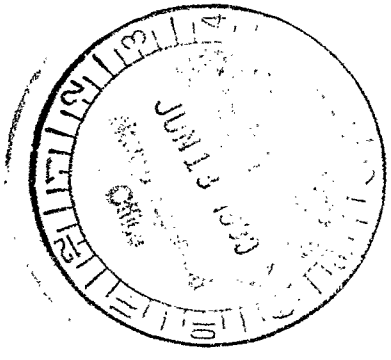
NAVAJO - BROWN VANDEVER URANIUM
MINE SPOILS CALCULATIONS ADDENDA
(PLEASE ATTACH TO REFERENCE # 4)



NAVAJO SUPERFUND OFFICE

NAVAJO - BROWN VAN-
DEVER URANIUM MINE

JUNE,'90 P. MOLLOY

NOTES ADDED IN PROOFS FOR THE NAVAJO - BROWN VANDEVER URANIUM MINE PRELIMINARY ASSESSMENT

1. FROM REFERENCE # 35, THE SOLUTION FOR THE ONE - DIMENSIONAL, STEADY - STATE RADON DIFFUSION EQUATION (EQ.(1)) IS;

$$J_t = 10^4 R\rho E(\lambda D_t)^{\frac{1}{2}}\tanh[(\lambda D_t^{-1})^{\frac{1}{2}}x_t]$$

WHERE

J_t - THE RADON FLUX FROM TAILINGS SURFACE IN $pCi.m^{-2}s^{-1}$

AND

x_t - THICKNESS OF TAILINGS IN cm.

2. REASONABLE VALUES FOR THE PARAMETERS ARE ASSUMED AND ARE;

ρ = 1.5 $gm.cm^{-3}$ (DRY BULK DENSITY OF TAILINGS)
E = 0.23(RADON EMANATION COEFFICIENT, DIMENSIONLESS, FROM FIGURE 15, PAGE 5 - 2)
D_t = 1.3(10^{-2}) $cm^2.s^{-1}$(DIFFUSION COEFFICIENT FOR RADON IN THE TOTAL PORE SPACE)
$R = K_a G$ = (.19)(2812 pCi) (SEE PAGE 5-1)
= 534.28 pCi

AND

λ = 2.1(10^{-6})s^{-1}(DECAY CONSTANT OF RADON)

3. FURTHER ASSUME THAT THE TAILINGS EQUILIBRIUM MOISTURE CONTENT(DRY WT.%) IS;

M = 11.7%

(FROM FIGURE 15): THIS VALUE YIELDS A RADON EMANATION COEFFICIENT CONSISTENT WITH THE VALUE 0.23.

4. COMPUTE THE RADON FLUX:

$$J_t = 10^4(534.28)(1.5)(0.23)[(2.1(10^{-6})(1.3(10^{-2})]^{\frac{1}{2}} \times \tanh[(2.1(10^{-6})(1.3(10^{-2})^{-1}]^{\frac{1}{2}}(300)$$
$$= 304.26\ pCi.m^{-2}.s^{-1}$$

5. FROM 6. AND 7. OF REFERENCE#4 OF THE PRELIMINARY ASSESSMENT, ASSUME THAT APPROXIMATELY 30% OF THE 251 ACRES IS COVERED WITH TAILINGS TO A DEPTH OF 3m(300 cm) WHEREBY

$$A_t = (0.3)[1.1(10^7)ft^2]$$
$$= 9.34(10^4)\ m^2$$

6. COMPUTE THE TOTAL FLUX

$$J_t A_t = 2.84(10^7)\ pCi.s^{-1}$$

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7. COMPUTE THE TOTAL YEARLY RADON PRODUCTION (IN CURIES);

$$P_{Rn} = (60)^2(24)(365)J_t A_t$$
$$= 8.97(10^{14})(10^{-12})Ci$$
$$= 897 \text{ Curies}$$

8. FROM REFERENCE #2, PAGE #43 THE VALUE FOR THE AVERAGE SPECIFIC FLUX FROM AGED TAILINGS PILES IS;

$$J_t' = (0.19)(10^3) = 190 \text{ pCi.m}^{-2}\text{s}^{-1}$$

WHERE 0.19% IS THE B. VANDEVER ORE GRADE VALUE.

9. THE ALTERNATE TOTAL FLUX FOR THE ASSUMED 75.3 ACRES IS;

$$J_t' A_t = (190)[9.34(10^4)] \text{ pCi.s}^{-1}$$
$$= 1.78(10^7) \text{ pCi.s}^{-1}$$

10. COMPUTE THE TOTAL YEARLY RADON PRODUCTION GIVEN THE ABOVE FLUX;

$$P_{Rn} = (60)^2(24)(365)$$
$$= 560 \text{ Curies}$$

11. THE VALUE FROM REFERENCE #2 FOR TAILINGS PILES IS;

$$J_t'' = (0.19)[3.3(10^3)] \text{ pCi.s}^{-1}$$
$$= 5.87(10^7) \text{ pCi.s}^{-1}$$

12. THE TOTAL YEARLY RADON PRODUCTION FOR A WORST CASE SCENARIO IS THEN;

$$P_{Rn} = (60)^2(24)(365)[5.87(10^7)] \text{ pCi}$$
$$= 1850 \text{ Ci}$$

REFERENCE # 35

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BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

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TJ
N28
25
no.3533
DOC

NUREG/CR-3533
PNL-4878
RAE-18-5

Radon Attenuation Handbook for Uranium Mill Tailings Cover Design

Prepared by V. C. Rogers, K. K. Nielson, RAE
D. R. Kalkwarf/PNL

Rogers & Associates Engineering Corporation

Pacific Northwest Laboratory

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JUN 7 1984
COLORADO STATE UNIVERSITY

Prepared for
U.S. Nuclear Regulatory
Commission

2. DETERMINING RADON ATTENUATION THROUGH COVER MATERIALS

The thickness of cover material required for uranium-mill tailings reclamation is usually determined by a radon flux or concentration criterion which must be satisfied. The general approach used in estimating the required thickness of a cover can be divided into two phases. First, the characteristic parameters of the tailings and cover must be measured or estimated. These include the radon diffusion coefficients, porosities and moistures of the tailings and cover, and the radium content and emanating power of the tailings. Second the thickness of cover needed to achieve a prescribed radon flux is determined by iteratively calculating radon fluxes for various cover thicknesses until the thickness giving the prescribed flux is found. Alternatively, an approximate expression can be used to calculate the cover thickness directly.

In the following equations and throughout this handbook, the diffusion coefficient for radon in the total pore space of the soil is designated by the symbol D, consistent with recent reports on radon movement. A second parameter, the effective bulk diffusion coefficient of the soil, is often designated D_e, and has sometimes been confused with D due to varying symbols and nomenclature used in the literature. The two are related by $D = D_e/p$, where p is the total soil porosity. Identical nomenclature but different symbols were used in the earlier handbook[1] and in the NRC's Generic Environmental Impact Statement on Uranium Milling (Appendix P). The symbol D in those reports corresponds to D_e in this handbook.

2.1 RADON DIFFUSION EQUATION

The one-dimensional steady-state radon diffusion equation is:

$$D \frac{d^2C}{dx^2} - \lambda C + R\rho\lambda E/p = 0 , \qquad (1)$$

where

C = radon concentration in the total pore space (pCi cm^{-3})

D = diffusion coefficient for radon in the total pore space ($cm^2 s^{-1}$)

λ = decay constant of radon (2.1×10^{-6} s^{-1})

R = specific activity of radium in the soil (pCi g^{-1})

ρ = dry bulk density of the soil (g cm^{-3})

E = radon emanation coefficient (dimensionless)

p = total porosity of the soil (dimensionless)

The radon flux from the bulk soil material is related to the radon concentration in its pore space by Fick's Law:

$$J = -10^4 \, Dp \, \frac{dC}{dx} \, , \qquad (2)$$

where

J = bulk radon flux (pCi m^{-2} s^{-1})

10^4 = factor to convert units from pCi $cm^{-2}s^{-1}$ to pCi $m^{-2}s^{-1}$

Appendix A contains the mathematical basis for Equation 1 as well as for the solutions used in this handbook. The solutions of interest are for bare tailings, tailings covered with homogeneous material, and a generalized multiregion problem with many tailings and cover layers.

2.2 FLUX FROM BARE TAILINGS

The solution of Equations 1 and 2 for the flux from a bare, homogeneous tailings pile is:

$$J_t = 10^4 \, R\rho E\sqrt{\lambda D_t} \, \tanh\sqrt{\frac{\lambda}{D_t}} \, x_t \, , \qquad (3)$$

where

J_t = radon flux from the tailings surface (pCi $m^{-2}s^{-1}$)

x_t = thickness of tailings (cm)

The subscript "t" refers to the tailings region. A graph of $J_t/R\,E$ is given in Figure 2 as a function of x_t, illustrating the limitation on the radon flux imposed by radon decay, particularly for low diffusion coefficients. As illustrated, most of the radon comes from the surface layers of tailings; hence there is an advantage in consolidating tailings into smaller, thicker piles.

2.3 FLUX FROM COVERED TAILINGS

The exact solution from diffusion theory to the two-region, tailings-cover problem is:

$$J_c = \frac{2J_t \, e^{-b_c x_c}}{\left[1 + \sqrt{a_t/a_c} \, \tanh(b_t x_t)\right] + \left[1 - \sqrt{a_t/a_c} \, \tanh(b_t x_t)\right] e^{-2b_c x_c}} \qquad (4)$$

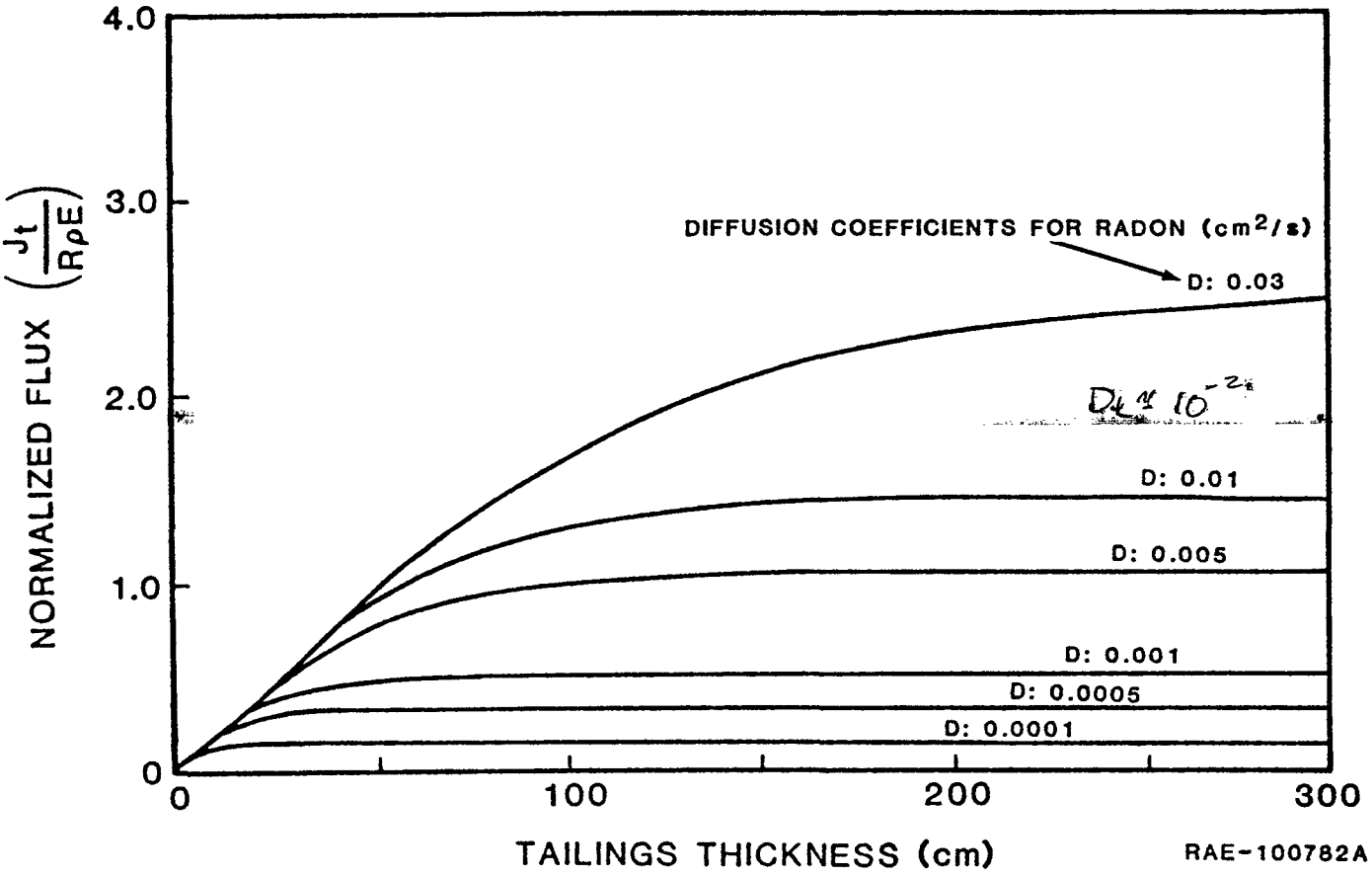

FIGURE 2. NORMALIZED FLUX FROM BARE TAILINGS AS A FUNCTION OF TAILINGS THICKNESS AND DIFFUSION COEFFICIENT.

$$x_c = \sqrt{\frac{D_c}{\lambda}} \ln\left[\frac{2J_t/J_c}{(1+\sqrt{a_t/a_c}\tanh b_t x_t) + (1-\sqrt{a_t/a_c}\tanh b_t x_t)(J_c/J_t)^2}\right] \quad (8)$$

Most practical applications require a significant degree of attenuation so that the last term in the denominator of Equation 8 can be neglected. The resulting simplified equation can be expressed in graphic form and is presented as a nomograph in Figure 4.(39)

The required cover thickness, x_c, is found by first determining the ratios J_c/J_t and a_c/a_t and then referring to the nomograph in Figure 4. The value of the ratio J_c/J_t is found on Column A and the value of a_c/a_t on Column B. These two values should be connected with a straight line, and a value read from Column C at the intersection with the line. That same value is located on the modified scale C' and a second line is drawn from that value on C' to the value of D_c on Column D. The intersection of the resulting line with Column E gives the cover thickness, in units of either meters or feet.

2.5 EXAMPLES OF SURFACE FLUX AND COVER THICKNESS DETERMINATIONS

Several examples are given in this section to illustrate the use of the equations and graphs. The first general examples are calculations of the surface flux from covered tailings. Figure 5 contains the results of cover calculations for a bare tailings flux of J_t = 280 pCi/m^{2}s. Various diffusion coefficients for the cover soils are used in Equation 4 to obtain the curves in the figure.(46) As shown in the next chapter, the cover moisture is the dominant parameter affecting the D, and hence, the radon attenuation.

As an example of the calculations used to generate the curves in Figure 5, it is assumed that a tailings pile has the following typical values:

R = 400 pCi/g

ρ = 1.5 g/cm^3

E = 0.2

D_t = 1.3x10^{-2} cm^2/s

p_t = 0.44

M_t = 11.7%

x_t = 300 cm

The radon flux from the surface of the uncovered tailings is calculated from Equation 3:

4. ESTIMATING DIFFUSION COEFFICIENTS

Radon diffusion coefficients for earthen materials have traditionally been determined from laboratory measurements with the subject soil at a prescribed moisture content and compaction. However, it is often desirable to estimate the diffusion coefficient of materials under varying conditions for which measured values are not available. This can be done with either complex models based upon physical characteristics of the soil, or upon empirical correlations based upon measured values of D. Both approaches are discussed in this chapter, and the advantages and disadvantages of each are given. Because soil moisture and compaction are important factors in the value of D for a given soil, they are also examined in detail in this chapter.

In order to predict the diffusion coefficient of radon from physical properties of an earthen material without conducting radon measurements, empirical correlations have generally been used. One of the earlier correlations is the correlation with moisture[55] which was used in the GEIS on uranium milling.[46] Another is a correlation with the air-filled porosity of the soil.[23] Although these correlations permit estimation of diffusion coefficients from soil properties rather than diffusion measurements, their basis is still a series of measured values of diffusion coefficients.

4.1 DIFFUSION COEFFICIENT MODEL

Recently, a theoretical model has been developed for estimating radon diffusion coefficients without relying on fitted parameters to radon diffusion data.[41] The formalism considers the detailed composition of the pore fluid as well as a statistical definition of the pore structure of the material. As illustrated in Figure 11, the pore fluid is modeled as a two-phase mixture of air and water, with radon diffusion occurring in both phases, and with radon exchange occurring between the air and water. The pore structure is modeled from the measured pore size distribution of the soil, and is described by the weighted average of all combinations of single and composite pores. The soil parameters required to estimate a radon diffusion coefficient are thus the moisture, the packing density and the pore size distribution.

Agreement between the model calculations and measured D values is generally within the experimental uncertainties in the data. A typical result is shown in Figure 12.[54] For the calculations, the pore size distribution was deduced both from water drainage curves and from particle size distributions.[54]

4.2 DIFFUSION COEFFICIENT CORRELATIONS

Empirical correlations for estimating D have the advantage of being simple and easy to use, with a minimal amount of information needed. One

of the early correlations related D with the wet weight-percent moisture in the soil.[55] Subsequently, the development of the model for D revealed that the fraction of saturation, m, was the primary fundamental parameter characterizing D. A more recent correlation using the parameter, m, is recommended for use. It is given by:

$$D = 0.07 \exp\left[-4(m - mp^2 + m^5)\right], \qquad (12)$$

and is plotted in Figures 10 and 12.

The relationship between the fraction of saturation, m, and the commonly-measured moisture percentage, M, is:

$$m = 10^{-2} M/(1/\rho - 1/g) , \qquad (13)$$

where

ρ = dry bulk density (g cm^{-3})

g = specific gravity (g cm^{-3})

M = dry weight percent moisture (gm water/gm dry soil) x 10^2

The exponential argument in the correlation is a simple power series in m, where the first term defines the general downward slope. The second term contains the porosity influence and also causes a more gradual decrease with moisture in the pore filling region. The final term in the exponential argument accounts for major pore blockage near saturation and causes the more rapid decreases needed in this region.

4.3 UNCERTAINTIES OF D CORRELATION ESTIMATES

The correlation shown in Figure 10 has a geometric standard deviation of 2.0. However, individual estimates for a particular soil at a given moisture may be uncertain by as much as an order of magnitude, especially for higher values of m.

A reduction can be achieved in the error associated with a D value from the correlation if just one measurement is made with the candidate soil. In general, if the D at a given m for a specific soil is higher than the correlation, it will remain higher for other values of m. As seen in Figure 13, this is also true if the measured D is lower than the correlation. Values for the four soils shown in the figure also indicate the fact that materials with a wide range of particle sizes have lower D values. Therefore, by normalizing the correlation to a measured value for the D of a specific soil at a given m, more accurate estimates can be made for the D

where

H = depth to the water table (ft)

Equation 14 can also be expressed in the form to estimate the dry-weight percent soil moisture:[59]

$$M = 3.1P^{\frac{1}{2}} - 0.03E + 3.9f_{cm} - 1.0 \quad (16)$$

where M is the dry weight percent soil moisture.

4.5 COMPACTION EFFECTS ON DIFFUSION COEFFICIENTS

Compaction of the cover materials generally reduces the equilibrium D value. The dominant effect is from the increase in the equilibrium m; however, for some soils, D also decrease with greater compaction at a fixed m. For soils with higher compactions, such as represented by the data in Table 3, systematic biases from the correlation are observed for certain types of soils.

The soil description in Table 3 is based upon the percentage of clays and silts in the material, which is determined from the fraction passing a No. 200 mesh screen. As stated previously, the soils are placed into four groups, according to the fraction passing a No. 200 sieve.

Diffusion coefficients from the first group are an average of 20 percent lower than the correlation, and those from the second group are 50 percent lower. Those in the third group are within one percent of the correlation, on the average, and the fourth group averages 30 percent higher than the correlation. These biases should be applied to the correlation in Equation 12 if it is used to obtain an estimate of D. For example, for a soil with f_{cm} less than 0.3, the D obtained from Equation 12 can be divided by 1.2 to obtain a more accurate estimate of D.

The biases are consistent with predictions from the diffusion coefficient computer model.[41] A material with a high clay-silt content is not as effective in attenuative radon as a material with a wide range of particle sizes, for a given saturation percentage. These characteristics should be considered when selecting cover materials.

A significant increase in the lower limit of the volumetric water content, θ, also occurs for many soils at higher compactions. The increase was particularly significant for densities exceeding 1.5 g/cm^3.[26,60] Examination of the relationship between m, θ and porosity, p, is helpful in explaining the increases

$$m = \theta/p \quad (17)$$

5. OTHER FACTORS INFLUENCING RADON MIGRATION

Three other factors influencing radon migration warrant consideration. They are the source term (the tailings), the effects of defects in the cover, and the effects of advection.

5.1 RADON SOURCE TERM

Characterization of the source term is a major step in performing the design analysis of an adequate cover system. As given by Equation 3, the key parameters for the source term are the radium concentration, the dry bulk density, the emanating power, and the diffusion coefficient.

Values for the radium concentration, R, of tailings can be measured directly from tailings samples by the radon equilibrium method, and by direct gamma spectroscopy.[26,61] If a radium analysis is not available, it can be estimated quite accurately from the uranium concentration of the ore as specified by the ore grade, using the following equation:

$$R = K_a G \tag{18}$$

where

G = ore grade (wt% U_3O_8)

K_a = 2812 pCi (^{226}Ra) per gram soil/(wt% U_3O_8)

This equation presumes equilibrium between the uranium and radium in the ore and all radium being contained in the tailings.

The bulk density, ρ_b, of the solid tailings material is a relatively easy measurement to perform. In the absence of measured data a typical value of 1.5 g/cm^3 can be used for the bulk dry density. The density of most tailings piles will be within 35 percent of this value.

The emanating power, E, for uranium tailings is the fraction of the radon generated that is free to diffuse in the pore spaces. It has been shown recently[62] that E varies with moisture. As shown in Figure 15, E can vary considerably for different tailings piles.[59] However, for most practical applications with uranium tailings, a value of 0.2 is a reasonable estimate of E. The data shown in Figure 15 are based upon a few grab samples per pile.

5.2 SOURCE TERM IMPACTS ON RECLAMATION DESIGN

The utilization of source term information can have beneficial impacts

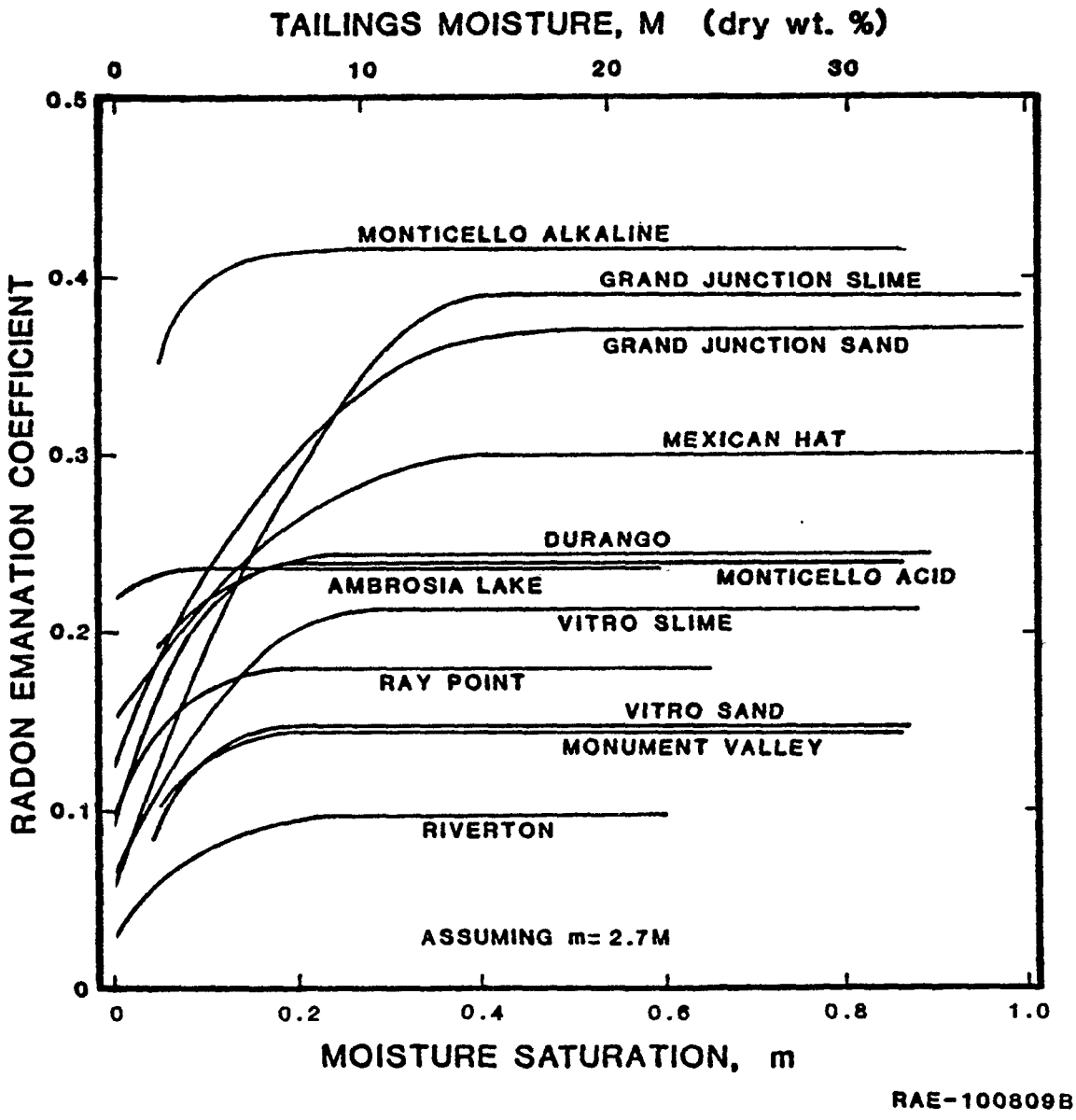

FIGURE 15. RADON EMANATION COEFFICIENTS FOR TAILINGS SAMPLES.

REFERENCE # 36

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

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No. 2407

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NUREG/CR-2407
PNL-4071

Radon and Aerosol Release from Open Pit Uranium Mining

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APR 29 1983
COLORADO STATE UNIVERSITY

Prepared by V. W. Thomas, K. K. Nielson, M. L. Mauch

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory
Commission

TABLE 8. Arithmetic Mean Specific Radon Flux Comparison with Other Studies

SURFACE	AVERAGE SPECIFIC FLUX pCi/m²-sec-% U_3O_8	REFERENCES
Soil	2,500	Wilkening, 1960 - Ref. 16
Soil	2,400	Junge, 1963 - Ref. 17
Soil	620	Clements, 1974 - Ref. 18
Undisturbed Topsoil Near Casper, WY	1,900	Thomas, 1982 - This Work
Undisturbed Topsoil on Mine Properties	2,200	"
Topsoil Piles at Mines	5,700	"
Overburden Piles	2,500	"
Recovered Overburden Piles	2,200	"
Undisturbed Ore in Mine Pit	204	Carson, 1980 - Ref. 19
Ripped Ore in Mine Pit	48	"
Mine Pit Floors	3,200	Thomas, 1982 - This Work
Ore in Mine Pits	3,200	"
Ore Piles at Mines	6,200	"
Lower Grade Ore Piles	5,400	"
Aged Tailings Piles (1)	~1,000	Carson, 1980 - Ref. 19
Tailings Piles (1)	3,300	Silker, 1979 - Ref. 20

Footnote:
(1) These values were calculated from results reported as if the ^{226}Ra present was in equilibrium with ^{238}U.

REFERENCE # 37

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MAY, '90 P. MOLLOY

RADIONUCLIDE LEVELS IN CATTLE RAISED NEAR URANIUM MINES AND MILLS IN NORTHWEST NEW MEXICO

BY

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INTRODUCTION

The development of a large uranium mining and milling industry in the Colorado Plateau during the past 30 years has led to concern about adverse health effects of these industrial activities on nearby human populations. Few studies have addressed radionuclide concentrations in domestic animals raised near uranium mines or mills. Yet evidence from two previous investigations indicates that there may be contamination in the food chain leading to humans.

In the first study, Holtzman et al. collected animals near Grants, New Mexico, in 1979, and found that muscle, lung, and kidney tissue from wild rabbits foraging near uranium mill tailings piles had higher mean concentrations of radium-226 (Ra-226) than did control rabbits (1). They also showed that grass irrigated with mine dewatering effluent had elevated Ra-226 concentrations and that cattle grazing on land irrigated by mine water had higher levels of both Ra-226 and radioactive lead, compared to controls.

Another study was conducted in 1979 at Church Rock, New Mexico, in response to an accidental spill of uranium tailings liquid into a stream of mine dewatering effluent (2). Investigation into the potential human health consequences of the accident included radiochemical analyses of muscle, liver, and kidney tissue from livestock that grazed near the banks of the stream and drank mine water. Radionuclide concentrations were higher than controls, both in animals exposed to the spill and in those exposed only to uranium mine dewatering effluent.

In 1983, New Mexico had nine operating underground uranium mines (3). There are seven conventional uranium-recovery facilities currently under licensure by the New Mexico Radiation Protection Bureau, Environmental Improvement Division (EID), although only two have operated in recent years (4). Seven large uranium tailings piles in the state cover 1355 acres (5), and the Jackpile open pit uranium mine is 2656 acres in size (6). All of these mines and mills are located in the Grants mineral belt, an area of about 4000 square kilometers (2500 square miles) (Figure 1). Since grazing land in this area of New Mexico supports about seven cattle per square mile (7), 17,500 animals potentially could be exposed to products of the uranium mining and milling industry.

We conducted the present investigation to determine whether cattle grazing in areas with uranium mining and milling activity have tissue concentrations of radionuclides that are significantly above background, and whether eating this tissue regularly could expose humans to excessive internal radiation doses. Existing U.S. standards for the nuclear fuel cycle limit radiation doses to members of the public to 25 millirem (mrem) per year to any organ except thyroid, but exempt radiation doses from uranium mine effluent and from radon and its daughters (8). Evidence of food chain contamination near mines and mills could raise questions as to the adequacy of these standards.

METHODS

Study Site Selection.

Two areas in the Ambrosia Lake region, an 80 square kilometer (km) valley

located in the Grants Mineral Belt (Figure 1) of northwestern New Mexico, were chosen for this study because Ambrosia Lake has been the site of intensive uranium mining and milling since the late 1950's. Numerous tunnels undermine the area, which is dotted with ventilation shafts (Figure 2). A large uranium milling facility, which Kerr-McGee opened in 1957, is licensed to process 7000 tons of ore per day. There are two uranium mill tailings piles in the valley. The Kerr-McGee pile was active until 1984 and is 245 acres in size, while the other (Phillips) pile, covering 105 acres, has been inactive since 1963. Continuous discharges of mine dewatering effluent, currently treated by ion exchange plants to remove Ra-226 and natural uranium, are available to domestic animals and provide the only water source for some. The Kerr-McGee tailings piles and the associated lagoons are fenced to prevent access. However, animals do have access to liquids collecting on top of the Phillips pile.

It was estimated that 122,000 curies of radon gas were released per year in the 1970's from mine vents in Ambrosia Lake (9). In addition, radon is released from the Kerr-McGee tailings pile, the Phillips tailings pile, numerous mine waste piles, and from soil in the area. The total radon released per year to the atmosphere was estimated to be 157,200 curies (10). Results of a 1978-1979 study conducted in Ambrosia Lake by Buhl et al. indicated that the state and federal radon limit of 3.0 picocuries per liter (pCi/l) above background (11, 12) was exceeded at four of nine air sampling stations (10). The overall two year average for all the stations (4.0 pCi/l) also exceeded the limit. However, this limit exempts contributions from any mining activities. Subsequent monitoring of radon levels in Ambrosia Lake between 1980-1984 (4) revealed similarly elevated

ambient air radon concentrations (Figure 2). Thus, cattle in the area are potentially exposed to radon and its decay products, windblown tailings or ore, and mining effluent.

The Church Rock study site is approximately 20 km north of Church Rock, New Mexico and 45 km west of Ambrosia Lake (Figure 1). A United Nuclear Corporation (UNC) uranium mill is located at the site and is licensed to process 3000 tons of ore per day. However, this facility has not processed ore since May, 1982. Two underground mines currently discharge effluents which form a perennial stream available to local animals (Figure 3). In addition, an ion exchange plant downstream of the mill discharges liquid effluent into the Rio Puerco. In 1979, a breach of the UNC mill tailings impoundment released 355 million liters of liquid wastes contaminated with toxic elements and radionuclides from the uranium-238 decay series (2). Therefore, animals at this study site were potentially exposed to accidental releases and chronic discharges.

Mean ambient air radon concentrations and standard errors in the Church Rock region were 1.5 $\pm$ 0.3 and 1.3 $\pm$ 0.2 pCi/l for 19 and 17 individual samples respectively, taken in 1980 at two stations within 0.5 $^{\mu}$m of the UNC tailings impoundment. From August, 1984 to February, 1985, radon averaged 1.7 $\pm$ 0.2 and 1.5 $\pm$ 0.2 and pCi/l from 14 samples collected at the same 1980 stations. Radon concentrations measured in 1980 averaged 0.5 $\pm$ 0.1 pCi/l five km from the tailings facility (13).

Crownpoint, the control study site, is also in the Grants Mineral Belt

approximately 40 km northwest of Ambrosia Lake and 22 km east of Church Rock. The nearest active uranium impoundment is an in situ pilot plant approximately 8 km to the northeast. An undeveloped mine shaft is located 5 km southeast of the control animals' grazing site. There are no other uranium industrial activities in the area. Thirty-seven radon measurements taken at distances of 0.8-5 km from the undeveloped mine and 5-8 km from the in situ pilot plant have averaged 0.15 $\pm$ 0.02 pCi/l (10). These radon concentrations are consistent with averages from unmined areas in the Grants Mineral Belt (10).

Natural background radioactivity was not measured in Ambrosia Lake or Church Rock prior to start-up of the mining and milling operations at these sites. However, the Crownpoint area of New Mexico is rich in underground uranium and is slated for uranium mine development in the future if the price of uranium increases. Therefore, it is an area with potentially high background radiation, yet is an undisturbed area in the Grants Mineral Belt. For these reasons Crownpoint represented an appropriate baseline for comparison to animals raised near uranium mines or mills.

Cattle Selection and Tissue Sampling.

All cattle were purchased and slaughtered in October, 1983. Five cattle were obtained from each of two ranchers in Ambrosia Lake. Group 1 cattle grazed in a 4.4 square km fenced area that had frequently been flooded by dewatering effluent from a nearby uranium mine. The ion exchange plant (Figure 2) that treated this water to remove uranium and Ra-226 was built in 1976 but has not been regulated by the EID due to pending litigation

(4). Group 1 cattle's only water source was mine dewatering effluent. Group 2 cattle grazed in a much larger open area and had access to surface impoundments as well as dewatering effluent. Seven cattle were purchased in Church Rock (Figure 3) and ten animals were purchased in the control area near Crownpoint. Information on sex, birth date, place of birth, health, and food and water sources, was obtained for all animals at the time of purchase.

Exposed and control cattle were transported to an abattoir and sacrificed within 48 hours. A United States Environmental Protection Agency (EPA) veterinarian and New Mexico EID staff obtained the specimens, while taking precautions to prevent cross-contamination of tissues. Nondisposable equipment was washed thoroughly between sample collections. Specimens were individually bagged and identified. Tissues obtained from each animal for analysis included several kilograms of the upper thigh muscle, the right lobe of the liver, a whole kidney, and the entire right femur. Tissues were refrigerated and transported to the analytical laboratory for analysis. Backup and quality control specimens (Appendix A) were frozen.

Environmental Sampling.

Composite samples of grass and soil were collected from grazing areas in Ambrosia Lake and Church Rock (Figure 2, 3) and from the control area. Grasses in a square meter area were clipped at soil level and analyzed unwashed. Soil samples were collected in each vegetation quadrat to a depth of 5 cm and a volume of 600 cm^3.

Water samples were obtained from all water sources available to the study cattle in Ambrosia Lake and Crownpoint. Water was sampled from the Pipeline arroyo and from the Rio Puerco in Church Rock. Approximately 3.8 liters of unfiltered water was collected at each source and treated with 20 ml of concentrated nitric acid to form a 0.5% HNO_3 solution. This technique prevented plating of radionuclides on the sample container.

Laboratory Methods.

Eberline Corporation in Albuquerque, New Mexico performed the radiochemical analyses. Each tissue was analyzed for uranium-238 (U-238), uranium-234 (U-234), thorium-230 (Th-230), Ra-226, lead-210 (Pb-210), and polonium-210 (Po-210). In addition, split samples of muscle, liver, and kidney tissues from two cattle chosen randomly from each of the three areas were analyzed for the above radionuclides by the EPA, Environmental Monitoring Systems, Las Vegas, Nevada, (EPA-Las Vegas) for quality control purposes (Appendix A).

The methods for measuring radionuclide concentrations in animal tissues and environmental samples were derived from published EPA and United States Department of Energy analytical procedures (14, 15). Tissue samples were weighed (Table 1) and dried at 105°C for approximately 24 hours. About 200 grams (gm) of the dried sample were ashed in a muffle furnace at 500°C, then wet ashed repeatedly with concentrated nitric acid (HNO_3) and hydrogen peroxide repeatedly to dissolve the sample. The final residue was dissolved in 8 normal HNO_3 and diluted to a measured volume. Aliquots of this solution were used for U-238, U-234, Ra-226, and Th-230 analyses.

Uranium and thorium were then measured by alpha spectroscopy, and Ra-226 was measured by radon de-emanation.

For the Pb-210 and Po-210 analyses, approximately 200 gm of the dried sample were digested (wet ashed) repeatedly with concentrated nitric acid, hydrochloric acid (HCl) and hydrogen peroxide at 85°C until the entire sample was completely oxidized and dissolved. The sample was then dissolved in 1 normal HCl to a measured volume. Aliquots of this solution were analyzed for Po-210 by electrodeposition and alpha counting, and for Pb-210 by bismuth-210 (Bi-210) separation and beta counting. Appropriate internal tracers and stable carriers were added to determine the chemical and radiochemical recovery fractions. The lower limits of detection (LLD) are presented in Table 1.

Bone samples were weighed and then cut into twelve approximately equal sections of about 3 centimeters in thickness. Alternate sections were combined. One combined sample was used for the determination of U-238, U-234, Ra-226, and Th-230. The remainder was analyzed for Po-210 and Pb-210, according to the above methods.

All environmental samples (vegetation, soil, and water) were analyzed for U-238, U-234, Th-230, Ra-226, Pb-210, and Po-210 using the same methods for measuring radionuclide concentrations as were used for tissue specimens. Tissue and bone concentrations of Po-210 were corrected for radioactive decay and the ingrowth of Po-210 from Pb-210 with the following equation:

$$\text{Corrected Po-210} = \frac{\text{Po-210 at separation date} - (1-e^{-\lambda t})\ \text{Pb-210 at separation date}}{e^{-\lambda t}}$$

Where λ = decay constant for Po-210

t = time between sample collection and Po-210 sample analysis when Po-210 was radiochemically separated from Pb-210.

If the corrected Po-210 concentration was a negative number, it was assigned a value of zero.

Methods used at the EPA-Las Vegas laboratory for detecting radionuclides in animal tissues have been previously described (2), with the exception that Th-230 recoveries were determined using a thorium-229 tracer, followed by alpha spectrometry. The major difference between procedures followed by the two laboratories involved the analysis of Pb-210. Technicians at Eberline counted the Bi-210 decay product of Pb-210 using beta detection equipment while those at the EPA-Las Vegas laboratory counted the Po-210 formed from Pb-210 decay using alpha spectrometry. In both laboratories, an error factor was calculated and reported as two standard deviations of the counting rate (16). Negative radionuclide concentrations were reported on occasion and resulted from subtraction of background counts from sample counts. Each laboratory also used its own protocol for assuring quality control.

Statistical Methods.

Statistical analysis was performed on the computerized data set using the Statistical Analysis System (17). Radionuclide concentrations in cattle

tissue and bone, and concentrations in the environmental samples from each of the two Ambrosia Lake groups, Church Rock, and Crownpoint were compared using both parametric (multiple analysis of variance (MANOVA) with General Linear Models (G.L.M.) for unequal sample sizes, Duncan's multiple range test) and nonparametric (Kruskal-Wallis and Wilcoxon's two-sample) statistical tests. In the MANOVA approach radionuclide concentrations were the dependent variables. Location (Ambrosia Lake Group 1, Group 2, Church Rock or Crownpoint) was the independent variable. Analyses of cattle tissue were performed with and without age added to the model to determine possible age dependent effects.

Since the sample size in each group was small, it was not possible to determine whether the data were normally distributed. Therefore, nonparametric tests were performed. The Kruskal-Wallis test was used to determine whether any of the three exposure groups or the control group differed significantly ($p < 0.05$). If significant differences were found, the Wilcoxon's rank-sum test, with continuity correction of 0.5, was used to compare each exposure group to the Crownpoint control group.

A discussion of the quality control comparisons is given in Appendix A. Results of split sample testing were compared using a two-tailed paired-sample t-test (18).

RESULTS

Cattle Data.

All of the cattle but one were female. The average age of Ambrosia Lake

Group 1 cattle was 5.0 (range 4-6 years). Ambrosia Lake Group 2 cattle were two- and three-year-olds with a mean age of 2.4. The mean age of the Church Rock cattle was 2.6 (range 2-5 years) and that of the Crownpoint controls was 4.8 (range 3-7 years). Except for one animal purchased as a calf from another owner, all animals were born and raised in the described areas. The owner of Ambrosia Lake Group 1 cattle stated that some of the animals in his herd were not gaining weight properly and reproduced poorly. The other owners reported their animals to be in good health. Animals from all four groups received supplemental fodder during winter. All seventeen animals in the three exposed groups and none of the ten animals in the control group had access to uranium mine dewatering effluent.

Radionuclide Concentrations in Cattle.

Mean radionuclide concentrations in muscle tissue from Ambrosia Lake Groups 1, 2, and from Church Rock cattle were similar to corresponding controls, with the exception that Ra-226 and Po-210 were significantly increased in Group 1 cattle and U-234 was elevated in Church Rock cattle (Table 2). Mean radionuclide concentrations in the majority of the liver, kidney, and femur samples were significantly above control levels among both Ambrosia Lake Group 1 and Group 2 cattle. Liver and femur from Church Rock cattle were significantly elevated in U-238 and U-234, and femur was elevated in Ra-226. Levels of Th-230 were generally higher among Church Rock cattle than controls but these elevations were not significant statistically. When age was added to location as an independent variable in the MANOVA model, the effect of location on mean radionuclide conentrations was unchanged, although differences between mean muscle Ra-226 and kidney Po-210 concentrations in Ambrosia Lake Group 1 cattle versus the remaining

groups became less significant statistically ($p=0.07$ and 0.05, respectively). Age did not alter significance levels in the other analyses.

Radionuclide Concentrations in Environmental Samples.

Radionuclide levels in soil sampled from Ambrosia Lake Group 1 were significantly elevated over those of controls. Concentrations of th-230 and Ra-226 were significantly higher than controls in vegetation samples (Table 3). Concentrations of Th-230 and Ra-226 in vegetation from Ambrosia Lake Group 2 were also significantly higher than controls. Mean radionuclide concentrations in soil from Ambrosia Lake Group 2 were several times higher than those of controls, but the differences did not attain statistical significance. Soil from sampling sites 11-13 in Group 1 and sites 2, 4, and 5 in Group 2 had much higher radionuclide levels than did soil collected at the other sites in the respective grazing areas (Appendix, Table B-2). Soil samples from Church Rock had higher mean radionuclide concentrations than those from Crownpoint but these levels were not significant statistically (Table 3). Radionuclide content of vegetation from Church Rock was higher than controls in Ra-226 and Po-210 but these difference did not attain statistical significance.

Water samples collected from Ambrosia Lake Group 1 and from Church Rock had higher mean concentrations of U-238 and U-234 than controls. Ambrosia Lake Group 2 water contained higher levels of these radionuclides than controls but the differences were not significant statistically.

DISCUSSION

Summary of Study Results.

The principal objective of the present study was to determine whether radionuclide concentrations in the tissues of cattle raised near uranium mines and mills were significantly higher than those of unexposed animals. Results indicated that all three groups of cattle exposed to uranium mine and mill discharges and wastes had elevated tissue radionuclides compared with controls.

Cattle exposed to the most active mining and milling area, Ambrosia Lake, were considerably closer to mines and mills than those from Church Rock. Ambrosia Lake Group 1 cattle grazed in an area with the highest measured concentrations of soil radionuclides, and dewatering effluent was their only water source. Water samples had higher levels of U-238 and U-234 than controls. These animals also were raised where ambient air radon levels were above background.

Most of the liver, kidney, and bone tissues from Ambrosia Lake Group 2 cattle also contained elevated radionuclide concentrations. These animals grazed in an area with elevated ambient radon concentrations. A portion of their grazing area abutted a uranium mill and tailings pile. However, these cattle roamed over a very large area and drank rainwater in addition to mine dewatering effluent. Environmental sampling revealed mean radionuclide concentrations in soil, vegetation, and water that were intermediate between Ambrosia Lake Group 1 and the controls.

Tissues from Church Rock cattle showed lower radionuclide levels than were found in cattle from Ambrosia Lake. These animals had exposure to much lower levels of ambient air radon (most levels were probably background). Most radionuclide concentrations in vegetation also were similar to background levels. The primary exposure of these cattle was to uranium mine dewatering effluent. Water samples taken from Church Rock were elevated in U-238 and U-234. Correspondingly, cattle tissue from Church Rock was elevated in U-238 and U-234.

Study Limitations.

This study had several limitations. First, only a small number of cattle were tested from each area. Since there was variability between radionuclide concentrations measured in animals from each group, the standard errors were large. Second, there was variability in the results of split sample testing, especially the Po-210 measurements (Appendix A). It is possible that the Po-210 concentrations reported by Eberline Laboratory may be twice as high as the true values.

A third problem was that the radionuclide concentrations measured in the environmental samples may not have been representative of those to which the cattle were actually exposed. The sample numbers were small and samples were taken at only one point in time. Since the cattle were living in their respective areas for two to seven years, many samples of soil, vegetation, and water, tested periodically, would have been required to characterize radionuclide levels in the cattle's environments.

The fact that only single samples were collected is a problem, especially

in interpreting the results of water analyses. Ion exchange plants treated the mine water drunk by cattle from both Ambrosia Lake Groups and from Church Rock. However, concentrations of contaminants in treated effluents may have fluctuated, depending on how well and how consistently these plants were maintained and operated. Untreated uranium mine water may contain significant levels of U-238 chain radionuclides. Gallaher and Goad, in a study of mine water in New Mexico, reported a median of 170 pCi/l Ra-226 and 5.4 mg/l uranium (equivalent to about 1800 pCi/l each of U-238 and U-234) (19). Thus, if ion exchange plants were not operating effectively, study cattle could have ingested water containing much higher radionuclide levels than those given in the present report.

Finally, only two of a possible four groups of cattle were sampled from Ambrosia Lake. One group not sampled was considered to be more heavily exposed to uranium activities than those that were sampled. Therefore, the results of this study should not be considered to completely describe the tissue levels of all animals grazing in Ambrosia Lake.

Estimation of Doses from Cattle Tissue Ingestion and Cancer Risk Estimates.

The internal dose commitment received when a person ingests cattle tissue for one year with known radionuclide concentrations was estimated for all four groups using dose conversion factors of Dunning (20). These conversion factors were used because they are based on the most current metabolic models for the uptake and elimination of radionuclides. Mean tissue concentrations for each exposed group and the control group were used for the calculations, and dose commitments were estimated for a 50 year period following one year of ingestion. F_1 uptake factors for absorption of

specific radionuclides across the human gut were 0.05 for U-238 and U-234, 0.0002 for Th-230, 0.2 for Ra-226, 0.2 for Pb-210, and 0.1 for Po-210 (21). A quality factor of 20 for alpha radiation was assumed for all dose conversion factors, in accordance with recommendations of the International Commission on Radiological Protection (ICRP) (22). We estimated doses to human kidney, liver, endosteum, and red marrow.

To estimate cancer risks from ingestion of cattle tissue, total picocuries of each radionuclide ingested per year were calculated and converted to mrem per year using the effective dose equivalents of Dunning (20). The total effective dose equivalent for each scenario was then multiplied by the ICRP risk coefficient of 125×10^{-6} per rem to estimate the expected number of cancer deaths (22). Lifetime cancer risks were expressed as the number of excess cancer deaths per million population attributable to the radiation dose received from one year and 20 years of ingestion.

Internal radiation doses and cancer risks were calculated according to three scenarios of tissue consumption. Scenario 1 assumed that a family living in the described areas would slaughter and ingest all the edible parts of an animal, including its liver and kidneys, over a one-year period. This scenario assumed a total beef consumption of 78 kilograms (kg) per year per individual, the average per capita yearly meat consumption in the United States (23) and a dietary proportion of muscle, liver, and kidney comparable to that organ's percentage of the combined average weight of beef muscle, liver, and kidney, 74 kg (94.8%), 2.7 kg (3.4)%, and 1.3 kg (1.87%) respectively (2).

Scenario 2 assumed that a person ingested 78 kg of muscle per year from each area but did not eat liver or kidney. Scenario 3, a worst case estimate, assumed that a person ate higher percentages of liver and kidney. These percentages were the 99th percentile of reported consumption from a 1984 dietary survey of 767 adult Hispanic and Non-Hispanic white New Mexicans selected randomly for a study (24). Worst case estimates assumed a liver consumption of 13.1 kg per year and a kidney consumption of 2.6 kg per year, with muscle constituting the remainder of the 78 kg yearly meat intake.

In scenario 1, the annual ingestion of muscle, liver, and kidney from control animals incurred a 50 year dose commitment of 25 mrem to the kidney and 27 mrem to endosteum (Table 4). Similar doses were calculated from eating beef from Church Rock. Consumption of ALG2 cattle resulted in radiation doses approximately twice those incurred from eating control cattle tissue. The dose incurred from eating Group 1 cattle for one year was associated with an even higher dose, especially to kidney (100 mrem above the control). Polonium-210 and Pb-210 were the most important nuclides in terms of dose to kidney, liver, and red marrow. Lead-210, followed by Ra-226 Po-210, and Th-230, contributed substantial fractions of the dose to endosteum. Because it is possible that the reported Po-210 measurements were higher than the true values, the dose contributions from Po-210 may be overestimates by a factor of about two.

Cancer risks associated with these doses for scenario 1 were one chance in 1,310,000 from ingesting control beef, one chance in 940,000 from eating Ambrosia Lake Group 2 cattle, one chance in 1,170,000 from Church Rock

cattle, and one chance in 280,000 from Ambrosia Lake Group 1 cattle. Continuous ingestion of Group 1 cattle for 20 years would incur a lifetime cancer risk of one chance in 14,000.

Eliminating liver and kidney from the diet and eating muscle tissue alone (scenario 2) reduces the internal radiation dose (Table 5). The dose from ingesting Ambrosia Lake Group 1 cattle, for example, is reduced by about 55%. The ingestion of Ambrosia Lake Group 2 or Church Rock cattle is associated with a negligible excess cancer risk. Consumption of beef from Ambrosia Lake Group 1 results in a cancer risk of one chance in 534,000.

The worst case estimates of scenario 3 predict much higher doses (Table 5). For instance, the resulting 50 year dose commitment to kidney from one year of ingestion was enhanced by a factor of 2.3, to 300 mrem. For one year of ingestion, corresponding cancer risk estimates are one chance in 120,000 for the highest exposure group (Ambrosia Lake Group 1) and one chance in 400,000 for Ambrosia Lake Group 2. The cancer risk for consuming Church Rock animals (one chance in 670,000) was similar to that from ingesting Crownpoint control cattle (one chance in 630,000) despite statistically higher uranium concentrations in tissues from Church Rock animals. This occurred since uranium contributed a small percentage of the total radiation dose.

The doses calculated for the various scenarios are based upon consumption of large amounts of muscle tissue, which contains lower radionuclide concentrations than liver or kidney. Eating liver and kidney incurs much higher internal radiation doses than eating muscle tissue. Since all of the dose and risk estimates are approximations, based upon numerous

assumptions concerning the uptake and retention of radionuclides and their cancer-causing potential at low doses, the actual doses and cancer risks may be higher or lower than the numbers we have presented. Although we calculated dose commitments according to estimates given by Dunning, other dose conversion factors which include higher and lower values than those of Dunning are reported in the literature (25). Furthermore, the fifty year dose commitments calculated in this report could underestimate the dose to potentially exposed children or infants since higher dose conversion factors are recommended for young age groups (26).

Interpretation and Significance of Elevated Radionuclide Levels in Exposed versus Control Cattle.

Despite the limitations of this investigation, the findings support the conclusion that the elevated radionuclide levels found in cattle tissues from Ambrosia Lake and Church Rock resulted from the cattle's exposures to radionuclide byproducts of the uranium mining and milling industry. The elevated tissue radioactivity in exposed compared to control cattle is confirmed by the statistical tests of significance and by the consistency of the data. Although the sample sizes in our study were small, the differences between exposed and control samples reached statistical significance for many of the radionuclides, and in most comparisons mean levels in all of the exposure groups exceeded those in controls. Thus, it is unlikely that the differences were due to chance. Since the cattle tissue was analyzed in a blind fashion by the laboratories, this reduced the possibility of bias in reporting results. The mean differences between radionuclide concentrations in exposed and control cattle, moreover, did

not result from high concentrations in a few isolated cattle. In Ambrosia Lake Group 1, 15 of the 24 comparisons to control animals were significant statistically. Radionuclide measurements in each each of the five cattle from Ambroisa Lake Group 1 exceeded mean levels of their respective controls in all but two of the 75 comparisons (Appendix Table B-1.). Further mean, radionuclide concentrations in the femurs of cattle from all three areas were numerically higher than controls in all but one of the 18 samples tested and the differences attained statistical significance in 10 of 18. This finding of high levels in bone tissue suggests that these animals were exposed chronically to U-238 chain radionuclides.

The environmental data collected in this investigation, although limited, strongly supports the conclusion that the elevated radionuclide levels in cattle tissue resulted from exposures to uranium mining and milling. Ambrosia Lake, the exposure area most impacted by the uranium mining and milling industry, had the highest concentrations of environmental radionuclides, and is the area in which cattle tissues contained the highest radionuclide levels. Animals from Ambrosia Lake were exposed to high ambient air radon, windblown tailings, and mine water. Church Rock, the exposure area farther removed from uranium mine operations had lower levels of environmental radionuclides compared to controls, and cattle tissue from this area had relatively lower radionuclide concentrations. The primary environmental source of radionuclides for these animals was mine water drunk by the cattle.

Data from this and other investigations provided evidence that the high radionuclide levels found in environmental samples were not due to natural sources of radiation. Natural background radioactivity was not measured

in Ambrosia Lake or Church Rock prior to start-up of the mining and milling operations. However, soil samples collected at Ambrosia Lake in another study indicated that true background concentrations were much lower than the radionuclide levels found in this investigation. In 1983 soils were collected at 16 locations across Ambrosia Lake from the surface and at a depth of 30 centimeters (cm) (10). The surface soil mean and standard error was 13.5± 6.6 pCi/gram for Ra-226, while soils collected at 30 cm depth averaged 0.57± 0.08 pCi/gram. Ra-226 concentrations in soil collected at 30 cm depth were similar to those collected at the surface at Crownpoint, NM. Therefore, the levels of Ra-226 in surface soil probably reflected contributions from the uranium mining and milling industry.

In the present study the grazing area for Ambrosia Lake Group 1 cattle has been flooded by mining effluent for years. Prior to 1979, when the ion exchange plant was built, the water that flooded this area was untreated uranium mine dewatering effluent. Soil from sample sites 11-13 contained extremely elevated levels of radionuclides, compared to the remaining samples. These sites were close to the discharge from the ion exchange plant but farther from the Phillips or other tailings piles than sample sites 10 and 14, which had much lower levels of soil radionuclides. In this case it appears that mine water rather than windblown tailings contributed more to high levels of U-238 chain radionuclides in grazing area 1.

The grazing area for Ambrosia Lake Group 2 cattle was not irrigated by uranium mine dewatering effluent. Soil containing the highest levels of U-238 chain radionuclides was from sampling sites 2, 4, and 5. These sites were very close to the Kerr-McGee tailings pile, and mine vents were

abundant in these areas. Radium-226 in soil from these sampling sites averaged 20.3 pCi/gram. Soil from sites 3, 6, and 7, which are farthest from the mill and its tailing pile, had levels of Ra-226 that averaged 1.3 pCi/gram. The elevated radionuclides in soil from grazing area 2 have therefore probably resulted from windblown tailings or radon daughters. These difference could not easily be attributed to variations in natural radioactivity.

The contribution of radon daughters to the radionuclide content of soil, vegetation, and cattle tissue is not clear. Radon gas is an important source of Pb-210 and Po-210, and ambient radon concentrations were elevated over background in Ambrosia Lake. Since radon is not a source of uranium, Th-230, or Ra-226, and since the soil, vegetation, and animal tissues contained relatively high levels of these radionuclides as well, it is evident that sources other than radon gas contributed significantly to the elevated radionuclide levels demonstrated in this investigation. Although cattle from Ambrosia Lake Group 1 had elevated levels of Po-210, cattle from Ambrosia Lake Group 2 were the only ones that had high levels of Pb-210 in any of the tissues, albeit only in kidney. It is possible that the elevated kidney Pb-210 levels resulted from exposure to radon gas and its daughter products.

In addition to the statistical significance, the consistency of this study's results, and evidence provided by environmental data, the conclusion of this investigation is also supported by previous research into cattle contamination by the uranium mining and milling industry. Holtzman et al. measured tissue concentrations of Ra-226, Pb-210 and Po-210 in two cows that foraged near the Anaconda uranium mill tailings pile

in New Mexico. Animals in this study had no access to uranium mine dewatering effluent (1). These cattle had muscle concentrations of 1.1 and 1.2 pCi/kg Ra-226, liver concentrations of 0.87 and 1.5 pCi/kg Ra-226, and kidney concentrations of 220 and 2.6 pCi/kg Ra-226. These Ra-226 levels and reported concentrations of Pb-210 (Appendix A, Table A-3) were generally intermediate between those found in Ambrosia Lake Group 1, Ambrosia Lake Group 2, and Church Rock cattle. Tissue concentrations of Po-210 were lower than those reported in the present study. The two control cattle in the Holtzman study had somewhat higher radionuclide concentrations than the averaged values for controls in this investigation.

Two cows collected from the Church Rock area in 1979 had muscle, liver, and kidney concentrations of U-238, U-234, Th-230, Ra-226, Pb-210, and Po-210, that were similar to the concentrations reported in the present analysis of Church Rock cattle (2). These cattle were from the same area as those in the present study. Another recent study examined ten sheep raised in Church Rock and ten controls. The findings of this investigation are presented elsewhere (27) but support the conclusion that radionuclide levels were higher than controls in sheep from Church Rock as well.

An additional objective of this investigation was to determine the risk to public health of eating exposed cattle over a long period of time. Owners of the purchased animals stated that they raise, slaughter, and consume their own animals. Further, it was assumed that some individuals buy a cow or a side of beef, freeze it, and consume it over several months. Thus, some New Mexican families might purchase an exposed animal and eat large quantities of meat containing elevated radionuclide concentrations.

To examine the importance of the elevated tissue radioactivity found in this study, we calculated estimates of internal radiation dose from ingesting exposed and control tissues. Dose estimates indicated that consumption of cattle tissue from Church Rock leads to approximately the same radiation dose as does eating control cattle. Consumption of Ambrosia Lake Group 2 cattle resulted in radiation doses approximately twice those incurred from control tissue consumption. Consuming cattle from Ambrosia Lake Group 1, however, is associated with a much higher dose estimate. After subtracting the dose estimated from ingestion of Crownpoint controls, which represents background doses for the area, the dose to human kidney from one year of ingestion exceeds 100 mrem. The general public, however, would not receive doses of this magnitude, as it is highly unlikely a person would consume a large amount of meat from one area of New Mexico. A person who buys and consumes 0.5 kg of muscle from Ambrosia Lake group 1 cattle, for example, would receive a 50 year dose commitment of 0.87 mrem to the kidney, compared with a dose of 0.17 mrem from eating this much control beef.

For all the assumed scenarios, cancer risks attributable to eating beef from each of the exposure groups were within the ICRP's acceptable limit of below one excess death per 100,000 individuals in a population (22). These calculations were based on the assumption that a person eats 78 kg of area beef for one year. It is probable that few residents are exposed to this extent. For those who have eaten area meat, especially liver and kidney, for a prolonged period of time, risk estimates may exceed the acceptable limit. The 20 year ingestion risk estimate for Ambrosia Lake Group 1, scenario 1, for example, is one death per 14,000 exposed individuals.

To place this risk in perspective, it has been estimated by the EPA that individuals living continuously next to some uranium mill tailings piles may have an excess lifetime lung cancer risk as high as 4 chances in a hundred (28). This risk is from exposure to radon decay products emitted directly from the tailings pile. If a person ingests Ambrosia Lake Group 1 beef (scenario 1) for 60 years but is not exposed to the uranium mining and milling industry in any other way, his lifetime risk of a cancer death, primarily from cancer of the kidney, liver, and bone, would be about one death in 4500.

EPA standards and New Mexico EID regulations limit the organ doses to individuals to 25 mrem per year, but currently exempt radiation exposures from uranium mine effluents, and from radon and its daughters, which include Pb-210 and Po-210 (8, 11). Doses incurred from ingesting Ambrosia Lake Group 1 cattle for one year exceeded the 25 mrem/yr limit. Lead-210 and Po-210 were identified as the major dose contributors following consumption of these tissues from cattle exposed most heavily to uranium mine effluents. Therefore, it may not be appropriate to exempt either radon daugthers or uranium mine effluents from present standards and regulations.

Current regulations are based on the assumption that the source of the exposure is known. However, the present investigation did not determine whether the source of radioactivity was mill tailings, mine dewatering effluent, or the inhalation and/or ingestion of radon and its daughters.

The most highly contaminated animals were exposed to all of these sources. Further environmental sampling and measurements of tissue radionuclide concentrations in animals exposed only to dewatering effluents, or to mill tailings, are needed to identify the relative contribution from each source. Until these studies are completed, restricting access of livestock to uranium mine dewatering effluent, and restricting grazing of animals on land that has been irrigated with mine water or is in proximity to mill tailings, would markedly reduce the probability of food chain contamination.

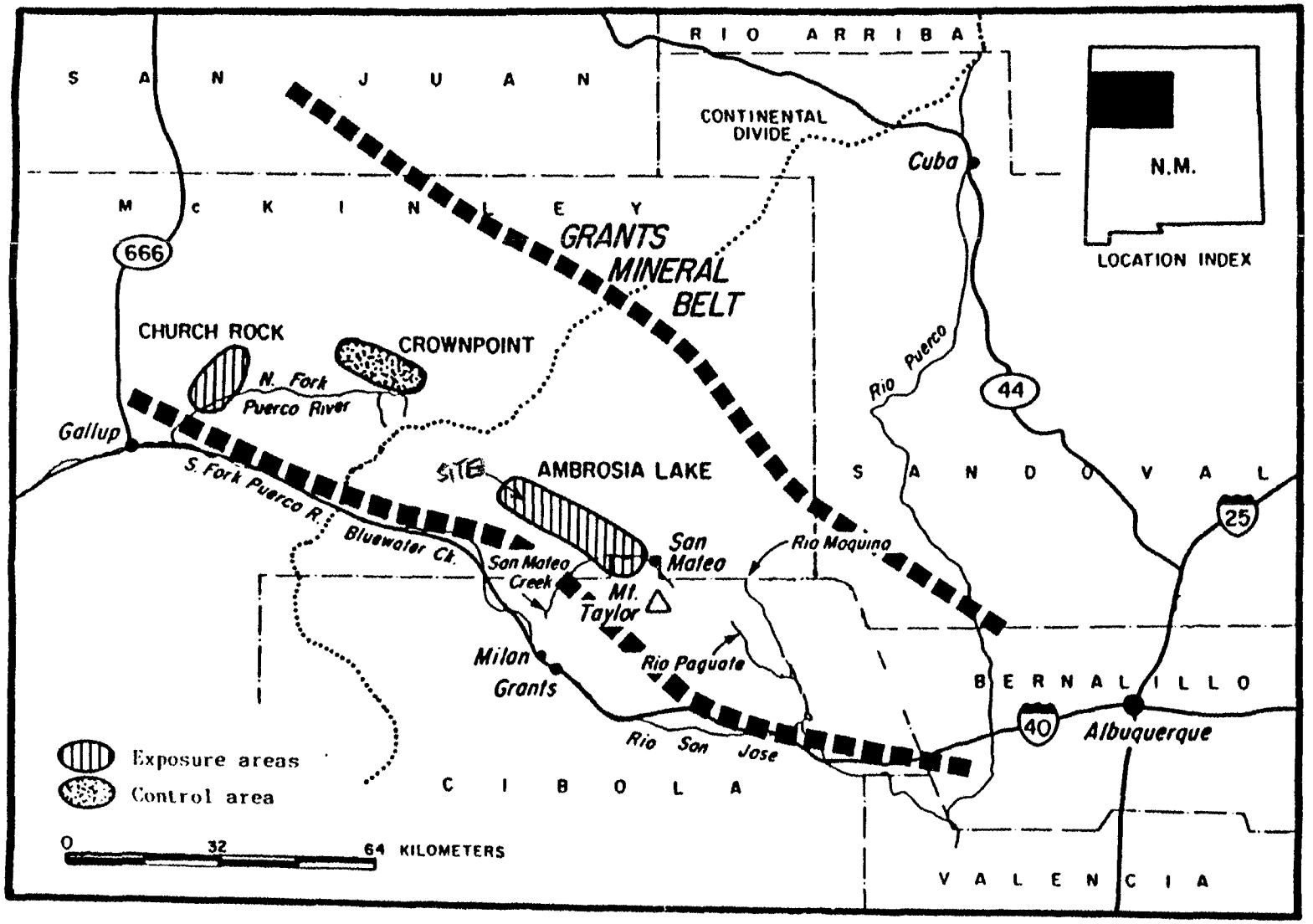

Figure 1. Grant's Mineral Belt, New Mexico.

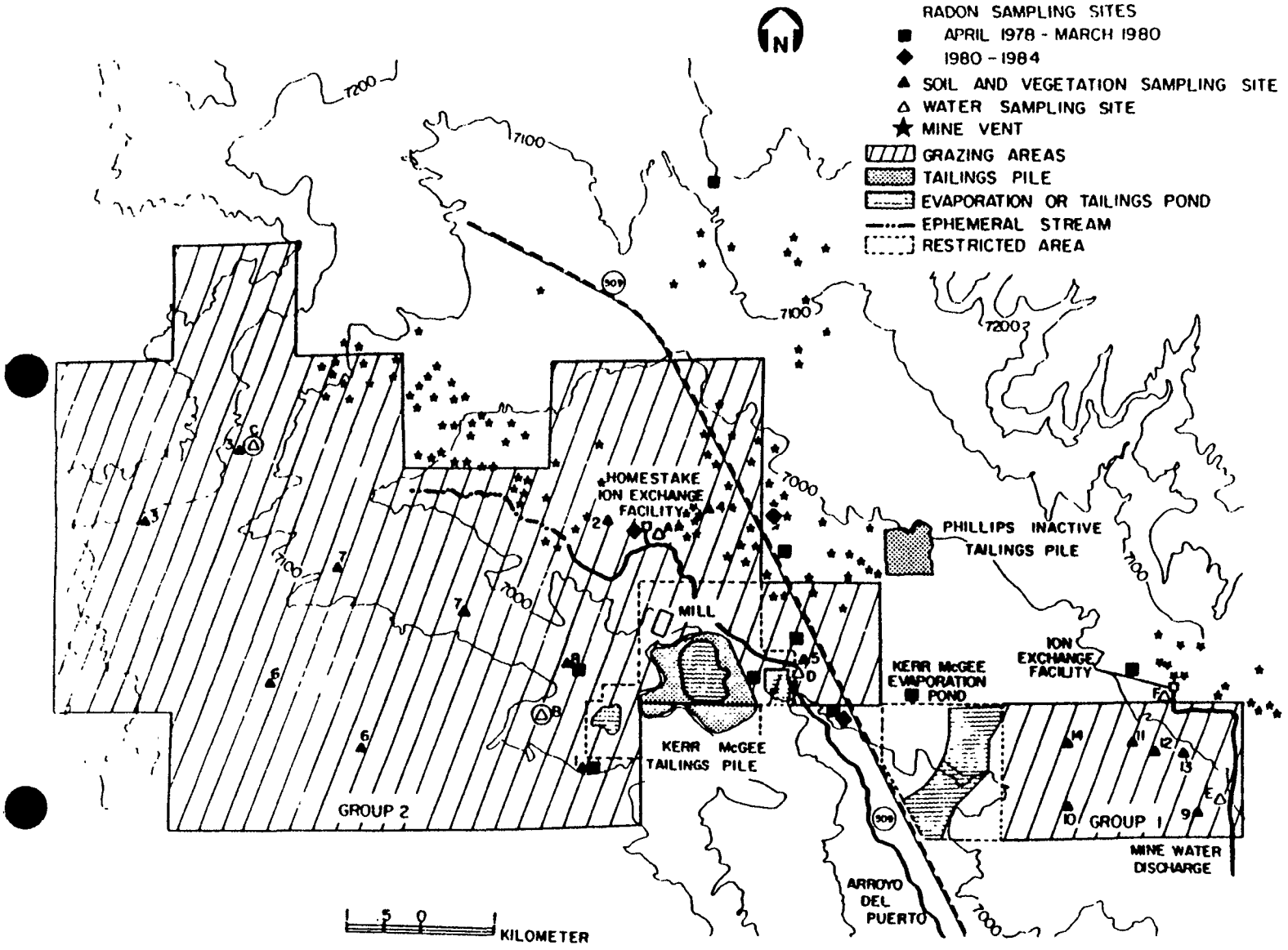

Figure 2. Cattle grazing areas and environmental sampling sites, Ambrosia Lake, New Mexico.

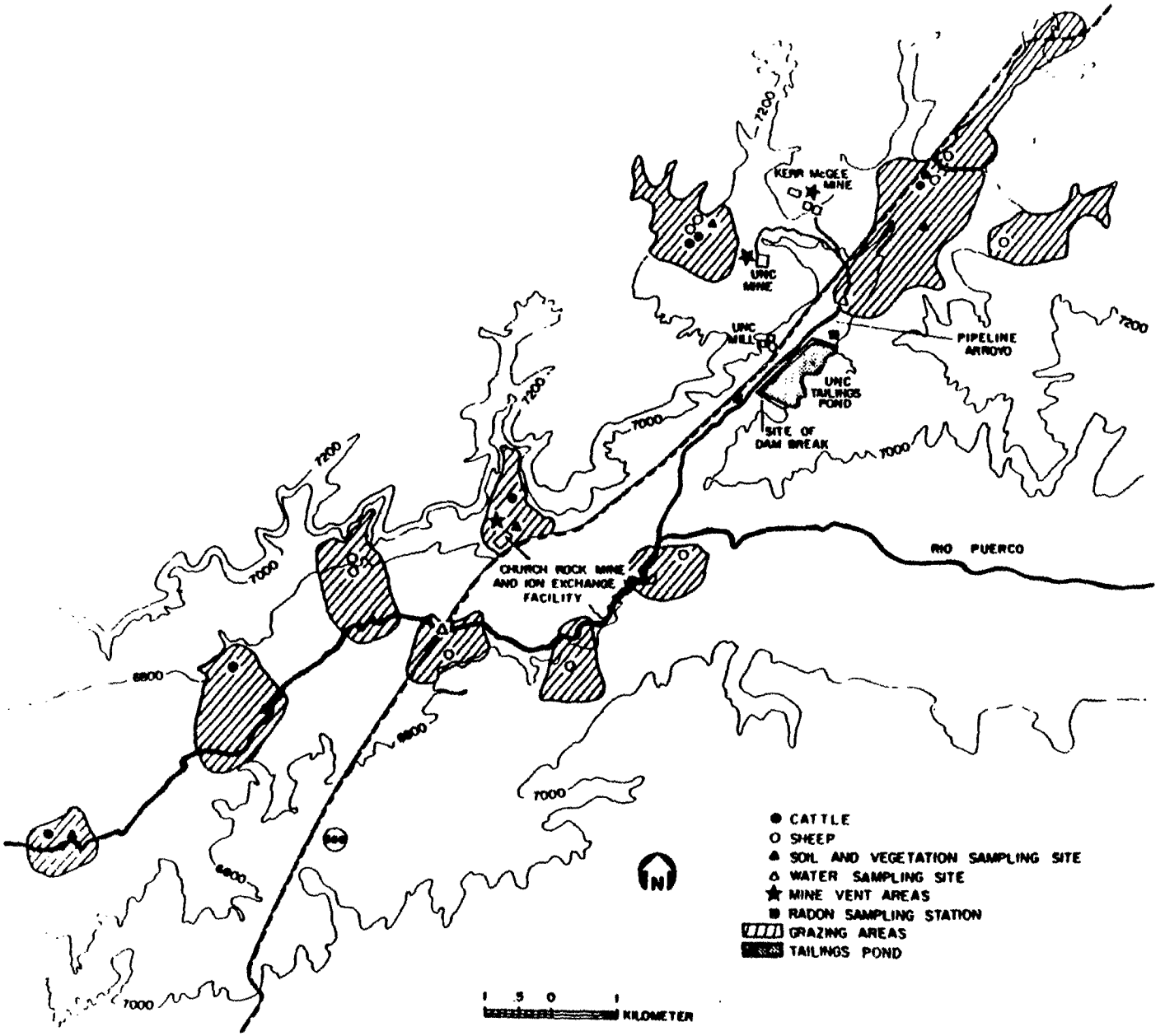

Figure 1. Cattle grazing areas and environmental sampling sites, Church Rock, New Mexico.

TABLE 1. Approximate sample weights and lower limits of detection (LLD) for radionuclide analysis of cattle tissue, vegetation, soil, and water.

Radionuclide	Liver, Muscle		Kidney		Bone	
	wet. wt. (g)	LLD (pCi/kg)	Wet wt. (g)	LLD (pCi/kg)	Wet. Wt. (g)	LLD (pCi/kg)
U-234, U-238	200	0.2	40	1.0	50	0.8
Th-230	200	0.2	40	1.0	50	0.8
Ra-226	100	0.2	20	1.0	100	0.2
Pb-210	500	1.0	200	2.5	200	2.5
Po-210	500	1.0	200	2.5	200	2.5

Radionuclide	Vegetation		Soil		Water	
	dry wt. (g)	LLD (pCi/gm)	dry wt. (g)	LLD(pCi/gm)	wet wt. (l)	LLD (pCi/l)
U-234, U-238	5	0.01	4	0.01	0.5	0.1
Th-230	5	0.01	4	0.01	0.5	0.1
Ra-226	5	0.01	1	0.05	0.5	0.1
Pb-210	20	0.05	10	0.10	1	1.0
Po-210	20	0.01	10	0.01	1	0.1

TABLE 7. Mean radionuclide concentrations in edible tissues and femurs from exposed and control cattle.

Exposure Group	Radionuclide Concentration (pCi/kg wet wt. ± standard error of the mean)					
	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210
Ambrosia Lake Group 1 (n=5)						
Muscle	0.8 ± 0.2	0.8 ± 0.3	0.7 ± 0.2	4.0 ± 1.6[ac]	2.2 ± 1.1	92 ± 15[ac]
Liver	5.2 ± 0.6[ac]	5.3 ± 0.5[ac]	4.7 ± 2.1[b]	12.4 ± 4.5[ac]	91 ± 87	1521 ± 458[ac]
Kidney	11.0 ± 1.9[ac]	11.2 ± 2.1[ac]	16.3 ± 5.7[ab]	117 ± 43[ac]	79 ± 23	1770 ± 502[ab]
Femur	87 ± 25[b]	94 ± 30[b]	10 ± 5.4[a]	7100 ± 2119[ac]	1132 ± 244	1436 ± 1359
Ambrosia Lake Group 2 (n=5)						
Muscle	0.5 ± 0.2	0.8 ± 0.2	0.26 ± 0.04	0.2 ± 0.4	2.1 ± 0.9	8.3 ± 3.6
Liver	1.8 ± 0.9[b]	1.6 ± 0.7[b]	1.1 ± 0.2	0.3 ± 0.3	10.2 ± 7.3	334 ± 124
Kidney	7.0 ± 2.5[ac]	7.2 ± 2.7[ab]	5.0 ± 1.0[b]	23 ± 9[b]	345 ± 141[a]	847 ± 189
Femur	166 ± 78[ab]	175 ± 70[ac]	5.4 ± 3.4	3860 ± 1078[ac]	952 ± 361	2353 ± 1831
Church Rock (n=7)						
Muscle	1.4 ± 0.5	1.9 ± 0.4[a]	0.9 ± 0.4	0.8 ± 0.2	0.4 ± 0.7	16.8 ± 3.8
Liver	1.4 ± 0.4[b]	1.9 ± 0.5[ab]	3.5 ± 1.4	0.3 ± 0.2	1.0 ± 0.7	175 ± 53
Kidney	2.6 ± 0.6	2.9 ± 0.6	5.8 ± 1.8	8.9 ± 3.1	84 ± 19	818 ± 201
Femur	101 ± 39[b]	100 ± 38[b]	1.6 ± 0.5	2690 ± 1258[b]	771 ± 310	2192 ± 995
Crownpoint Control (n=10)						
Muscle	0.7 ± 0.2	0.8 ± 0.1	0.4 ± 0.1	0.3 ± 0.2	2.4 ± 1.5	14.0 ± 3.4
Liver	0.4 ± 0.1	0.4 ± 0.1	1.6 ± 1.3	0.3 ± 0.2	6.8 ± 3.8	249 ± 56
Kidney	1.3 ± 0.3	1.5 ± 0.5	2.3 ± 0.8	4.6 ± 1.8	81 ± 15	455 ± 147
Femur	6.6 ± 4.0	7.1 ± 2.6	2.3 ± 1.0	152 ± 52	411 ± 74	288 ± 187

[a] Significantly ($p < .05$) higher than Crownpoint control, analysis of variance, Duncan's multiple range test
[b] Significantly ($p < .05$) higher than Crownpoint control, Wilcoxon's two-sample test
[c] Significantly ($p < .003$) higher than Crownpoint control, Wilcoxon's two-sample test

TABLE 3. Mean radionuclide concentrations in vegetation, soil, and water.

Exposure Group	Type of Sample (n)	Radionuclide Concentration (pCi/gm dry wt; water, pCi/l ± standard error of the mean)					
		U-238	U-234	Th-230	Ra-226	Pb-210	Po-210
Ambrosia Lake Group 1	Vegetation (5)	1.5 ± 1.0	1.6 ± 1.1	0.9 ± 0.3[b]	3.4 ± 1.5[b]	0.6 ± 0.1	3.4 ± 1.3
	Soil (6)	30 ± 20[b]	34 ± 22[b]	115 ± 63[ab]	514 ± 311[a]	590 ± 437[b]	398 ± 224[ab]
	Water (2)	670 ± 20[a]	770 ± 10[a]	0.2 ± 0.05	2.0 ± 0	7.0 ± 3.0	16 ± 12
Ambrosia Lake Group 2	Vegetation (8)	1.1 ± 0.5	1.0 ± 0.5	3.4 ± 1.9[b]	1.7 ± 0.8[b]	5.0 ± 2.5	3.0 ± 1.3
	Soil (8)	4.0 ± 1.9	4.5 ± 2.3	15 ± 9	8.4 ± 4.2	13 ± 6	1.8 ± 0.8
	Water (4)	79 ± 74	77 ± 71	1.2 ± 0.7	1.4 ± 0.9	6.5 ± 1.5	17 ± 11
Church Rock	Vegetation (5)	0.3 ± 0.2	0.3 ± 0.2	0.22 ± 0.008	2.0 ± 1.5	0.5 ± 0.3	2.7 ± 2.1
	Soil (5)	1.7 ± 0.6	1.8 ± 0.6	2.9 ± 0.9	2.9 ± 1.2	4.1 ± 1.5	4.1 ± 1.5
	Water (2)	515 ± 75[a]	530 ± 60[a]	0.7 ± 0.1	0.9 ± 0.2	2.5 ± 0.5	0.8 ± 0.6
Crownpoint Control	Vegetation (4)	0.2 ± 0.06	0.2 ± 0.05	.05 ± 0.03	0.08 ± 0.03	1.0 ± 0.1	0.4 ± 0.2
	Soil (4)	0.8 ± 0.1	0.7 ± 0.1	0.9 ± 0.2	0.8 ± 0.1	2.3 ± 0.6	1.9 ± 0.4
	Water (2)	0.9 ± 0.6	1.0 ± 0.5	0.2 ± 0.1	2.3 ± 0.7	5.0 ± 0	2.0 ± 2.0

[a] Significantly ($p < .05$) higher than Crownpoint control, analysis of variance, Duncan's multiple range test
[b] Significantly ($p < .05$) higher than Crownpoint control, Wilcoxon's two-sample test

TABLE 4. Dose to human target organs from ingestion of cattle tissue assuming Scenario 1[a] conditions.

Exposure Group I	Nuclide	Target Organs (50 year dose commitments in mrem, per year of ingestion) Kidney	Liver	Endosteum	Red Marrow
Ambrosia Lake Group 1	U-238	.131	.00071	.305	.020
	U-234	.152	.00076	.355	.023
	Th-230	.00021	.0019	1.12	.086
	Ra-226	.160	.160	12.12	1.07
	Pb-210	5.06	11.65	40.51	2.79
	Po-210	123.8	21.07	3.95	3.95
	Total	129	33	58	7.9
Ambrosia Lake Group 2	U-238	.081	.00046	.196	.013
	U-234	.129	.00070	.311	.019
	Th-230	.00008	.00063	.370	.029
	Ra-226	.015	.016	1.20	.106
	Pb-210	6.41	14.74	51.29	3.53
	Po-210	24.68	4.20	.784	.788
	Total	31	19	54	4.5
Church Rock	U-238	.166	.00094	.401	.027
	U-234	.260	.0014	.624	.039
	Th-230	.00021	.0019	1.10	.084
	Ra-226	.024	.024	1.79	.158
	Pb-210	1.43	3.30	11.46	.788
	Po-210	26.25	4.47	.837	.837
	Total	28	7.8	16	1.9
Crownpoint Control	U-238	.079	.00044	.188	.013
	U-234	.104	.00057	.249	.016
	Th-230	.00010	.00087	.510	.039
	Ra-226	.009	.0092	.661	.059
	Pb-210	3.06	7.03	24.45	1.68
	Po-210	21.61	3.68	.690	.690
	Total	25	11	27	2.5

a Scenario 1 assumes an annual ingestion of 74 kg muscle, 2.7 kg liver, and 1.3 kg kidney.

TABLE 5 Dose to human target organs from ingestion of cattle tissue assuming Scenario 2 and 3 conditions.

Scenario 2	Target Organs (50 year dose commitments in mrem per year of ingestion)			
Location	Kidney	Liver	Endosteum	Red Marrow
Ambrosia Lake Group 1	69.3	15.5	24.5	3.9
Ambrosia Lake Group 2	7.9	4.8	14.4	1.2
Church Rock	13.1	2.8	6.3	0.8
Crownpoint Control	12.4	6.1	16.9	1.5

Scenario 3	Target Organs (50 year dose commitments in mrem per year of ingestion)			
Location	Kidney	Liver	Endosteum	Red Marrow
Ambrosia Lake Group 1	300	84.0	153	19.0
Ambrosia Lake Group 2	78.6	38.1	98.2	8.8
Church Rock	54.4	14.7	26.6	3.4
Crownpoint Control	54.7	18.9	39.7	4.2

a This scenario assumes an annual ingestion of 78 kg of muscle (no liver or kidney).

b This scenario assumes an annual ingestion of 62.3 kg muscle, 13.1 kg liver, 2.6 kg kidney.

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APPENDIX A.

Quality Control Comparisons.

Split samples of muscle, liver, and kidney from six cattle were analyzed for each radionuclide by both laboratories. Eleven analyses were not completed by EPA-Las Vegas due to technical problems. Thus, 97 pairs of split sample results were compared. A range, consisting of the reported radionuclide concentration $\pm$ the counting error, was calculated. The ranges overlapped for 56 (58%) of the pairs. For statistical comparison, paired results were grouped by radionuclide and analyzed (Table A-1) using a two-tailed, paired-sample t-test (1).

Differences between polonium-210 values reported by the two laboratories were significant statistically. Mean polonium values reported by Eberline for muscle, liver, and kidney were 1.7, 2.4, and 1.7 times higher, respectively, than those reported by EPA-Las Vegas (Table A-2). None of the paired-sample t-tests for the remaining radionuclides were significant statistically at the $p<0.05$ level of significance.

Since Po-210 is the radionuclide that contributed most to the internal dose received from eating cattle, this discrepancy between the two laboratories is of concern. Eberline Laboratory reported consistently higher values for Po-210, although the methods used by both laboratories in determining Po-210 activity were the same. Both laboratories, moreover, analyzed the tissues for Po-210 several months after the samples were collected. Thus, laboratory delays in performing Po-210 analyses may have contributed to

errors in Po-210 measurements. Po-210 has a short half life (138 days) (2). Both laboratories separated the muscle for Pb-210 and Po-210, 110 days, almost one half life, after the animals were sacrificed. Eberline performed the analyses on liver samples 318, and in one sample 354, days after collection, and on kidney samples 195 or 200 days post collection. EPA-Las Vegas analyzed liver and kidney 129 and 101 days after collection, respectively. Although the Po-210 concentrations were corrected for ingrowth from Pb-210 and for Po-210 decay, performance of laboratory analyses several half-lives after sample collection and mathematical correction of the concentrations to the separation date could introduce error into the results when there is low specific activity in the tissues.

In order to evaluate the differences noted between Po-210 measurements by the two laboratories, we compared Po-210/Pb-210 ratios reported in this investigation with Po-210/Pb-210 ratios reported for femurs and soft tissues elsewhere in the literature. Po-210/Pb-210 ratios in human bone have been reported to approximate 1.0 (3). However, reported Po-210/Pb-210 ratios in animal femurs have not been found to equal one consistently. In two previous reports, Po-210/Pb-210 ratios in animal femurs ranged from 0.84 to 23.8 (Table A-3). Average Po-210/Pb-210 ratios in femurs reported by Eberline Laboratory in the present study were from 1.3 to 15.1 in cattle from the three exposed groups and 0.8 among femurs from control cattle (Table A-4). In some cases, these averages are small numbers primarily because of very low corrected Po-210 concentrations. For example, 6 of 10 individual measurements in control femurs had corrected Po-210 values of zero (Appendix B). EPA-Las Vegas did not perform radiochemical analyses of bone in the present study.

It has been suggested by Osborne that Po-210 may be concentrated in the soft tissues, particularly liver and kidney, of humans and animals, the Po-210 being measurably in excess of Pb-210 (2). He reported Po-210/Pb-210 ratios for the human liver and kidney of 1.8 to 8.9 (Table A-3). Polonium-210/Pb-210 ratios reported for livers and kidneys of cattle raised in a rural area averaged 2.6 and 4.1 respectively (5), while ratios in cattle, sheep, and goats exposed to products of the uranium mining and milling industry in previous reports (4, 6) ranged from 0.2-26 in liver and 0.65-8.95 in kidney (Table A-3). Most of the averaged Po-210/Pb-210 ratios for muscle, liver, and kidney calculated from values reported by Eberline Laboratory were much higher values than those reported previously and were also higher than those reported by EPA-Las Vegas (Table A-4). This casts doubt on the accuracy of either the Pb-210 or the Po-210 measurements performed by Eberline Laboratory.

The Po-210 concentrations reported by Eberline Laboratory for the exposed and control cattle were higher, both when compared to EPA-Las Vegas' measurements and when compared to other published reports. Thus, it is probable that the Po-210 measurements were in error. Eberline Laboratory's reported values were approximately twice those of EPA-Las Vegas. Thus, the true values for Po-210 may have been half those reported in Table 2.

TABLE A-1. Differences between radionuclide concentrations reported by two laboratories for split samples of muscle, liver, and kidney tissue.

Radionuclide	(N)	Mean Difference [a]	SEM [b]	t value	t value required for statistical significance $t_{0.05(2)}$, df=N-1
U-238	(16)	-0.9	0.71	-1.27	±2.13
U-234	(16)	-0.53	0.77	-0.69	±2.13
Th-230	(16)	1.5	1.09	1.38	±2.13
Ra-226	(18)	-7.54	5.11	-1.48	±2.11
Pb-210	(15)	6.49	18.63	0.32	±2.145
o-210	(16)	89.8	32.7	2.7[d]	±2.13

[a] Mean difference = $\frac{\text{(Eberline's reported value - EPA-Las Vegas' reported value}}{N}$

[b] Standard error of the mean

[c] $t = \frac{\text{mean difference}}{SEM}$

[d] Significant at $p < 0.02$

TABLE A-2. **Mean radionuclide concentrations reported by two laboratories for split samples of muscle, liver, and kidney.**

		Mean Radionuclide Concentrations ±SEM (pCi/kg wet wt)[a]					
Laboratory	Tissue	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210[b]
Eberline	Muscle	0.53± 0.09(6)[c]	0.92± .17(6)	0.57±0 0.20(6)	2.4±1.5(6)	1.5±0.8(5)	15± 8(6)
EPA-Las Vegas		0.23± 0.06(6)	0.21± .05(6)	0.34± 0.11(6)	2.6± 1.8(6)	2.4± 0.2(5)	8.7± 3.5(6)
Eberline	Liver	1.2± 0.8(4)	1.4± 0.9(4)	2.8± 1.8(4)	6.2± 4.1(6)	88± 88(5)	159± 65(4)
EPA-Las Vegas		1.7± 1.1(4)	1.8± 1.3(4)	1.1± 0.8(4)	13.2±9.5(6)	66± 38(5)	67± 42(4)
Eberline	Kidney	4.4± 2.0(6)	5.3± 2.3(6)	8.2± 2.6(6)	33± 20(6)	62± 14(5)	408± 108(6)
EPA-Las Vegas		6.0± 3.6(6)	7.1± 3.0(6)	7.7± 3.8(6)	49± 33(6)	63± 19(5)	235±80(6)

[a]Standard error of the mean

[b]Eberline's Po-210 reported values were corrected for radioactive decay and for the ingrowth from Pb-210, to EPA-Las Vegas' (earlier) separation date.

[c]( ) indicates the number of samples within each mean

[redacted]LE A-3. Reported Po-210/Pb-210 ratios in liver, k[redacted]nd bone

Tissue Type	Animal	Po-210 Concentration (pCi/kg)	Pb-210 Concentration (pCi/kg)	Po-210/ Pb-210 Ratio	Author	Reference
Vertebra	Human	17 (average of 9 samples)		3.82 0.43	Osborne	2
Liver	Human	10 (average of 4 samples)		3.1 1.8		
Kidney	Human	7.1 (average of 2 samples)		8.9 4.1		
Femur	Cattle				Holtzman et al.	4
Exposed[a]		Cow 1 6600 (pCi/kg ash)	7000 (pCi/kg ash)	0.94		
		Cow 2 -	3080 (pCi/kg ash)	-		
Control		Cow 3 8330 (pCi/kg ash)	3550 (pCi/kg ash)	2.35		
		Cow 4 1700 (pCi/kg ash)	2020 (pCi/kg ash)	0.84		
Muscle						
Exposed[a]		Cow 1 36	9.5	3.79		
		Cow 2 60	1.8	33.3		
Control						
		Cow 3 80	28	2.86		
		Cow 4 330	2.6	126.92		
Liver						
Exposed[a]		Cow 1 230	209	1.10		
		Cow 2 340	73	4.66		
Control		Cow 3 -	31	-		
		Cow 4 -	12	-		
Kidney						
Exposed [a]		Cow 1 685	420	1.63		
		Cow 2 270	41	6.59		
Control		Cow 3 1800	260	6.92		
		Cow 4 -	330	-		
Liver	Cattle			2.58 average for 27 cattle not exposed to traffic or industry (range 1.1-9.1)	Bunzel et al.	5
Kidney	Cattle			4.13 average for 32 cattle not exposed to traffic or industry (range 1.8-9.2)		
Femur						
Exposed[b]	Cattle	300	72	4.17	Ruttenber et al.	6
Exposed[b]	Sheep	1000	230	4.35		
Control-1		1800	870	2.07		
Control-2		760	32	23.75		
Exposed[b]	Goat	480	150	3.20		
Muscle						
Exposed[b]	Sheep	12	4.1	2.93		
	Sheep	11	26	.42		
Liver						
Exposed[b]	Cow	56	5.4	10.37		
	Cow	130	44	2.95		
Control-1		29	1.1	26.36		
Control-2		25	7.6	3.29		
Exposed[b]	Sheep	50	290	0.17		
	Sheep	29	43	0.67		
	Sheep	17	26	0.65		
Exposed[b]	Goat	72	210	0.34		
Kidney						
Exposed[b]	Cow	260	56	4.64		
Exposed[b]		650	130	5.0		
Control		160	44	3.64		
Exposed[b]	Sheep	460	710	0.65		
Exposed[b]	Sheep	150	28	5.36		
Exposed[b]	Sheep	220	72	3.06		
Control-1	Sheep	200	80	2.50		
Control-2	Sheep	170	19	8.95		
Exposed[b]	Goat	540	470	1.15		

[a]Exposed cattle grazed near Anaconda mill in New Mexico
[b]Exposed cattle were from Church Rock, New Mexico

TABLE A-4. Po-210 to Pb-210 ratios in muscle, liver, and kidney tissue reported by two laboratories.

		Eberline[a]	EPA-Las Vegas[b]
Ambrosia Lake Group 1	Muscle	58	
	Liver	641	6.5, 7.2
	Kidney	29.5	2.6 -
	Femur	1.3	6, 4.3
Ambrosia Lake Group 2	Muscle	11.8	
	Liver	247	
	Kidney	5.3	
	Femur	15.1	
Church Rock	Muscle	54.2	
	Liver	220	1.0 -
	Kidney	16.5	2.2 -
	Femur	4.8	3.4, 4.6
Crownpoint	Muscle	13.5	
	Liver	190	1.3, 1.4
	Kidney	9.8	- 1.2
	Femur	0.8	- 2.2

[a]Determined by averaging the individual Po-210/Pb-210 ratios for tissues from each animal. All negative and zero numoers for Po-210 or Pb-210 concertrations were set to equal one.

[b]Individual determinations

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LOC=Ambrosia Lake Group 1

OBS	ID1	SEX	AGE	MU234M	MU234E	MU238M	MU238E	MTH230M	MTH230E	MRA226M	MRA226E	MPB210M	MPB210E	MPO210M	MPO210E	MWETWT	MDRYWT	MCARD	ID2	LU234M	LU234E	LU238M	LU238E
1	C02	F	5	0.6	0.3	0.2	0.2	0.4	0.2	1.7	0.7	1.2	1.6	136.611	4.0774	1703	411	1	C02	4.0	0.8	3.5	0.8
2	C03	F	5	1.3	0.7	0.7	0.8	1.4	1.0	10.0	1.0	3.0	2.0	73.822	4.6328	2387	658	1	C03	5.0	0.7	4.3	0.7
3	C07	F	6	1.3	1.1	1.2	1.2	0.8	0.2	3.1	1.1	1.0	1.7	68.989	4.2111	2533	588	1	C07	7.0	0.8	6.3	0.7
4	C14	F	5	0.8	0.5	0.5	0.5	0.5	0.2	4.1	0.7	6.0	4.0	116.482	7.8597	1915	486	1	C14	6.1	1.3	5.6	1.3
5	C23	F	4	-0.1	0.6	1.2	1.2	0.4	0.2	1.1	0.4	-0.4	6.8	63.056	12.7813	1538	404	1	C23	4.5	1.3	6.5	1.5

OBS	LTH230M	LTH230E	LRA226M	LRA226E	LPB210M	LPB210E	LPO210M	LPO210E	LWETWT	LDRYWT	LCARD	ID3	KU234M	KU234E	KU238M	KU238E	KTH230M	KTH230E	KRA226M	KRA226E	KPB210M
1	2.4	0.3	7.3	0.7	-2.9	4.6	1082.68	104.001	2262	569	2	C02	7.3	2.6	7.3	2.7	8.0	1.4	31	2	71
2	13.0	1.0	26.0	3.0	440.0	20.0	1113.08	197.321	1334	341	2	C03	16.0	4.0	13.0	4.0	19.0	7.0	130	10	53
3	3.8	0.5	6.0	0.6	3.4	3.0	932.25	99.567	2410	664	2	C07	15.0	3.0	16.0	3.0	37.0	7.0	260	10	10
4	3.0	0.6	20.0	2.0	1.9	2.2	3349.02	98.004	2005	507	2	C14	5.6	2.1	5.6	2.0	12.0	4.0	140	10	130
5	1.3	0.2	2.7	0.6	14.0	2.0	1129.38	97.686	1956	523	2	C23	12.0	3.0	13.0	3.0	5.4	3.8	25	4	130

OBS	KPB210E	KPO210M	KPO210E	KWETWT	KDRYWT	KCARD	BU234M	BU234E	BU238M	BU238E	BTH230M	BTH230E	BRA226M	BRA226E	BPB210M	BPB210E	BPO210M	BPO210E	BWETWT	BDRYWT	BCARD	MPO210
1	13	3429.08	61.8271	531	104	3	20	15	23	18	6	7	5500	100	1200	100	238.46	1291.05	965	614	4	.
2	13	1830.29	61.8271	392	76	3	180	20	160	20	11	6	15000	999	1900	100	0.00	986.60	1350	717	4	.
3	11	403.01	57.2581	397	81	3	150	20	130	20	30	15	7500	100	1100	100	0.00	1291.05	770	502	4	.
4	10	2007.73	55.1403	512	99	3	52	9	49	9	4	2	4800	100	1100	100	6869.23	1291.05	936	556	4	.
5	20	1178.03	80.2563	319	69	3	68	9	73	9	-1	5	2700	100	360	20	71.54	602.10	871	483	4	.

Prefix Letter:
M=muscle
L=liver
K=kidney
B=femur

Letter following each radionuclide:
M=Individual measurement in picocuries per kilogram wet weight
E=counting error, (2 standard deviations)

LOC=Ambrosia Lake Group 2

OBS	ID1	SEX	AGE	MU234M	MU234E	MU238M	MU238E	MTH230M	MTH230E	MRA226M	MRA226E	MPB210M	MPB210E	MPO210M	MPO210E	MWETWT	MDRYWT	MCARD	ID2	LU234M	LU234E	LU238M	LU238E
6	C04	F	2	0.4	0.4	0.2	0.3	0.2	0.1	-0.8	0.6	1.5	1.5	7.7323	3.09271	2472	440	1	C04	0.9	0.4	0.7	0.3
7	C10	F	3	0.9	0.7	0.1	0.6	0.3	0.3	1.2	0.2	0.8	1.2	17.5139	2.61606	2033	562	1	C10	1.3	0.2	1.1	0.2
8	C16	F	2	1.3	1.2	1.0	1.1	0.2	0.2	-0.3	0.3	2.4	1.3	9.1989	2.63844	2830	842	1	C16	0.8	0.7	1.5	0.9
9	C19	F	2	0.5	0.3	0.6	0.3	0.2	0.2	0.1	0.4	0.4	1.0	11.1649	2.31639	1914	486	1	C19	0.6	0.3	0.4	0.3
10	C21	F	3	1.1	0.6	0.8	0.4	0.4	0.2	0.9	0.3	5.6	1.6	-4.3150	3.05324	2280	573	1	C21	4.2	1.2	5.5	1.4

OBS	LTH230M	LTH230E	LRA226M	LRA226E	LPB210M	LPB210E	LPO210M	LPO210E	LWETWT	LDRYWT	LCARD	ID3	KU234M	KU234E	KU238M	KU238E	KTH230M	KTH230E	KRA226M	KRA226E	KPB210M	KPB210E
6	0.9	0.2	0.6	0.5	2.8	2.2	562.415	21.2533	1398	370	2	C04	5.2	1.4	4.6	1.3	2.5	0.9	14	2	55	11
7	1.8	0.4	-0.6	0.3	5.9	1.8	468.400	24.7045	1867	511	2	C10	5.0	2.0	3.8	1.8	7.7	3.4	14	1	320	20
8	1.0	0.3	1.1	0.5	2.6	2.4	0.000	20.8772	1228	337	2	C16	4.7	1.8	4.3	1.6	3.3	1.5	9	2	210	30
9	0.8	0.2	0.0	0.3	39.0	8.0	67.846	71.5557	1569	432	2	C19	2.9	1.9	5.2	3.3	4.3	1.4	19	2	260	30
10	1.2	0.4	0.3	0.4	0.6	2.6	571.754	29.5226	2930	880	2	C21	18.0	3.0	17.0	3.0	7.1	2.8	60	3	880	40

OBS	KPO210M	KPO210E	KWETWT	KDRYWT	KCARD	BU234M	BU234E	BU238M	BU238E	BTH230M	BTH230E	BRA226M	BRA226E	BPB210M	BPB210E	BPO210M	BPO210E	BWETWT	BDRYWT	BCARD	MPO210
6	950.20	57.258	374	84	3	54	13	51	14	1	2	2100	100	130	10	9456.92	965.390	1245	757	4	.
7	1149.69	80.256	479	101	3	280	40	240	40	1	3	5600	100	660	20	0.00	258.210	1180	699	4	.
8	734.02	110.040	308	60	3	49	2	39	24	19	9	1400	100	770	30	2308.46	811.491	1054	582	4	.
9	172.66	110.040	326	64	3	91	20	62	21	4	18	3100	100	900	20	0.00	510.714	1100	640	4	.
10	1229.34	141.575	453	90	3	400	30	440	30	2	6	7100	100	2300	100	0.00	943.492	1221	733	4	0

LOC= Crownpoint

OBS	ID1	SEX	AGE	MU234M	MU234E	MU238M	MU238E	MTH230M	MTH230E	MRA226M	MRA226E	MPB210M	MPB210E	MPO210M	MPO210E	MWETWT	MDRYWT	MCARD	ID2	LU234M	LU234E	LU238M
11	C01	F	4	0.9	0.7	0.4	0.6	0.3	0.2	0.6	0.9	0.9	1.2	5.9992	2.35792	1564	43	1	C01	0.2	0.2	0.0
12	C05	F	6	0.4	0.3	0.5	0.3	0.1	0.2	0.8	0.5	3.5	2.1	4.6331	3.94172	2060	530	1	C05	0.3	0.1	0.2
13	C12	F	5	1.5	0.7	1.3	0.9	0.4	0.3	0.9	0.5	0.7	1.7	7.7822	3.22969	1990	475	1	C12	1.0	0.7	0.9
14	C13	F	7	1.5	0.4	1.6	0.5	1.3	0.3	1.0	0.4	15.0	5.0	26.3314	9.59216	2440	590	1	C13	0.4	0.1	0.2
15	C18	F	3	0.6	1.0	0.5	0.7	0.2	0.2	0.3	0.2	0.7	0.9	8.6320	2.00128	2084	583	1	C18	0.8	0.3	1.1
16	C22	F	3	0.2	0.8	-0.1	0.7	0.3	0.1	-0.4	0.2	0.3	1.4	12.4813	2.93098	2830	672	1	C22	0.4	0.2	0.8
17	C24	F	5	0.8	1.6	0.8	2.0	0.6	0.2	-0.6	0.2	0.0	2.0	10.4816	3.83687	2223	611	1	C24	0.3	0.5	0.1
18	C25	F	7	0.7	0.5	0.5	0.5	0.4	0.2	-0.3	0.2	4.8	1.3	18.1144	2.77194	2253	527	1	C25	0.4	0.1	0.4
19	C26	F	4	0.6	0.5	0.5	0.6	0.4	0.2	0.1	0.2	-0.6	1.4	6.7654	2.80507	3868	1026	1	C26	-0.1	0.2	0.3

OBS	LU238E	LTH230M	LTH230E	LRA226M	LRA226E	LPB210M	LPB210E	LPO210M	LPO210E	LWETWT	LDRYWT	LCARD	ID3	KU234M	KU234E	KU238M	KU238E	KTH230M	KTH230E	KRA226M
11	0.1	0.1	0.1	1.0	0.4	1.3	1.8	152.262	18.247	1061	269	2	C01	3.5	2.0	1.6	1.7	1.9	1.6	3.5
12	0.1	0.5	0.2	1.5	0.5	-0.5	1.8	456.231	18.247	902	240	2	C05	0.8	0.6	0.4	0.4	8.3	2.3	15.0
13	0.8	0.5	0.5	0.1	1.2	14.0	7.0	214.000	54.600	2101	547	2	C12	-0.3	0.9	0.3	0.7	1.3	0.9	3.3
14	0.2	0.2	0.1	-0.2	0.4	-0.1	1.2	7.592	10.733	1988	559	2	C13	0.4	0.2	0.3	0.2	1.1	0.7	1.9
15	0.3	0.5	0.2	0.0	0.3	-0.2	1.1	444.031	13.501	1669	474	2	C18	2.4	0.8	2.6	0.8	4.4	1.2	13.0
16	0.6	0.2	0.1	0.5	0.3	1.1	2.3	432.831	22.025	1734	474	2	C22	0.3	1.1	0.8	0.9	1.5	1.4	-2.0
17	0.5	13.0	2.0	-0.1	0.4	38.0	20.0	0.000	172.351	1492	388	2	C24	1.7	1.3	1.7	1.3	1.0	0.5	1.1
18	0.1	0.5	0.2	-0.3	0.6	4.8	3.1	227.877	28.386	1689	458	2	C25	1.4	1.0	1.9	1.1	-0.3	1.8	7.6
19	0.2	0.5	0.4	-0.1	0.2	10.0	7.0	154.231	61.069	2667	754	2	C26	0.6	0.5	0.5	0.6	2.0	1.1	2.4

OBS	KRA226E	KPB210M	KPB210E	KPO210M	KPO210E	KWETWT	KDRYWT	KCARD	BU234M	BU234E	BU238M	BU238E	BTH230M	BTH230E	BRA226M	BRA226E	BPB210M	BPB210E	BPO210M	BPO210E	BWETWT	BDRYWT	BCARD	MPO210
11	0.8	39	18	1091.40	74.697	388	80	3	13	10	-4	6	5	4	170	10	190	20	190.00	421.449	890	524	4	.
12	3.0	32	13	1245.97	61.827	365	84	3	6	5	11	7	-1	3	580	10	530	10	626.15	394.147	1036	617	4	.
13	1.5	100	10	73.80	34.782	493	98	3	4	2	1	4	4	4	76	3	400	20	0.00	336.006	1144	701	4	.
14	0.4	54	7	473.21	49.622	448	98	3	10	7	-1	3	10	6	120	10	980	30	0.00	387.314	975	538	4	.
15	2.0	150	30	281.00	110.040	366	74	3	-2	3	-1	2	1	15	210	10	530	20	0.00	694.782	877	506	4	.
16	1.0	160	30	29.00	110.040	362	81	3	27	13	40	16	1	3	140	10	160	20	0.00	336.006	922	510	4	.
17	0.7	59	12	893.06	59.491	314	71	3	5	4	11	6	2	3	32	3	310	20	0.00	421.449	1502	876	4	.
18	1.1	110	20	415.68	80.256	400	83	3	1	1	4	3	1	1	8	1	280	30	183.85	545.840	1112	610	4	.
19	1.5	37	49	23.90	165.205	485	94	3	5	3	4	3	0	2	130	10	390	30	0.00	463.391	1552	858	4	.

LOC= Crownpoint Cont.

ID1	SEX	AGE	MU234M	MU234E	MU238M	MU238E	MTH230M	MTH230E	MRA226M	MRA226E	MPB210M	MPB210E	MPO210M	MPO210E	MWETWT	MDRYWT	MCARD	ID2	LU234M	LU234E	LU238M
1	C27	F	4	0.7	0.7	0.7	0.7	0.3	0.4	0.3	0.2	-1	1.3	38.6601	3.70168	1791	454	1	C27	0.6	0.4	0.4

LU238E	LTH230M	LTH230E	LRA226M	LRA226E	LPB210M	LPB210E	LPO210M	LPO210E	LWETWT	LDRYWT	LCARD	ID3	KU234M	KU234E	KU238M	KU238E	KTH230M	KTH230E	KRA226M
4	0.5	0.4	0.3	0.3	-0.7	1.2	400.262	14.1188	1834	461	2	C27	4.1	1.5	3.3	1.5	1.8	1.8	-0.3

KRA226E	KPB210M	KPB210E	KPO210M	KPO210E	KWETWT	KDRYWT	KCARD	BU234M	BU234E	BU238M	BU238E	BTH230M	BTH230E	BRA226M	BRA226E	BPB210M	BPB210E	BPO210M	BPO210E	BWETWT	BDRYWT	BCARD	MPO210
1	71	27	27.3319	92.5669	417	89	3	2	2	1	2	0	2	51	2	340	20	1878.46	510.714	1676	754	4	.

LOC= Church Rock

OBS	ID1	SEX	AGE	MU234M	MU234E	MU238M	MU238E	MTH230M	MTH230E	MRA226M	MRA226E	MPB210M	MPB210E	MPO210M	MPO210E	MWETWT	MDRYWT	MCARD	ID2	LU234M	LU234E	LU238M	LU238E
21	C06	F	2	0.8	0.5	0.8	0.5	0.3	0.3	1.4	0.4	-1.2	4.1	7.5819	7.56263	1413	455	1	C06	1.2	0.6	0.9	0.6
22	C09	F	2	3.3	1.6	3.8	1.8	1.5	0.4	1.0	0.6	-1.2	1.3	9.5649	2.52975	2790	723	1	C09	3.0	0.9	2.3	0.8
23	C11	F	2	3.6	1.0	3.0	1.0	2.9	0.7	0.8	0.4	3.9	1.2	24.0133	3.58615	2090	477	1	C11	0.8	0.4	0.5	0.4
24	C15	F	3	1.0	0.5	0.2	0.4	0.2	0.2	1.5	0.3	1.4	1.2	5.9326	2.35792	2055	466	1	C15	1.1	0.7	0.6	0.5
25	C17	F	5	1.5	0.7	0.6	0.7	0.9	0.2	0.1	0.3	0.3	1.3	12.7646	2.77194	1682	508	1	C17	1.5	0.9	1.1	0.8
26	C20	M	2	1.2	0.7	1.0	0.7	0.1	0.1	0.9	0.2	0.1	1.8	28.1453	4.34850	2434	650	1	C20	1.4	0.4	1.1	0.4
27	C28	F	2	2.2	1.1	0.5	1.5	0.5	0.2	-0.1	0.4	-0.6	1.3	29.4283	3.70168	2502	681	1	C28	4.2	0.8	3.0	0.8

OBS	LTH230M	LTH230E	LRA226M	LRA226E	LPB210M	LPB210E	LPO210M	LPO210E	LWETWT	LDRYWT	LCARD	ID3	KU234M	KU234E	KU238M	KU238E	KTH230M	KTH230E	KRA226M	KRA226E	KPB210M
21	8.0	1.0	1.1	0.4	3.0	3.3	253.000	30.0127	1103	279	2	C06	2.0	1.1	2.4	1.1	1.8	1.0	10.0	2.0	42
22	2.4	0.9	0.3	0.3	1.8	1.5	167.185	16.1078	2114	531	2	C09	3.0	1.7	2.6	1.5	5.7	1.7	3.8	1.0	22
23	0.2	0.1	0.2	0.3	0.4	1.1	371.554	13.5007	1776	445	2	C11	1.0	0.3	0.8	0.4	3.0	0.9	1.0	1.3	34
24	2.9	0.6	0.7	0.3	-1.0	2.5	143.231	23.5873	1962	490	2	C15	4.1	1.5	4.0	1.7	4.7	1.1	3.4	1.0	130
25	1.1	0.3	0.2	0.3	-0.2	1.9	280.569	25.2542	1435	378	2	C17	2.1	0.6	1.8	0.7	10.0	2.0	10.0	1.0	110
26	0.4	0.2	-0.6	0.4	3.4	3.5	0.000	30.2915	1236	308	2	C20	2.3	1.6	1.3	1.3	1.3	0.7	8.0	2.0	140
27	9.8	1.6	0.2	0.4	-0.3	1.1	7.392	9.9062	2313	593	2	C28	5.6	1.5	5.6	1.7	14.0	2.0	26.0	1.0	110

OBS	KPB210E	KPO210M	KPO210E	KWETWT	KDRYWT	KCARD	BU234M	BU234E	BU238M	BU238E	BTH230M	BTH230E	BRA226M	BRA226E	BPB210M	BPB210E	BPO210M	BPO210E	BWETWT	BDRYWT	BCARD	MPO210
21	15	644.62	66.764	394	84	3	35	10	41	10	2	12	49	3	190	10	1440.00	301.05	1153	680	4	.
22	28	1497.98	103.894	491	100	3	240	20	210	20	4	2	7200	100	1000	100	6769.23	1291.05	1043	605	4	.
23	24	82.03	81.859	628	126	3	34	9	23	7	1	1	270	10	730	20	0.00	258.21	1215	628	4	.
24	20	697.69	80.256	462	102	3	11	6	12	6	1	1	310	10	230	10	1480.00	301.05	1448	705	4	.
25	30	503.01	110.040	781	144	3	110	30	120	30	0	3	2100	100	540	20	4963.08	976.86	1202	723	4	.
26	40	751.35	141.575	367	80	3	30	14	29	16	1	7	1200	100	210	20	690.77	602.10	862	495	4	.
27	20	1551.05	80.256	437	87	3	240	40	270	40	2	1	7700	100	2500	300	0.00	2757.68	1157	716	4	.

LOC=Ambrosia Lake Group 1

OBS	ID	TYPE	COL_DATE	U234M	U234E	U238M	U238E	TH230M	TH230E	RA226M	RA226E	PB210M	PB210E	PO210M	PO210E	VOL_WET
1	W05	W	110483	780.0	20.0	690.0	20.0	0.2	0.1	2.0	1.0	4.0	1.0	28.4	3.1	3790
2	W06	W	110483	760.0	20.0	650.0	20.0	0.1	0.1	2.0	1.0	10.0	2.0	4.5	1.2	3790
3	S09	S	110483	2.0	0.2	1.8	0.2	1.8	0.1	0.7	0.2	4.4	0.4	5.6	0.8	1265
4	S10	S	110483	9.3	0.5	7.6	0.4	2.8	0.3	13.0	4.0	8.0	0.5	5.8	1.1	787
5	S11	S	110483	26.0	2.0	21.0	2.0	100.0	10.0	170.0	50.0	110.0	10.0	170.0	30.0	834
6	S12	S	110483	27.0	1.0	21.0	1.0	190.0	20.0	1100.0	300.0	710.0	70.0	1143.0	153.0	448
7	S13	S	110483	140.0	10.0	130.0	10.0	390.0	40.0	1800.0	500.0	2700.0	300.0	1058.0	333.0	401
8	S14	S	110983	0.9	0.1	1.0	0.1	4.1	0.1	1.1	0.3	6.2	0.4	3.1	0.6	985
9	V09	V	110483	0.3	0.1	0.3	0.0	0.1	0.1	0.3	0.1	0.6	0.2	0.6	0.2	290
10	V10	V	110483	0.6	0.1	0.5	0.1	1.5	0.2	2.0	1.0	0.2	0.1	3.5	0.4	123
11	V11	V	110483	0.9	0.1	0.9	0.1	1.0	0.1	8.0	2.0	0.6	0.2	8.3	1.7	129
12	V12	V	110483	5.9	0.3	5.6	0.3	0.6	0.1	6.0	2.0	0.6	0.2	3.1	0.4	222
13	V13	V	110983	0.3	0.1	0.3	0.1	1.5	0.1	0.9	0.3	1.1	0.3	1.3	0.3	67

LOC=Ambrosia Lake Group 2

OBS	ID	TYPE	COL_DATE	U234M	U234E	U238M	U238E	TH230M	TH230E	RA226M	RA226E	PB210M	PB210E	PO210M	PO210E	VOL_WET
14	N01	N	110983	290.0	20.0	300.0	20.0	0.2	0.1	-0.1	0.1	8.0	1.0	0.0	0.5	3360
15	N02	N	111083	16.0	3.0	13.0	3.0	0.2	0.2	0.6	0.2	4.0	1.0	0.0	0.5	3730
16	N03	N	111083	1.0	0.2	0.9	0.2	1.4	0.3	1.3	0.4	10.0	2.0	24.8	3.1	3690
17	N04	N	111083	0.2	0.2	0.1	0.2	3.0	1.0	4.0	1.0	4.0	1.0	43.9	4.5	3670
18	S01	S	111083	0.6	0.1	0.6	0.1	0.8	0.1	1.1	0.3	2.6	0.3	2.3	0.3	1084
19	S02	S	110983	19.0	1.0	16.0	1.0	60.0	2.0	32.0	3.0	40.0	4.0	6.5	3.4	734
20	S03	S	111083	2.6	0.1	2.6	0.1	1.8	0.1	2.0	1.0	1.8	0.3	1.1	0.2	1518
21	S04	S	110983	9.4	0.7	7.7	0.7	4.7	0.2	8.0	2.0	10.0	1.0	0.0	0.5	946
22	S05	S	111083	2.6	0.2	2.8	0.2	46.0	5.0	21.0	6.0	43.0	4.0	0.0	2.1	930
23	S06	S	111083	0.5	0.1	0.5	0.1	0.9	0.2	0.8	0.2	1.7	0.3	0.3	0.2	1791
24	S07	S	111083	0.6	0.1	0.6	0.1	0.7	0.2	1.0	0.3	3.2	0.3	0.0	0.2	1351
25	S08	S	110983	1.0	0.2	1.1	0.2	1.2	0.2	1.4	0.4	3.0	0.3	3.9	0.6	1018
26	V01	V	111083	0.3	0.0	0.2	0.0	0.2	0.1	0.2	0.1	1.5	0.1	0.0	0.2	101
27	V02	V	111083	0.2	0.0	0.3	0.0	0.1	0.0	0.1	0.0	1.5	0.4	0.0	0.3	184
28	V03	V	110983	1.5	0.2	2.3	0.2	4.8	0.6	6.0	2.0	6.0	1.0	4.3	1.8	87
29	V04	V	111083	0.3	0.1	0.3	0.1	0.2	0.1	0.3	0.1	2.3	0.2	0.1	0.2	148
30	V05	V	110983	4.3	0.5	3.9	0.5	4.7	0.6	2.0	1.0	4.0	1.0	5.7	1.8	81
31	V06	V	111083	0.9	0.1	0.7	0.1	16.0	1.0	4.0	1.0	22.0	5.0	10.1	4.9	163
32	V07	V	111083	0.2	0.1	0.2	0.1	0.3	0.2	0.1	0.1	2.0	0.2	1.0	0.2	158
33	V08	V	110983	0.5	0.1	0.6	0.1	0.5	0.1	0.7	0.2	0.6	0.1	2.7	0.4	110

LOC=Crownpoint

OBS	ID	TYPE	COL_DATE	U234M	U234E	U238M	U238E	TH230M	TH230E	RA226M	RA226E	PB210M	PB210E	PO210M	PO210E	VOL_WET
34	N09	N	110383	1.5	0.3	1.5	0.3	0.3	0.1	3.0	1.0	5.0	1.0	0.0	0.5	2930
35	N10	N	110383	0.5	0.2	0.3	0.1	0.1	0.1	1.6	0.5	5.0	1.0	3.9	0.8	3870
36	S15	S	110383	0.5	0.1	0.5	0.1	0.7	0.1	0.8	0.2	1.5	0.3	1.5	0.3	1388
37	S16	S	110383	0.8	0.1	0.9	0.1	0.9	0.2	0.6	0.2	4.1	0.4	1.1	0.4	901
38	S17	S	110383	0.8	0.1	0.9	0.1	0.7	0.1	0.7	0.2	1.5	0.3	2.8	0.3	982
39	S18	S	110383	0.7	0.1	0.8	0.1	1.4	0.1	1.1	0.3	2.1	0.3	2.3	0.3	1360
40	V14	V	110383	0.2	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.8	0.3	0.3	0.3	82
41	V15	V	110383	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.9	0.1	0.2	0.2	103
42	V16	V	110383	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	1.0	0.2	1.0	0.2	93

LOC=Crownpoint

OBS	ID	TYPE	COL_DATE	U234M	U234E	U238M	U238E	TH230M	TH230E	RA226M	RA226E	PB210M	PB210E	PO210M	PO210E	VOL_WET
43	V17	V	110383	0.3	0.1	0.3	0.1	0.1	0	0.1	0	1.2	0.1	0.1	0.2	96

LOC=Church Rock

OBS	ID	TYPE	COL_DATE	U234M	U234E	U238M	U238E	TH230M	TH230E	RA226M	RA226E	PB210M	PB210E	PO210M	PO210E	VOL_WET
44	W07	W	120183	470.0	20.0	440.0	20.0	0.7	0.3	1.0	0.3	3.0	1.0	0.2	0.4	3410
45	W08	W	120183	590.0	20.0	590.0	20.0	0.6	0.2	0.7	0.2	2.0	1.0	1.3	0.4	4170
46	S19	S	111883	0.6	0.1	0.6	0.1	0.7	0.1	1.1	0.3	1.2	0.3	2.0	0.3	1175
47	S20	S	111883	1.1	0.1	1.1	0.1	4.2	0.2	1.5	0.5	2.3	0.3	2.1	0.4	813
48	S21	S	111883	2.4	0.4	2.4	0.4	4.0	0.2	4.0	1.0	6.5	0.4	7.1	0.9	722
49	S22	S	111883	0.9	0.1	1.0	0.1	0.9	0.2	1.0	0.3	1.8	0.3	1.0	0.2	1053
50	S23	S	111883	3.8	0.2	3.6	0.2	4.8	0.2	7.0	2.0	8.6	0.5	8.5	1.3	901
51	V18	V	111883	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.2	0.1	11.0	0.2	180
52	V19	V	111883	0.1	0.0	0.1	0.0	0.1	0.0	0.2	0.1	0.1	0.1	0.6	0.2	91
53	V20	V	111883	0.3	0.1	0.3	0.0	0.3	0.0	8.0	2.0	1.5	0.6	0.0	0.4	178
54	V21	V	111883	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.2	0.1	0.9	0.2	96
55	V22	V	111883	0.9	0.1	0.9	0.1	0.5	0.0	1.7	0.5	0.7	0.3	0.9	0.2	116

Type:

W=water
S=soil
V=vegetation

Letter following each radionuclide:
M=individual measurement in pCi/kg dry wt. for soil and vegetation, wet wt. for water
E=counting error (2 standard deviations)

REFERENCE # 38

NAVAJO SUPERFUND OFFICE

BROWN VANDEVER URANIUM MINE REFERENCE MATERIAL

MAY,'90 P. MOLLOY

CONTACT REPORT

Meeting: (X) **Telephone:** ( ) **Other:** ( )

CONTACT LOCATION: U. S. PUBLIC HEALTH SERVICE, INDIAN HEALTH SERVICE, NAVAJO AREA OFFICE

ADDRESS: NAIHS
P. O. BOX G, WINDOW ROCK, AZ 86515

PERSON CONTACTED AND TITLE : MICHAEL TAYLOR, HEALTH PHYSICIST

PHONE: (602) 871-1396

FROM (Contacting Party) : PATRICK MOLLOY Pat

DATE : JUNE 6,1990

SUBJECT: INFORMATION AND DATA FOR RADON BACKGROUND LEVELS FROM IHS RADON SURVEY FOR HAYSTACK COMMUNITY

CONTACT SUMMARY REPORT:

1) DATA FOR FIVE RESIDENCES NEAR HAYSTACK MOUNTAIN AREA (NEAR TWO FAULT BUTTE, 2 MILES NORTH OF THE BROWN VANDEVER URANIUM MINE)

$$1.8,\ 1.6,\ 7.5,\ 4.5,\ 4.5\ pCi.l^{-1}$$

2) ASSAY DONE BY US EPA/EASTERN ENVIRONMENTAL RADIATION FACILITY

JUNE 5, 1990: STF MTG
◊ HONEYWELL FACILITY!
◊ SONAR IMAGING OF LANDFILL ?
FY91 PA { ? TOHATCHI LANDFILL
? WINDOW ROCK "
? CROWNPOINT "
? PONDEROSA PRODUCTS DUMP

JUNE 6, 1990: MTG. W/ M. TAYLOR, HD, NAHS: RADON SURVEY
□ DATA (pCi · l⁻¹) FOR PREWITT/HAYSTACK
- 1.8, 1.6, 7.5, 4.5, 4.5 @ 5 HOMES NEAR TWO FAULT BUTTE
□ DATA (pCi · l⁻¹) FOR S OF PREWITT
- 1, 0, 1, 0 NOT SIG.
* □ DATA (pCi · l⁻¹) FOR KITSILLIE/FOREST LAKE
- SIGNIFICANT
□ EPA CONTRACTOR / RES. TRIANG. INST.
□ LAE. / ASSAY DONE BY USEPA / EASTERN ENV. RADIATION FACILITY
□ AT EASE RADON MONITOR FOR ALMOST REAL TIME
□ JULIE ORR, U-MINES IN GALLUP / CHAMBERS, SANDERS
* "RECO. LANDS"

JUNE 6, 1990
□
JUNE 7, 1990
□ INSTR.
- ESP-I
- L#19
- FR# 1
☆□ NEW PR
◊ B'GRN
- ESP-
- L#19
* 2nd Fr
MIDD
- M. TA
* PLACE 1
- CAN
REL.
- FR#
- FR#
* PLACE 1
- FR#
- ESP-
- L#19
* - 9740
* - E-3
* - FR#6:
- 11:30
* HOGAN E.
- L#19
- ESP-I
- PLACE
- "
NSR - ESP-II

NAVAJO SUPERFUND OFFICE

NAVAJO - BROWN VANDEVER URANIUM MINE

PRELIMINARY ASSESSMENT REFERENCES

JUNE '90 P. MOLLOY

PA QUESTIONNAIRE

Name PATRICK MOLLOY Location 35° 21' 02" ; 107° 56' 25"

Site Name NAVAJO - BROWN VANDEVER URANIUM MINE Date JUNE,1990

MAJOR CONSIDERATIONS

A) DOES ANY QUALITATIVE OR QUANTITATIVE INFORMATION EXIST THAT MAY INDICATE AN OBSERVED RELEASE TO AIR, GROUND WATER, SOIL OR SURFACE WATER? YES

Describe: GAMMA RATEMETER READING OF 10^5 cpm ON "HOT ROAD" CONSISTENT WITH Rn^{222} CONCENTRATION OF 10^4 ATOMS PER CUBIC CENTIMETER

B) IF THE ANSWER TO #1 IS YES, IS THERE EVIDENCE OF DRINKING WATER SUPPLY CONTAMINATION OR ANY OTHER TARGET CONTAMINATION (i.e., foodchain, recreation areas, or sensitive environments)? NO

Describe:

C) ARE THERE SENSITIVE ENVIRONMENTS WITHIN A 4-MILE RADIUS OR 15 DOWNSTREAM MILES OF THE SITE? YES IF YES, DESCRIBE IF ANY OF THE FOLLOWING APPLY:

- Multiple sensitive environments? YES

- Federally designated sensitive environment(s)? YES

- Sensitive environment(s) downstream on a small or slow flowing surface water body?

NO

D) IS THE SITE LOCATED IN AN AREA OF KARST TERRAIN? NO

Describe:

E) IS THE AQUIFER UNDERLYING THE SITE A "SOLE SOURCE" AQUIFER AS DESIGNATED ACCORDING TO SECTION 1424(e) OF THE SAFE DRINKING WATER ACT? NO

Describe:

F) DOES ANY QUALITATIVE OR QUANTITATIVE INFORMATION EXIST THAT PEOPLE LIVE OR ATTEND SCHOOL ON ONSITE CONTAMINATED PROPERTY? YES*

Describe: APPROXIMATELY 65 PEOPLE LIVE ON SITE

SITE INFORMATION

SITE NAME: BROWN VANDEVER URANIUM MINE

ADDRESS: FOUR MILES NNE OF BLUEWATER, NEW MEXICO

CITY: BLUEWATER COUNTY: McKINLEY STATE: NM ZIP: 87045

EPA ID: ** NOT ASSIGNED **

LATITUDE: 35° 21' 02" ; LONGITUDE: 107° 56' 25"

2. DIRECTIONS TO SITE (From nearest public road): FROM ATSF UNDERPASS ON INTERSTATE 40 FRONTAGE ROAD PROCEED E ON IMPROVED DIRT ROAD, TURN N AT APPROXIMATELY 4.5 mi., PROCEED N 1.2 mi., TURN W, GATE WITH HOOK .1 mi., SITE ENVIRONS

3. SITE OWNERSHIP HISTORY (Use additional sheets, if necessary):

A. Name of current owner: VANDEVER OUTFIT/NAVAJO NATION

Address: P. O. BOX 308 (NN)

City: WINDOW ROCK County: APACHE State: AZ Zip: 86515

Dates: From 1868 To PRESENT Phone: (602) 871 - 4941

B. Name of previous owner: NO PREVIOUS OWNER

Address: _____

City: _____ County: _____ State: __ Zip: _____

Dates: From _____ To _____ Phone: _____

Source of ownership data: TREATY OF 1868

4. TYPE OF OWNERSHIP (Check all that apply):

____ Private ____ State ____ Municipal

____ Federal ____ County __X__ Other (describe): NAVAJO NATION

NAME OF SITE OPERATOR: NONE: MINING ACTIVITY HAS CEASED

ADDRESS: N/A

CITY: _____ COUNTY: _____ STATE: __ ZIP: _____

PHONE: _____

BACKGROUND/OPERATING HISTORY

6. DESCRIBE OPERATING HISTORY OF SITE: MINE WAS OPENED IN 1952 BY SUTTON, THOMPSON AND WILLIAMS: OPERATED IN 1953 BY WILLIAMS: OPERATED IN 1955 BY SANTA FE URANIUM: OPERATED IN 1955 - 1956 BY SANTA FE URANIUM AND FEDERAL URANIUM: OPERATED IN 1957 - 1959 BY FEDERAL URANIUM: OPERATED IN 1963 - 1964 BY MESA MINING CO.: OPERATED IN 1966 BY CIBOLA MINING CO.

Source of information: REFERENCE # 2

7. DESCRIBE SITE AND NATURE OF SITE OPERATIONS (property size, manufacturing, waste disposal, storage, etc.): SITE IS LOCATED AT THE SOUTHEASTERN MARGIN OF HAYSTACK MOUNTAIN IN A RURAL SHEEP RAISING AREA. SITE IS COMPRISED OF APPROXIMATELY ¼ SECTION. INACTIVE URANIUM MINE; MINE SPOILS DISPOSED OF ON SITE; NO BARRICADES OR CONTAINMENT OF SPOILS.

Source of information: WINDSHIELD SURVEY (REFERENCE # 3)

8. DESCRIBE ANY EMERGENCY OR REMEDIAL ACTIONS THAT HAVE OCCURRED AT THE SITE:

NONE

Source of information: MR. BROWN VANDEVER

9. ARE THERE RECORDS OR KNOWLEDGE OF ACCIDENTS OR SPILLS INVOLVING SITE WASTES? NO

Describe: _____

Source of information: NONE

10. DISCUSS EXISTING SAMPLING DATA AND BRIEFLY SUMMARIZE DATA QUALITY (e.g., sample objective, age/comparability, analytical methods, detection limits and QA/QC):

RADIATION SURVEY CONDUCTED AT SITE APRIL 11,1990: BACKGROUND TAKEN AT SITE WITH EBERLINE ESP - II IN RATEMETER MODE : DATA TAKEN AT "SHINE" (1 METER ABOVE SURFACE) : RATEMETER UTILIZED SPA - 3 HIGH GAMMA SENSITVITY PROBE: CALIBRATION DATE JAN 5, 1990; DETECTION LIMITS 1200kcpm per $mR.hr^{-1}$ WITH Cs^{137} CALIBRATION SOURCE: QA/QC REPEATABILITY $\simeq \pm$ .003%

Source of information: WINDSHIELD SURVEY, REFERENCE # 15

WASTE CONTAINMENT/HAZARDOUS SUBSTANCE IDENTIFICATION

11. FOR EACH SOURCE AT THE SITE, SUMMARIZE ON TABLE 1 (page 12): 1) Methods of hazardous substance disposal, storage or handling; 2) size/volume/area of all features/structures that might contain hazardous waste/ 3) condition/integrity of each storage disposal feature or structure; and 4) types of hazardous substances handled.

12. BRIEFLY EXPLAIN HOW WASTE QUANTITY WAS ESTIMATED (e.g., historical records or manifests, permit applications, air photo measurements, etc.):

PHOTOGRAPHS, VEHICLE ODOMETER READINGS; GEOMETRIC AND PHYSICAL CONCEPTS

Source of information: WINDSHIELD SURVEY, REFERENCES # 3, #14, #15, # 18

13. DESCRIBE ANY RESTRICTIONS OR BARRIERS ON ACCESSIBILITY TO ONSITE WASTE MATERIALS:

ONE GATE WITH IRON HOOK

Source of information: WINDSHIELD SURVEY

GROUND WATER CHARACTERISTICS

14. ANY POSITIVE OR CIRCUMSTANTIAL EVIDENCE OF A RELEASE TO GROUND WATER? ?

Describe: INDIAN HEALTH SERVICE INSTALLATION OF A COMPLETE WATER SYSTEM FOR THE COMMUNITY; AREA HAS A REPUTATION FOR HAVING RADIOSPECIES-CONTAMINATED WATER SOURCES

Source of information: REFERENCES #19, #21

15. ON TABLE 2 (page 13), GIVE NAMES, DESCRIPTIONS, AND CHARACTERISTICS OF GEOLOGIC/HYDROGEOLOGIC UNITS UNDERLYING THE SITE.

16. NET PRECIPITATION: * MINUS 44 in.*

SURFACE WATER CHARACTERISTICS

17. ARE THERE SURFACE WATER BODIES WITHIN 2 MILES OF THE SITE? YES

X Ditches ____ Lakes ____ Pond

____ Creeks ____ Rivers X Other WASH

18. DISCUSS THE PROBABLE SURFACE RUNOFF PATTERNS FROM THE SITE TO SURFACE WATERS:
FROM THE TAILINGS ASSOCIATED WITH THE INCLINED ADITS, SURFACE WATER RUNOFF FLOWS EASTSOUTHEASTWRD FOR APPROX. 1 mi.; RUNOFF THEN PROCEEDS SOUTHEAST APPROX. 3 mi. BEFORE TERMINATING. FROM THE STRIP MINE TAILINGS SURFACE RUNOFF PROCEEDS OVERLAND APPROX. .7 mi. BEFORE CONVERGING WITH ABOVE DRAINAGE: FLOW IS ENE

19. PROVIDE A SIMPLIFIED SKETCH OF SURFACE RUNOFF AND SURFACE WATER FLOW SYSTEM FOR 15 DOWNSTREAM MILES (see item #36).

20. ANY POSITIVE OR CIRCUMSTANTIAL EVIDENCE OF SURFACE WATER CONTAMINATION? YES

Describe: RADIATION SURVEY RESULTS CONSISTENT WITH RADIOSPECIES MIGRATION INTO SOUTHEAST TRENDING DRAINAGE: READINGS WERE 10 - 15 TIMES BACKGROUND.

Source of information: WINDSHIELD SURVEY, FIELD NOTES(REF'S.#14,#18)

21. ESTIMATE THE SIZE OF THE UPGRADIENT DRAINAGE AREA FROM THE SITE: 73.4 acres

Source of information: REFERENCES #3, #4;WORKSHEET#1,#7

22. DETERMINE THE AVERAGE ANNUAL STREAM FLOW OF DOWNSTREAM SURFACE WATERS

Water body: RIO SAN JOSE Flow: 2.97cfs

Water body: _____ Flow: ____ cfs

Water body: _____ Flow: ____ cfs

Source of information: REFERENCE#20

23. IS THE SITE OR PORTIONS THEREOF LOCATED IN SURFACE WATER? NO

24. IS THE SITE LOCATED IN A FLOODPLAIN (indicate flood frequency)? ?

25. IDENTIFY AND LOCATE (see item #36) ANY SURFACE WATER RECREATION AREA WITHIN 15 DOWNSTREAM MILES OF THE SITE: NONE

Source of information: REFERENCE # 16

26. TWO YEAR 24-HOUR RAINFALL: 1.26 in.

TARGETS

27. DISCUSS GROUND WATER USAGE WITHIN FOUR MILES OF THE SITE: AN INDIAN HEALTH SERVICE WATER SYSTEM, WHICH HAS BEEN TURNED OVER TO THE NAVAJO NATION WATER RESOURCES DIVISION (NNWRD), SERVES APPROXIMATELY 430 PERSONS IN THE HAYSTACK COMMUNITY: IT IS ESTIMATED THAT APPROXIMATELY 100 PERSONS TOO INDIGENT TO AFFORD PLUMBING FOR THEIR RESIDENCES UTILIZE OTHER NNWRD WELLS IN THE AREA WHICH ARE SOURCED BY UNCONFINED ALLUVIAL UNIT AND THE DAKOTA SANDSTONE AQUIFER.
Source of information: REFERENCES # 3, 4,18,19,21

28. SUMMARIZE THE POPULATION SERVED BY GROUND WATER ON THE TABLE BELOW:

Distance (miles)	Population
>0 - 1/4	65 est.
>1/4 - 1/2	0
>1/2 - 1	77
>1 - 2	180
>2 - 3	133
>3 - 4	46

Source of information: REFERENCES #4;WORKSHEET#2,7,21

29. IDENTIFY AND LOCATE (see item #36) POPULATION SERVED BY SURFACE WATER INTAKES WITHIN 15 DOWNSTREAM MILES OF THE SITE: NONE

Source of information: REFERENCES#14,18

30. DESCRIBE AND LOCATE FISHERIES WITHIN 15 DOWNSTREAM MILES OF THE SITE (i.e., provide standing crop or production and acreage, etc.):

NONE

Source of information: REFERENCE#16

31. IF SURFACE WATER RECREATION AREAS EXIST, CHOOSE RECREATIONAL USE CATEGORY, AND THEN DETERMINE THE POPULATION WITHIN THE ASSIGNED RADIUS FROM THE RECREATION AREA. (Use GEMS to allocate into distance rings).

<15 mi. downstream

*** NOT APLICABLE ***

a. Capital use and access improvements _____(assigned radius=125 miles)
b. Access improvements only _____(assigned radius=80 miles)
c. Observed use only _____(assigned radius=40 miles)
d. None of the above apply and access is not restricted _____ (assigned radius=10 miles)

Distance (miles)	Population
>0 - 5	
>5 - 10	
>10 - 20	
>20 - 40	
>40 - 60	
>60 - 80	
>80 - 100	
>100 - 125	

32. DETERMINE THE DISTANCE FROM THE SITE TO THE NEAREST OF EACH OF THE FOLLOWING LAND USES.

Description	Distance (miles)
Commercial/Industrial/ Institutional	.GT.4 mi.
Single Family Residential	0 mi.
Multi-Family Residential	0 mi.
Park	.GT.4 mi.
Agricultural	0 mi.

Source of information: WINDSHIELD SURVEY

33. SUMMARIZE THE POPULATION WITHIN A FOUR-MILE RADIUS OF THE SITE:

Distance (miles)	Population
onsite	65
>0 - 1/4	65
>1/4 - 1/2	0
>1/2 - 1	93
>1 - 2	197
>2 - 3	149
>3 - 4	62

Source of information: REFERENCES#4;WORKSHEET#2,7,21

OTHER REGULATORY INVOLVEMENT

34. DISCUSS ANY PERMITS/VIOLATIONS:

County: _____

State: _____

Federal: _____

Other: NAVAJO NATION

Source of information: REFERENCE#17

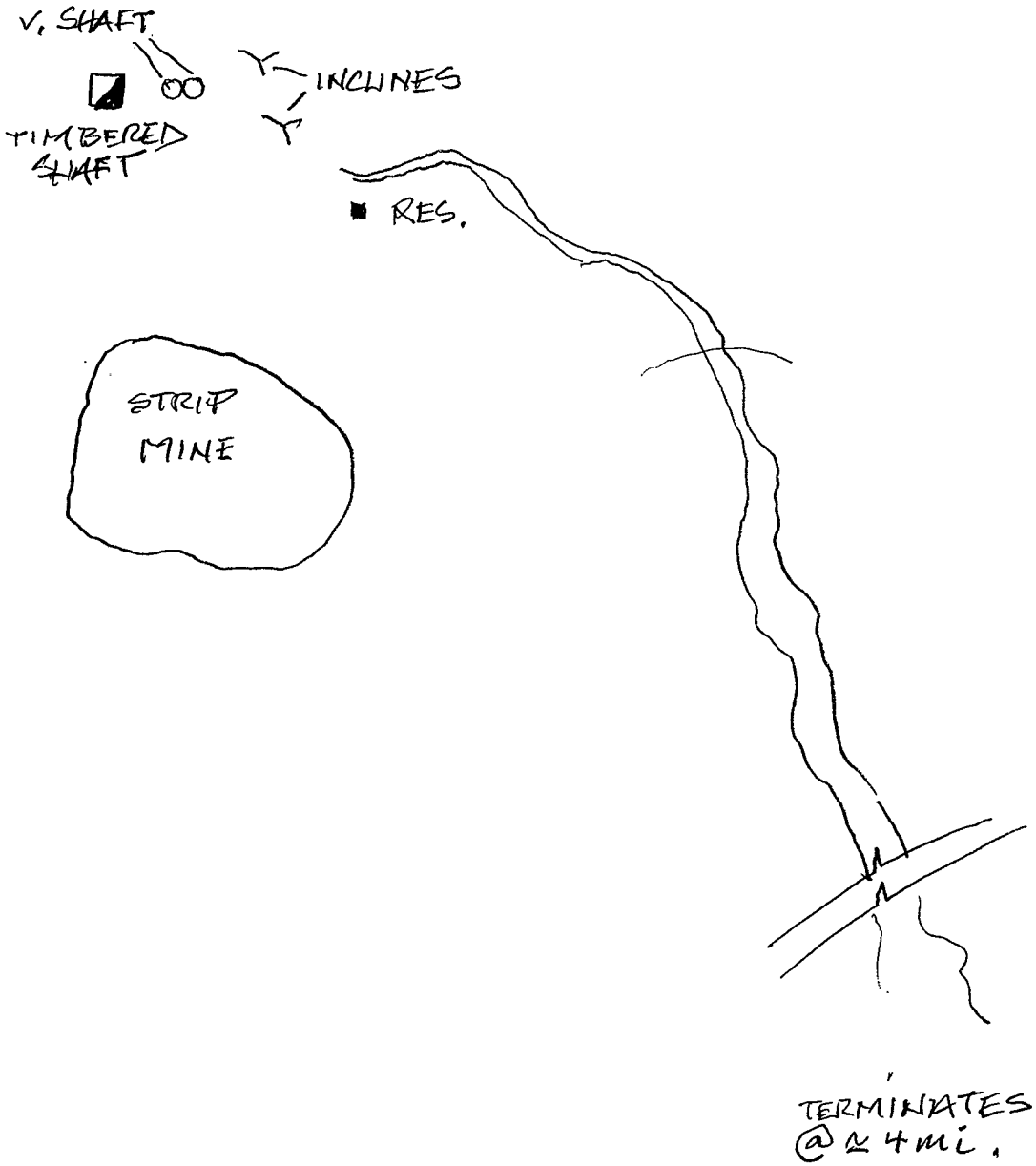
35. SKETCH OF SITE

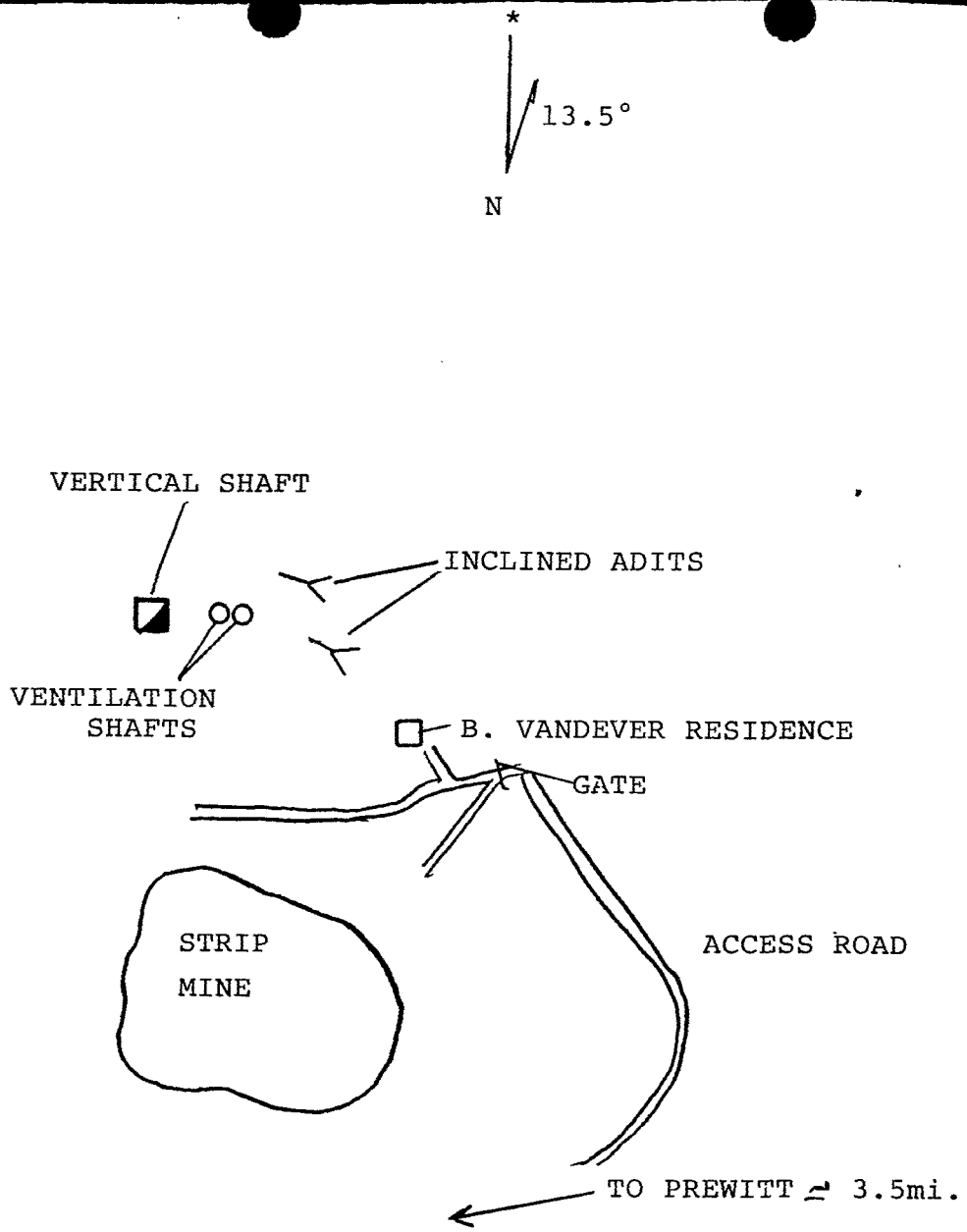
Include all pertinent features, e.g., wells, storage areas, underground storage tanks, waste areas, buildings, access roads, areas of ponded water, etc. Attach additional sheets with sketches of enlarged areas, if necessary.

*** SEE ATTACHED ***

36. SURFACE WATER FEATURES

Provide a simplified sketch of surface runoff and surface water flow system for 15 downstream miles. Include all pertinent features, e.g., intakes, recreation areas, fisheries, gauging stations, etc.





SCALE - 1" ≃ 1418 ft.

NAVAJO SUPERFUND OFFICE

NAVAJO-BROWN VANDEVER URANIUM MINE SITE SKETCH

JUNE,'90 P. MOLLOY

WASTE CONTAINMENT AND HAZARDOUS SUBSTANCE IDENTIFICATION

SOURCE TYPE	SIZE (Volume/Area)	ESTIMATED WASTE QUANTITY	SPECIFIC COMPOUNDS	CONTAINMENT[2]	SOURCE OF INFORMATION
Adits, Shafts	7.02 Acres	Unknown	U_3O_8, V_2O_5, Radon	None	Ref's # 3,4,14
Tailings Piles	125 acres	1880.3 tons	U_3O_8, V_2O_5, Radon	None	Ref's # 3,4,14

1 Use additional sheets if necessary

2 Evaluate containment of each source from the perspective of each migration pathway (e.g., ground water pathway - nonexistent, natural or synthetic liner, corroding underground storage tank; surface water - inadequate freeboard, corroding bulk tanks; air - unstabilized slag piles, leaking drums, etc).

TABLE 2
HYDROGEOLOGIC INFORMATION[1]

STRATA NAME/DESCRIPTION	THICKNESS (ft.)	DEPTH TO WATER (ft.)	HYDRAULIC CONDUCTIVITY (cm/sec)	TYPE OF DISCONTINUITY[2]	SOURCE OF INFORMATION
Entrada SS (Je) Sandstone, Reddish orange, poor aquifer, mapped with wingate sandstone in this area (Trw)	0-50	N/A /	10^{-3} to 10^{-5}	None	Ref's # 3,5, 6, 8
Chinle formation (Trc) red beds, shale, siltstone. Sonsela sandstone is fair to good aquifer: water brackish	1600	150	10^{-3} to 10^{-5}	None	"
Shinarump conglomerate (Trcs) sandstone - conglomerate-mudstone, orange to purple. Comprises an aquifer in some regions.	100	1950	10^{-3} to 10^{-5}	"	"
Moenkopi formation (Trm) siltstone and sandstone, red to white	50	N/A	"	"	"
San Andres LS (Psa) dolomitic Limestone. Excellent aquifer north, east and west of Zuni Mountains.	100	1900	"	"	"

1 Use additional sheets if necessary

2 Identify the type of discontinuity within four-miles from the site (e.g., river, strata "pinches out", etc.)

CONTACT REPORT

Meeting: (X) **Telephone:** ( ) **Other:** ( )

CONTACT LOCATION: U. S. PUBLIC HEALTH SERVICE, INDIAN HEALTH SERVICE, NAVAJO AREA OFFICE

ADDRESS: NAIHS
P. O. BOX G, WINDOW ROCK, AZ 86515

PERSON CONTACTED AND TITLE : MICHAEL TAYLOR, HEALTH PHYSICIST

PHONE: (602) 871-1396

FROM (Contacting Party) : PATRICK MOLLOY

DATE : JUNE 6,1990

SUBJECT: INFORMATION AND DATA FOR RADON BACKGROUND LEVELS FROM IHS RADON SURVEY FOR HAYSTACK COMMUNITY

CONTACT SUMMARY REPORT:

1) DATA FOR FIVE RESIDENCES NEAR HAYSTACK MOUNTAIN AREA (NEAR TWO FAULT BUTTE, 2 MILES NORTH OF THE BROWN VANDEVER URANIUM MINE)

$$1.8,\ 1.6,\ 7.5,\ 4.5,\ 4.5\ pCi.l^{-1}$$

2) ASSAY DONE BY US EPA/EASTERN ENVIRONMENTAL RADIATION FACILITY

JUNE 5, 1990: STF MTG
- ◊ HONEYWELL FACILITY.
- ◊ SUNAL IMAGING @ LANDFILL - ?
- FY91 { ? TOHATCHI LANDFILL
- PA { ? WINDOW ROCK "
- ? CROWNPOINT "
- ? PONDEROSA PRODUCTS DUMP - PCM

JUNE 6, 1990: MTG. W/ M. TAYLOR, HD, NAHS: RADON SURVEYS
- ◻ DATA (pCi · l⁻¹) FOR PREWITT/ HAYSTACK.
  - 1.8, 1.6, 7.5, 4.5, 4.5 @ 5' HOMES NEAR TWO FAULT BUTTE
- ◻ DATA (pCi · l⁻¹) FOR S OF PREWITT
  - 1, 0, 1, 0 NOT SIG.
- * ◻ DATA (pCi · l⁻¹) FOR KITSILLIE/ FOREST LAKE
  - SIGNIFICANT
- ◻ EPA CONTRACTOR / RES. TRIANGL INST.
- ◻ LAB. / ASSAY DONE BY: USEPA/EASTERN ENV. RADIATION FACILITY.
- ◻ AT EASE RADON MONITOR FOR ALMOST REAL TIME
- ◻ JULIE ORR, U-MINES IN GALLUP / CHAMBERS, SANDERS "HELO. LANDS"

JUNE 6, 1990:
- ◻
- JUNE 7, 1990
- ◻ INSTR.
  - ESP-II
  - L#19 -
  - FR#1
- * ◻ NEW PR
  - ◻ B'GRND
  - ESP-
  - #19
- * 2nd FR:
  - MIDDL
  - M. TA
- * PLACE
  - CAN
  - REL.
  - FR#
  - FR#
- * PLACE
  - FR#
  - ESP-
  - L#19
- * - 9
- * - E-3
- * - FR#6:
  - 11:30
- * HOGAN E.
  - L#19 -
  - ESP-II
  - PLACE
  - "

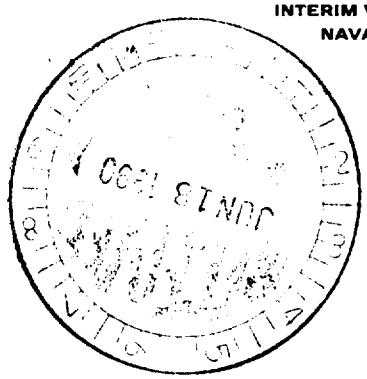
N50 - ESP-II -

Barbara Rec'd 6/25/90
6/25
→ 6H-MA

THE NAVAJO NATION

LEONARD HASKIE
INTERIM PRESIDENT
NAVAJO NATION

IRVING BILLY
INTERIM VICE PRESIDENT
NAVAJO NATION



June 11,1990

Mr. Mark Satterwhite
Indian Superfund Coordinator
US-EPA,Region-VI
1445 Ross Avenue
Dallas, Texas 75202-2733

Dear Mr. Satterwhite:

Find enclosed Addenda to the Preliminary Assessment Package for the Navajo-Brown Vandever Uranium Mine.

Additional information, pertinent to the site and Bioaccumulation of Radiospecies has become available(Reference#37). More reliable calculations regarding the area Radon burden have been produced(mine spoils calculations Addenda). Dr. Gaurav Rajen(Senior Environmental Engineer) and Patrick Molloy worked on the calculations. References#35 and #36 are included in support of the calculations. Reference#38 pertains to Radon levels obtained during an Indian Health Service Radon survey in the area of residences approximately two miles from the site. It is intended that the levels be considered as background parameters for the area.

If you have any questions regarding this material, please contact me, Dr. Rajen or Patrick Molloy at (602) 871-7329 or -7332. Thank you.

Sincerely,

Gaurav Rajen, for Clara Bia

Clara Bia
Executive Director
Navajo Superfund Office

Enclosures

CB/pm

X SA, VOL 1
NMD986669117

NAVAJO SUPERFUND OFFICE

NAVAJO - BROWN VANDEVER URANIUM MINE

PRELIMINARY ASSESSMENT NARRATIVE

JUNE '90 P. MOLLOY

PRELIMINARY ASSESSMENT FOR THE NAVAJO - BROWN VANDEVER URANIUM MINE

BY

PATRICK MOLLOY
HEALTH PHYSICIST, NAVAJO SUPERFUND OFFICE

SUMMARY

The Brown Vandever Mine contains about 1880 tons of uranium mine tailings abandoned on-site. Small quantities of ore grade material are to be found scattered all over the site. The material is uncovered and easily accessible by site residents and visitors. There are several uncovered ventilation shafts, timbered shafts and inclined adits on the site. There are no warning signs or fences preventing access to the site.

The population affected directly by the site is at least 75 people, and could be as high as 500 people. Over thirty children are known to play on the tailings and in the immediate vicinity of the mine.

There is a haulage road on the site "paved" with tailings. Radiometric evidence indicates off-site migration of contaminants at least 2 mi from this road via automobiles driven on this road by area residents.

MAJOR CONCLUSIONS

The site has a status of immediately dangerous to life and health.

Immediate action is recommended.

3682

Brown Uranium Mines
SA 1

Site log missing
1/23/90
4/6/90
5/7/90
6/1/90
6/11/90
6/11/90
6/26/90
8/3/90
8/22/90
10/20/94

622 pages 59 Documents

Barbara
file 3682

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION VI
1445 ROSS AVENUE, SUITE 1200
DALLAS, TEXAS 75202

DATE: 8/22/90

MEMORANDUM

SUBJECT: Potential Hazardous Waste Site - Site Inspection Report

FROM: O. Thomas Love, Jr., P.E.
Acting Chief
Water Supply Branch (6W-S)

TO: Betty Williamson
Chief
Superfund Management Branch (6H-M)

In response to the CERCLA investigation reports which you recently sent to the Water Supply Branch, I am attaching our comments. Thank you for the opportunity to review these documents.

Attachment:
Site Name: NAVAJO-BROWN VANDEVER Brown Uranium Mines
Site Location: Blue Water NM
Site Number: NMD 986 669 177

cc: Carl Hickam (6H-ES)

SUPERFUND
FILE

DEC 2 1991

REORGANIZE

P TION REPORT REVIEW
POTENTIAL HAZARDOUS WASTE SITE

SITE NAME : NAVAJO-BROWN VANDEVER URANIUM MINE SITE
LOCATION : BLUEWATER
SITE NUMBER: NMD986669177
SURVEY DATE: ___/___/___ INSPECTED BY: STATE FIT TAT OTHER: _____
LABORATORY : ___CLP ___EPA ___OTHER_____

RECEIVED FROM: _____ DATE RECEIVED: 8/6/90

SAMPLE TYPE(s):

SOIL	SURFACE WATER	GROUND WATER	DRINKING WATER
off / on -site	off / on -site	off / on -site	off / on -site

CONTAMINANT(s): Organics Inorganics Radionuclides Microbiological

FOLLOW UP (Y/N):

___ (Re)Sampling Requested
___ Further Action is URGENT
___ Locate Drinking Water Sources
___ Keep Site Active ("N"=No Further Action)
___ Concur with Report Recommendations

SUMMARY:

I agree with the report recommendation that a screening site inspection be conducted. Part of this SSI should be a review of existing radionuclide data for the community well 16T-551 which the ~~BIA~~ Indian Health Service should have at the Window Rock, Arizona office. This should include Gross alpha and radium analyses.

SUPERFUND

Jim Pardue 8/17/90
ENGINEER/REVIEWER

Concurrence:
F. Warren Norris 8/20/90

SITE NAME : NAVAJO-B (DEVER URANIUM MINE SI)

SITE LOCATION: BLUEWATER

SITE NUMBER : NMD986669177

LOG NUMBER : 90

ROUTE SLIP

HAZARDOUS WASTE SITE - INSPECTION REPORT

	INITIALS	DATE	TIME (HOURS)
1. LEN PARDEE	LAP	8/17/93	1.0
~~2. TOM LOVE~~	RWN	8/20/93	—
3. HERB DAVIS (Cover memo, Xerox copies of report, log out of file, file) (Copies to Hickam, Wright 6H-ES)		9/22/93	.30

FILE CODE: SFD-24-1-3

(1193)

Mr. Steve Cary
Program Manager
Superfund Section
Hazardous Waste Bureau
P.O. Box 968
Santa Fe, New Mexico 87504-0968

Dear Mr. Cary:

Enclosed for your files are the Superfund Site Strategy Recommendations for the following sites:

SITENAME	EPAID	RECOMMENDATION
Nanabah Vandever Uranium Mine	NMD986669109	PA; SSI recommended
Jimmy King #2 Uranium Mine	NMD986667558	PA; No further action
Brown Vandever Uranium Mine	NMD986669117	PA; SSI recommended

If you have any questions about the enclosed material or need additional information, please call me at (214) 655-6740.

Sincerely,

Barbara Driscoll
Environmental Protection Specialist
Superfund Site Assessment Section (6H-MA)

Enclosure

bcc: Mark Satterwhite (6H-SA)
files

6H-MA:DRISCOLL;BD:8/3/90: COMPAQ A:NM9:X6740

TAYLOR

Superfund Site Strategy Recommendation Region 6

Site Name: Navajo - Brown Vandever Uranium Mine Site Number: NMD986669117

Alias Site Name(s):

Address: Four Miles ENE of Bluewate, NM

City/County or Parish/State/Zip: Bluewater/McKinley/NM/87045

Recommendation:

[ ] 1. No further remedial action planned under Superfund.

[XX] 2. Further pre-remedial investigative action needed under Superfund:
PA_____ Priority: High XX
SSI XX_____ Medium_____
To be performed by Navajo

[ ] 3. Action may be appropriate under other authority:
NPDES_____SPCC_____404_____TSCA_____
UIC_____SMCRA_____ STATE_____RCRA_____
OTHER ERB

REORGANIZE

Discussion: PA

The Brown Vandever Mine contains about 1880 tons of uranium mine tailings abandoned on-site. Small quantities of ore grade material are found scattered over the site. The material is easily accessible by site residents and visitors. There are several uncovered ventilation shafts, timbered shfts and inclined adits on the site. There are no warning signs or fences preventing access to the site. The population within 1/4 mile of the site is around 75 persons. Over 30 children are known to play on the tailings in the immediate vicinity of the mine. The road to the site is paved with tailings. There is potential for exposure of individuals via the air pathway as some of the material is fine, and Radon is also emitted from the slag material. The primary substances of concern are Uranium, and its progeny Th 232, Bi 214, Po 214, isotopes of Pb and Radon gas. The heavy metals potentially present in the mining waste are arsenic, barium, magnesium, manganese, strontium, titanium, and zinc. Many of these materials have been demonstrated to be mobile in waters associated with Uranium mines. Three wells and a spring are located within a 4 mile radius, and serve approximately 430 persons. Ground water from 2 of the wells is at 400 feet. The adits from the mine reach to within 100 feet of the groundwater and might convey contaminants. There is no surface source of water used by the people for drinking water. Because of the air pathway and soil exposure routes as well as the potential for ground water contamination, this site is recommended for a Screening Site Inspection.

Copies to (please list) NAVAJO SF, 6T-AS, 6E-E, 6W-S, ATSDR

Recommended By: Barbara Driscoll Date: 7/17/90

Approved By: Bill Taylor for Betty Williamson Date: 7/17/90

7/2 → 64/MA 3682

THE NAVAJO NATION

LEONARD HASKIE
INTERIM PRESIDENT
NAVAJO NATION

IRVING BILLY
INTERIM VICE PRESIDENT
NAVAJO NATION

NSO-90-72

June 26, 1990

Mr. Mark Satterwhite
Indian Superfund Coordinator
USEPA - Region VI
1445 Ross Avenue
Dallas, Texas 75202-2733

Dear Mr. Satterwhite:

Find enclosed Addenda and Errata to the Preliminary Assessment Package for the Brown Vandever Uranium Mine.

If you have any questions regarding this material, please contact me or the scientist who prepared it, Patrick Molloy at (602) 871-6284 or 7332. Thank you.

Sincerely,

Clara Bia, Director
Navajo Superfund Office

Encls:

URANIUM IN THE SAN JUAN BASIN—AN OVERVIEW*

WILLIAM L. CHENOWETH
U.S. Energy Research and Development Administration
Grand Junction, Colorado

INTRODUCTION

The San Juan Basin of northwest New Mexico has been the source of more uranium production than any other area in the United States. Nearly all of the production has come from the Grants mineral belt (fig. 1). This paper describes the geologic setting of the ore deposits in the San Juan Basin, summarizes the growth of the uranium raw materials industry, and reviews the resource base.

GEOLOGIC SETTING

In the San Juan Basin, bedded and vein uranium deposits are in several different rock-types of Mesozoic and Tertiary age. Tabular deposits, which occur primarily in continental, fluvial sandstone of Jurassic age, are the most important. Only the more significant occurrences are discussed in this paper.

Most uranium deposits are in the Grants mineral belt in McKinley, Sandoval and Valencia counties. This cluster of large deposits extends for nearly 100 miles across the southern flank of the San Juan Basin. Although poorly defined, the belt is 10 to 20 miles wide. The four principal mining areas in the belt are Gallup, Smith Lake, Ambrosia Lake and Laguna (fig. 1). Ore deposits occur from the surface to depths greater than 4,000 feet, although to date all production has come from deposits shallower than 2,000 feet. Deposits in the Grants mineral belt have been described in detail by Kelley (1963) and by Hilpert (1969).

The Todilto Limestone of Jurassic age contains uranium ore bodies along the southern margin of the Grants mineral belt, where the limestone has been deformed by intraformational folding and faulting. Some 2,718 tons of U_3O_8 have been produced from 42 properties, mainly in the Ambrosia Lake area, accounting for two percent of the total output of the mineral belt. At a few places in the Todilto, ore also has been mined from the underlying Entrada Sandstone of Jurassic age where the ore bodies cross the contact between the two formations. Uranium also occurs in the Todilto in the Sanostee area of San Juan County, where small trial shipments have been made from two properties.

The Morrison Formation of Jurassic age was deposited in a continental environment. It consists of interbedded fluvial sandstone, claystone and mudstone. In the southern San Juan Basin, the Morrison consists of three members, all of which contain ore deposits. In ascending order, they are the Recapture, Westwater Canyon and Brushy Basin members. In the Ambrosia Lake and Laguna areas, the Recapture contains minor sandstone beds that are hosts for small uranium deposits.

The Westwater Canyon Member consists of thick sandstones with interbedded lenses of relatively thin discontinuous claystone. This member contains large uranium deposits in the Ambrosia Lake and Gallup areas. The Brushy Basin Member consists of greenish-gray mudstone and claystone with interbedded sandstone and a few thin beds of limestone. A thick lens of sandstone, the Jackpile Sandstone, occurs in the upper part of the Brushy Basin in the Laguna area, where it contains large ore deposits. The Brushy Basin also is host for deposits in the Smith Lake area, although these are smaller than those at Laguna.

Uranium deposits of the Grants mineral belt are irregular in shape and generally are parallel to paleostream channels (fig. 2). The deposits range in size from thin pods a few feet in width and length to large masses of ore several thousand feet long, several hundred feet wide and several tens of feet thick.

The deposits are in many different sandstone beds and form clusters along distinct trends. Some ore has been redistributed, generally in areas of faulting (fig. 3). The principal ore mineral in the Grants sandstone deposits is coffinite, a uranium silicate ($U(SiO_4)_{1-x}(OH)_{4x}$), which is intimately associated with grayish-black to brown carbonaceous humate, which impregnates the sandstone. Production from the Morrison Formation in the Grants mineral belt has amounted to 114,795 tons U_3O_8.

In the northwestern San Juan Basin, uranium-vanadium deposits occur in the Salt Wash Member of the Morrison Formation on the eastern side of the Carrizo Mountains. This member, composed of interbedded mudstones and fluvial sandstones, is the lowermost member of the Morrison and is present nowhere else in the basin. Mines in the eastern Carrizo Mountains, astride the New Mexico-Arizona line, have produced 110 tons U_3O_8.

South of the Carrizo Mountains, in the Chuska Mountains near Sanostee, both the Salt Wash and Recapture members have yielded ore. Sandstones in the Recapture have been the most productive host rock, from which 80 tons of U_3O_8 have been obtained.

On the eastern flank of the San Juan Basin, the Morrison Formation has yielded 395 tons of ore, averaging 0.13 percent U_3O_8, from two properties on the Ojo del Espiritu Santo Grant, northwest of San Ysidro.

The Dakota Sandstone of Cretaceous age has yielded 246 tons of U_3O_8 from nine properties in the Gallup and Ambrosia Lake areas. The Dakota host rocks are carbonaceous sandstone, carbonaceous shale and lignite. On the eastern flank of the basin, south of Cuba, New Mexico, 23 tons containing 0.63 percent U_3O_8, have been mined from carbonaceous shale and lignite at one property in the Dakota Sandstone.

Uranium occurs in rocks of the Mesaverde Group of Cretaceous age, at various locations in the San Juan Basin. The most significant area is near La Ventana on the eastern flank of the basin. Here, uranium-bearing coal, carbonaceous shale and carbonaceous sandstone form a mineralized zone several feet thick in the upper part of the Menefee Formation immediately below the La Ventana Tongue. Studies by Bachman and others (1959), suggest that a resource of 132,000 tons, averaging 0.10 percent uranium is present; principally on North Butte.

A small amount of ore has been produced from a sandstone

Publication authorized by the U.S. Energy Research and Development Administration, Grand Junction Office.

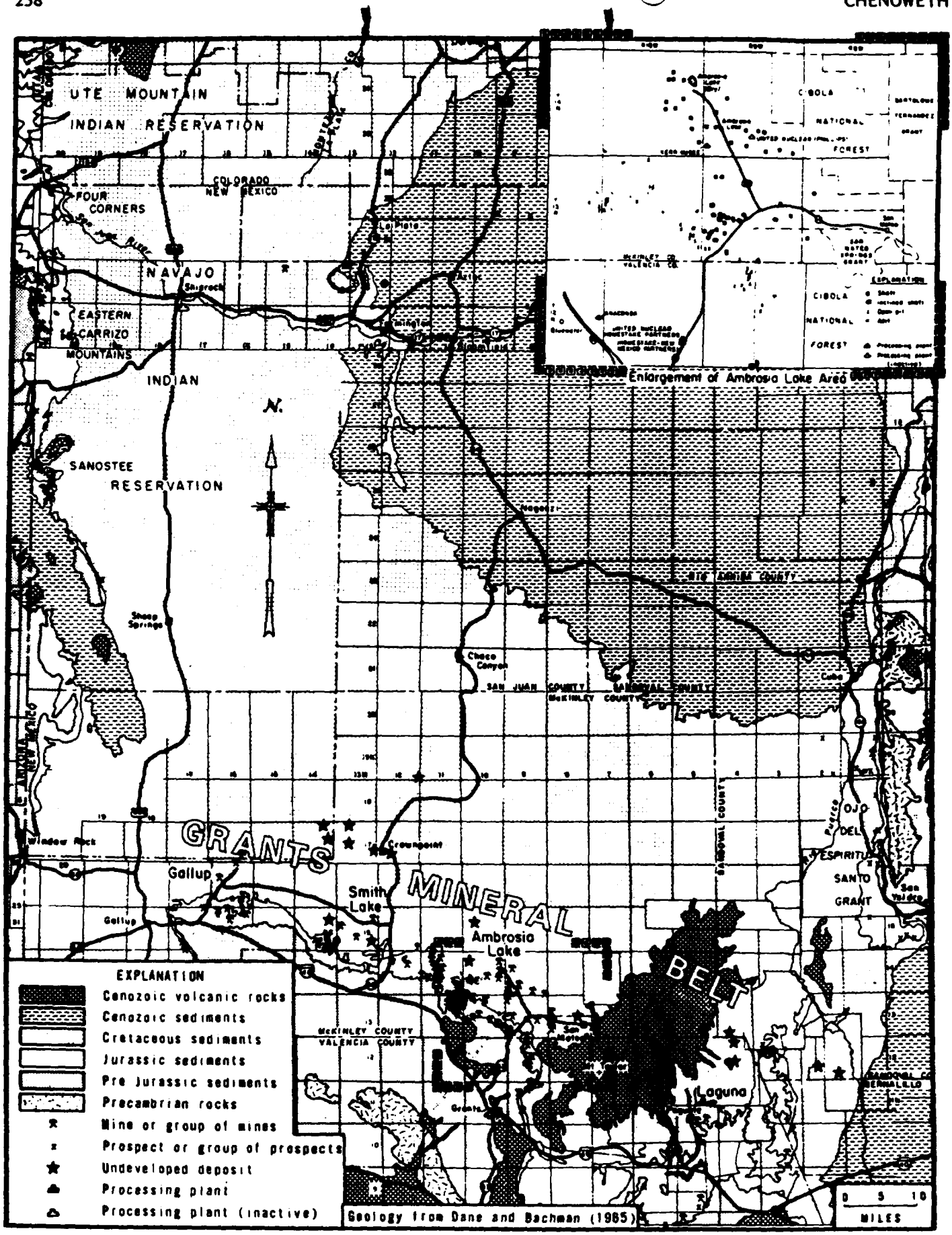


Figure 1. Uranium occurrences, mines and mills, San Juan Basin.

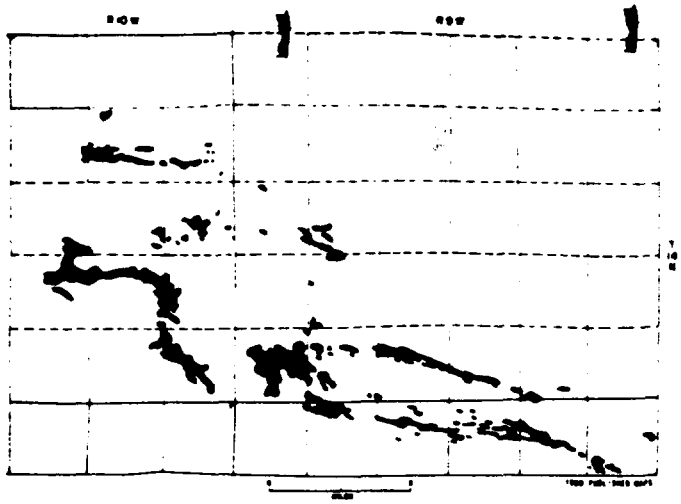


Figure 2. Plan map of ore bodies, Ambrosia Lake area.

in the lower part of the Fruitland Formation of Cretaceous age, northwest of Farmington.

The Ojo Alamo Sandstone of Paleocene age and the San Jose Formation of Eocene age contain uranium in Rio Arriba and San Juan counties. To date, no commercial deposits have been developed.

In the San Juan Basin, vein-type deposits occur in collapsed pipe structures in the mineral belt. The most significant structure is that exploited by the Woodrow mine, north of Laguna. This mine yielded 67 tons U_3O_8 during the middle 1950s.

HISTORY OF EXPLORATION

The first significant discovery of uranium in the San Juan Basin was in vanadium-bearing carnotite ores in the eastern Carrizo Mountains west of Shiprock by John Wade in 1918. By 1920, Wade had 41 claims in various parts of the Carrizo Mountains (personal communication, 1955), including the eastern flank. No ore was mined then, due to lack of demand for either vanadium or uranium.

One of the earliest observations of uranium minerals in the Grants area was made in 1937 when V. C. Kelley (1963, p. 1) noted carnotite in a hand specimen which had been collected by Mr. Whiteside, a local prospector. Since Kelley's observation was unrecorded, the occurrence of uranium minerals of the Grants area was overlooked for many years.

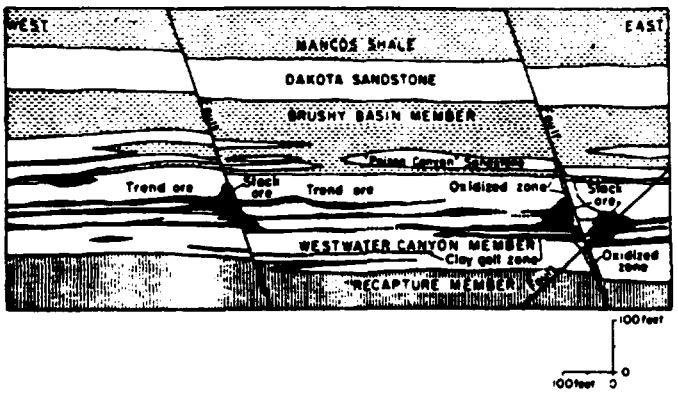


Figure 3. Generalized cross section through ore bodies, Ambrosia Lake area.

World War II increased the demand for vanadium. Early in 1942, Wade, Curran and Company leased a few plots in the east Carrizos. In July 1942, the Vanadium Corporation of America (VCA) leased 12 plots in the east Carrizo area. From 1942 to 1944, these two companies mined carnotite ore from surface exposures in the Salt Wash Member of the Morrison Formation. Although these ores were mined for their vanadium content, uranium was later recovered from the mill tailings. Following the termination of vanadium mining in 1944, the Union Mines Development Corporation systematically studied the vanadium-uranium deposits in the Morrison Formation in the Carrizo Mountains as part of a general uranium resource appraisal of the Colorado Plateau by the federal government's Manhattan Engineer District. Their work was very thorough and few surface exposures of uranium known today were overlooked. Coleman (1944) and Webber (1947) of Union Mines estimated the early ore production for the eastern Carrizo Mountains as 12,000 tons, averaging 0.27 percent U_3O_8 and 3.00 percent V_2O_5.

In 1948, prospecting for uranium was stimulated by the ore-buying schedules and other incentives of the U.S. Atomic Energy Commission (AEC). In the years that followed, uranium deposits were discovered in the Sanostee area, south of the Carrizo Mountains, and in the Cuba-San Ysidro area on the eastern side of the basin. The well publicized uranium discovery by Paddy Martinez in the Todilto Limestone near Haystack Butte in Valencia County in the fall of 1950 brought a wave of prospectors into the Grants area. In January 1951, uranium was discovered nearby in the Morrison Formation in Poison Canyon. This discovery led to the subsequent delineation of the Poison Canyon trend deposits. In November 1951, an airborne radioactive anomaly was detected north of Laguna in Valencia County, by the Anaconda Copper Mining Company, which led to the development of the Jackpile mine. Prospecting continued throughout the San Juan Basin, and by 1956 all surface occurrences had been discovered.

Using the cuttings of an oil well on the nearby Ambrosia dome to ascertain the drilling depths to the Morrison Formation, Louis Lothman began a wildcat uranium drilling project in April 1955, in sec. 11, T. 14 N., R. 10 W. (Louis Lothman, 1956, written communication). The second hold penetrated uranium-bearing sandstone in the Westwater Canyon Member. The discovery stimulated an intensive exploration effort and led to eventual development of the multi-million-ton deposits in the Ambrosia Lake area.

During the extensive prospecting that followed the initial discoveries in the Grants area in late 1951 and early 1952, several small ore bodies were discovered in outcrops of the Morrison and Dakota formations in the Gallup and Thoreau areas. Drilling downdip from these deposits led to the discovery of the larger Blackjack and Church Rock ore bodies in 1958 by the Lance Corporation and Phillips Petroleum, respectively.

In 1962, an ore body was found by Sabre Pinon Corporation in the northeast Church Rock area, where previous drilling had penetrated ore-grade material at a depth of about 1,875 feet in the Westwater Canyon Member. Exploration by Kerr-McGee on adjacent Navajo Tribal lands led to the discovery of its northeast Church Rock ore body in 1966. Following the competitive sale of Navajo leases in 1971, exploration efforts have continued in the northeast Church Rock area and have been extended eastward into the Crownpoint area, where large

ore bodies are currently being developed by several companies.

The discovery of ore at a depth of 2,700 feet in the Westwater Canyon Member near San Mateo by the Fernandez Joint Venture in the fall of 1968, led to the eastward extension of the Ambrosia Lake area. Nearly a year later, ore-grade intercepts were found at a depth of 4,000 feet in a hole drilled by the Bokum Corporation on the flanks of Mt. Taylor. By early 1971, Gulf Oil had purchased the San Mateo and Mt. Taylor ore bodies to consolidate its holdings in the east Ambrosia area. At about the same time, exploration on the eastern side of Mt. Taylor, especially in the Marquez area, identified ore in the Westwater Canyon Member in an area previously explored only for ore in the Jackpile sandstone of the overlying Brushy Basin Member. In August 1976, Continental Oil Company announced a major find at the extreme eastern end of the mineral belt on the Bernabe Montano Grant.

In January 1974, the Exxon Company signed an agreement with the Navajo Tribe to explore 400,000 acres of tribal land in the western San Juan Basin. This agreement was approved by the Secretary of the Interior in January 1977. As a part of the agreement, the Navajo Tribe received a $6,327,300 bonus from Exxon.

In December 1975, the Phillips Petroleum Company announced the discovery of a large deposit, approximately 25 million pounds U_3O_8, 12 miles north of Crownpoint in McKinley County at depths of 3,000 to 3,500 feet. Since this discovery is considerably north of the present concept of the Grants mineral belt, it has revived deeper exploration in the San Juan Basin.

The Mobil Oil Corporation entered into an exploration agreement with the Ute Mountain Tribe in January 1976, for uranium exploration on 162,176 acres of tribal land in southwestern Colorado. This agreement brought the Ute Mountain Tribe a bonus of $2,432,640.

The magnitude of the exploration efforts expended in the San Juan Basin can be measured by the amount of surface drilling that has taken place. Records of ERDA's Grand Junction Office show that from 1964 to 1977, there were 12,622 holes, having a total footage of 16,002,368 feet, drilled in the search for new deposits. In addition, 10,991 holes having a total footage of 13,059,300 feet were drilled for the development of deposits. The San Juan Basin had its peak year in 1976 when 7,104 holes having a total footage of 10,916,302 feet were drilled. This footage represents 32 percent of the total U.S. surface drilling for uranium in 1976.

PRODUCTION

ERDA records indicate that during 1948-1976, the San Juan Basin produced 55,649,500 tons of ore averaging 0.21 percent U_3O_8, and containing 118,018 tons U_3O_8. In addition, 1,145 tons U_3O_8 have been recovered from mine water. These totals constitute 40 percent of the domestic production through 1976. Details of this production are summarized in Table 1. The most productive area is Ambrosia Lake, where the mines, shown in Figure 2, have produced 62,760 tons U_3O_8 or 53 percent of the basin's total production.

When AEC buying schedules for uranium went into effect in 1948, mining commenced in the King Tutt Mesa area of the eastern Carrizo Mountains and uranium production in the San Juan Basin began. The yearly production is shown graphically in Figure 4.

As the mines in the Ambrosia Lake area came into production, the amount of uranium ore produced increased rapidly (fig. 4). Production reached an all-time high of slightly more than 7,900 tons of U_3O_8 in 1962, but declined sharply in 1963 during the AEC's stretchout program. This program, announced November 17, 1962, extended the government's procurement program from January 1, 1967, to December 31, 1970. It deferred delivery to 1967 and 1968 of some uranium concentrates which were originally contracted for delivery before 1967, and provided for purchase of additional amounts of concentrates in 1969 and 1970 equal to the amounts deferred to 1967 and 1968.

Since January 1, 1971, when the AEC ceased its procurement program, most uranium purchases have been made by

Table 1. Summary of uranium production, San Juan Basin.

Area and Source	Member	Number Of Properties	Type Of Mines	Years Of Production	Production Tons U_3O_8	Remarks
Grants Mineral Belt						
[illegible]	[illegible]	129	[illegible]	[illegible]	114,795	[illegible]
[illegible]	–	42	[illegible]	[illegible]	2,218	
[illegible]	–	3	[illegible]	[illegible]	246	
[illegible]	–	–	–	[illegible]	145	
[illegible]	–	1	[illegible]	[illegible]	67	
East Carrizo Mountains						
[illegible]	[illegible]	35	[illegible]	[illegible]	[illegible]	[illegible]
Senostee						
[illegible]	[illegible]	1	[illegible]	[illegible]	81	
[illegible]		1	[illegible]	[illegible]		
Nacimiento						
[illegible]	[illegible]	1	[illegible]	[illegible]	–	
[illegible]		1	[illegible]	[illegible]		
Farmington						
[illegible]		1	[illegible]	[illegible]		
				TOTAL	**118,163**	

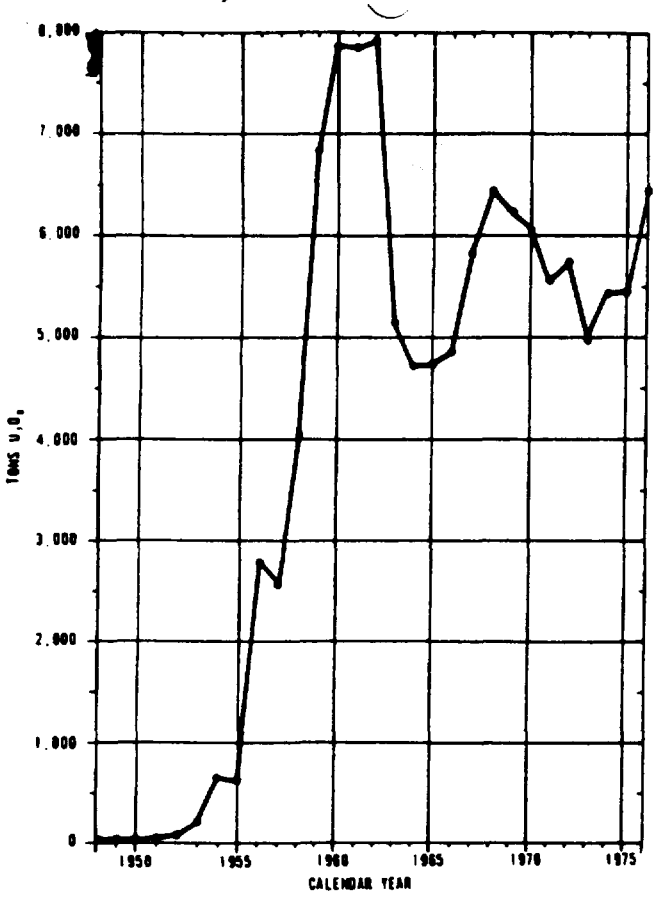


Figure 4. San Juan Basin uranium production, 1948 through 1976.

the nuclear electrical power industry. The decline in uranium sales in the early 1970s was due to a saturated market and was accentuated in 1973 by a long strike against Kerr-McGee. The rise in production in recent years reflects increased demand by the electric-power utility companies.

Recent large increases in spot prices being paid for uranium have had little affect on the production in the Grants mineral belt during 1976. In a recent survey by ERDA, U.S. producers reported that the prices for uranium delivered in 1976 ranged from slightly over $6 to nearly $42 per pound. The average price of uranium reported for actual deliveries in 1976 was $16.10 per pound. This is due to the fact that most of the current production is tied to long-term contracts that were negotiated before the sharp rise occurred. The price of uranium sold by the producers in the Grants area in 1976 probably is near the national average.

PROCESSING FACILITIES

Early output from the eastern Carrizo Mountains was shipped to the Vanadium Corporation of America's (VCA) mill at Durango, Colorado. Shipments continued to the Durango mill until it closed in March 1963. In January 1952, the AEC opened an ore-buying station at Shiprock, New Mexico, and closed it in 1954 when Kerr-McGee Oil Industries began operating a mill at Shiprock. Although this mill was built to treat ore from the Lukachukai Mountains in northeastern Arizona, it also treated ore from non-VCA properties in the eastern Carrizo Mountains. VCA acquired the Shiprock mill in March 1963, and operated it until it closed in 1968.

At first, limestone and sandstone ores from the Grants area were shipped to the AEC buying station at Monticello, Utah. In June 1952, an AEC buying station was established at Bluewater, New Mexico, and closed when the Anaconda mill went on-stream at Bluewater in mid-1953. This mill, using a carbonate-leaching circuit, was constructed to treat limestone ores and operated until May 1959. In 1955, Anaconda constructed a second mill to treat sandstone ores derived chiefly from its Jackpile mine.

Following the discovery of the Ambrosia Lake ore bodies, the AEC established a buying station at Milan, New Mexico, in mid-1956. In late-1956, the AEC contracted to purchase uranium concentrate from Homestake-New Mexico Partners. During 1957, additional purchase contracts were signed with Homestake-Sapin Partners, Kermac Nuclear Fuels and Phillips Petroleum Company. The four uranium mills required to fulfill these contracts began operating in 1958.

After the consolidation of the two Homestake mills in November 1961, the Homestake-New Mexico Partners mill was shut down in April 1962. When Phillips sold its interests to United Nuclear Corporation in March 1963, the Phillips mill was shut down and United Nuclear began shipping its ore for processing, on a toll basis, to the Homestake-Sapin Partners' mill. This is the only remaining carbonate-leach mill in the Grants area, and it is now operated by United Nuclear in partnership with Homestake Mining Company.

In 1973, Sohio Petroleum Company and Reserve Oil and Minerals Corporation announced their intention to build a 1,600-tons-per-day mill on their property near Cebolleta, New Mexico. Construction of this facility began in 1974, and the mill became operational in August 1976.

In early 1977, the four mills operating in New Mexico had a combined nominal operating capacity of 15,100 tons of ore per day, which is nearly half of the total daily national capacity. These mills and operating capacities are as follows:

	Tons of Ore Per Day
The Anaconda Company	3,000
Kerr-McGee Nuclear Corporation	7,000
Sohio Petroleum Co.-Reserve Oil and Minerals Corp.	1,600
United Nuclear-Homestake Partners	3,500
Total	15,100

United Nuclear announced plans to build a mill in the northeast Church Rock area in the early 1970s. In November 1975, ground was broken and the construction of this 3,000 TPD mill commenced; the target date for operations is the summer of 1977. United Nuclear and the Sohio-Reserve mills are the first to be constructed in New Mexico without benefit of government concentrate-purchase contracts.

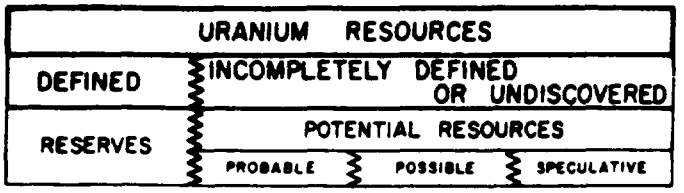
During the latter part of 1976, Phillips Petroleum announced plans for a mill on its Nose Rock property and the Anaconda Company announced plans to enlarge its plant to a capacity of 6,000 TPD.

RESOURCES

Uranium resources consist of reserves and potential resources. Reserves are the firmest element of resources, comprising deposits that have been delineated by drilling or other direct sampling methods. Potential resources are the quantities of uranium estimated to be present in deposits that are incompletely defined or undiscovered. By declining order of

reliability, potential resources are divided into three categories: probable, possible and speculative.

The relationship of reserves to potential resources is illustrated below.



Ore reserves are calculated from drill hole data and other engineering sources which are made available to the Grand Junction Office voluntarily by the uranium companies. Separate evaluations are made of the amounts of uranium that could be exploited at maximum forward costs of $15 and $30 per pound U_3O_8, using established engineering, geologic and economic techniques and criteria.

Forward costs are those operating and capital costs yet to be incurred at the time an estimate is made. Profit and "sunk" costs, such as prior expenditures for property acquisition, exploration and mine development, are not included. Therefore, the forward costs are independent of the market price at which the estimated resources would be sold.

Potential resources, as used by ERDA, are estimates based on geological judgment of the undiscovered tons of U_3O_8 present in minable amounts in areas that are relatively unexplored in detail, but about which enough is known of the uranium geology to permit prediction of the nature and extent of favorable geologic environments. The geographic locations of potential deposits may be definable only within broad limits. Providing the subjective nature of potential is recognized and taken into account, potential plus reserves provide a more useful base for long-range predictions of domestic supply than do reserves alone.

The reliability of potential estimates varies with the classes. It is greatest in the probable class where there has been extensive exploration and where mines have been developed, thus defining ore habits, the nature and extent of the favorable host rocks, etc. The reliability is least in the speculative class where areas of favorability must be inferred solely from literature surveys, geological reconnaissance of formation outcrops and/or the examination of the logs and cuttings of wells drilled for petroleum or other purposes.

The uranium resources of the San Juan Basin as estimated by ERDA, as of January 1, 1977, are given in Table 2.

Nearly all of the reserves in both cost categories are in the Grants mineral belt, and most are associated with operating mines. The $15 reserves represent 55 percent of the total domestic $15 reserves, and the $30 reserves represent 52 percent of the total $30 reserves of the nation.

Probable potential resources in the San Juan Basin are estimated to occur in the uranium areas as extensions of known deposits, or as new deposits in trends or areas of mineralization that have been identified by exploration. Possible potential resources are estimated to occur as new deposits within the Morrison Formation in areas of the basin which are not yet completely explored. Subsurface data, largely from oil and gas wells (Sears and others, 1972) have been used to determine the extent of the favorable ground. Speculative potential resources are restricted to Upper Cretaceous and Tertiary rocks which have not been productive, yet contain uranium occurrences and favorable geology for larger deposits.

Table 2. Uranium resources of the San Juan Basin.

	Tons U_3O_8			
$/lb. U_3O_8 Cost Category	Discovered Ore Reserves	Undiscovered (Potential) Probable	Possible	Speculative
$15	225,800	230,000	250,000	50,000
$30*	356,400	395,000	455,000	65,000

*Includes $15

Potential estimates are revised as new information becomes available. Recent increases in both the probable and possible classes are the result of new exploration which increased the size of the areas considered favorable. Speculative potential estimates are currently under review and will probably be decreased due to unfavorable exploration results. The extensive exploration currently underway within the basin is expected to convert a large population of the potential resources into reserves in the foreseeable future.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of Harlen K. Holen of the Albuquerque field office for his contribution of the potential resource estimates, and the help of Bette Learned for compiling the statistics.

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TABLE 1. Quantity of Undisseminated Toxic Compounds and Elements Within Tailings Piles at Brown Vandever Uranium Mine

	Waste	Quantity of Undisseminated Hazardous Waste*	Disposal Location	Origination
1.	U_3O_8	6.35 (10^5) kg	On-Site	Low Grade Uranium/ Vanadium
2.	V_2O_5	1.04 (10^6) kg	On-Site	"
3.	Radium	Unknown	"	"
4.	Thorium	"	"	"
5.	Arsenic	"	"	"
6.	Selenium	"	"	"
7.	Radon	"	"	"
	TOTAL	**1880 tons**		

* CUSTOMARY UNITS FOR REPORITNG ABUNDANCES OF RADIOISOTOPES ARE MASS UNITS.

Barbara Rec'd 6/25/90
6/25
→ 6H-MA

THE NAVAJO NATION

LEONARD HASKIE
INTERIM PRESIDENT
NAVAJO NATION

IRVING BILLY
INTERIM VICE PRESIDENT
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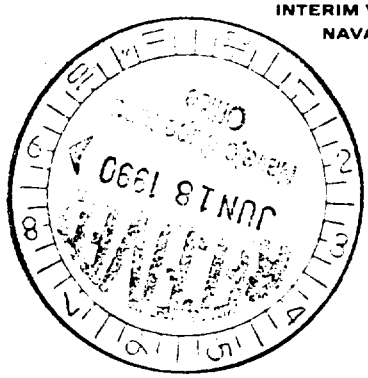

June 11,1990

Mr. Mark Satterwhite
Indian Superfund Coordinator
US-EPA,Region-VI
1445 Ross Avenue
Dallas, Texas 75202-2733

Dear Mr. Satterwhite:

Find enclosed Addenda to the Preliminary Assessment Package for the Navajo-Brown Vandever Uranium Mine.

Additional information, pertinent to the site and Bioaccumulation of Radiospecies has become available(Reference#37). More reliable calculations regarding the area Radon burden have been produced(mine spoils calculations Addenda). Dr. Gaurav Rajen(Senior Environmental Engineer) and Patrick Molloy worked on the calculations. References#35 and #36 are included in support of the calculations. Reference#38 pertains to Radon levels obtained during an Indian Health Service Radon survey in the area of residences approximately two miles from the site. It is intended that the levels be considered as background parameters for the area.

If you have any questions regarding this material, please contact me, Dr. Rajen or Patrick Molloy at (602) 871-7329 or -7332. Thank you.

Sincerely,

Gaurav Rajen, for Clara Bia

Clara Bia
Executive Director
Navajo Superfund Office

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REORGANIZE

Enclosures

CB/pm

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