United States
Environmental Protection
Agency

Office of Radiation and Indoor Air
National Air and Radiation
Environmental Laboratory

EPA 402-R-09-007
June 2009
www.epa.gov/narel

Radiological Laboratory Sample Analysis Guide for Incidents of National Significance – Radionuclides in Air

9471424

EPA 402- R-09-007
www.epa.gov
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Revision 0

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U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Radiation and Indoor Air
National Air and Radiation Environmental Laboratory
Montgomery, AL 36115

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This report was prepared for the National Air and Radiation Environmental Laboratory of the Office of Radiation and Indoor Air, United States Environmental Protection Agency. It was prepared by Environmental Management Support, Inc., of Silver Spring, Maryland, under contracts 68-W-03-038, work assignment 35, and EP-W-07-037, work assignments B-33 and I-33, all managed by David Garman. Mention of trade names or specific applications does not imply endorsement or acceptance by EPA.

Preface

The document describes the likely analytical decision paths that would be made by personnel at a radioanalytical laboratory following a radiological or nuclear incident, such as that caused by a terrorist attack. EPA's responsibilities, as outlined in the *National Response Framework*, include response and recovery actions to detect and identify radioactive substances and to coordinate federal radiological monitoring and assessment activities. This document was developed to provide guidance to those radioanalytical laboratories that will support EPA's response and recovery actions following a radiological or nuclear incident of national significance (INS).

The need to ensure adequate laboratory infrastructure to support response and recovery actions following a major radiological incident has been recognized by a number of federal agencies. The Integrated Consortium of Laboratory Networks (ICLN), created in 2005 by 10 federal agencies[1], consists of existing laboratory networks across the Federal Government. The ICLN is designed to provide a national infrastructure with a coordinated and operational system of laboratory networks that provide timely, high quality, and interpretable results for early detection and effective consequence management of acts of terrorism and other events requiring an integrated laboratory response. It also designates responsible federal agencies (RFAs) to provide laboratory support across response phases for chemical, biological, and radiological agents. To meet its RFA responsibilities for environmental samples, EPA has established the Environmental Response Laboratory Network (ERLN) to address chemical, biological, and radiological threats. For radiological agents, EPA is the RFA for monitoring, surveillance, and remediation, and will share responsibility for overall incident response with the U.S. Department of Energy (DOE). As part of the ERLN, EPA's Office of Radiation and Indoor Air is leading an initiative to ensure that sufficient environmental radioanalytical capability and competency exists to carry out EPA's designated RFA responsibilities.

This document presents three radioanalytical scenarios, responding to two different public health questions, that address the immediate need to determine the concentration of known or unknown radionuclides in air particulate samples. The scenarios are based upon the radionuclides that probably would be released by a radiological dispersal device into the atmosphere. The first analytical scenario assesses whether air particulate samples indicate immediate threats to human health, at identified Protective Action Guides doses, and warrant implementation of protective measures specific to radiation concerns. The second assesses the radionuclide content of samples subsequent to the initial response phase and assesses radionuclide concentrations down to the lowest risk levels.

The third situation assumes that the radioactive contaminants are known, and a shortened version of the first two analytical scenarios is used to help expedite the analysis process. Use of established analytical schemes will increase the laboratory efficiency so that large numbers of samples can be analyzed in a timely manner. The use of the analytical schemes and the associated measurement quality objectives also will ensure that the radioanalytical data produced will be of known quality appropriate for the intended incident response decisions.

[1] Departments of Agriculture, Commerce, Defense, Energy, Health and Human Services, Homeland Security, Interior, Justice, and State, and the U.S. Environmental Protection Agency.

As with any technical endeavor, actual radioanalytical projects may require particular methods or techniques to meet specific measurement quality objectives. The document cannot address a complete catalog of analytical methodologies or potential radionuclides. Radiochemical methods to support response and recovery actions following a radiological or nuclear INS can be found in *Standardized Analytical Methods for Environmental Restoration Following Homeland Security Events, Revision 4.0*.

Detailed guidance on recommended radioanalytical practices may be found in the *Multi-Agency Radiological Laboratory Analytical Protocols Manual* (MARLAP) referenced in this document. Familiarity with Chapters 2 and 3 of MARLAP will be of significant benefit to the users of this guide.

This document is one in a planned series designed to present radioanalytical laboratory personnel, Incident Commanders (and their designees), and other field response personnel with key laboratory operational considerations and likely radioanalytical requirements, decision paths, and default data quality and measurement quality objectives for samples taken after a radiological or nuclear incident, including incidents caused by a terrorist attack. Documents currently completed or in preparation include:

- *Radiological Laboratory Sample Analysis Guide for Incidents of National Significance – Radionuclides in Water* (EPA 402-R-07-007, January 2008)
- *Radiological Laboratory Sample Analysis Guide for Incidents of National Significance – Radionuclides in Air* (EPA 402-R-09-007, June 2009)
- *Radiological Laboratory Sample Screening Analysis Guide for Incidents of National Significance* (EPA 402-R-09-008, June 2009)
- *Method Validation Guide for Qualifying Methods Used by Radiological Laboratories Participating in Incident Response Activities* (EPA 402-R-09-006, June 2009)
- *Guide for Radiological Laboratories for the Identification, Preparation, and Implementation of Core Operations for Radiological Incident Response* (in preparation)
- *Guide for Radiological Laboratories for the Control of Radioactive Contamination and Radiation* (in preparation)
- *Radiological Laboratory Sample Analysis Guide for Incidents of National Significance – Radionuclides in Soil* (in preparation)

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Acknowledgments

This manual was developed by the National Air and Radiation Environmental Laboratory (NAREL) of EPA's Office of Radiation and Indoor Air (ORIA).

Dr. John Griggs served as project lead for this document. Several individuals provided valuable support and input to this document throughout its development. Special acknowledgment and appreciation are extended to Dr. Keith McCroan, ORIA/NAREL; Mr. Daniel Mackney for his support in instrumental analysis, ORIA/NAREL; Ms. Lindsey Bender, ORIA/Radiation Protection Division (RPD); Dr. Lowell Ralston and Mr. Edward Tupin, CHP, both of ORIA/RPD; Ms. Schatzi Fitz-James, Office of Emergency Management, Homeland Security Laboratory Response Center; and Mr. David Garman, ORIA/NAREL. We also wish to acknowledge the external peer reviews conducted by Carolyn Wong, David Burns, and Sherrod Maxwell, whose thoughtful comments contributed greatly to the understanding and quality of the report. Numerous other individuals both inside and outside of EPA provided peer review of this document, and their suggestions contributed greatly to the quality and consistency of the final document. Technical support was provided by Dr. N. Jay Bassin, Dr. Anna Berne, Dr. Carl V. Gogolak, Dr. Robert Litman, Dr. David McCurdy, and Mr. Robert Shannon of Environmental Management Support, Inc.

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Acronyms, Abbreviations, Units, and Symbols

(Excluding chemical symbols and formulas)

α . . . . . alpha particle
α . . . . . probability of a Type I decision error
AAL . . . . . analytical action level
ADL . . . . . analytical decision level
AL . . . . . action level
AS . . . . . alpha spectrometry
β . . . . . beta particle
β . . . . . probability of a Type II decision error
Bq . . . . . becquerel (1 dps)
CERCLA . . . . Comprehensive Environmental Response, Compensation, and Liability Act of 1980 ("Superfund")
cfm . . . . . cubic feet per minute
CFR . . . . . *Code of Federal Regulations*
cm . . . . . centimeter
COC . . . . . chain of custody
cpm . . . . . counts per minute
d . . . . . day
DAC . . . . . derived air concentration
DCF . . . . . Dose Conversion Factor
DL . . . . . discrimination limit
DOE . . . . . United States Department of Energy
DP . . . . . decay product(s)
dpm . . . . . disintegration per minute
dps . . . . . disintegration per second
DQO . . . . . data quality objective
DRP . . . . . discrete radioactive particle
e^- . . . . . electron
$E_{\beta max}$ . . . . . maximum energy of the beta-particle emission
EDD . . . . . electronic data deliverable
ERLN . . . . . Environmental Response Laboratory Network
EPA . . . . . United States Environmental Protection Agency
γ . . . . . gamma ray
g . . . . . gram
Ge . . . . . germanium [semiconductor]
GM . . . . . Geiger-Muller [detector]
GP . . . . . gas proportional
GPC . . . . . gas proportional counting/counter
GS . . . . . gamma spectrometry
Gy . . . . . gray
h . . . . . hour
H_0 . . . . . null hypothesis
H_1 . . . . . alternate hypothesis
HF . . . . . hydrofluoric acid

HPGe . . . . . high-purity germanium [detector]
IC . . . . . Incident Commander
ICC . . . . . Incident Command Center
ICLN . . . . . Integrated Consortium of Laboratory Networks
ICRP . . . . . International Commission on Radiological Protection
IND . . . . . improvised nuclear device (i.e., a nuclear bomb)
INS . . . . . incident of national significance
keV . . . . . kilo (thousand) electron volts
L . . . . . liter
LBGR . . . . . lower bound of the gray region
LEPD . . . . . low-energy photon detector
LS . . . . . liquid scintillation
LSC . . . . . liquid scintillation counter/counting
MARLAP . . . . *Multi-Agency Radiological Laboratory Analytical Protocols Manual*
MARSSIM . . . *Multi-Agency Radiation Survey and Site Investigation Manual*
MeV . . . . . mega (million) electron volts
mg . . . . . milligram (10^{-3} g)
mL . . . . . milliliter (10^{-3} L)
mrem . . . . . millirem (10^{-3} rem)
µg . . . . . microgram (10^{-6} g)
MDC . . . . . minimum detectable concentration
min . . . . . minute
MQO . . . . . measurement quality objective
NaI(Tl) . . . . . thallium-activated sodium iodide detector
NORM . . . . . naturally occurring radioactive materials
φ_{MR} . . . . . required relative method uncertainty
PAG . . . . . protective action guide
pCi . . . . . picocurie (10^{-12} Ci)
QA . . . . . quality assurance
QC . . . . . quality control
rad . . . . . radiation absorbed dose
RDD . . . . . radiological dispersal device (i.e., “dirty bomb”)
RDL . . . . . required detection limit
REGe . . . . . reverse electrode germanium [detector]
RFA……responsible federal agency
rem . . . . . roentgen equivalent man
s . . . . . second
SI . . . . . International System of Units
SOP . . . . . standard operating procedure
Sv . . . . . sievert
TAT . . . . . turnaround time
TEDA . . . . . triethylenediamine
TEDE . . . . . total effective dose equivalent
UBGR . . . . . upper bound of the gray region
u_{MR} . . . . . required method uncertainty
y . . . . . year

Radiometric and General Unit Conversions

To Convert	To	Multiply by	To Convert	To	Multiply by
years (y)	seconds (s) minutes (min) hours (h) days (d)	3.16×10^{7} 5.26×10^{5} 8.77×10^{3} 3.65×10^{2}	s min h d	y	3.17×10^{-8} 1.90×10^{-6} 1.14×10^{-4} 2.74×10^{-3}
disintegrations per second (dps)	becquerels (Bq)	1	Bq	dps	1
Bq Bq/kg Bq/m^3 Bq/m^3	picocuries (pCi) pCi/g pCi/L Bq/L	27.0 2.70×10^{-2} 2.70×10^{-2} 10^{-3}	pCi pCi/g pCi/L Bq/L	Bq Bq/kg Bq/m^3 Bq/m^3	3.70×10^{-2} 37.0 37.0 10^{3}
microcuries per milliliter (µCi/mL)	pCi/L	10^{9}	pCi/L	µCi/mL	10^{-9}
disintegrations per minute (dpm)	µCi pCi	4.50×10^{-7} 4.50×10^{-1}	pCi	dpm	2.22
cubic feet (ft^3)	cubic meters (m^3)	2.83×10^{-2}	cubic meters (m^3)	cubic feet (ft^3)	35.3
gallons (gal)	liters (L)	3.78	liters	gallons	0.264
gray (Gy)	rad	10^{2}	rad	Gy	10^{-2}
roentgen equivalent man (rem)	sievert (Sv)	10^{-2}	Sv	rem	10^{2}

NOTE: Traditional units are used throughout this document instead of International System of Units (SI) units. Protective Action Guides (PAGs) and their derived concentrations appear in official documents in the traditional units and are in common usage. Conversion to SI units will be aided by the unit conversions in this table. Conversions are exact to three significant figures, consistent with their intended application.

I. INTRODUCTION

This guide deals with the analysis of air samples that may have been contaminated as the result of a radiological or nuclear event, such as a radiological dispersal device (RDD), improvised nuclear device (IND), or an intentional release of radioactive materials into the atmosphere via mechanical or other methods. In the event of a major incident that releases radioactive materials to the environment, EPA will turn to selected radioanalytical laboratories to support its response and recovery activities. In order to expedite sample analyses and data feedback, the laboratories will need guidance on EPA's expectations.

A response to a radiation release to the environment likely will occur in three phases: "early," "intermediate," and "recovery." Each phase of an incident response will require different and distinct radioanalytical resources to address the different consequences, management, priorities, and requirements of each phase. Some of the more important radioanalytical laboratory responsibilities germane to an incident response consist of:

- Radionuclide identification and quantification,
- Sample load capability,
- Sample processing turnaround time,
- Quality of analytical data, and
- Data transfer capability.

The early phase begins at the initial event and lasts for three or four days, during which data are scarce and pre-planned dispersion models may be used when appliable. During this phase, responders are primarily concerned about evacuating people, sheltering them in place, or restricting exposure to ambient air and dust. The purpose of the actions and evaluations taken during the early phase is to minimize exposure and to prevent acute health effects. The Protective Action Guides (PAGs) for radiological emergencies recommend evacuation of a population if the projected short-term total effective dose equivalent[1] (TEDE) exceeds 1 rem.[2] The nominal trigger for sheltering is 1-rem over four days (projected avoided inhalation dose). The radioanalytical resource requirements (field or fixed laboratory) for this early phase may vary significantly depending on the time frame, source-term nuclide (see glossary), and the extent of the contamination.

The intermediate phase begins when no more radiation releases are expected, and the source term contamination radionuclides have been qualitatively identified. In this phase, radionuclide concentrations, extent of the contaminated zone, and matrices (air, water, soil) required for analysis may not be well defined. The radioanalytical resources needed will depend on the radionuclide analytical action level (AAL) developed for the various media important to human exposure. The AAL may change depending upon the stage of the event, the appropriate PAGs, or risk values. The radionuclide AALs (derived concentrations) for different media types are based on the PAGs or risk values. For

[1] The sum of the effective dose equivalent (for external exposure) and the committed effective dose equivalent (for internal exposure). TEDE is expressed in units of sievert (Sv) or rem.

[2] The common unit for the effective or "equivalent" dose of radiation received by a living organism, equal to the actual dose (in rads) multiplied by a factor representing the danger of the radiation. "Rem" stands for "roentgen equivalent man," meaning that it measures the biological effects of ionizing radiation in humans. One rem is equal to 0.01 Sv.

the intermediate phase, PAGs have been established to limit the projected radiation doses for different exposure periods: not to exceed 2-rem TEDE over the first year, 500-mrem TEDE during the second year, or 5 rem over the next 50 years (including the first and second years of the incident). In addition, radionuclide concentration limits for food and water as regulated by the Food and Drug Administration and EPA would be applicable.

The final, or "recovery," phase occurs as part of a radiological incident site-remediation effort. During this phase, when site atmospheric characterization and remediation cleanup effectiveness are determined, there is a potential for more extensive radiochemical analyses at the lowest radionuclide concentrations. Airborne radionuclide concentrations therefore should be compared to derived air concentrations (DACs) corresponding to 10^{-4} and 10^{-6} lifetime cancer morbidity risk factors for long-term exposures.

During all phases of an incident response, radioanalytical resources are needed for identifying the radionuclide source term and quantification of the radionuclides in a variety of sample media. Additionally, gross screening of samples to prioritize sample processing or to obtain information related to the general level of contamination in samples is also necessary. This guide has been developed to provide the Incident Commander (IC)[3] and the laboratories used during an incident with a logical processing scheme to prioritize sample processing in relation to the radionuclide air concentrations corresponding to established PAGs or risk levels.

A. Purpose and Objectives

This document is intended to assist those analytical laboratories that will be called upon to provide rapid support to field personnel and decision makers following a radiological release to the atmosphere. Because EPA recognizes that in the early and intermediate period following such a release there may not be sufficient time for the Incident Command Center (ICC) to coordinate and communicate complete measurement quality objectives and analytical priorities to the laboratory, this document will enable laboratories to proceed with a consistent approach to developing and reporting data suitable for the anticipated use.

The ultimate purpose of the screening process described in this guide is to ensure that laboratories can adequately respond to the Incident Commander's requirements with timely analytical results so that public health is protected. The recommendations in this guide are based upon EPA's PAGs and risk factors for radionuclides in air.[4] The PAGs and risk factors are converted to air concentrations for individual radionuclides based on the decay particle, its energy, and inhalation/residence time dose models for a standard person.

Analytical action levels (AALs) are derived radionuclide-specific activity concentrations in air that correspond to specific EPA PAG dose limits or acceptable Agency risk levels. In this document, EPA uses AALs to prioritize air filter samples for radiochemical analyses. Subsection C, on page

[3] Throughout this guide, the term "Incident Commander" (or "IC") includes his or her designee.

[4] Eckerman et al.(1999), EPA (2002), ICRP (1995, 1996)

5, describes the methods and assumptions EPA uses to calculate AALs for the radionuclides discussed in this document.

One of the key objectives in this document is to explain the responsibilities indicated above in terms of analytical processes. While the IC should provide the necessary information (analytes, matrices, measurement quality objectives) that define the scope of the laboratory's processing requirements and results, the laboratory should ensure that the methods used have been validated and will meet the desired measurement quality objectives (MQOs) and the required turnaround time. In the event that laboratories receive samples without complete documentation or direction, laboratories may follow the procedures and examples in this document and be confident that their analyses will provide reasonable and consistent results.

This document is not meant to replace any field monitoring decisions on sample prioritization. It is intended as a guide for how to establish priorities for samples received at the laboratory at different times throughout the response, and it should provide to the IC the basis for understanding the nature and limitations of the data received from the laboratories.

B. Scope of Radiological Scenarios

Radiological events can be subdivided into three phases, which are generally defined in this document as: early (onset of the event to about day 4), intermediate (about day 4 to about day 30), and recovery (beyond about day 30). This guide concentrates on the time from the end of the early phase, through the intermediate phase, and into the recovery phase. During the early phase, analytical priorities need to address the protection of the public and field personnel due to potentially high levels of radioactivity and to provide for *qualitative* identification of radionuclides.

Action Levels: AALs and ADLs

This guide relies heavily on the use of the terms "analytical action level" (AAL), "required method uncertainty" (u_{MR}), and "analytical decision level" (ADL) in characterizing the desired levels of performance of analytical methods and the radioanalytical results for use in decisions.

The term "analytical action level" (AAL) is used as a general term denoting the radionuclide concentration at which action must be taken by incident responders. The AAL will correspond to a PAG value (short-term dose-based) or a risk-based value (related to long-term health effects). Ideally, the Incident Commander (IC) will provide the laboratory with the dose- or concentration-based action level and the acceptable decision error rates. If not, this guide provides "default"values. For example, the air concentration of ^{226}Ra corresponding to the 500-mrem PAG is 1.8 pCi/m^3. Tables 7A, 7B, 7C, and 7D show the AALs associated with the 2-rem, 500-mrem, 10^{-4} risk and 10^{-6} risk values for selected alpha, beta, and gamma-emitting radionuclides. Incident-specific action levels different from the ones used in the tables may be promulgated. In these cases, the corresponding AALs can be calculated as a linear function of either the 500-mrem AALs or the 10^{-4} or 10^{-6} risk values (see Scenario 3 for an example of an event-specific AAL calculated in this manner).

The selection, validation, and execution of a particular analytical method rely on the ability of that method to produce a result with the specified uncertainty, u_{MR}, at the AAL. These conditions assure that the quality of the final sample analysis data will be adequate for making critical decisions. Whenever the reported sample activity or concentration exceeds a pre-defined decision level (the ADL), appropriate action is warranted. The derivation and use of AAL, u_{MR}, and ADL are discussed in detail throughout this guide. While closely interrelated, it is important to note that the use of AAL (and associated u_{MR}) and ADL represent distinct concepts; they may not be used interchangeably but rather should be interpreted and applied according the guidelines of this document.

The required method uncertainty and ADL will change depending upon the acceptable decision error rate. Tables provided in Appendix I list the AAL, ADL, and u_{MR} values for the radionuclides of concern. The tables present gross screening and radionuclide-specific measurements for alpha and beta/gamma-emitting radionuclides. Derivation of the ADL values for each of these tables can be found in Appendix VI. The listed AALs are applicable as default values based on generic conversions of the dose level to concentration in air for a specific radionuclide. The IC may provide incident-specific action levels or decision error rates that would supersede these values. In this case, the laboratory will need to develop new tables for all values, using the process described in Appendix VI.

During the intermediate phase, the radionuclides and matrices of concern are known *qualitatively*, and the *quantitative* levels suitable for making decisions based on action levels need to be determined rapidly. The time period of an incident where this document will find its greatest utility is early in the intermediate phase through the end of the recovery phase. Laboratories performing analyses must optimize sample processing and rapid delivery of sample results to permit assessment in a timely manner of whether or not AALs have been exceeded. During the recovery phase, the screening techniques used for samples will be less significant because the radionuclides from the event are likely to have been characterized already. This is represented by the lower portions of the flowcharts, which address analyses of specific radionuclides.

This document presents three analytical scenarios to aid laboratories in establishing priorities for analyzing samples received during the response to a radiological release. The first two assume that the radioactive material is unknown. Table 1 summarizes the relevant responsibilities of the IC and the laboratory manager during such a response, and Figure 1 depicts how they relate to the response team's needs for sample prioritization.

TABLE 1 – Analytical Response Responsibilities

Information Provided...	Sample Priority	Method Uncertainty	DQOs/ MQOs	Reporting (Results, Anomalies)	Analyte Selection	Sampling Specs (Time, Volume)	Hot Particles	Turnaround Time Compliance	Filter Media	Procedure Selection
By:	IC	IC	IC	Lab	IC*	IC	Lab	Lab	IC	Lab
To:	Lab	Lab	Lab	IC	Lab	Lab	IC	IC	Lab	IC

*During the early phase, the laboratory will identify the radionuclides present. Once it is determined which radionuclides are present, the IC may decide analytical priorities.

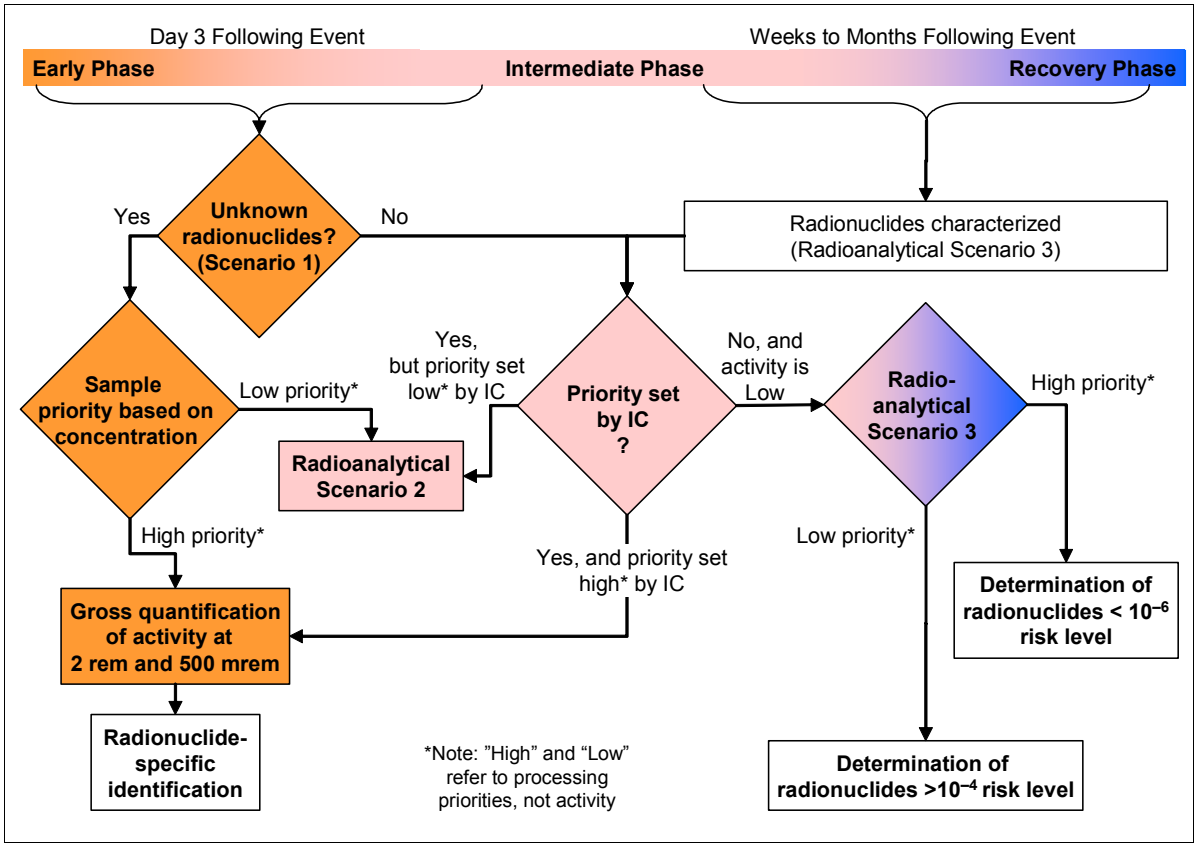

Figure 1 – Air Sample Scenarios and Response Phases

- In Radioanalytical Scenario 1, the identity of the radionuclides and potential concentrations are unknown. This is most likely to occur during the early phase of the event. The laboratory's priority is to identify all the radionuclides present and their air concentrations. Air particulate samples (filters) and aerosol samples (canisters, see page 19), taken from an area in the vicinity of the radiological event, are suspected to be highly contaminated with an unknown quantity of yet unidentified radionuclides. The radionuclide identities and concentrations taken from various analyses will be compared to the 2-rem and 500-mrem AAL values, giving priority to the highest activity samples. MQOs for these AALs can be met with smaller volume air samples than normal, allowing shorter sampling times.

- The second scenario (Radioanalytical Scenario 2) addresses the need to identify areas of acceptable air quality and will occur later in the intermediate phase and into the recovery phase. This scenario requires the laboratory to determine whether identified or partially identified airborne radionuclide concentrations are above the 500-mrem AAL value or correspond to concentrations in the 10^{-4} to 10^{-6} risk levels. Decisions regarding priority are based on EPA's PAGs or risk factors. Samples with concentrations corresponding to the 10^{-4} and 10^{-6} risk-based factors are of lower analytical priority at this time.

- Radioanalytical Scenario 3 is where the radionuclides have been identified, and this scenario would normally occur during the intermediate/recovery phase. This scenario is focused on assessing air-particulate filters that have concentrations below an associated 10^{-4} long-term risk factor. So while Figure 1 depicts Scenario 3 occurring during the later intermediate phase, Scenario 3 could occur earlier, in which case the laboratory need not waste analytical processing time trying to identify which radionuclides are present. The flow focuses on establishing the priority for processing samples based on the gross concentration screening values for the specific radionuclides. Formal evaluation of other naturally occurring radionuclides may be necessary when assessing the long-term risks of the sampled aerosol. In the later phases, sample input from Radioanalytical Scenario 1 or 2 flow schemes (as is the case for Scenario 2) is not anticipated.

These scenarios may be applicable in different phases of the event, although as was previously indicated, Scenario 1 is usually the early phase, and Scenario 2 is the late-intermediate to recovery phase. The flow charts (Figures 2–4) assume that the laboratory already has acquired or developed the general guidance discussed for each scenario. However, laboratories should note that at any time samples may be assigned a specific priority based on the status or phase of the incident.

Samples that may become evidence in a criminal investigation must be handled separately (particularly with respect to chain of custody), and the laboratory should receive information form the Incident Commander or lead law-enforcement agency on how to process these samples.

C. Relationship of PAG, AAL, ADL, Risk Levels, and u_{MR}

PAGs reflect the limits of dose that are allowed to be received by individuals during different phases of an incident. Because laboratories will determine sample concentrations in pCi/m^3, AALs (see Tables 7A–7D) are action levels expressed in units of pCi/m^3 that equate to PAG annual dose limits of 2 rem (first year) and 500 mrem (second year). These are based on:

- Maximum inhalation dose coefficients (DCFs) (in units of Sv/Bq) taken from ICRP Publication 72 (ICRP 1996) or from Federal Guidance Report 13 CD Supplement (EPA 2002). From among the coefficients listed for each radionuclide for lung clearance classifications of fast (F), medium (M), and slow (S), EPA chose the coefficient that gave the largest or maximum committed effective dose per unit intake for the adult member of the public. Dose coefficients in Sv/Bq were converted to units of mrem/pCi by multiplying by a conversion factor of 3,700.
- An exposure duration of 1 year (365 days).
- An inhalation rate of 22.1 m^3/d taken from ICRP Publication 66 (ICRP 1995) for an adult member of the public.

Accordingly, PAG-derived AALs are calculated for each radionuclide according to the following equation:

$$\text{AAL (pCi/m}^3\text{)} = \text{PAG / (DCF} \times 22.1\ \text{m}^3\text{/d} \times 365\ \text{d/y)}$$

For example, the AAL for ^{241}Am corresponding to the 2000 mrem/y dose limit is calculated as:

$$\text{AAL } ^{241}\text{Am} = 2000\ \text{mrem/y / (0.36 mrem/pCi} \times 22.1\ \text{m}^3\text{/d} \times 365\ \text{d/y)}$$
$$= 0.7\ \text{pCi/m}^3$$

Action levels can be either risk-based or dose-based. Risk-based AALs (Tables 8A and 8B) are expressed in units of pCi/m^3 that equate to EPA's acceptable lower and upper cancer risk levels for cleanup, namely 1 in 1 million (1×10^{-6}) and 1 in 10,000 (1×10^{-4}). These are based on:

- Maximum inhalation risk coefficients (in units of Sv/Bq) taken from Federal Guidance Report 13 (Eckerman et al., 1999) or from Federal Guidance Report 13 CD Supplement (EPA 2002). From among the coefficients listed for each radionuclide for lung clearance classifications of fast (F), medium (M), and slow (S), EPA chose the coefficient that gave the largest or maximum lifetime, age-averaged, excess morbidity (total cancer) risk per unit intake. Risk coefficients in Risk/Bq were converted to units of Risk/pCi by dividing by the conversion factor of 27.027.
- An exposure duration of 1 year (365 days)
- An inhalation rate of 22.1 m^3/y taken from ICRP Publication 66 (ICRP 1995) for an adult member of the public.

Accordingly, risk-based AALs are calculated for each radionuclide according to the following equation:

$$\text{AAL (pCi/m}^3\text{)} = \text{Risk Level / (Risk coeff.} \times 22.1\ \text{m}^3\text{/d} \times 365\ \text{d/y)}$$

For example, the AAL for ^{241}Am corresponding to the 10^{-4} risk level is calculated as:

$$\text{AAL } ^{241}\text{Am} = 1\times10^{-4}\ \text{risk / (}3.8\times10^{-8}\ \text{risk/pCi} \times 22.1\ \text{m}^3\text{/d} \times 365\ \text{d/y)}$$
$$= 0.33\ \text{pCi/m}^3.$$

Decisions related to the processing and prioritization of specific samples will be made by laboratory personnel at the laboratory by comparing the results of radioanalytical measurements to "analytical decision level" (ADL) concentrations. Whenever the measured analyte concentration equals or exceeds the applicable ADL concentration, it will be concluded that the AAL (PAG or risk factor) has been exceeded. The ADL concentrations are always less than the corresponding AAL values by an interval calculated to provide statistical confidence when deciding whether the corresponding AAL has or has not been exceeded. The magnitude of this interval corresponds to the maximum uncertainty that would be consistent with acceptable decision error rates established during the data quality objective (DQO)/MQO process.[5] This uncertainty is referred to as the required method uncertainty, u_{MR}, and is defined in MARLAP.

MQOs are statements of performance objectives or requirements for selected method performance characteristics. Method performance characteristics include the method uncertainty, the method's detection capability, the method's quantification capability, the method's range, the method's specificity, and the method's ruggedness. An example MQO for the method uncertainty at a specified concentration, such as the action level, could be:

> "A required method uncertainty for ^{226}Ra of 2.1 pCi/m^3 or less at the analytical action level of 7.0 pCi/m^3 for screening methods of analysis."

Table 2 provides examples of a dose and its corresponding AAL, ADL, and required method uncertainty (u_{MR}) for ^{226}Ra. Note that there are differences in these values not only based on the dose or risk, but also on whether or not a screening instrument or radiochemical-specific methods are used.

TABLE 2 – Relationship Among Dose, AAL, ADL, and u_{MR} for ^{226}Ra

Measurement Type	Dose (mrem) or Risk-Based Value	AAL[6] (pCi/m^3)	ADL* (pCi/m^3)	u_{MR} (pCi/m^3)
Screening[7]	2,000	7.0	3.5	2.1
Radionuclide-Specific	2,000	7.0	4.9	0.88
Radionuclide-Specific	(at 10^{-4} risk)[8]	0.44	0.31	0.055

*ADL values are calculated per equations in Appendix VI

[5] Appendix VI provides the derivation and detailed discussion of MQOs, required method uncertainties, and ADLs.

[6] See Tables 7A–7D for 2-rem and 500-mrem AALs and Tables 8A and 8B for risk-based AALs.

[7] Tables 7A and 7B summarize default ADLs and u_{MR} for gross screening measurements at 2 rem and 500 mrem. Tables 7C and 7D summarize default ADLs and u_{MR} for radionuclide-specific measurements at 2 rem and 500 mrem.

[8] Tables 8A and 8B summarize ADLs and u_{MR} for radionuclide-specific measurements at 10^{-4} and 10^{-6} risk levels.

The values in the tables in Appendix I are calculated based on tolerable Type I and Type II error rates for each measurement type as described in Appendix VI.

Laboratories will perform both gross activity measurements and radionuclide-specific measurements during an incident. Because different DQOs and MQOs are applicable to different types of measurements, different u_{MR} and the corresponding ADL values are provided for screening and radionuclide-specific analyses. The values for u_{MR} and corresponding ADL for screening and radionuclide-specific determinations presented in Tables 7A–D, 8A, and 8B (Appendix I) provide laboratories with a starting point for developing methods and systems for recovery activities. It is anticipated that incident-specific DQOs and MQOs may be developed by the IC and provided to the laboratory.

Once the radionuclides are identified, the focus of response activities will shift to assessment of dispersion, habitability, and long-term health effects. This is the focus of the second scenario, and again the laboratory's main job will be to prioritize the order of sample analysis based on activity. It should be noted that, during the intermediate and recovery phases, resuspension of particulates during remediation may cause airborne radionuclide concentrations to increase. Thus, one cannot assume that all radionuclide concentrations on air particulate filters will decrease as the event progresses. Continued sample screening will help provide the laboratory staff with accurate information regarding activity on the filters.

The attached charts and accompanying numbered notes and data tables depict the anticipated analytical flow that will assist the lab to respond rapidly and consistently. In keeping with concepts of the *Multi-Agency Radiological Laboratory Analytical Protocols Manual* (MARLAP) , this guide does not specify analytical methods. A performance-based approach for the selection of appropriate analytical methods by the laboratory will be used to achieve MQOs specified by this document and incident responders.

The MQOs and any other analytical requirements serve as the basis for the laboratory's selection of a method under a performance-based approach. The laboratory should have method validation and performance data to demonstrate the method's ability to achieve the project-specific MQOs.

This document presents a default set of MQOs. Actual MQOs, however, always will depend upon events and may need to be modified by incident responders and project planners to better address a particular event. However, in order to have an analytical approach in place to address a variety of incident scenarios, the identified decision points in the accompanying flow diagrams refer to the default MQOs. The important MQO is the required method uncertainty at the AAL, which together with the acceptable decision error rates, is used to establish the ADL. At most decision points in the diagram, the decision is related to the ADL based on either PAG values or risk-based values.

D. Analytical Response Time

Decisions regarding the extent of air contamination will need to be made in a timely manner. Approximate times required for laboratory processing of these samples and finalizing the sample results are shown in Appendix V for each radioanalytical scenario. They identify the workflow for making qualitative and quantitative measurements of high-activity contaminated air particulate samples (Radioanalytical Scenario 1) and determine whether lower-concentration samples still

present longer-term risk (Radioanalytical Scenario 2). The information regarding sample radioactivity measurements also needs to be communicated vigorously to the IC so that decisions regarding movement of population, sheltering, other protective actions, or additional sampling can be assessed accurately.

E. Implementation

It may be necessary for laboratories to incorporate key aspects of this document into their standard operating procedures (SOPs). For example, the gross screening process will require specific standards and response factors for each of the instruments used by the laboratory. This could be a departure from the laboratory's current screening practice because the activity levels, sample geometries, and matrices may be significantly different from what the laboratory normally experiences. Generally, it should be expected that higher activity tracers and QC standards may be needed for the analysis of higher activity samples.

This guide focuses on the prioritization of sample analyses and some of the technical issues encountered in performing analyses on air particulate samples received by the laboratory following a radiological incident. The guidance on how to prepare and calibrate screening instruments for the support of a radiological incident is outlined in *Radiological Laboratory Sample Screening Analysis Guide for Incidents of National Significance* (EPA 402-R-09-007, June 2009). The guide describes calibration and measurement techniques, instruments used for screening, and provides guidance on interpretation of screening results.

Laboratories should become proficient with these procedures because they could be tasked to respond to analytical requests in hours rather than weeks. Thus, laboratory personnel should become familiar with the recommendations and procedures, and laboratories should conduct both training and actual "drills" or exercises where analytical scenarios and samples are tested during a controlled scenario. The frequency and depth of these exercises will be at the discretion of the laboratory management.

Laboratory personnel also should be cross-trained in different areas of the incident response activities listed below to help ensure continuity of sample analysis throughout the duration of the response and cleanup:

- Equipment calibration and QC checks
- Sample receipt and log-in
- Sample tracking and storage
- Screening
- Sample preparations
- Analytical separations
- Counting
- Contamination monitoring
- Report generation
- Data review
- Waste management

The scope of these activities may be different for incident response than for normal laboratory operations. In order for the laboratories to be able to begin to process the samples promptly, certain presumptive values are identified in the tables in this document for action levels, which may be relied upon in the absence of explicit action levels received from the IC. However, these values may change based on the needs of the particular event. MQOs will be stipulated by the IC and should be communicated to the laboratory as early as possible so that analysis can meet project objectives.

For air monitoring, MQOs typically would be stated for analytical action levels. In most air monitoring applications, it is impractical to specify an exact "standard" air volume that is passed through an air particulate filter, or an iodine cartridge. The activity collected on an air filter (or cartridge) will vary according to the sampling duration and flow rate. For operational practicality, the analytical method and analysis time of the measurement should be adjusted to a "hypothetical minimum" volume sampled so that the MQOs for an AAL can be met for all samples collected (representing a batch) as long as the actual volume sampled for any sample is equal to or larger than the "minimum" volume. The value of the "minimum volume" would be selected for a batch of samples by evaluating the field sample submission form that contains the sample identifications and corresponding total volumes sampled. For both gross screening and radionuclide-specific analyses, most laboratories will standardize the counting time of a batch of samples to a single value, normally the limiting counting time to meet the u_{MR} at the AAL or a detection level. The flow diagram for Scenario 1 (Figure 2) assumes a collected volume of 68 m^3, but volumes may be in the range of 3 to 100 m^3. The analytical decision paths in Figure 3 (Scenario 2), which are based on discriminating 500-mrem AAL samples from10^{-4} and 10^{-6} risk levels, assume a collected volume of 200 to 1,600 m^3. Figure 4 (Scenario 3) outlines the flow path when the radionuclides are known.

Once the appropriate method and the appropriate volume have been selected, the laboratory can select the proper counting time and other parameters to meet the MQOs in the most efficient manner. Presumably, the volume provided by the IC will exceed the minimum volume that a laboratory will need when analyzing a batch of samples. It is also important for laboratories to be in contact with the ICC regarding requirements for split samples and reserving aliquants of sample digestate for additional analyses. This may require that more than the minimum volume is collected, that longer counting times are specified, or that the laboratory has a procedure for splitting a sample before starting analysis. The measurement uncertainty of the calculated air concentration from the sample analyzed will be compared to the absolute and required relative method uncertainty.

Finally, it should be noted that laboratories that perform radiochemical analyses on a routine basis only determine the total activity for a specific radionuclide and do not differentiate among different chemical species that may be present. This requires a methodology that is not part of the normal analytical processes for these laboratories.

F. References

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II. RADIONUCLIDES

Table 3 lists some of the radionuclides that are believed to be accessible and possibly could be used in a radiological dispersal device (RDD), or "dirty bomb," and the major (noninclusive) dose-related radionuclides that might be formed from the detonation of an improvised nuclear device (IND). These radionuclides are addressed in this report. In the case of an IND, numerous short- and long-lived radionuclides will be present, requiring proper identification and quantification. Several of the radionuclides on the list have progeny that will coexist with the parents. Thus, if ^{228}Th were to be found, ^{224}Ra also would be present (although it is not listed). Several different radionuclides may be present even if only one RDD is used.

TABLE 3 – Radionuclides of Concern

Alpha Emitters			Beta/Gamma Emitters		
Radionuclide	**Half-Life**	**Emission Type**	**Radionuclide**	**Half-Life**	**Emission Type**
^{241}Am	432.6 y	α, γ	Ac-227†	21.77 y	β, γ
^{252}Cf	2.64 y	α, γ			
^{242}Cm	163 d	α	Ce-141*	32.51 d	β, γ
^{243}Cm	29.1 y	α, γ	Ce-144‡	284.9 d	β, γ
^{244}Cm	18.10 y	α	Co-57*	271.7 d	ε, γ, x-ray
^{237}Np	2.14×10^{6} y	α, γ, x-ray	Co-60*	5.271 y	β, γ
^{210}Po *	138.4 d	α	Cs-134*	2.065 y	β, γ
^{238}Pu	87.7 y	α	Cs-137§	30.07 y	β, γ
^{239}Pu	2.41×10^{4} y	α	H-3*	12.32 y	β only
^{240}Pu	6.56×10^{3} y	α	I-125*	59.40 d	ε, γ, x-ray
^{226}Ra†	1.60×10^{3} y	α, γ	I-129†	1.57×10^{7} y	β, γ, x-ray
^{228}Th	1.912 y	α, γ	I-131*	8.021 d	β, γ
^{230}Th	7.538×10^{4} y	α, γ	Ir-192*	73.83 d	β, γ
^{232}Th	1.405×10^{10} y	α	Mo-99†	65.94 h	β, γ
^{234}U	2.455×10^{5} y	α	P-32*	14.26 d	β only
^{235}U	7.038×10^{8} y	α, γ	Pd-103*	16.99 d	β, γ
^{238}U	4.468×10^{9} y	α	Pu-241	14.29 y	α, β
U-Nat	—	α	Ra-228†	5.75 y	β only
			Ru-103†	39.26 d	β, γ
			Ru-106†	373.6 d	β only
			Se-75*	119.8 d	ε, γ
			Sr-89*	50.53 d	β only
			Sr-90†	28.79 y	β only
			Tc-99*	2.11×10^{5} y	β only

The half-lives of the nuclides are given in years (y), days (d) or hours (h)

* No radioactive progeny or progeny not analytically useful.

† Radioactive progeny with short half-lives, and the progeny may be used as part of the detection method for the parent.

‡ Radioactive progeny not used for quantification, only screening.

§ Radioactive progeny used for quantification only, not screening.

III. DISCUSSION

In order to illustrate the typical decisions and actions to be taken by a laboratory for each scenario, examples of the three scenarios using theoretical samples and measurement results are provided in Appendices II, III, and IV. These examples represent only three of many different possible permutations, however, and should not be construed as limiting. Each example is keyed back to the steps in its respective diagram and notes.

A. Sampling and Processing at the Laboratory

These scenarios assume that the time period from taking of sample to the actual beginning of the analysis by the laboratory will be short (< 1–2 days). During the intermediate or recovery phases, actual sampling duration can be up to one week, so that risk-based ADL concentrations of some radionuclides can be achieved within a reasonable count time (i.e., lower radionuclide concentrations will require larger sample volume to achieve detectability). For the three scenarios discussed in this guide, it is assumed that field personnel have performed some type of radiation screening survey of the samples prior to sending them to the laboratory. If appropriate, field personnel may determine which samples are to be submitted first to the laboratory based on these survey results. The laboratory's surveys and analyses of the samples are not intended to confirm the field survey results, but should be used by the laboratory to prioritize samples and determine the potential presence of short-lived radionuclides.

In some instances, field monitoring results (measured with NaI(Tl), HPGe detectors, scintillation detectors or proportional counters for field use) will provide information that may help establish the radionuclides' identity or energy-specific information regarding the radionuclides involved in the event. This will help the laboratory to expedite more accurate assessment of the concentration of these radionuclides.

Only laboratories using validated radioanalytical methods (see *Method Validation Guide*, EPA 2009a, and MARLAP, Chapter 6) should be used in order to process samples in a timely and effective manner. These laboratories will have the necessary radioanalytical capability and sample-processing capacity to conduct the required gross screening and radionuclide-specific analyses defined for the scenarios. This guide recommends the following analytical process flow:

1. General screening based on total radiation emitted from the sample.
2. Screening based on type of radiation emitted (i.e., alpha, beta, or gamma).
3. Radionuclide-specific analytical techniques applied after screening indicates the most significant activities or when the radionuclide(s) have been identified.

This is the sequence used for screening in the flow diagrams for each scenario. Each decision point in the flow diagram relates to an ADL that is part of the overall analytical process. Many of the flow diagram boxes have numbers indicating the sequence of the analytical process. The boxes are color-coded, indicating the most important flow path (red) to the least important (yellow) based on the time requirements for returning the analytical results.

Prior to starting the screening process, it is imperative that the laboratory have some specific information about the air filters themselves and the sampling parameters:

- Volume of air sampled.
- Beginning and ending times of the sampling period.
- Type of filter medium.
- Percent area of the filter sent to the laboratory (e.g., if the filter was split or "punched" prior to shipment to the laboratory).
- Contact activity or dose reading of the filter at the end of the sampling period.

This information must be communicated to the laboratory by the field sampling personnel in the chain-of-custody form. There may be occasions where the entire filter is not sent to the laboratory, or when the size of the filter sent to the laboratory does not match a calibrated detector geometry:

- When the entire filter is not to be sent to the laboratory, the air particulate filter may need to be "field split" if there are different laboratories involved with the analytical process, and each one has different radioanalytical capabilities (e.g., determination of $^{239}Pu/^{240}Pu$ ratio, or analysis for a unique radionuclide like ^{241}Am).
- When the size of the filter does not match a calibrated detector geometry, the laboratory may have the analytical capability to perform the direct screening measurement on the filter. However, if the detector geometry that is calibrated does not match the filter geometry, the filter will need to be "punched" to accommodate this instance.

In both of these instances, it is imperative that the fraction of the sample used in the screening and subsequent radionuclide-specific analyses be included in the final radionuclide concentration calculations. For example, if a 4"-diameter circle is cut from 8×12" filter (e.g., field split), the sample results must be multiplied by 7.64 to correct for the activity on the whole filter. Another possibility is that the field sample is a 4"-diameter filter and the laboratory must reduce the size to 2" diameter (using a punch) to accommodate the laboratory's instrumentation. In this case, the final value would be multiplied by 4. Other filter sizes that do not fit a laboratory counting geometry would need to be corrected as appropriate.

It is likely that particulate matter collected on air filters following an INS will not be uniformly distributed on that filter. Hot particles and inhomogeneous distributions are likely on the filter. Therefore, the most representative sub-samples from a filter would be obtained by converting the entire air particulate filter to a homogeneous form, such as a digestate, prior to sub-sampling. In some cases, a portion of the filter should be retained for future use, or a filter may need to be punched to create a reproducible geometry for rapid screening of the sample. A universally accepted methodology for splitting or sub-dividing an air particulate filter does not exist. In cases where the filter must be split prior to digestion, it is important that the laboratory has (and adheres to) written guidance on how the sub-sampling is performed. For example, the guidance may stat to use a 10× magnification and visually identify an area that visually appears uniform in particle deposition.[9] Sub-

[9] This is one of several options that potentially could be used. Another option might be to select a portion of the filter that has a higher loading of the particulates containing the radionuclides. In this instance it may be anticipated that the final result will be biased high if it is known that the particulates contain the radionuclide(s) of interest.

sampling will create bias in the analytical results, and subsequent results should be used with this understanding. Once a filter has been sub-divided for screening (by cutting or punching out a section), the remaining filter should be retained so that all sample constituents are included in the final analysis.

The screening techniques outlined in the first steps of the flowcharts assume that the laboratory maintains the necessary instrumentation and can perform the initial gross sample screening (at or immediately subsequent to sample receipt) functions identified below:

- Micro-R meters for evaluating radiation exposures and doses on low-activity samples.
- Dose-rate meters capable of detecting gamma-beta exposures and doses.
- Hand-held gross alpha frisker for assessing the alpha count rate on sample contact.
- Probes that can be used to determine whether samples exceed the maximum dose rate that can be handled or analyzed at the laboratory.

It is important to note that none of these screening instruments are suitable for all types of emissions. It may take measurements from two or three different types of screening instruments to assess the total *potential* activity present and only the combination of the results should be used to prioritize the sample processing at the laboratory. Further discussion of some of the assessment of these measurements may be found in *Radiological Laboratory Sample Analysis Guide for Incidents of National Significance – Gross Sample Screening Analysis* (in preparation).

The laboratory also should have the instrumentation to perform gross radioactivity measurements either before or after chemical separation (e.g., gas proportional or liquid scintillation counters) and radionuclide-specific analyses (e.g., high-purity germanium detectors). Some of the radionuclides listed in Table 3 (e.g., ^{103}Pd) can be detected only with a specific type of gamma-ray detector because of their low gamma-ray emission energy (60 keV is the usual lower limit of calibration for many high-purity germanium [HPGe] detectors).

Each numbered box has an associated note that provides additional detail for that particular part of the process. Clarification is also provided in these notes as to when parallel paths of analysis should be followed to help expedite the processing of samples.

Appendix V (Table 9) contains generic assumptions that can help laboratory personnel in assessing count times for screening samples for gross radioactivity. The information in the table may assist in determining the approximate time it will take to achieve the required method uncertainty for the decision points in the flow diagram for two different screening methodologies. Laboratories should prepare their own spreadsheets, in advance of an event, using their preferred methodology. Laboratories also should determine (in advance) whether their individual analytical protocols will need to be revised to accommodate this process. The flow sheets used in this document that describe the screening process use gas proportional counting for various air volumes collected and instrument-count times. It is important to point out that the volume of air collected will most likely be highly variable. Thus it is incumbent on the laboratory personnel to know that the count times on each instrument are based on the total number of picocuries that may have been deposited.

The number of samples that will be analyzed and their level of radioactivity may be significantly greater than samples routinely analyzed. Laboratories must also consider the following:

- Establishing separate procedures for sample handling and storage.
- Identifying protocols for personal protective equipment that are commensurate with the radiological hazard.
- Additional protocols for personnel and sample radiation monitoring.
- Increasing the frequency of detector background analyses.
- Obtaining tracer solutions of higher activity.
- Increasing the frequency of QC checks.
- Adjusting the QC-check activity level to more closely align with the activity of the anticipated samples.
- Increasing the frequency of contamination assessments (i.e., smears/swipes) on working surfaces in the laboratory.
- Separating the storage location for high activity samples from personnel and instrumentation (possibly with additional shielding).
- Monitoring dead time for individual samples.
- Revise automated count times based on achieving the required method uncertainties.

If laboratory protocols for routine situations cannot ensure that the MQOs for incident-specific samples are achievable with the laboratory's SOPs, then a separate set of SOPs for incident response sample conditions will need to be developed and validated. Further information on developing incident-response laboratory operations may be found in EPA's *Guide for Radiochemical Laboratories for the Identification, Preparation, and Implementation of Core Operations for Radiological Incident Response* (in preparation).

B. Discrete Radioactive Particles

An important consideration for air particulate samples taken following a radiological or nuclear event is the likelihood of encountering "hot" particles. The radioactive components used to make an RDD, for example, likely would be from commercially available, solid materials. The conventional explosive used to disperse the radioactive material would intermix radioactive fragments with other debris, resulting in a distribution of particle sizes, all mixed together and trapped on an air particulate filter according to the filter's characteristics. Hot particles, termed "discrete radioactive particles" (DRPs), will be small, on the order of 1 mm or less. Discrete radioactive particles are typically not evenly distributed on an air particulate filter, and their radiation emissions are not uniform in all directions (anisotropic).

The radioactive sources/materials that may be potentially used in an RDD event emit alpha, beta, or gamma radiation (see Table 3), and although highly radioactive, they may not be identified with field equipment using conventional scanning techniques on field surfaces such as concrete or soil due to their small size. This will present problems to the field sampling teams from certain perspectives:

- A hand-held field scanner may provide low activity or dose readings if it is not performed slowly enough. This can lead to exposure to individuals because they think the air particulate sample is not highly radioactive based on the area deposition surveys.

- It may cause them to classify an area under one category of contamination (when using only scanning techniques on surfaces) when in fact it may have higher exposure concerns due to the DRPs.

The laboratory will have similar issues to those of the field sampling team. When processing samples that contain DRPs, the material may be relatively inert and not easily dissolved (^{192}Ir is an example of a material that would not be dissolved easily by traditional laboratory digestion techniques). Laboratory personnel should be aware that significant information may be derived from solution residues that contain radioactive materials (e.g., DRPs). These residues should undergo either fusion or digestion with hydrofluoric acid (HF) to ensure that they are solubilized. HF may be better for samples that only have alpha-emitting radionuclides because its use minimizes the addition of other solid matter to the final counting form, which in turn minimizes sample self-absorption. Alternately, the entire particulate filter may need to be analyzed directly, as a solid matrix (this may require special processes). Great care should be used when deciding to sub-sample an air particulate filter that may have DRPs. This type of material, by its nature, will result in non-uniform deposition on the filter. Either the whole filter should be used, or an alternative means for identifying a representative portion of the filter should be determined. In addition, because these recommendations identify analytical priorities for samples based on their screening values, samples with DRPs could get misclassified and put on a lower-priority track.

DRPs usually will have a high electrostatic charge due to their high specific activity. This phenomenon has been observed at nuclear power plants that have had major fuel defects. The small fuel fragments can be transported to various locations throughout the reactor coolant system. When the system is opened for maintenance, and liquid, air, or swipe samples are obtained and the samples allowed to dry out, the DRPs will "jump." This jumping phenomenon may occur with any highly radioactive, micron-sized particles.

Finally, laboratory personnel also must be wary of dosimetry readings involving DRPs if they are not experienced with personal frisking techniques. The personal dosimeter reading either will yield a very high reading (if the DRPs are near or in contact with dosimeter) or a background reading (if the DRPs are distant from the frisker or probe). The technique used in frisking should take into account these concepts and should allow accurate assessment (assignment) of dose based on the particle and its location.

C. Sampling for Iodine and Tritium

Air particulate filters are not acceptable methods for collecting samples containing radioiodines or tritium, because of the volatility of these elements under environmental conditions. Therefore, during the initial phase of an event, additional matrices described below may be presented to the laboratory for analysis of these two radionuclides. If neither radioiodine nor tritium is present, these additional sample matrices will not be necessary. Tritium is a radioactive form of hydrogen. If tritium is used in an RDD, it will become exclusively associated with water (chemical formula, ^{1}H-O-^{3}H, tritiated water) regardless of its initial chemical form. The sampling techniques used for normal water in a vapor phase also can be used for tritiated water. The following list includes only some of the media that the laboratory may receive if tritium-aerosol sampling is performed:

- Drierite®
- Molecular sieve
- Water (from an air bubbler collection method)
- Sodium carbonate
- Ethylene glycol solution
- Silica gel

These matrices would be preceded by the particulate air filter in the sample flow path so that particulate matter is trapped only by the particulate filter. The above media cannot be prioritized for analysis by the laboratory following receipt because neither field nor laboratory survey instruments are effective at detecting tritium in these matrices. Thus, all sample media for tritium analysis would need to follow a prioritization designated by the IC. Samples should be appropriately packaged, shipped, and handled to avoid inadvertent dilution with water or loss during processing. The most effective methods of tritium separation from all other radionuclides are ion exchange (to remove all other radionuclides), distillation, or freeze-drying (although other techniques can be successfully employed).

Iodine, as compounds of inorganic iodide, is susceptible to oxidation to molecular iodine, I_2. In this case, iodine may not be captured effectively on a particulate filter. Iodine may also exist in the atmosphere as an organically bound compound and would likewise not be captured effectively on a particulate filter.

In order to accommodate the potentially different chemical forms of iodine that may be present, different collection media may be required. Some techniques that have been used for field sampling of volatile radioisotopes of iodine include:

- Charcoal or activated carbon cartridges (usually containing triethylenediamine, TEDA)
- Molecular sieve (containing silver halide, also known as silver zeolite cartridges)
- Charcoal or activated carbon cartridge (containing silver halide)
- Water containing alkaline thiosulfate solution (from an air bubbler collection method)

The three radioisotopes of concern, $^{125/129/131}I$, all can be sampled effectively using these media as long as the chemical form of the iodine is susceptible to air oxidation. If the iodine compound is chemically stable with respect to oxidation, it may be possible to collect the material on the filter. Organically bound iodine will be effectively removed from an aerosol using charcoal cartridges containing TEDA. Regardless of the media, potential radionuclides of concern that have short half-lives, such as ^{131}I ($t_{½} \approx 8$ d) and ^{125}I ($t_{½} \approx 60$ d), should be analyzed promptly upon receipt. For example, ^{131}I is easily detected, without any sample preparation, using gamma-ray spectrometry. The detection of ^{125}I can be done using a low-energy gamma-ray detector. Based on environmental conditions, the sampling cartridges may be face- or fully loaded (see page 25).

Once the radionuclides have been identified, special measures will need to be taken to detect the particular radionuclides resulting from this event. These will involve modification of scanning techniques (both in the laboratory and in the field measurements), more frequent contamination-control measures, and attention to the total particulate mass and moisture content of the samples. It

will also require that laboratory personnel be vigilant in the observation of residues in the sample digestion processes.

D. Crosswalk of Data Values

The values corresponding to different terms referred to in this document are located in the tables listed below:

TABLE 4 – Crosswalk of PAG, AAL, ADL, and u_{MR} Values

Data or Value	AAL	ADL	u_{MR}
2-rem/500-mrem (Screening)Tables 7A and 7B	Tables 7A and 7B	Tables 7A and 7B	Tables 7A and 7B
2-rem/500-mrem (Radionuclide-specific)Tables 7C and 7D	Tables 7C and 7D	Tables 7C and 7D	Tables 7C and 7D
10^{-4} risk—	Tables 8A and 8B	Tables 8A and 8B	Tables 8A and 8B
10^{-6} risk—	Tables 8A and 8B	Table 8A and 8B	Table 8A and 8B
DQO and MQO Derivations—	—	Tables 11A, 11B, 12A, 12B and 13	Tables 11A, 11B, 12A, 12B and 13
Estimated counting timeTables 9 and 14	Tables 9 and 14		

IV. SCENARIO 1 (Identifying Air Samples with Highest Activities)

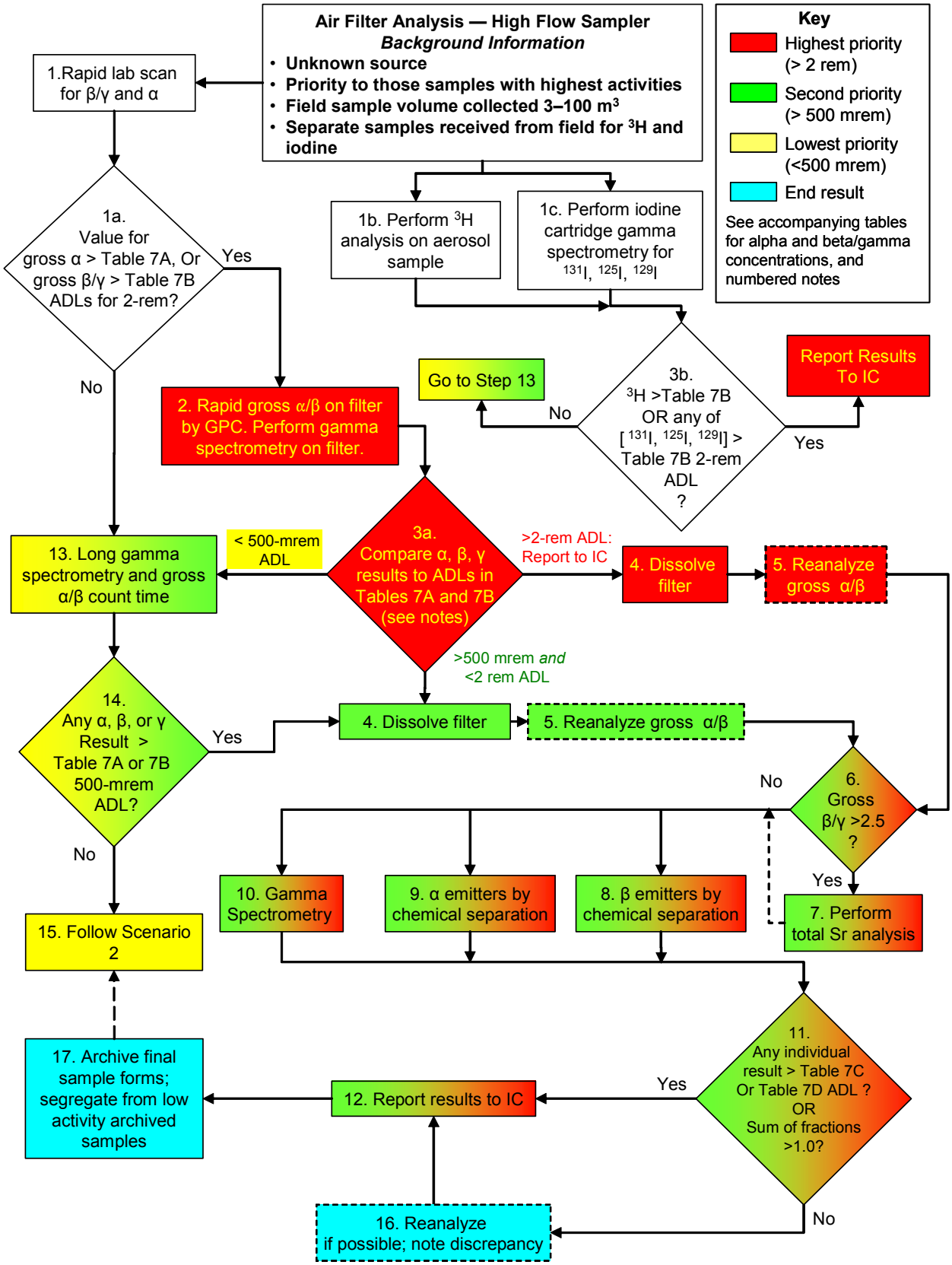

Figure 2 – Air Scenario 1 Analytical Flow

Notes to Scenario 1: High-Flow Air Sampling
Purpose: Priority to those samples with highest activities
Important Sampling Notes: Sample time will be short; sample volume will be small

In this scenario, prioritization of sample analyses in the laboratory is based on the observed sample activity at the various steps in the analytical process. Samples with activity that exceed the 2-rem ADLs will get the highest priority. Samples with activity less than the 2-rem ADLs but more than the 500-mrem ADLs will get an intermediate priority, and samples with activity below the 500-mrem ADLs will get the lowest priority. Samples may arrive over several days; those with the highest priority (red flow path on this diagram) are always to be analyzed first. Only after an analytical step or procedure has been completed for the highest-priority samples should lower-priority samples be addressed. Lower-priority samples (those following the green and yellow flow paths on this chart) may need to be stored for several days until analysis of the highest-priority samples has been completed. Some of the information in Step 1 is the responsibility of the field sampling team but is needed by the laboratory so that the final analytical result can be calculated.

High-flow sampling rates are on the order of 30–50 ft^3/min (0.85–1.4 m^3/min) with sample volumes typically greater than 2×10^3 ft^3 (55 m^3), but between 100 and $3.5\text{x}10^3$ ft^3 (between 3 and 100 m^3) for a one-hour collection time. A one-hour nominal volume of ~$2.4\ \text{x}10^3$ ft^3 (~68 m^3) taken through a 4" air filter is assumed for this scenario.

The laboratory will need to be notified by the sampling team if sampling was conducted in a highly dusty environment (much greater than 100 $\mu g/m^3$). If this is the case, the solids loading (mg/cm^2) on the filter will need to be assessed[10] so that self-attenuation factors can be determined, especially for alpha analysis. The charcoal cartridge will be downstream of the particulate filter. The flow-monitoring device should be placed downstream of the filter housing but upstream of the pump, ensuring that the net flow through the media can be calculated accurately.

Many of the flow diagram shapes are color-coded to reflect the highest-priority analytical flow path (red), intermediate (next important) flow path (green), or the lowest-priority flow path (yellow) based on the time needed to return the required analytical results to the IC. The accompanying numbered notes are color-coded in the same fashion, as are the examples in Appendix II. It is highly advisable to study the flow paths in color, as a black-and-white printing may be confusing or ambiguous.

Note also that as the sample screening and analysis progresses in the laboratory, there are sequential decision steps to guide the sample to the correct priority path. For example, Diamond 14 in the preceding figure checks for gross alpha/beta on the filter using GPC or gamma analysis, with longer count times to ensure that the sample activity is less than the 500-mrem AAL.

[10] The sampling team needs to provide the laboratory with an unused particulate air filter, so that a blank weight can be determined. This would be used to assess the total particulate loading on the filter so that self-attenuation factors can be estimated.

1. The laboratory instruments used might include a survey meter (with alpha and beta channels) or a Geiger-Muller (GM) counter with appropriately calibrated beta and gamma detector probes, or a micro-roentgen meter (gamma only). This step will be conducted in the laboratory initially with the particulate filter in its container. The first measurement will be for gross β/γ to assess overall exposure and potential contamination. Once it has been determined if any other precautions are necessary for direct measurement (e.g., fume hood, protective breathing equipment, etc.), then the filter is removed from its container so that the alpha measurement can be assessed more accurately. Unless the identity of the radionuclide contaminant is known, the hand-held survey instrument should be calibrated using a standard source (e.g., ^{241}Am for α, ^{90}Sr for β, or ^{137}Cs for γ) that will replicate the particulate filter geometry.

Activity measurements of one type of radiation that are high due to the level of contamination present may cause a measurable response with a different screening detector although significant quantities of that radiation may not be present (e.g., crosstalk). For example, a sample that is highly contaminated with ^{90}Sr may appear to contain alpha activity if beta emissions are misclassified as alpha emissions as a result of beta-to-alpha crosstalk. A discussion of this type of instrument response is found in *Radiological Laboratory Sample Analysis Guide for Incidents of National Significance – Gross Sample Screening Analysis* (in preparation).

Important sampling information will be the start and stop times of the air sampler, total volume sampled, and the time that survey-meter measurements of the filters were made. Field staff may prioritize the samples being sent to laboratory based on their survey-meter scans of the air filter samples. Field survey meters using gas proportional (GP) or GM detectors should be able to detect the radioactivity collected in 68 m^3 of air having a 2-rem or 500-mrem AAL for most targeted β-emitting radionuclides (NRC, 1998).

During this sample processing phase, special precautions should be taken to avoid sample cross-contamination as well as laboratory contamination from samples that may have loosely held radioactive particulate matter.

Special precautions should be taken when performing initial scans to account for the potential presence of DRPs, especially if the filter is large enough so that more than a single reading is required. If "hot" particles are found, it is very important to communicate this information immediately to field personnel. If DRPs are present, additional sample handling controls may be necessary, such as:

- Establishing a "hot-particle" sample handling and storage area with step-off pads;
- Extra personal protective equipment for normally exposed body surfaces; and
- Single-sample handling until the sample digestion has started (to prevent cross-contamination).

The MQOs at the 2-rem and 500-mrem AALs for required method uncertainty can be found in Tables 7A and 7B.

Laboratory personnel should be aware that when using the nominal volume for the sample (68 m^3), the 2-rem AAL concentrations correspond to a *total* activity of about 48 pCi for alpha and 29,000 pCi for beta. Laboratories should have screening equipment that is capable of detecting the range of activities at the 2-rem ADL total activity (for a 68 m^3 sample) of 24 pCi for alpha emitters and 14,000 pCi for beta emitters.

1a. If the gross screening value is less than the 2-rem ADL values listed in this diamond, the sample reverts to a lower priority (green). The ADL values for alpha and beta are 0.35 and 210 pCi/m^3, respectively. If sample screening measurements are less than these values when the $\underline{u}_{MR}$ is achieved, the sample is put on the lower-priority flow path. Otherwise, the sample stays on the high-priority pathway.

1b. Tritium assessment generally is not performed with screening equipment because of the low energy of its emitted beta particle and the significant effects of non-radiological interferences with its analysis. Sample volumes and times will usually be different for samples obtained for tritium analysis (the volumes for tritium sampling routinely are lower). The media used for trapping tritium are described in Section III. The laboratory must have a procedure in place to handle the media used for trapping tritium, as each has separate retention factors and potential diluents (water) that can alter the final tritium concentration. Screening measurements on the aerosol's water fraction are made without removing interfering radionuclides. This means that at this step in the process, tritium results are of screening quality only. Inspection of liquid scintillation spectra may enable elimination of some radionuclide interferences based on beta particle energy distributions.

The gross alpha/beta air filter and the gamma spectrometry on the iodine cartridge analyses should be performed in parallel. Information from this gross screening may provide insight into potential for interference with tritium analysis.

A simple distillation, collecting approximately 5 mL of liquid, may provide the most effective removal of all interfering radionuclides from the collection media used for water. Sample count times using liquid scintillation will be short in order to demonstrate that the sample concentration exceeds the 2-rem ADL value of 1.3×10^5 pCi/m^3. The u_{MR} value is 7.9×10^4 pCi/m^3.

The laboratory should *not* make decisions regarding the priority for the corresponding particulate filter or iodine cartridge based on the tritium analysis until Step 3b is completed.

1c. Similar consideration for a standard source calibration (^{137}Cs for γ) and geometry should be given to the cartridge used for iodine/noble gas sampling.

An iodine cartridge may be used in combination with a particle filter (the filter preceding the radioiodine collection cartridge in the flow path) during the sample collection process. Thus, the sample time and volume should be the same for these two separate collection media. At the laboratory, the alpha-beta gross analysis of the particulate filter by gas proportional counting (GPC) should be corrected for self attenuation if the mass of material collected on the filter can be or has been determined.

Gamma spectrometry of the cartridge is specifically for ^{131}I (364.5 keV is the principal gamma ray). Although the ^{129}I or ^{125}I may be present, their activities would need to be verified in the longer gamma count intervals using a low-energy gamma-ray detector. It is likely that an iodine cartridge will be "face-loaded."[11] However, the laboratory must be able to confirm this assumption. Laboratory counting techniques must be able to account for differences in face or fully loaded cartridges. Cartridge orientation when counting, as well as proper calibration for that geometry, must be ensured. Although possible, it is not likely to detect $^{131, 129, 125}$ I on the particulate filter.[12] If iodine is present on the filter, the most likely form would be an iodide salt. Additionally, because the energy of the ^{129}I and ^{125}I gamma rays are ~35 keV, the laboratory should ensure that a valid calibration curve exists at the energies of these radionuclides and that they consider corrections for self attenuation of the gammas by the sample matrix. If radioisotopes of iodine are present on both particulate filter and cartridge the sum of the two contributions (for the same radioisotope of iodine) must be assessed versus the ADL for that radioisotope of iodine.

It is also possible that noble gasses, such as krypton and xenon (if present from a nuclear detonation or power plant accident) or radon (and its decay products), would be captured on the iodine cartridge. Thus, the gamma-ray energies from these radionuclides and their decay products should be in the gamma-ray library. Count times should be 5 to 10 minutes. Gamma-ray lines with net peak area uncertainties <50% (at the 1-sigma level) should be positively identified and quantified to aid in direction of additional analyses. Significant quantities of radon on the radioiodine collection cartridge should alert the laboratory to the presence of unsupported progeny on the filter or cartridge that emit alpha, beta, or gamma radiation. The gross alpha/beta air filter and the gamma spectrometry on the iodine cartridge analyses should be performed in parallel.

The laboratory should *not* make decisions regarding the priority for the corresponding particulate filter or tritium sample based on the iodine analysis.

The 2-rem u_{MR} values for screening analysis for iodines are based upon the *sum of iodine activity* from vapor trapped on a cartridge or any particulate caught on the filter upstream of the iodine cartridge. The specific values for ^{125}I, ^{129}I, and ^{131}I are presented in Table 7B. Proceed with Step 3b.

2. Direct gross alpha/beta analysis of the particulate filters may be performed with a portable or laboratory, low-background GPC unit. When making these measurements, consider the levels of activity that were measured for each of the samples in Step 1 to avoid contaminating low-level background detectors with samples that have very high activity.

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[11] This term describes the concentration of the radionuclides of interest in a thin slice of the entire cartridge width that *faces* the inlet air flow. At low concentrations, this will usually be the case, but loading can be affected by humidity, temperature, and presence of other gases that may be adsorbed by the cartridge. One technique that may avoid the issue of face versus fully loaded is to "side count" the cartridge. The gamma spectrometry detector must be calibrated for this special geometry.

[12] For an event that involves a nuclear power plant release, there may be a significant amount of radioiodines on the particulate filter. This depends on several factors including the chemical form of aerosols during the release.

Special contamination-control procedures should be implemented when transferring filters that may contain high activity in order to avoid contaminating areas that normally have low background and contamination. Examples of such procedures include a separate enclosed area for transferring a sample from one container to another, double containers, and thin encapsulating film such as collodion on the filter surface.

Lab assessment of the total activity decay during transport can provide information regarding the half-life of the principal radionuclides. The activity ratio of field to lab analysis for gross β/γ activity may be used to estimate the composite half-life of the radionuclides contained in the sample to help resolve discrepancies between field versus laboratory gross-activity measurements. For example, if a sample is received 24 hours post-incident and the laboratory gross β activity is ~20% of the field activity measurement, thoron (^{220}Rn) decay products of ^{212}Pb/^{212}Bi may be involved.

If the laboratory finds that its receipt survey is significantly different from the field survey of the sample, it may be important to know which reference radionuclide was used to calibrate the field survey detector.

> NOTE: Laboratory personnel also must know if the shipped sample is only part of a larger sample, so that appropriate correction factors can be applied before reporting final results. For example, if a 4"-diameter circle is cut from 8×12", or if a 4"-diameter filter is received and the laboratory needs to reduce the size to 2" diameter, then the laboratory must calculate the appropriate correction factor for the fraction of filter analyzed (see discussion of filter sizes on page 15).

The sample chain-of-custody form must specify if the field measurements were made on the entire filter, or just the portion shipped, so that lab measurement can be compared with the field measurements. This will assist in gaining insight into the quantity of short-lived radionuclides that may be present (this will help in the gross activity assessment when compared to the sum of individual radionuclides in Step 11). The field sample team should have provided specific information regarding the composition of the filter medium (including a blank sample) so that appropriate steps can be taken during the filter-digestion process.

Gamma spectrometry is performed on the entire filter sample initially to assess which gamma emitters may be present. Although possible, it is not likely to detect $^{131,\ 129,\ 125}$I on the particulate filter. If iodine is present on the filter, the likely forms would be an iodide salt or iodine trapped with particulate matter. Additionally, because the energy of the ^{129}I and ^{125}I gamma rays are ~35 keV, the laboratory should ensure that a valid calibration curve exists at the energies of these radionuclides and that it considers corrections for self attenuation of the gammas by the sample matrix. Count times will vary depending upon the sample size and efficiency of the detector. However, count time should be at least 15 minutes (this helps to ensure software routines have sufficient data to properly perform peak fitting algorithms).

The u_{MR} values at the 2-rem and 500-mrem ADL for gross alpha are 0.21 and 0.052 pCi/m^3 and that for the gross beta 130 and 33 pCi/m^3, respectively (Tables 7A and 7B).

3a. Initial assessment of the activity is made based on comparison with the 2-rem ADL values:

- The gross alpha-beta analysis of the filter (gross $\alpha > 0.35$ and gross $\beta > 210$ pCi/m^3), and
- The short-count gamma spectrometry results (Step 2, $\gamma >$ 2-rem ADL values; see Table 7B).

If any 2-rem ADL is exceeded, notify the IC immediately and indicate that these results are based on screening methods and radionuclide-specific analyses have not yet been performed.

> NOTE: If either the gross alpha or beta ADL (at 2-rem or 500-mrem) is exceeded, a second analysis should be performed for gross alpha and beta after dissolution, for the ADL (alpha or beta) that was exceeded (see Step 5a). See a more detailed explanation of this under "Additional Points" on page 31.

Based on gamma spectrometry results, determine if the radionuclide used for gross beta calibrations should be adjusted. For example, if gross beta was determined using a ^{90}Sr/^{90}Y calibration source and the only radionuclide is ^{60}Co, an adjustment in the attenuation factor may be necessary (this could be made based on actual sample measurements or calibration with the radionuclide source if available).

Determine if any individual gamma emitter exceeds its 2-rem ADL. Gamma-ray lines with net peak area uncertainties (or as identified by the instrument manufacturer) below 50% should be identified and quantified to aid in direction of additional analyses.

Review the original gross alpha/beta results based on the self-attenuation assessment above. Determine if the gross alpha/beta ADL assessments have changed from the original assessment made in Step 2.

3b. The following analyses will have been completed:

- Tritium-specific analysis from a separate sample (Step 1b), and
- Iodine-specific analysis from a cartridge (Step 1c).

The IC should be notified immediately if any of the following 2-rem ADL values identified in Tables 7A or 7B are exceeded :

- ^{3}H
- ^{125}I
- ^{129}I
- ^{131}I

If not, a longer gamma count for the iodines and a longer liquid scintillation analysis for tritium should be performed for Step 13 (to be conducted later). It is important to note that this analysis flow path is only for tritium and iodines. The particulate filter associated with the tritium and iodine analysis may remain on the high-priority flow path based on its screening analysis completed in Steps 1 or 2. If radioiodines are detected on the cartridge, a gamma count of the particulate filter should be performed to identify any additional radioiodine contribution prior to assessing what AAL may have been exceeded.

4. Once the α, β, and γ analyses from Step 3 are complete, the entire filter sample should be dissolved so that separate aliquants of the final digestate may be analyzed simultaneously for specific α- and β-emitting radionuclides. A fusion technique that uses a low-temperature flux, or an acid digestion that ensures a single, homogeneous phase should be applied.[13] If glass-fiber filters have been used, some form of fluoride treatment should be used to eliminate silica precipitation later in the analytical process (for example, sodium fluoride [NaF] fusion or hydrofluoric acid [HF] removal of silica are commonly used techniques). HF may be better for samples that only have alpha-emitting radionuclides because its use minimizes the addition of other solid matter to the final counting form, which in turn minimizes sample self-absorption. Note that any method used to dissolve the filter may reduce or eliminate the activity of any volatile or semi-volatile radionuclides present on the filter. Therefore, analyses for tritium and radioisotopes of iodine, phosphorus, and sulfur will need to be performed in a manner that prevents their loss during sample preparation and analysis.

Sufficient final volume of the digested sample should be saved for subsequent removal of aliquants for specific alpha- and beta-emitting radionuclides. This should include an aliquant that may need to be recounted by gamma spectrometry for a longer period of time (2–3 hours). Ensure that the calculation of the final activity of the sample corrects for that fraction of the digested solution or filter actually used in the analysis.

5. If either the gross alpha or beta ADL determined in Step 3 was exceeded (2-rem or 500-mrem values), a re-analysis should be performed for the corresponding ADL (α or β) that was exceeded. Based on the screening analyses, it may be best to gamma-count the *entire* digestate for a longer period of time (such that the u_{MR}, see Table 7B, is achieved, e.g., 4–6 hours) *before* subdividing the digested sample for other individual analyses. Any gamma-emitting radionuclide with a measured activity greater than its calculated critical level should be included in the total gamma activity sum.

6. Calculate the total gamma activity per cubic meter in the samples as the sum of all gamma-emitting radionuclides (Step 2) with measured activity greater than the critical level. If the ratio of gross beta (from Step 5) and total gamma indicate a gross beta/gamma ratio > 2.5, immediately start total strontium ($^{89+90}$Sr) analysis. The alpha-spectrometric and beta-only analyses always should be performed as soon as possible after the start of the Sr analysis, regardless of the strontium results. If gross β/γ ratio is < 2.5, perform Steps 8, 9 and 10 in parallel. If β/γ ratio is > 2.5, immediately start total strontium analysis ($^{89+90}$Sr).

7 The strontium analysis should provide a rapid assessment of total radioactive strontium ($^{89+90}$Sr) in the sample. If total radiostrontium analysis indicates the presence of radiostrontium at greater than 0.71×AAL for ^{90}Sr (this represents the corresponding ADL for 2-rem or 500-mrem), the sample should be recounted 24 hours later to assess the distribution of the two radiostrontium isotopes in the sample. Some beta measurement techniques may allow for assessment of ^{89}Sr and ^{90}Sr, separately, based on the beta particle energy distribution.

[13] This is particularly important if the presence of DRPs is known or suspected.

8. Using input from the gross beta and gamma spectrometry measurements, begin pure beta-specific analyses (plus ^{227}Ac) based on the radionuclides identified in Table 3. This includes analysis for ^{90}Sr if not already started. The corresponding ADL and u_{MR} values are found in Table 7D.

9. Using input from the gross alpha and gamma spectrometry measurements, begin alpha-specific analyses for the radionuclides identified in Table 3.The corresponding ADL and u_{MR} values are found in Table 7C.

10. Conduct gamma spectrometry of sufficient time to meet the corresponding ADL and u_{MR} values that are found in Table 7D. All gamma-ray-emitting radionuclides that result in a radionuclide activity above the critical level should be included with their associated uncertainty on the final report to the IC. This would make the IC aware of other radionuclides that may be present at lower concentration that may not be of dose consequence, but that may affect remediation efforts. Any gamma-emitting radionuclide with a measured activity greater than its calculated critical level should be included in the total gamma activity sum and in the sum of the fractions (Step11).

NOTES:
- Steps 8, 9, and 10 should be performed in parallel. Although all the radionuclides listed in Table 3 are possible contaminants, perform those analyses that are most probable based on previous sample results and direction by the IC.
- Samples from the same event and area may be queued more accurately using the information already obtained on the first batch of samples. For example, if ^{241}Am is one of the known contaminants, that analysis would be started first in Step 9.

11. As testing results become available, verify that data quality requirements have been met for each of the analyses and take action promptly to address any deficiencies identified. This includes any quality control sample requirement results (e.g., liquid scintillation counters [LSCs]) imposed on the laboratory by the available project plan documents or contract. Once a final result is available, compare the individual radionuclide concentrations to the individual ADL values listed in Tables 7C and 7D. When the high- and intermediate-priority radionuclide-specific analyses are completed, verify that no major nuclide has been missed and that data quality requirements have been met. This can be done by verifying that the sum of the individual nuclide concentrations is approximately equivalent to the gross activity concentration (a rule of thumb is within a range of about half to twice the gross value). Activity concentrations due to decay products should be included in the verification.

NOTE: The sum of the fractions (individual beta/gamma radionuclide concentrations divided by their respective 500-mrem AAL value—see Table 7B and "sum of the fractions" in the glossary) of all radionuclide concentrations above their individual critical level is to be calculated. This includes all naturally occurring radionuclides above their respective critical level even if the naturals are not part of the event. If the summed value exceeds unity, then the 500-mrem AAL has been exceeded, even though an individual radionuclide activity value does not exceed its respective AAL. If all comparisons are satisfactory and data quality requirements have been met, report results to the IC. If there are outstanding data quality requirements or activity measurement issues, go to Step 16.

12. Report all final reviewed results to the IC and provide electronic data deliverable (EDD). Clearly identify any sample activity or concentration totals that do not compare favorably with the original gross activity or concentration measurements.

13. On this lower-priority flow path, the gross screen of the samples has indicated lower activity. The sample count time should be long enough so that the required method uncertainties for 10^{-4} and 10^{-6} risk factors listed in Tables 8A and 8B can be achieved. This will assist in identifying the presence of lower activity radionuclides that may be present.

This count is performed to assess if the sample result is greater than the 500-mrem ADL as indicated in Tables 7A and 7B for:

- Gross alpha
- Gross beta
- Any beta-gamma emitter

If the sample result is less than the 500-mrem ADL, the sample is put on the low-priority track (yellow, Step 14). If the sample result is greater than the 500-mrem ADL, the sample goes to Step 4 for an intermediate priority.

The radioiodine collection matrix may be re-counted now for sufficient time to meet the required measurement uncertainties identified in Table 8B, and should be counted on a detector that is calibrated for gamma rays as low as 30 keV. Do not allow significant delay in counting the iodine cartridge due to short half-life of ^{131}I.

A longer gross α/β count of the filter is appropriate using GPC to assess if the sample activity is between ADLs corresponding to the 500-mrem and 2-rem AAL values (use Tables 7A and 7B). The length of count will depend on the fraction of original sample which is being analyzed.

If tritium was not initially identified above the 500-mrem AAL (Step 3b), a longer liquid scintillation count at this time may be warranted to assess its presence at greater than ambient levels.

14. If the gross alpha or gross beta results, or the longer gamma count results do not exceed the 500-mrem ADL for any radionuclide concentrations listed in Tables 7A and 7B, then go to Step 15 (sample has not yet been dissolved). If the sample is greater than the 500-mrem ADL, return sample processing to the analysis flow path, Steps 5–12, with a secondary (green) priority.

15. Samples that have activities that are low enough to fall into this category should be preserved (if needed) for analysis in the future (as directed by project management) using the scheme outlined for Scenario 2 (specifically at Steps 13a or 13b).

16. Recount samples or re-analyze aliquants of the remaining solution after digestion to determine if an interfering radionuclide or non-radioactive contaminant interfered with the

analysis. Determine if gross alpha/beta efficiency factors used for the gross activity measurements (Step 5) should be updated to radionuclides now known to be present in the sample. If no cause of the discrepancy can be determined, make note of the discrepancy in the report to the IC.

17. Archive final sample test sources that were counted and digested in Step 4. These samples should be segregated from the lower activity samples, such as those that may have been archived in Step 15 due to their difference in activity. Although a potential cross-contamination issue, it is also a personnel exposure issue.

Additional Points

Analysts should recognize that when performing gross α or gross β analysis directly on the air particulate filters, the mass loading will have a significant effect on the reliability of the results when they are compared to the total α or β analysis following radiochemical separations. Step 11 notes that the analyst should compare the radiochemical specific analyses to the gross analyses and see whether they are within a factor of two. If not, and if there are additional samples being analyzed that have similar characteristics, a correction factor may need to be applied to the efficiency factor in the gross analysis to adjust for sample interference with the gross measurement.

It is important to remember also that gross α or gross β analysis by evaporation, following sample digestion (Step 4), will result in a significant loss of volatile radionuclides (such as technetium and iodine).

Change in activity of samples from decay during transport may be significant depending upon the radionuclide mix. If the time from completion of field sampling to sample receipt at a laboratory is about 12 hours, any accumulated ^{222}Rn progeny will have decayed to ^{210}Pb (yielding negligible activity due to its 22 y half-life). Any collected ^{220}Rn progeny will be reduced by one-half (due to the 11-hour half-life of ^{212}Pb). With an upper estimate of 3.5 pCi/m^3, ^{220}Rn surface concentration for most sites, ~210 pCi of ^{212}Pb (ignoring decay while sampling) would be collected on the filter (for a 60 m^3 sample) and ~100 pCi (220 dpm) would be present after the 12-hour delay to begin the laboratory's gross beta analysis. The laboratory would calculate a gross beta concentration of ~3.5 pCi/m^3 (from ^{212}Pb plus ^{212}Bi and an additional contribution from ^{208}Tl of about 36%) and ~1.5 pCi/m^3 gross alpha concentration from ^{212}Po. Gamma-ray spectrometry may detect ^{212}Pb, ^{212}Bi and ^{208}Tl at this concentration (depending upon total activity on particulate filter).

Gross alpha and beta radioactivity contributions to these analyses due to airborne dust (generally ~100 μg/m^3) from typical soil concentrations of ^{238}U, ^{232}Th, or ^{40}K will be negligible for a 1-hour sampling duration using either a high- or low-volume sampler.

Certain α- and β-emitting radionuclides have very low abundance γ rays. These γ rays are not normally used for analysis of those radionuclides when trying to determine them at normal, environmental levels. Thus, the gamma-spectrometry software may not have these γ rays in its analysis library. It is recommended that a separate library for incident response samples be created which has these low abundance γ rays. Table 5 provides some examples.

TABLE 5 – Radionuclides with Low-Abundance Gamma Rays*

Radionuclide	^{89}Sr	^{90}Y	^{129}I	^{210}Po	^{226}Ra**		^{228}Th
Principal Decay	β^-	β^-	β^-	α	α		α
Gamma, keV	909	2,186	40 (32 X-ray)	80.3	186 (262)		84
Abundance, %	9.6×10^{-3}	1.4×10^{-6}	7.5 (92.5)	1.1×10^{-3}	3.3 (5×10^{-3})		1.21
Radionuclide	**^{232}Th**	**^{235}U****	**^{237}Np**	**^{238}Pu**	**^{239}Pu**	**^{240}Pu**	**^{241}Am**
Principal Decay	α	α	α	α	α	α	α
Gamma, keV	911 (from ^{228}Ac)	186 (143, 163)	86.5	55.3	112.9	54.3	59.5
Abundance, %	27.2	54 (11, 5)	12.6	4.7×10^{-2}	4.8×10^{-2}	5.2×10^{-2}	35.7
Radionuclide	**^{241}Pu**	**^{242}Pu**	**^{243}Cm**	**^{227}Ac**			
Principal Decay	β^-	α	α	β^-			
Gamma, keV	149	44.9	278	236			
Abundance, %	1.9×10^{-4}	4.2×10^{-2}	14	11.5			

* Values in parentheses represent the next most abundant photopeaks.

**Care must be taken with this identification as ^{226}Ra and ^{235}U gamma rays may not be resolved at this energy.

These gamma rays can be used for qualitative identification of these radionuclides. Their presence in the gamma-ray spectrum should direct the analyst to perform chemical separations followed by α- or β-specific detection.

Aluminum absorbers can be used to qualitatively identify the presence of beta-emitting radionuclides based on the ability of their beta emissions to penetrate the aluminum. Thus if an aluminum absorber of 6.5 mg/cm^2 thickness is used and the measured beta activity is reduced to background, one could qualitatively state that the beta particle energy of the radionuclide is < 0.067 MeV. Conversely if the absorber has little effect on the count rate, it can be stated that the beta particle energy is >0.067 MeV. Table 6 identifies some beta-only emitters with their energies and range in aluminum absorbers. This technique is one option to help estimate the energy of the beta particle, which assists in the identification of the beta-emitting radionuclide.

TABLE 6 – Beta "Only" Emitters

Radionuclide	^{241}Pu	^{63}Ni	^{129}I	^{35}S	^{99}Tc	^{32}P	^{90}Sr/^{90}Y
Maximum β Energy, MeV	0.021	0.067	0.150	0.167	0.294	1.711	(0.546)/2.28 [1]
Range [2], mg/cm^2 for $E_{\beta max}$	0.8	6.5	27	32	75	800	1,100

[1] Based on the sampling plus sample transit time ^{90}Sr/^{90}Y may be in secular equilibrium by the time any analysis is started. Thus, the 2.28 MeV beta particle of ^{90}Y will, most likely, be present.

[2] U.S. Department of Health, Education and Welfare (HEW). 1970. *Radiological Health Handbook*, p.123.

V. SCENARIO 2 (Priority to Air Samples with Highest Activities)

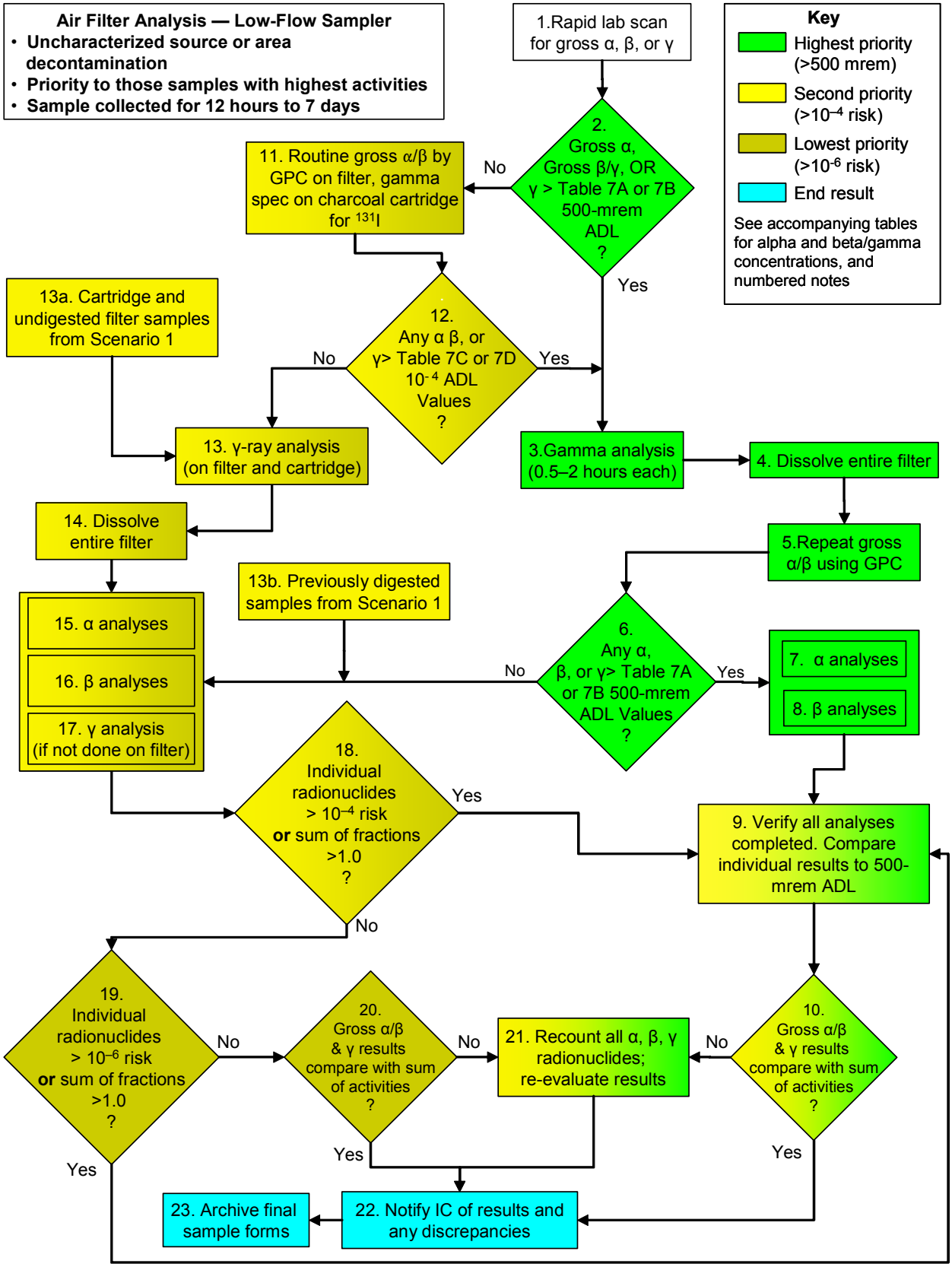


Figure 3 – Air Scenario 2 Analytical Flow

Notes to Scenario 2: Low-Flow Air Sampling
Purpose: Source of contamination may not be completely identified during early phase of event.
Considerations: Samples may have been taken from an uncharacterized area. Samples are taken in the intermediate to recovery phase of the event. Priority to samples with highest activities (> 500 mrem AAL)

The samples may arrive over several days; those with the highest priority are always to be analyzed first. Only after an analytical step or procedure has been completed for the highest-priority samples should lower-priority samples be addressed. Lower-priority samples (those following the yellow and brown flow paths on this chart) may need to be stored for several days until the highest-priority samples have been analyzed. The samples with the highest priority (green path) will be the ones with the *highest activity*. Some of the information in Step 1 is provided to the laboratory by the field sampling team.

A low-flow sampler 0.50 to 4.0 ft^3/min (1.4×10^{-2} to 1.1×10^{-1} m^3/min) is used to obtain a particulate sample over a longer time period (12 hours to 7 days, compared to Scenario 1 where the sample collection is minutes to hours) to help ensure representative sampling. Of those samples taken during the recovery phase of an event, many will be at areas distant from the original event site. These samples will be used to determine if the 10^{-4} and 10^{-6} risk AALs are exceeded (by comparison with their corresponding ADL values in Tables 8A and 8B).

For low-volume samples, a two-inch filter is typically used, with an iodine cartridge following the particulate filter (in series) when sampling for radioiodines is needed. However, when different filter sizes are used, lab personnel must know if the shipped sample is only part of a larger filter . For example, if a 4"-diameter circle is cut from 8×12" filter, the sample results must be multiplied by 7.64 to correct for the activity on the whole filter. The sample chain-of-custody form must specify if the field measurements were made on the entire filter, or just the portion shipped, so that the lab measurements can be compared with the field measurements. This will assist in getting insight into the quantity of short-lived radionuclides that may be present. It is also important to know the composition of the filter medium so that appropriate steps can be taken during the filter digestion process. It should also be established by this time in the event if DRPs exist. Sub-sampling of the particulate filter must be done very carefully (if at all) to avoid non-representative results.

Low-flow sampling taken over a long period (> 1 day) will collect larger air volumes and may provide higher radionuclide activities on the collection matrices. This may provide a more representative average concentration.

Many of the flow diagram shapes are color-coded to reflect the highest-priority analytical flow path (green), intermediate (next important) flow path (yellow), or the lowest-priority flow path (brown) based on the time needed to return the required analytical results to the IC. The accompanying numbered notes are color-coded in the same fashion, as are the examples in Appendix III. It is highly advisable to study the flow paths in color, as a black-and-white printing may be confusing or ambiguous.

1. Upon receipt, the laboratory will make a rapid scan with a hand-held instrument (or other instrument capable of high sample scan throughput). The laboratory instruments used for this purpose might include a survey meter (with alpha and beta channels) or a Geiger-Muller

(GM) counter with appropriately calibrated beta and gamma detector probes, or a micro-roentgen meter (gamma only). This step will be conducted in the laboratory initially with the particulate filter in its container (e.g., a glassine envelope). The first measurement will be for gross alpha (outside surface), beta and gamma to assess overall exposure and potential contamination. Once it has been determined if any other precautions are necessary for direct measurement (e.g., fume hood, protective breathing equipment, etc.), then the filter is removed from its container so that the alpha measurement can be assessed more accurately.

Unless the identity of the radionuclide contaminant is known, the hand-held survey instrument should be calibrated using a standard source (e.g., ^{241}Am for α, ^{90}Sr for β, or ^{137}Cs for β or γ) that will replicate the particulate filter geometry.

During this sample processing phase, special precautions should be taken to avoid sample cross-contamination as well as laboratory contamination from samples that may have loosely held particulate matter that is radioactive.

Factors to consider when making the gross screening measurements:

- The solids loading (mg/cm^2) on the filter medium should be determined (by the laboratory) in order to assess accurately the activities relative to background. This can be done by taking the average mass of an unloaded filter and subtracting it from the final mass of each filter received from the sample team. This mass can then be used to estimate the normal concentration of naturally occurring radionuclides in airborne dust and solids within a sampled area (including any unaffected areas). A dust concentration of ~100 μg/m^3 is typical for non-industrial areas due to terrestrial dust resuspension. (See the discussion of naturally occurring radionuclides in terrestrial dust under "Additional Points" following the notes to Scenario 1.)

- Iodine cartridges also must be counted by a gross gamma screen in order to be able to assess the 500-mrem AAL (including decay correction to the midpoint of the sampling interval for the ^{125}I and ^{131}I radionuclides). This is determined using the 500-mrem ADL of 1.6×10^3, 240, and 1.2×10^3 pCi/m^3 for ^{125}I, ^{129}I, and ^{131}I, respectively (these are for the sum of the individual iodines on the cartridge from the analysis of the iodine filter plus the particulate filter), at the 500-mrem ADL. It is likely that an iodine cartridge will be "face-loaded."[14] However, the laboratory must be able to confirm this assumption. Cartridge orientation when counting, as well as proper calibration for that geometry, must be ensured. If the radioiodines are detected on the cartridge, a gamma count of the particulate filter should be performed to identify any additional radioiodine contribution prior to assessing what AAL may have been exceeded.

[14] This term describes the concentration of the radionuclides of interest in a thin slice of the entire cartridge width that *faces* the inlet air flow. At low concentrations, this will usually be the case, but loading can be affected by humidity, temperature, and presence of other gases that may be adsorbed by the cartridge. One technique that may avoid the issue of face versus fully loaded is to "side count" the cartridge. The gamma spectrometry detector must be calibrated for this special geometry.

It is possible that noble gasses, such as krypton and xenon (if present from a nuclear detonation or power plant accident), also would be captured on the iodine cartridge, and thus the identifying gamma lines of the noble gas radionuclides should be in the gamma-ray library.

- Decay products of radium may be found on both the particulate filter and the iodine cartridge. Change in activity of samples during transport may be significant depending upon the radionuclide mix. An example of this occurs for radioactivity on an air filter when the time from the end of sample collection to receipt at a laboratory is about 12 hours. Any collected ^{222}Rn progeny will have decayed to ^{210}Pb (yielding negligible activity due to its 22 y half-life), since the decay chain is broken by ^{222}Rn not being collected on the filter.

  For ^{224}Ra, the surface concentration existing naturally at many locations yields an air concentration of ^{220}Rn of 3.5 pCi/m^3. This would yield about 2,100 pCi of ^{212}Pb (ignoring decay while sampling) on the filter (for a 600 m^3 sample). Less than 1,000 pCi ($\leq$2,200 dpm) would remain during the laboratory's gross beta analysis (when initiated ~12 hours later). The laboratory would calculate a gross beta concentration of ~3.5 pCi/m^3 from ^{212}Pb plus ^{212}Bi and a gross alpha concentration of ~1.75 pCi/m^3 from ^{212}Po. Gamma-ray spectrometry will detect ^{212}Pb/^{212}Bi at this concentration.

- Gross alpha and beta radioactivity due to airborne dust (100 µg/m^3) from typical soil concentrations of ^{238}U, ^{232}Th, or ^{40}K may not be negligible for a 24-hour or longer sampling duration using a high-flow sampler. Because this decision tree addresses the late intermediate and recovery phases, when turnaround times (TATs) may be longer, it may be desirable to wait (when permissible) 72 hours from the end of sample collection before performing the gross alpha and beta analyses. Waiting 72 to 100 hours will allow for decay of ^{212}Pb and progeny, so that the radionuclides from the event will be measured with greater precision by gross techniques.

- Ideally, laboratory screening of samples should be detailed enough to assess if there is an absence of DRPs. If the screen is a single measurement taken on the entire sample, this assessment may not be possible. If DRPs are detected/suspected, field personnel should be notified.

- Tritium sampling of the aerosol at this stage of the event will most likely be *unnecessary* as atmospheric moisture and precipitation will rapidly dilute any tritium present.

  The presence of ^{208}Tl is as good an indicator of the presence of naturally occurring radionuclides as ^{212}Pb, since the half-life of ^{208}Tl is short and gamma yield (at 583 keV) is relatively good.

2. A gross α/β screen is performed with a hand-held device to assess the activity level for laboratory prioritization. The results of the gross α/β screen are compared to the ADLs for the 500-mrem exposure level to assess the activity level for laboratory prioritization. If all

measurements are less than their respective ADL values, then the sample follows the lower-priority path to Step 11.

If the gross α/β screen (performed with a hand-held laboratory device) exceeds *any* alpha or beta radionuclide 500-mrem ADL, gamma spectrometry analysis is performed at Step 3.

If the gamma spectrometry results for the iodine cartridge or the filter exceed the ADLs of 1.6×10^3, 240, and 1.2×10^3 pCi/m^3 for ^{125}I, ^{129}I, and ^{131}I, respectively, then the filter and cartridge should be processed along the higher-priority flow path with gamma spectrometry analysis at Step 3.

3. The entire filter should be counted by gamma spectrometry. The count time should be long enough to meet the u_{MR} in Tables 7C and 7D for the 500-mrem AAL. If a sample was taken using a radioiodine cartridge, ensure that this is counted on a low-energy photon detector so that the long-lived isotopes of iodine (that have low gamma-ray energies below 60 keV) can be determined.

4. Effective sample digestion should use a fusion technique that uses a low-temperature flux or else an acid digestion technique that ensures a single, homogeneous phase. If glass fiber filters have been used, some form of fluoride treatment (for example, NaF fusion or HF removal of silica are commonly used techniques) should be used to eliminate silica precipitation later in the analytical process. Note that any method used to dissolve the filter will reduce or eliminate the activity of any volatile or semi-volatile radionuclides present on the filter. Therefore, analyses for radioisotopes of iodine, phosphorus, and sulfur will need to be performed in a manner that prevents their loss during sample preparation and analysis.

Sufficient final volume of the digested sample should be saved for removal of subsequent aliquants for specific alpha- and beta-emitting radionuclides. This should include an aliquant that may need to be recounted by gamma spectrometry for a period of time sufficient to meet the u_{MR} in Tables 7C and 7D for the 500-mrem AAL. This count time will be much longer than if the gamma-spectrometric analysis were performed on the entire filter. Ensure that the calculation of the final activity of the sample corrects for that fraction of the digested solution or filter actually used in the analysis.

5. A gross α/β analysis of the filter digestate is made at this point. The analytical method and low-level radiation detection instrumentation should produce an improved detection capability and a reduced measurement uncertainty for these analyses compared to the survey meter measurements of Step 1. These results supersede those obtained in Step 2.

6. The results of the gross α/β analyses from Step 5 and the gamma-spectrometric analysis from Step 4 are compared to the 500-mrem ADL values in Table 7A and 7B. If no 500-mrem ADL value is exceeded, then the sample follows the lower-priority sample queue (Steps 15, 16, and potentially 17). Otherwise, alpha- and beta-specific analyses are started immediately (Steps 7 and 8).

7. **8.** These two steps are done in parallel to improve TAT. Each analysis is performed to determine if 500-mrem ADL values in Tables 7C and 7D have been exceeded. Priority should be based on:

- IC input (when provided)
- Results from previous samples for this location or event;
- Gross analysis that yielded the greatest count rate above background; or
- Results of gamma spectrometry from Step 3 (that may indicate certain low γ-yield radionuclides).

NOTES:

- Steps 7 and 8 should be performed concurrently. Although all the radionuclides listed in Table 3 are possible contaminants, perform those analyses that are most probable based on previous samples and direction by the IC.
- Samples from the same event and area may be queued more accurately using the information already obtained on the first batch of samples. For example, if ^{241}Am is one of the known contaminants, that analysis would be started first in Step 7.

9. Ensure that all analytical results are available for all of the radionuclides to be analyzed for each sample. Select the corresponding 500-mrem ADL values for each of the radionuclides analyzed and compare to the analytical results. Compute the sum of the fractions for all radionuclides identified above their respective sample-specific critical values.

10. If the results of the analyses performed in Steps 7 and 8 exceed an individual 500-mrem ADL (values are in Tables 7C and 7D) or if the sum of the fractions results are >1.0, go to Step 22.

The sum of the individual radionuclide concentrations should be approximately equal to the respective gross activity concentrations (the rule of thumb is within a range of about half to twice the respective gross value if the measurement is made more than 72 hours after sample collection[15]) for each sample. Ensure that any dilution factors or sample splitting have been taken into account. If there is a discrepancy between the sum of the individual results and the respective gross results, there may be either missing radionuclides or an error in the analyses since the gross results indicated activity above the 500-mrem AAL. This discrepancy should be resolved by recount or re-analysis (Step 21).

11. The gross scan performed at the laboratory has identified these samples as being less than or equal to the ADL corresponding to the 500-mrem AAL. A gross alpha/beta screen using a GPC for a longer period of time (see Tables 7C and 7D) should be performed to get a more accurate assessment of the sample activity.

The solids loading (mg/cm^2) on the filter medium should be determined (by the laboratory) in order to assess accurately the activities relative to background. This can be done by taking the average mass of an unloaded filter and subtracting it from the final mass of each filter received from the sample team. This mass can then be used to estimate the normal concentra-

[15] If counting were to take place within 72 hours of sampling, the radon progeny would still contribute to the gross alpha/beta results, and the ½ value should be carefully examined because early gross count values could be artificially high.

tion of naturally occurring radionuclides in airborne dust and solids within a sampled area (including any unaffected areas). A dust concentration of ~100 μg/m^3 is typical for non-industrial areas due to terrestrial dust resuspension.

The exception to this flow path is for the iodine cartridge. If the iodine-cartridge screening results indicate a decay-corrected concentration greater than a 500-mrem ADL for any iodine isotope [e.g., ^{131}I > 1.2×10^3 pCi/m^3], go directly to Step 3 and gamma-count the *cartridge and filter* (separately), regardless of the gross α/β result. This becomes a high-priority analysis because this high an activity from short-lived radionuclides like ^{131}I or the noble gases is unlikely weeks after the event and should be immediately investigated. The longer-lived iodine isotopes will not be detected by gross beta analysis. It is important therefore to assess their presence by performing gamma spectrometry with a low-energy photon detector.

12. The screening results from Step 11 are compared to the values of 10^{-4} risk ADL for

- Gross alpha (from Table 7A),
- Gross beta (from Table 7B),
- Gamma isotopic, and
- ^{131}I for the cartridge [If radioiodines are detected on the cartridge, a gamma count of the particulate filter should be performed to identify any additional radioiodine contribution prior to assessing what AAL may have been exceeded].

See Table 12B for derivation of these ADL values. Values greater than the ADL will send the sample to the high-priority path at Step 3. Samples below their respective ADLs are sent to the lower-priority queue (Step 13) for gamma spectrometry analysis at a later time to determine if the 10^{-6} risk ADL has been exceeded. It may be advantageous to use simultaneous (e.g., a multi-chamber detector system) versus sequential gross alpha/beta counting for longer time periods than for the previous screening measurements. This will ensure that the counting time is sufficient to meet the u_{MR} so that a valid comparison to the ADL for the 10^{-4} and 10^{-6} risk can be made.

13. A longer gamma spectrometry analysis (to meet the 10^{-6} risk MQOs) should be performed to identify any gamma-emitting radionuclides that may have been undetected during the gross screening analysis. The gamma spectrometry analysis using a low-energy photon detector also should be performed on both the filter and any iodine cartridges that may have been used in the sampling. Ensure that aliquant size and counting time are sufficient to meet the u_{MR}, so that a valid comparison to the ADL for a 10^{-6} risk AAL can be made.

13a. Samples from Radioanalytical Scenario I (Step 15) would feed into the analytical processing scheme at this point and be ready for Step 13 if these samples have not yet been digested.

13b. Samples from Radioanalytical Scenario I (Step 17) would feed into the analytical processing scheme at this point. Go to Steps 15, 16, and 17 if these samples already have been digested. If the filter has not been counted by gamma spectrometry in Step 17 of Scenario 1 flow diagram, longer count times will be required here.

14. Samples in this step have gross α/β and γ isotopic activities less than the 500-mrem ADL and consequently are a lower priority. When detectors are available, the entire filter should be dissolved and aliquants apportioned for α and β analysis (with sufficient reserve aliquants for analysis that may require either lower detectability or analysis for radionuclides not in Table 3).

A fusion technique that uses a low-temperature flux, or an acid digestion that ensures a single, homogeneous phase, should be applied. If glass fiber filters have been used, some form of fluoride treatment (for example, NaF fusion or HF removal of silica are commonly used techniques) should be used to eliminate silica precipitation later in the analytical process. HF may be better for samples that only have alpha-emitting radionuclides because its use minimizes the addition of other solid matter to the final counting form, which in turn minimizes sample self-absorption.

Sufficient final volume of the digested sample should be saved for removal of aliquants in the future for specific alpha- and beta-emitting radionuclides. This should include an aliquant that may need to be recounted by gamma spectrometry for a period of time sufficient to achieve u_{MR} for the 10^{-6} risk level. Ensure that the calculation of the final activity of the sample corrects for that fraction of the original sample that was used for the analysis after sample digestion.

NOTES:
- Steps 15, 16, and 17 should be performed concurrently. Although all the radionuclides listed in Table 3 are possible contaminants, perform those analyses that are most probable based on previous samples and direction by the IC.
- Samples from the same event and area may be queued more accurately using the information already obtained on the first batch of samples. For example, if ^{241}Am is one of the known contaminants, that analysis would be started first in Step 15.

15. 16. 17. These three steps should be done concurrently. Prioritization of radionuclide-specific analysis should be based on:
- IC input (when provided)
- Results from previous samples for this location or event;
- Gross analysis that yielded the greatest count rate above background; or
- Results of the gamma count from Step 13 (that may indicate certain low gamma-yield radionuclides).

Samples that were originally on the green path (high priority) may be routed here. They will have been digested already. An aliquant of the digestate should be analyzed by gamma spectrometry with a longer count than previously performed (long enough to meet the u_{MR} from Tables 8A and 8B). Ensure that aliquant size and counting time are sufficient to determine if the ADL for the 10^{-6} risk AAL has been exceeded.

18. As the analytical values are obtained for each of the radionuclides in the tables, they are compared with the 10^{-4} risk factor AAL. If more than one radionuclide is present above its detection limit (i.e., critical level concentration), the sum of the fractions of the 10^{-4} risk factor is used to assess whether the10^{-4} risk factor AAL is exceeded. If the sum of the

fractions exceeds 1.0 or an individual result exceeds the ADL, proceed to Step 9. Otherwise go to Step 19.

19. Compare the sample results to the 10^{-6} risk factor ADL and the sum of the fractions (if more than one radionuclide is present) to the 10^{-6} risk factor AAL. Any time the specific radionuclide value for 10^{-6} risk factor ADL is exceeded, proceed to Step 9. Otherwise, the sample processing continues with a lower priority at Step 20. Check to ensure that the gross sample analyses agree with the sum of the individual analyses for that sample.

20. If there is poor agreement between initial gross screen and final radionuclide-specific analyses, proceed to Step 21. If all comparisons have been made and found valid and results are less than the applicable 10^{-6} risk factor ADL, and sum of the fractions of all radionuclides above their detection limit is less than one, proceed to Step 22.

21. If the radionuclide specific analyses do not agree within the range of 0.5 to 2.0 times the gross sample analysis for alpha and beta, respectively, the discrepancy should be resolved quickly if possible.

The discrepancy should be quickly resolved, if possible. The samples either should be recounted or reserved aliquants should be reprocessed to attempt to resolve the discrepancy. If reprocessing resolves the discrepancy, re-evaluate the sample results against respective ADL values, and then recalculate the sum of the fractions.

If reprocessing does not resolve the discrepancy, results should be reported with a notation that the gross activity and radionuclide-specific activity sums do not agree.

22. Notify the IC of the sample results. Specific note should be made of any radionuclide that exceeds an ADL or if the sum of the fractions exceeds 1.0. Any discrepancies between the gross activity measurement and the sum of the final activity results should also be identified. All results for samples are reported to the IC, along with any unresolvable discrepancies in the analytical results.

23. The final sample test source should be archived so that their integrity is maintained and that they are in a retrievable condition to reproduce counting. Any remaining final sample fractions should be archived as well, e.g., remaining solution from the digestion of the air filter. Provide electronic data deliverable (EDD) to field personnel or IC.

VI. SCENARIO 3 (Radionuclides in Air Particulate Samples Have Been Identified)

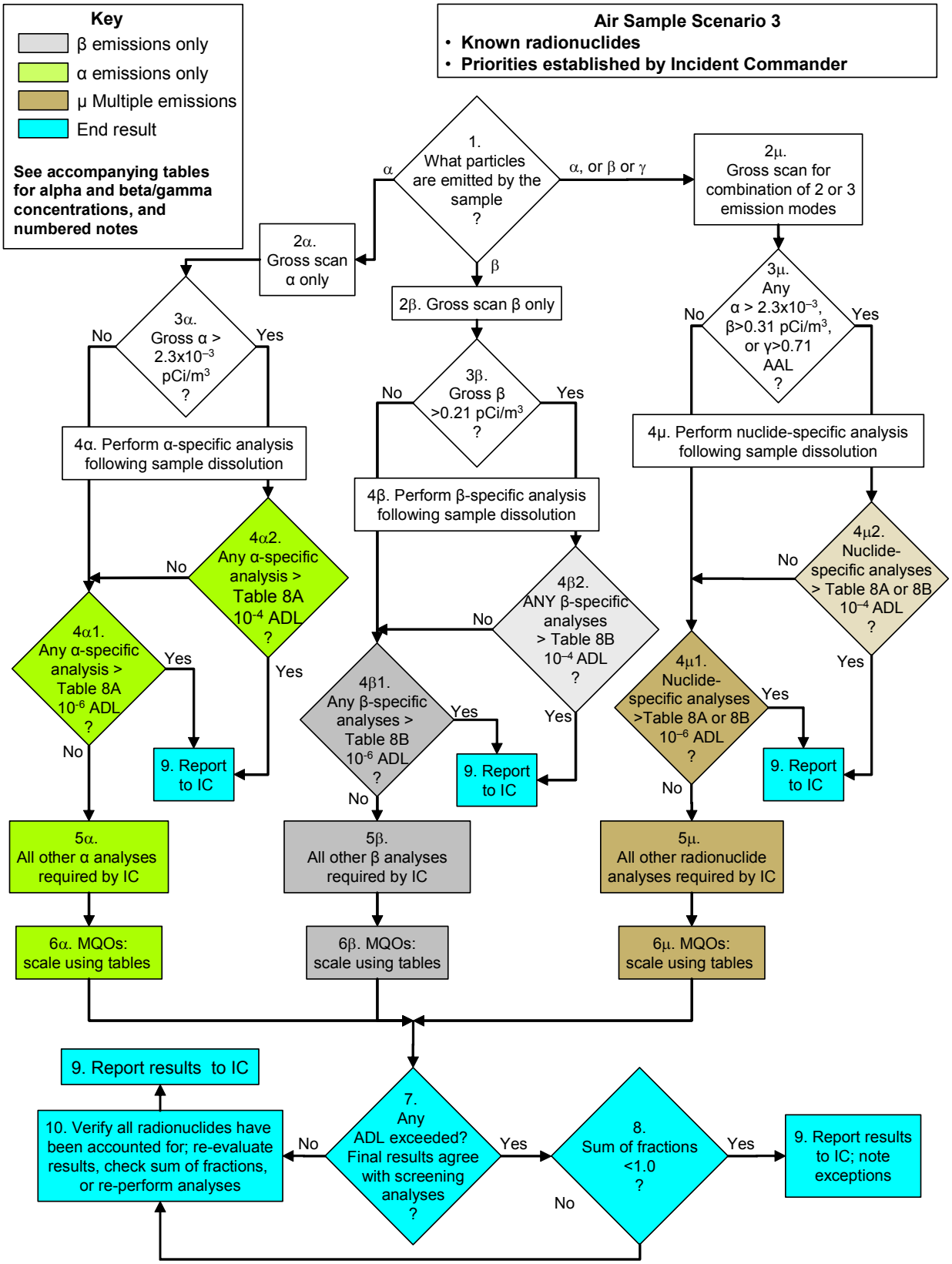


Figure 4 – Air Scenario 3 Analytical Flow

Notes for Scenario 3: Contaminating Radionuclides Known
Purpose: Support the Specific Needs of the IC

For this scenario, "α" and "β" designate paths that are to be followed (and their associated notes) when samples received from the field contain radionuclides that emit only alpha or only beta particles, respectively, and "μ" designates samples that contain a gamma emitter or a mixture of emitters (alpha or beta or gamma).

Scenario 3 takes place when the radioactive contaminants have been well characterized. Detailed analyses are required for the radionuclide(s) known to be in the samples, and at the direction of the IC. Thus, the radioanalytical process chart becomes more streamlined, and sample priority is based upon what is needed by the Incident Commander at the time the samples are taken. Either high- or low-activity samples may take priority.

Because the radionuclides are known, the gross-screening instruments should be calibrated for the specific radionuclides of interest if possible. This allows rapid and more accurate assessment of the activity before more time-consuming analytical separations are performed.

Many of the flow diagram shapes are color-coded to reflect the analytical flow path for various combinations of decay modes (green for alpha, gray for beta, or brown for multiple emitters). The accompanying numbered notes are color-coded in the same fashion, as are the examples in Appendix IV. It is highly advisable to study the flow paths in color, as a black-and-white printing may be confusing or ambiguous.

1. The event that has taken place is now characterized and the radionuclide(s) of concern have been identified. The flowchart is trimmed to deciding which of the three different radionuclide emissions are present. The emission mode generally determines the final radioanalytical method that will be used to assess the concentration. Generally, β-only emitters will be analyzed by GPC or LSC (2β), α-only emitters by either GPC or alpha spectrometry (AS) (2α), and any combination of the three types of emission by an appropriate combination of alpha spectrometry, GPC, LSC, or gamma spectrometry (2μ). The choice is determined by what is known about the event. If more than one type of radionuclide emitter is present, the choice is to follow the multiple emissions mode path (2μ). The ranking of total activity in the samples will be aided by sample gross screening when the samples are received by the laboratory (see discussion in beginning of description for Scenario 2).

2α. This path is selected only if radionuclides from the event are all pure α emitters.[16] The samples still should be screened to distinguish high- from low-activity samples. Thus, the instrument used to perform the screening analysis should be calibrated to permit specific determination of the concentration of the radionuclide of interest.

[16] It should be noted that the evaluation for pure alpha or beta emitters should be done based on the principal particle emission used for routine detection. This means that for the concentrations in air particulate samples below the 10^{-4} risk-level AAL, that ^{241}Am would be considered "alpha only."

2β. This path is selected only if all radionuclides from the event are β emitters.[17] The samples still should be screened to distinguish high- from low-activity samples. Thus, the instrument used to perform the screening analysis should be calibrated using the radionuclide of interest.

2μ. This path is selected only if the radionuclides from the event emit a combination of α, or β, or γ emitters. The samples still should be screened to distinguish high- from low-activity samples. The instrument used to perform the screening analysis should be calibrated with the radionuclides of interest.

3α. **3β.** **3μ.** The purpose of this step is to distinguish high-activity samples from low-activity samples and to rank the samples in order of their activity level. The subsequent flow paths would be selected based on the priority from the IC. Thus, it is important that this screening method is able to distinguish high-activity samples from low-activity samples in a reasonably short time. Table 14 in Appendix VI provides an insight into the minimum detectable concentration (MDC) and 10% relative counting uncertainty that can be achieved routinely using specified sampled volumes, and detector count times using GPC. Although these MDCs are not equivalent and do not relate to a specific AALs, they are low enough to be used for screening purposes. Once classified as high or low analytical priority, the samples should be ranked based on their gross activity measurements.

> NOTE: The flow of priority splits here. Either of the paths for the suffixes 1 or 2 may get the priority. The priority is event-specific and determined by the IC. Suffix 1 designates the 10^{-6} risk requirements, and suffix 2 designates other event-specific MQOs. Flow path 2 would be scaled to the appropriate ADL based on the 10^{-4} risk level.

It may be advantageous to use simultaneous versus sequential gross alpha/beta counting (e.g., using a multi-chamber detector system) for longer time periods than for the previous screening measurements to be able to assess expeditiously if sample activities are less than the 10^{-4} and 10^{-6} risk ADLs and also to achieve the respective u_{MR} values.

The IC may stipulate an event-specific AAL, ADL, and u_{MR}, whose values are based on a fraction of the values found in Tables 8A and 8B.

4α. **4β.** **4μ.** The first analytical priority when this path is chosen is to determine the *known* contaminant(s) from the event. A radionuclide-specific method(s) should be chosen for all previously identified radionuclides. This will usually require digestion of the particulate filter as described in Scenario 1.

$4\alpha_1$ **$4\beta_1$** **$4\mu_1$** The analytical methods chosen should be able to meet the u_{MR} at the 10^{-6} risk AAL concentration (Tables 8A and 8B). This path would be chosen if the intent was to look for unrestricted habitability. As results are validated, if the event-specific

[17] See previous footnote concerning the evaluation of pure alpha or beta emitters based on the principal particle emission.

contaminant concentration is greater than its respective 10^{-6} risk ADL (Tables 8A or 8B), notify the IC. Otherwise, proceed with all other analyses and report results when all are completed.

$4\alpha_2$ **$4\beta_2$** **$4\mu_2$** This branch of the flow diagram would be chosen if the direction were to identify air particulate filters that have sufficient activity to cause exposure in excess of the 10^{-4} risk level, or other event-specific risk level defined by the IC. If the event-specific contaminant is less than its respective ADL (based on scaling of concentrations and in Tables 8A and 8B), then analysis for all other contaminants of concern should proceed. If the event-specific contaminant concentration is greater than its respective ADL for that event, notify the IC that this sample has exceeded the event-specific AAL.

5α. **5β.** **5μ.** Perform all other radionuclide analyses required by the IC.

6α. **6β.** **6μ.** Select the ADL values from Tables 8A or 8B to be compared with the final analytical concentrations for the air sample, and scale the ADL values to the incident-specific AAL. For example, if the AAL required by the project was 10^{-5} risk for ^{232}Th, start with the 10^{-4} ADL value of 2.1×10^{-1} pCi/m^3 (from Table 8A) and divide it by 10. The resulting value for the ADL will be 2.1×10^{-2} pCi/m^3, with a u_{MR} value of 3.8×10^{-3} pCi/m^3.

7. Start by comparing each individual radionuclide result with the incident-specific risk level ADL values (see Tables 8A and 8B for the default values of 10^{-4} and 10^{-6}). If the final reviewed result for any single radionuclide exceeds the project-specific ADL, or the sum of the fractions exceeds 1.0, report the results immediately to the IC.

8. Compare the radionuclide-specific results to the screening analyses and verify that no major nuclide has been missed. Verify that the sum of the individual nuclide concentrations is approximately equivalent to the gross activity concentration (a rule of thumb is within a range of about half to twice the gross value). However, this may not hold true for low-energy beta emitters, like tritium, if the screening measurement was made by GPC. This check will ensure that the sum of the measurements compares reasonably to the total measured gross activity. Activity concentrations due to decay products should be included in the verification.

If there is a discrepancy between the summed activity concentration of all statistically significant individual nuclide concentrations (i.e., sum all results detected at levels greater than the critical level, rather than the incident-specific discrimination limit), check for errors and resolve any discrepancies prior to proceeding.

9. Two paths lead to this step:

- In Steps 4α1, 4β1, and 4μ1, the result for the event-specific radionuclide exceeded the 10^{-4} or 10^{-6} risk level, or
- All analyses have been completed, and the result is $< 10^{-6}$ risk factor. The priority path was previously determined by the IC.

10. If the results from the radionuclide-specific analysis and the gross measurement do not match to within a factor of 0.5 to 2.0, then a potential mismatch exists between the individual radionuclide concentration sum and the gross analysis (potentially missing a radionuclide contributor. This would indicate a potential mismatch between the individual radionuclide concentration sum and the gross analysis (potentially missing a radionuclide contributor). This may require re-analysis starting with the gross-activity measurement.

It is possible that either a short-lived radionuclide decayed away prior to having been analyzed, or a radionuclide analysis was missed. It may also be possible that a low-energy alpha, beta, or gamma emitter was not detected during the gross analysis due to self shielding effects. In either case, the discrepancy should be resolved, which may include specific correlations for the radionuclides from this event.

Final results are then transmitted to the IC.

APPENDIX I. Tables of Radioanalytical Parameters for Radionuclides of Concern

The following tables list the AAL, ADL, and u_{MR} values for the radionuclides of concern. The tables present gross screening and radionuclide-specific measurements for alpha and beta/gamma-emitting radionuclides. Derivation of the ADL values for each of these tables can be found in Appendix VI. Tables 7A and 7B show activities of specific radionuclides. These values were calculated based on the Type I and Type II error rates presented in Appendix VI.

The listed AALs are applicable as default values based on generic conversions of the dose level to concentration in air for a specific radionuclide. The required method uncertainty and ADL will change depending upon the acceptable decision error rate. The IC may provide incident-specific AALs or decision error rates that would supersede these values. In this case, the laboratory will need to develop new tables for all values, using the process described in Appendix VI.

TABLE 7A – Analytical Decision Levels (ADL) and Required Method Uncertainty Using Gross Alpha Screening Methods

Radionuclide	(pCi/m^3)					
	2-rem AAL [1]	2-rem ADL	Required Method Uncertainty ($u_{[3]R}$)	500-mrem AAL [1]	500-mrem ADL	Required Method Uncertainty ($u_{[3]R}$)
Gross α Screen	0.70	0.35	0.21	0.17	0.085	0.052
Am-241	0.70	0.35	0.21	0.17	0.085	0.052
Cm-242	11	5.5	3.3	2.8	1.4	0.85
Cm-243	0.97	0.49	0.29	0.24	0.12	0.073
Cm-244	1.2	0.60	0.36	0.29	0.15	0.088
Np-237 [2]	1.3	0.65	0.40	0.34	0.17	0.10
Po-210	16	8.0	4.9	3.9	2.0	1.2
Pu-238	0.62	0.31	0.19	0.15	0.075	0.046
Pu-239	0.56	0.28	0.17	0.14	0.070	0.043
Pu-240	0.56	0.28	0.17	0.14	0.070	0.043
Ra-226 [2]	7.0	3.5	2.1	1.8	0.90	0.55
Th-228 [2]	1.7	0.85	0.52	0.42	0.21	0.13
Th-230	0.66	0.33	0.20	0.17	0.085	0.052
Th-232	0.61	0.31	0.19	0.15	0.075	0.046
U-234	7.1	3.6	2.2	1.8	0.90	0.55
U-235	7.9	4.0	2.4	2.0	1.0	0.61
U-238	8.3	4.2	2.5	2.1	1.1	0.64

Notes:

[1] Derived air concentration yielding stated committed effective dose assuming a 365-day year. Child as receptor. Value corresponds to solubility class having lowest value.

[2] Includes decay products in the body for the calculation of concentration.

[3] Required method uncertainty values are calculated for the 2-rem or 500-mrem AALs in Appendix VI.

TABLE 7B – Analytical Action and Decision Levels (AAL and ADL) and Required Method Uncertainty Using Gross Beta-Gamma Screening Methods

Radionuclide	pCi/m³					
	2-rem AAL [1]	2-rem ADL	Required Method Uncertainty (u_{MR}) [3]	500-mrem AAL [1]	500-mrem ADL	Required Method Uncertainty (u_{MR}) [3]
Gross β Screen [4, 5]	420	210	130	110	55	33
Ac-227+DP [2]	0.43	0.22	0.13	0.11	0.055	0.033
Ce-141	1.8×10^4	9.0×10^3	5.5×10^3	4.5×10^3	2.3×10^3	1.4×10^3
Ce-144	1.3×10^3	650	400	320	160	97
Co-57[7]	6.7×10^4	3.4×10^4	2.0×10^4	1.7×10^4	8.5×10^3	5.2×10^3
Co-60	2.2×10^3	1.1×10^3	670	550	280	170
Cs-134	3.3×10^3	1.7×10^3	1.0×10^3	820	410	250
Cs-137	1.7×10^3	850	520	430	220	130
H-3[3]	2.6×10^5	1.3×10^5	7.9×10^4	6.4×10^4	3.2×10^4	1.9×10^4
I-125 [6,7,4]	1.3×10^4	6.5×10^3	4.0×10^3	3.2×10^3	1.6×10^3	970
I-129 [6,4]	1.9×10^3	950	580	470	240	140
I-131 [6,4]	9.1×10^3	4.6×10^3	2.8×10^3	2.3×10^3	1.2×10^3	700
Ir-192	1.0×10^4	5.0×10^3	3.0×10^3	2.5×10^3	1.3×10^3	760
Mo-99	6.8×10^4	3.4×10^4	2.1×10^4	1.7×10^4	8.5×10^3	5.2×10^3
P-32	1.7×10^4	8.5×10^3	5.2×10^3	4.3×10^3	2.2×10^3	1.3×10^3
Pd-103	1.5×10^5	7.5×10^4	4.6×10^4	3.8×10^4	1.9×10^4	1.2×10^4
Pu-241	29	15	8.8	7.3	3.7	2.2
Ra-228 [2]	4.2	2.1	1.3	1.0	0.50	0.30
Ru-103	2.3×10^4	1.2×10^4	7.0×10^3	5.7×10^3	2.9×10^3	1.7×10^3
Ru-106	1.0×10^3	500	300	250	130	76
Se-75	5.0×10^4	2.5×10^4	1.5×10^4	1.3×10^4	6.5×10^3	4.0×10^3
Sr-89	8.4×10^3	4.2×10^3	2.6×10^3	2.1×10^3	1.1×10^3	640
Sr-90[2]	420	210	130	110	55	33
Tc-99	5.0×10^3	2.5×10^3	1.5×10^3	1.3×10^3	650	400

Notes:

[1] Derived air concentration yielding stated committed effective dose assuming a 365-day year. Child as receptor. Value corresponds to solubility class having lowest value.

[2] Includes decay products in the body for the calculation of concentration.

[3] Required method uncertainty values are calculated for the 2-rem or 500-mrem AALs in Appendix VI.

[4] All nuclides can be collected on a fibrous or membrane air filter media except ^{3}H, ^{125}I, ^{129}I, and ^{131}I in the vapor states.

[5] Value determined excluding ^{227}Ac and ^{228}Ra. Sr-90 is used for gross beta screening because it is the most restrictive in the table and commonly used for instrument calibration.

[6] These values are based on the vapor plus particulate dose rate.

[7] Several nuclides decay by electron capture (see Table 3). These radionuclides cannot be detected using gross β analysis. The electron-capture decay leads to characteristic X-rays of the progeny nuclide. The most effective way to detect the X-rays from these electron-capture-decay radionuclides is either with a low-energy photon detector (LEPD) or a reverse electrode germanium detector N-type semiconductor detector. The lower range of energy with these detectors is about 10 keV.

TABLE 7C – Analytical Action and Decision Levels (AAL and ADL) and Required Method Uncertainty Using Alpha Radionuclide Specific Methods

Radionuclide	(pCi/m^3)					
	2-rem AAL [1]	2-rem ADL	Required Method Uncertainty (u_{MR})	500-mrem AAL [1]	500-mrem ADL	Required Method Uncertainty (u_{MR})
Am-241	0.70	0.49	0.088	0.17	0.12	0.021
Cm-242	11	7.8	1.4	2.8	2.0	0.35
Cm-243	0.97	0.69	0.12	0.24	0.17	0.030
Cm-244	1.2	0.85	0.15	0.29	0.21	0.037
Np-237 [2]	1.3	0.92	0.16	0.34	0.24	0.043
Po-210	16	11	2.0	3.9	2.8	0.49
Pu-238	0.62	0.44	0.081	0.15	0.11	0.020
Pu-239	0.56	0.40	0.071	0.14	0.099	0.018
Pu-240	0.56	0.40	0.071	0.14	0.099	0.018
Ra-226 [2]	7.0	4.9	0.88	1.8	1.3	0.23
Th-228 [2]	1.7	1.2	0.21	0.42	0.30	0.053
Th-230	0.66	0.47	0.083	0.17	0.12	0.021
Th-232	0.61	0.43	0.077	0.15	0.11	0.019
U-234	7.1	5.0	0.89	1.8	1.3	0.23
U-235	7.9	5.6	0.99	2.0	1.4	0.25
U-238	8.3	5.9	1.0	2.1	1.5	0.26

Notes:

[1] Derived air concentration yielding stated committed effective dose assuming a 365-day year. Child as receptor. Value corresponds to solubility class having lowest value.

[2] Includes decay products in the body for the calculation of concentration.

[3] Required method uncertainty values are calculated for the 2-rem or 500-mrem AALs in Appendix VI.

TABLE 7D – Analytical Action and Decision Levels (AAL and ADL) and Required Method Uncertainty Using Beta-Gamma Radionuclide-Specific Methods

Radionuclide	pCi/m³					
	2-rem AAL [1]	2-rem ADL	Required Method Uncertainty (u_{MR}) [3]	500-mrem AAL [1]	500-mrem ADL	Required Method Uncertainty (u_{MR}) [3]
Ac-227+DP [2]	0.43	0.30	0.054	0.11	0.078	0.014
Ce-141	1.8×10^4	1.3×10^4	2.3×10^3	4.5×10^3	3.2×10^3	570
Ce-144	1.3×10^3	920	160	320	230	40
Co-57[6]	6.7×10^4	4.7×10^4	8.4×10^3	1.7×10^4	1.2×10^4	2.1×10^3
Co-60	2.2×10^3	1.6×10^3	280	550	390	69
Cs-134	3.3×10^3	2.3×10^3	420	820	580	100
Cs-137	1.7×10^3	1.2×10^3	210	430	300	54
H-3[3]	2.6×10^5	1.8×10^5	3.3×10^4	6.4×10^4	4.5×10^4	8.1×10^3
I-125[5]	1.3×10^4	9.2×10^3	1.6×10^3	3.2×10^3	2.3×10^3	400
I-129[5,6]	1.9×10^3	1.3×10^3	240	470	330	59
I-131[5]	9.1×10^3	6.4×10^3	1.1×10^3	2.3×10^3	1.6×10^3	290
Ir-192	1.0×10^4	7.1×10^3	1.3×10^3	2.5×10^3	1.8×10^3	310
Mo-99	6.8×10^4	4.8×10^4	8.6×10^3	1.7×10^4	1.2×10^4	2.1×10^3
P-32	1.7×10^4	1.2×10^4	2.1×10^3	4.3×10^3	3.0×10^3	540
Pd-103	1.5×10^5	1.1×10^5	1.9×10^4	3.8×10^4	2.7×10^4	4.8×10^3
Pu-241	29	21	3.7	7.3	5.2	0.92
Ra-228 [2]	4.2	3.0	0.53	1.0	0.71	0.13
Ru-103	2.3×10^4	1.6×10^4	2.9×10^3	5.7×10^3	4.0×10^3	720
Ru-106	1.0×10^3	710	130	250	180	31
Se-75	5.0×10^4	3.5×10^4	6.3×10^3	1.3×10^4	9.2×10^3	1.6×10^3
Sr-89	8.4×10^3	5.9×10^3	1.1×10^3	2.1×10^3	1.5×10^3	260
Sr-90[2]	420	300	53	110	78	14
Tc-99	5.0×10^3	3.5×10^3	630	1.3×10^3	920	160

Notes:

[1] Derived air concentration yielding stated committed effective dose assuming a 365-day year. Child as receptor. Value corresponds to solubility class having lowest value.

[2] Includes decay products in the body for the calculation of concentration.

[3] Required method uncertainty values are calculated for the 2-rem or 500-mrem AALs in Appendix VI.

[4] All nuclides can be collected on a fibrous or membrane air filter media except ^{3}H, ^{125}I, ^{129}I, and ^{131}I in the vapor states.

[5] These values are based on the vapor phase dose rate and would be applied to the cartridges only for screening purposes.

[6] Several nuclides decay by electron capture (see Table 3). These radionuclides cannot be detected using gross β analysis. The electron-capture decay leads to characteristic X-rays of the progeny nuclide. The most effective way to detect the X-rays from these electron-capture-decay radionuclides is either with a low-energy photon detector (LEPD) or a reverse electrode germanium detector N-type semiconductor detector. The lower range of energy with these detectors is about 10 keV.

TABLE 8A – Analytical Action and Decision Levels (AAL and ADL) and Required Method Uncertainty at 10^{-4} and 10^{-6} Risk Using Alpha Radionuclide-Specific Methods

Radionuclide	pCi/m³					
	10^{-4} Risk AAL [1]	10^{-4} Risk ADL	Required Method Uncertainty (u_{MR}) [3]	10^{-6} Risk AAL [1]	10^{-6} Risk ADL	Required Method Uncertainty (u_{MR}) [3]
Am-241	0.33	0.23	0.042	3.3×10^{-3}	2.3×10^{-3}	4.2×10^{-4}
Cm-242	0.62	0.44	0.078	6.2×10^{-3}	4.4×10^{-3}	7.8×10^{-4}
Cm-243	0.34	0.24	0.043	3.4×10^{-3}	2.4×10^{-3}	4.3×10^{-4}
Cm-244	0.35	0.25	0.044	3.5×10^{-3}	2.5×10^{-3}	4.4×10^{-4}
Np-237 [2]	0.43	0.30	0.054	4.3×10^{-3}	3.0×10^{-3}	5.4×10^{-4}
Po-210	0.86	0.61	0.11	8.6×10^{-3}	6.1×10^{-3}	1.1×10^{-3}
Pu-238	0.24	0.17	0.030	2.4×10^{-3}	1.7×10^{-3}	3.0×10^{-4}
Pu-239	0.22	0.16	0.028	2.2×10^{-3}	1.6×10^{-3}	2.8×10^{-4}
Pu-240	0.22	0.16	0.028	2.2×10^{-3}	1.6×10^{-3}	2.8×10^{-4}
Ra-226 [2]	0.44	0.31	0.055	4.4×10^{-3}	3.1×10^{-3}	5.5×10^{-4}
Th-228 [2]	0.094	0.066	0.012	9.4×10^{-4}	6.6×10^{-4}	1.2×10^{-4}
Th-230	0.36	0.25	0.045	3.6×10^{-3}	2.5×10^{-3}	4.5×10^{-4}
Th-232	0.30	0.21	0.038	3.0×10^{-3}	2.1×10^{-3}	3.8×10^{-4}
U-234	0.45	0.32	0.057	4.5×10^{-3}	3.2×10^{-3}	5.7×10^{-4}
U-235	0.49	0.35	0.062	4.9×10^{-3}	3.5×10^{-3}	6.2×10^{-4}
U-238	0.52	0.37	0.065	5.2×10^{-3}	3.7×10^{-3}	6.5×10^{-4}

Notes:
[1] Morbidity for long-term inhalation. Value corresponds to solubility class having lowest value.
[2] Includes decay products in the body for the calculation of risk or concentration.
[3] Required method uncertainty values are calculated for the 10^{-4} and 10^{-6} risk values in Appendix VI.

TABLE 8B – Analytical Action and Decision Levels (AAL and ADL) and Required Method Uncertainty at 10^{-4} and 10^{-6} Risk Using Beta-Gamma Radionuclide-Specific Methods

Radionuclide[2]	pCi/m³					
	10^{-4} Risk AAL [1]	10^{-4} Risk ADL	Required Method Uncertainty u_{MR} [3]	10^{-6} Risk AAL [1]	10^{-6} Risk ADL	Required Method Uncertainty u_{MR} [3]
Ac-227+DP [4]	0.083	0.059	0.010	8.3×10^{-4}	5.9×10^{-4}	1.0×10^{-4}
Ce-141	920	650	120	9.2	6.5	1.2
Ce-144	69	49	8.7	0.69	0.49	0.087
Co-57 [6]	3.3×10^{3}	2.3×10^{3}	420	33	23	4.2
Co-60	120	85	15	1.2	0.85	0.15
Cs-134	180	130	23	1.8	1.3	0.23
Cs-137	110	78	14	1.1	0.78	0.14
H-3 Vapor	1.5×10^{4}	1.1×10^{4}	1.9×10^{3}	150	110	19
I-125 [5]	1.2×10^{3}	850	150	12	8.5	1.5
I-129 [5, 6]	200	140	25	2	1.4	0.25
I-131 [5]	640	450	81	6.4	4.5	0.81
Ir-192	510	360	64	5.1	3.6	0.64
Mo-99	2.6×10^{3}	1.8×10^{3}	330	26	18	3.3
P-32	890	630	110	8.9	6.3	1.1
Pd-103	7.0×10^{3}	4.9×10^{3}	880	70	49	8.8
Pu-241	14	9.9	1.8	0.14	0.099	0.018
Ra-228 [4]	0.28	0.20	0.035	2.8×10^{-3}	2.0×10^{-3}	3.5×10^{-4}
Ru-103	1.2×10^{3}	850	150	12	8.5	1.5
Ru-106	56	40	7.1	0.56	0.40	0.071
Se-75	2.5×10^{3}	1.8×10^{3}	310	25	18	3.1
Sr-89	410	290	52	4.1	2.9	0.52
Sr-90 [4]	29	21	3.7	0.29	0.21	0.037
Tc-99	330	230	42	3.3	2.3	0.42

Notes:

[1] Morbidity for long-term inhalation. Value corresponds to solubility class having lowest value.

[2] All nuclides can be collected on a fibrous or membrane air filter media except ^{3}H, ^{125}I, ^{129}I, and ^{131}I when their chemical form is in the vapor (vap) state. It is possible for iodine to be in the particulate (part) form. Note the differences in concentrations for the respective ADL values.

[3] Required method uncertainty values are calculated for the 10^{-4} and 10^{-6} risk values in Appendix VI.

[4] Includes decay products in the body for the calculation of concentration.

[5] These values are based on the vapor phase dose rate and would be applied to the cartridges only for screening purposes.

[6] Several nuclides decay by electron capture (see Table 3). These radionuclides cannot be detected using gross β analysis. The electron-capture decay leads to characteristic X-rays of the progeny nuclide. The most effective way to detect the X-rays from these electron-capture-decay radionuclides is either with a low-energy photon detector (LEPD) or a reverse electrode germanium detector N-type semiconductor detector. The lower range of energy with these detectors is about 10 keV.

APPENDIX II. Example of High-Concentration Air Particulates (Radioanalytical Scenario 1)

The number of samples have been minimized and the screening processes have been simplified in this example. In an actual event, the number and complexity of samples will be much greater than identified here.

Description

Air samples have been taken in the vicinity of a detonation where it is suspected an RDD has been used. Initial field readings show indications of radioactivity although no identification of radionuclides has been made. The sequence of events in the laboratory assumes a single analyst following the analytical flow chart, under conditions of a single sample process stream.

Event Sequence

The incident response organization has just established a field office for coordinating the response efforts, including a laboratory project manager who reports to the Incident Commander (IC). At *1200 hours of Day 1*, the incident response team sends three air particulate samples and three iodine cartridge samples from areas they believe to have the highest concentrations of airborne particulate radionuclides based on the field measurements of these samples. The samples arrive at the laboratory three hours later: it is *Day 1, 1500 hours.*

Analysis Paths

Field sampling personnel have noted on the chain-of-custody (COC) form that the samples were taken at a flow rate of 4.0 cfm for 1 hour, yielding a total volume of air sampled of 6.8 m^3. Field measurements of the filter surface using a hand-held alpha probe and a GM detector calibrated with ^{241}Am for gross alpha and ^{137}Cs for gross beta and gamma, respectively, are noted in the tables below.

Step 1. The lab performs a receipt survey of the samples using hand-held instruments for alpha, beta, and gamma. The data produced by the lab measurements are also listed in the tables below.

Filter ID	Gross Alpha, cpm (Field)	Gross Alpha, cpm (Lab)	Gross Beta, cpm (Field)	Gross Beta, cpm (Lab)	Gross gamma, µR/h (Field)	Gross Gamma, µR/h (Lab)
1	70.0	25.4	46.0	9.0	53	37
2	8.0	1.3	15.8	8.3	51	37
3	1.8	1.2	15	8.2	50	37
Back-ground	1.5	1.1	15	8.1	50	36

Cartridge ID	Gamma spectrometry Results	Gross Gamma, µR/h
1	No ^{131}I identified	41
2	No ^{131}I identified	38
3	No ^{131}I identified	36
Background	^{40}K	36

When the field measurements are compared to the lab measurements, it appears that the alpha and beta emission rates have both decreased significantly during transport, indicating that there are short-lived emitters present. Given the similar gamma-count rates between the background and the measurements of both the particulate filters and the iodine cartridges, there does not appear to be a significant concentration of gamma emitters present. It is not clear whether the short-lived radionuclides are radon-decay progeny, radionuclides of concern related to the incident, or both. *It is Day 1, 1515 hours.*

Step 1a Filters 1, 2, and 3. If the laboratory value for the gross alpha on Filter 1 is used to calculate[18] pCi/m^3, we find:

$$\frac{[25.4-1.1]\text{ cpm}}{(0.1[\text{cpm}/\text{dpm}])\times(2.22\text{ dpm}/\text{pCi})}\times\frac{1}{6.8\text{ m}^3}=16.1\text{ pCi}/\text{m}^3$$

This value exceeds all the 2-rem ADL values for the alpha-emitting radionuclides shown in Table 7A.

For the beta value, we find

$$\frac{[9.0-8.1]\text{ cpm}}{(0.3\text{ [cpm}/\text{dpm}])\times(2.22\text{ dpm}/\text{pCi})}\times\frac{1}{6.8\text{ m}^3}=0.20\text{ pCi}/\text{m}^3$$

which is below all the 2-rem and the 500-mrem ADL values for the beta-emitting radionuclides in Table 7B (with the exception of ^{227}Ac which is a ^{235}U decay product and based on the scenario evidence ^{235}U was not a possibility).

The dose rate in μR/h is at the background level.

Filter 1 gets the red path for processing (Step 2), with the additional input that beta and gamma analyses have no significant contribution to the total activity.

For Filter 2, the gross alpha values yield 0.13 pCi/m^3, which is less than the 2-rem ADL gross alpha value but greater than the gross-alpha 500-mrem ADL value in Table 7A. Following the Scenario 1 flow chart (Figure 2), because the gross alpha is between 500 mrem and 2 rem and the gross beta-gamma is insignificant. The filter should be analyzed as a second priority for all analytes starting at Step 4.

For Filter 3, the concentration for alpha is 6.6×10^{-2}, which is less than the 500-mrem ADL for alpha emitters. Thus, this sample analysis would be continued as a *second priority* at Step 13.

Step 1b. No samples have been taken for tritium analysis.

[18] The detection efficiencies for the laboratory hand-held instruments used in this example are 0.1 for gross alpha and 0.3 for gross beta.

Step 1c. Cartridges 1, 2, and 3. The gamma-ray spectrometer used for analysis of these cartridges is calibrated down to 25 keV. It is determined that the u_{MR} values for the three iodine radionuclides have been met based on the gamma spectrometry count time. Go to Step 3b. *It is Day 1, 1530 hours.*

Step 2, Filter 1. The microR-meter indicates activity at about the background level. Filter 1 is counted by gamma spectrometry for 15 minutes. The filter is next counted on the GPC for 10 minutes (See Table 9). It is determined that the u_{MR} values for gross alpha, gross beta and gamma-specific analyses by screening techniques (Tables 7A and 7B) have been met based on the gamma spectrometry and GPC count times. Laboratory personnel begin to review the sample results; go to Step 3a. *It is Day 1, 1550 hours.*

Step 3a, Filter 1. No gamma-ray peaks above their respective critical levels for the radionuclides of concern are identified by the software. The GPC analysis results on the entire filter are 15.5 pCi/m^3 gross alpha, and 2.0 pCi/m^3 gross beta. Sample stays on the high-priority path at Step 4, and a preliminary report is sent to the IC notifying the IC of the high result for this filter by laboratory screening analyses.

Step 3b, Cartridges 1, 2, and 3. There were no samples submitted for tritium analysis, and all the iodine cartridges have concentrations for the three iodine radionuclides less than their respective 500-mrem ADL values. These samples should be archived until a longer gamma count can be performed (Step 13).

Step 4, Filter 1. Filter 1 is dissolved using HF digestion that completely solubilizes the filter material. Laboratory personnel have visually checked the final solution to ensure that no visible particulate matter is present. Aliquants of the final solution are taken for gross alpha/beta, beta emitters and alpha isotopic (radium plus uranium and the transuranic elements) analysis. An aliquant of the remaining solution is archived for any additional analyses (like a follow-up gamma-ray analysis) that may be required. *It is Day 1, 2145 hours.*

Step 5, Filter 1. Because the gross alpha 2-rem AAL was exceeded for Filter 1, an aliquant of the dissolved filter solution is analyzed for gross alpha/beta by GPC. The alpha result is 20.1 pCi/m^3, beta result is 8.2 pCi/m^3 . This confirms the results from the rapid analysis of the filter with survey instruments. Note: The sample has been counted about 4 hours after the fusion step has occurred so that radium progeny will have the opportunity to build in. *It is Day 2, 0100 hours*

Step 6, Filter 1. The values for gross beta and gross gamma *do not* yield a ratio of greater than 2.5. Therefore, there is no indication of the presence of ^{90}Sr at this time. Sample processing should proceed with alpha analysis started first and the beta emitters next. Proceed to Steps 8 and 9.

Step 7, Filter 1. The analysis of the digestate for this filter for beta emitters is still a high priority due to the gross alpha activity. The sample should be analyzed *eventually* for ^{90}Sr.

Steps 8 and 10, Filter 1. The beta and gamma analyses are not above the 500-mrem AAL. The significant decay of activity determined in the field vs. the laboratory indicates the short-lived beta components may be progeny of radium. An analysis of the digestate aliquanted for archiving is counted by gamma spectrometry for 90 minutes.

Step 9, Filter 1. This sample should be given the top priority for alpha analyses. Analysis for transuranics, radium, and uranium would be started before the analyses in Steps 8 and 10.

Step 11, Filter 1. The only alpha emitter identified is ^{226}Ra, at a concentration of 15 pCi/m^3. Subsequent beta analyses do not identify any other beta emitters in Table 8B. However, the longer gamma spectrometry count time of the archived digestate portion will identify the gamma rays from ^{214}Pb/ ^{214}Bi. This result is consistent with radiological decay of ^{226}Ra. The required relative method uncertainty for radium are met (<13%). The result exceeds the 2-rem ADL (i.e., 15 pCi/m^3 is greater than the ADL of 4.9 pCi/m^3). The sum of the fractions of these beta emitters is unnecessary as the dose is accounted for in the ^{226}Ra activity. *It is Day 2, 0800 Hours.*

Step 12, Filter 1. The IC is notified that a 2-rem AAL has been exceeded on Filter 1for ^{226}Ra. The only radionuclides present are ^{226}Ra and its decay products. *It is Day 2, 1200 hours.*

Step 13, Filters 2 and 3. Filters 2 and 3 are counted by gamma spectrometry for 2 hours. Gamma-ray peaks from ^{214}Pb and ^{214}Bi are observed as they have now had a significant "in-growth" period. The GPC count time for gross alpha/beta has been 90 minutes. The count times have been long enough for each screening analysis to meet the u_{MR} values cited in Tables 7A and 7B for the 500 -mrem ADL values.

Step 14, Filters 2 and 3. The GPC results are gross alpha 0.15 and 0.050 and gross beta 1.1 and 0.60 pCi/m^3, respectively for Filters 2 and 3. Filter 2 takes a second-priority flow path at Step 4 while Filter 3 is relegated to Step 15.

Step 4, Filter 2. Filter 2 is dissolved using a low-temperature flux fusion technique that completely solubilizes the filter material. Laboratory personnel have visually checked the final solution to ensure that no visible particulate matter is present. Aliquants of the final solution are taken for gross alpha/beta, beta emitters and alpha isotopic (radium plus transuranic elements) analysis. An aliquant of the remaining solution is archived for any additional analyses (like a follow-up gamma-ray analysis) that may be required.

Step 5, Filter 2. Because the gross alpha 500-mrem AAL was exceeded for Filter 2, an aliquant of the dissolved filter solution is analyzed for gross alpha/beta. The gross alpha result is 0.25 pCi/m^3 and gross beta is 1.4 pCi/m^3. This confirms the results from the filter analysis. Note: The sample has been counted about 4 hours after the dissolution has occurred so that short-lived progeny will have had the opportunity to build in.

Step 6, Filter 2. The ratio of the gross beta to gamma activity is much less than 2.5, based on laboratory protocols for this comparison. Sample processing proceeds to Steps 8, 9, and 10.

Step 7, Filter 2. This step is a low priority because there is no indication of the presence of strontium. The sample eventually should be analyzed for ^{90}Sr.

Step 8, Filter 2. The beta analyses are a secondary priority as they are possibly above the 500-mrem PAG AAL. Analysis will be started first for ^{226}Ra as this has already been identified as the main contaminant.

Step 9, Filter 2. As the gross alpha was above the 500-mrem ADL, the alpha emitters analysis gets the focus (^{226}Ra is started first as it has already been identified). The beta emitters aliquant is started shortly after. The results for Filter 1 have indicated that radium progeny were present in this sample. Analysis for transuranics also proceeds at this point. The u_{MR} values for all the alpha emitters have been achieved.

Step 10, Filter 2. Gamma spectrometry count time is 2 hours. The u_{MR} values for all the gamma emitters have been achieved.

Step 11, Filter 2. The analysis results from Filter 2 show the concentration of ^{226}Ra is 0.32 pCi/m^3. Note: The sample has been counted about 4 hours after the dissolution has occurred so that progeny have had some opportunity to build in. (For this example, re-analysis at Step 16 is unnecessary.)

Step 12. The IC is notified that the only radionuclides present are ^{226}Ra and its decay products.

Step 15, Filter 3. Filter 3 is archived for analysis at a later time. Store the filter in a closed container to avoid cross-contamination from other higher activity samples based on the presence of ^{226}Ra.

Step 16. Whenever on the green path and this step has been reached, and an activity that exceeds the ADL for 500 mrem or 2 rem is determined, the laboratory staff need to assess the discrepancy between the radiochemical separation value being above the action level and the original screening value being below the action level.

Step 17. The final sample test sources are archived, as is the residual solution from the fusion of the filter.

APPENDIX III. Example of Air Particulate Filters Contaminated at Less than 2 rem (Radioanalytical Scenario 2)

The number of samples have been minimized and the screening processes have been simplified in this example. In an actual event, the number and complexity of samples will be much greater than identified here.

Description

Three weeks ago, a terrorist group detonated an RDD (using several pounds of dynamite) on the roof of an office building in an urban area. The radionuclides that were identified during the early phase of the event were ^{226}Ra, ^{137}Cs, and ^{90}Sr. The event sequence in the laboratory assumes a single analyst following the analytical process chart, under conditions of a single sample process stream.

Event Sequence

The event occurred at *1200 hours on Day 1.* Three radionuclides were identified in the first 36 hours: ^{226}Ra, ^{137}Cs, and ^{90}Sr. Recovery activities have been proceeding as expected. The current samples are from areas that have been decontaminated, and ambient air analysis is being performed to assess unrestricted use. It is now 22 days *after* the detonation, no other radionuclides have been detected, and six samples have been collected by a field team. The sampling location was 10 miles downwind of the RDD site. Samples were taken at a flow rate of 2 cfm for 6 hours, starting on *Day 21* at 1200 hours.

The samples arrive at the laboratory on *Day 22 at 1600 hours*.

Analysis Paths

Step 1, Filters and Cartridges 7, 8, and 9. The three samples are surveyed upon arrival using a micro-R or survey meter yielding the following results for alpha, beta and gamma:

Filter ID	Gross Alpha, cpm (Field)	Gross Alpha, cpm (Lab)	Gross Beta, cpm (Field)	Gross Beta, cpm (Lab)	Gross gamma, µR/h (Field)	Gross Gamma, µR/h (Lab)
7	16.9	1.4	72	14	50	36
8	16.5	1.1	70	13	50	36
9	60	11.0	306	14	53	39
Back-ground	1.5	1.1	15	8.1	50	36

Cartridge ID	Gamma spectrometry Results	Gross Gamma, µR/h
7	^{40}K	36
8	^{40}K	36
9	^{214}Pb/ ^{214}Bi, ^{40}K	38
Background	^{40}K	36

Steps 2 and 3, Filters 7, 8, and 9. Sample dose rates are measured using a survey meter[19], and the results of the measurements are used to calculate the concentrations. (Note that because the radionuclides are now known, the survey meter was calibrated using a ^{230}Th source whose energy is very similar to ^{226}Ra.)

An example of the calculation used by the laboratory for gross alpha on Filter 9 is:

$$\frac{[11.0-1.1]\ \text{cpm}}{(0.1[\text{cpm}/\text{dpm}])\times 2.22\ (\text{dpm}/\text{pCi})}\times\frac{1}{20.38\ \text{m}^3}=\ 2.2\ \text{pCi}/\text{m}^3$$

This value exceeds the 500-mrem ADL for ^{226}Ra of 0.90 pCi/m^3 (Table 7A), but does not exceed the 2-rem ADL value of 3.5 pCi/m^3. This sample stays on the green path for analysis.

The gross alpha and beta activities for Filters 7 and 8 are 0.066 and 0.000 pCi/m^3 (alpha) and 0.43 and 0.36 pCi/m^3 (beta), respectively. After comparing these results to the ADL values in Tables 7A and 7B, it is clear that analysis of Filters 7 and 8 will be resumed at Step 11 at a later time.

The iodine cartridges are analyzed by a short count using gamma spectrometry. No iodine activity is found on any of the cartridges (this would be expected based on the radionuclides found during the early phase of the incident). *It is Day 22 1630 hours.*

Step 3, Filter 9. The filter is counted on the gamma-ray spectrometer for 30 minutes to meet the u_{MR} value of 0.71×AAL (500-mrem) for the gamma emitters. The iodine cartridges are counted on their side in a calibrated geometry to meet the u_{MR} values for iodines in Table 7B. Both the filter and the cartridge for Filter 9 have measurable levels of ^{214}Pb/^{214}Bi. Although these radionuclides are not directly used in risk assessment, their elevated activities indicate the presence of ^{226}Ra.
It is Day 22 at 1800 hours.

Step 4, Filter 9. The filter is dissolved using an HF dissolution technique. The residual HF is driven off and the sample volume reduced to about 50 mL. *Digestion is completed on Day 22 at 2200 hours.*

Step 5, Filter 9. A 10-mL aliquant of the Filter 9 digestate is evaporated on a planchet for gross alpha/beta analysis by GPC. Making the appropriate correction for the fraction of total taken for analysis, the count time is 120 minutes to achieve the u_{MR} value in Table 7A. (Note: Sufficient time has elapsed since sampling to allow for the decay of all unsupported decay products.) *It is Day 23, 0100 hours.*

Step 6, Filter 9. The concentration for gross alpha is calculated from the sample activity as 2.8 pCi/m^3 and the concentration is greater than the 500-mrem ADL for ^{226}Ra (from Table 7A). This value supersedes the previous gross alpha measurement made directly on the filter. The gamma spectrometry result from Step 3 on Filter 9 has a ^{137}Cs peak and the concentration calculated from

[19] The efficiency of detection for the laboratory hand-held instruments used in this example are 0.1 for gross alpha and 0.3 for gross beta.

that peak area is 100 pCi/m^3 This sample analysis remains on the green path due to the alpha activity exceeding the 500-mrem PAG value.

Steps 7, 8, and 9, Filter 9. Based on the historical assessment of the incident, the analyses for the three radionuclides already identified (^{226}Ra, ^{137}Cs, and ^{90}Sr) would be the priority. Aliquants of the final solution from the digestion are taken for analysis of the other listed beta emitters and transuranic elements (the other gamma emitters would have been determined when the ^{137}Cs was determined in Step 3). The remaining solution is to be archived for any additional analyses that may be required. Aliquanting is completed and priority analyses are started. Other analyses are started when the priority analyses are completed. *It is Day 23, 0130 hours*.

Step 10, Filter 9. The values for the radionuclides identified from the incident are ^{226}Ra (1.8 pCi/m^3), ^{137}Cs (100 pCi/m^3) and ^{90}Sr (2.0×10^{-3} pCi/m^3). The result for ^{226}Ra is above the 500-mrem ADL (Table 7C) while the values for ^{137}Cs and ^{90}Sr are less than the 500-mrem ADL(Table 7D). The results compare favorably with the original laboratory gross activity measurements; however, the 2-rem AAL may have been exceeded. Whenever an individual ADL is exceeded, or the sum of the fractions exceeds 1.0 at any decision level, the same criteria should be evaluated at the next higher action level to determine whether the radionuclide-specific data was exceeded. This is particularly important for the sum of the fractions. In cases where the next highest action level has been exceeded, the IC should be notified immediately.

The sum of the fractions (based on the 2-rem AAL values in Tables 7C and 7D) is:

$$\text{Sum} = (1.8/7.0) + (100 / 1.7\times10^{3}) + (2.0\times10^{-3}/4.2\times10^{2})$$
$$= 0.26 + 0.059 + 4.8\times10^{-6} = 0.32$$

The sum of the fractions does not exceed the 2-rem AAL. The IC is notified of the final results. *The analyses are completed on Day 23, 0430 hours.*

Step 11, Filters 7 and 8. These analyses were started about 10 hours after the samples were initially screened by laboratory personnel. Each filter is analyzed using GPC for 4 hours. The iodine cartridges are counted for four hours by gamma spectrometry. All u_{MR} values are achieved using these count times. *It is Day 23, 0630 hours.*

Step 12, Filters 7 and 8. The individual activity values are given below, and these do not exceed the gross alpha, gross beta, or iodine 500-mrem ADL values. *It is Day 23, 0700 hours.*

Filter	Gross Alpha	Gross Beta	Iodine Cartridges
7	0.077	0.50	No iodine isotopes above the critical level
8	0.052	0.33	No iodine isotopes above the critical level

Step 13, Filters 7 and 8. Based on the low gross gamma screening value for Filters 7 and 8, a 4-hour gamma spectrometry analysis is performed. Cs-137 is identified in Filter 7 at 0.55 pCi/m^3; but no activity other than that expected from background naturally occurring radioactive materials (NORM) is found in Filter 8. *It is Day 23 1100 hours.*

Step 13b, Filters from Scenario 1. No filters have been carried over from the earlier part of this event (Scenario 1 for this event). Step 17 is not necessary.

Step 14, Filters 7 and 8. Filters 7 and 8 are dissolved using an HF dissolution technique. The residual HF is driven off and the sample volume reduced to about 50 mL. *It is Day 23 1530 hours.*

Steps 15 and 16, Filters 7 and 8. Based on the historical identification of radionuclides from this incident, analyses for ^{226}Ra and ^{90}Sr (^{137}Cs has already been determined) begin first. Aliquants of the final solution from the digestion are taken for alpha and beta emitters. The remaining solution is to be archived for any additional analyses that may be required.

Step 17, Filters from Scenario 1. None.

Step 18, Filters 7 and 8. The values for the radionuclides identified from the incident are:

- Filter 7: ^{137}Cs (0.55 pCi/m^3), ^{226}Ra (0.0051 pCi/m^3), and ^{90}Sr less than its critical level[20] (actual value is 1.6×10^{-3} pCi/m^3) [proceed at Step 9].
- Filter 8: All values are less than their respective critical levels [proceed at Step 19].

All radionuclides on both filters are below their 10^{-4} risk ADL values. Filter 7 ^{226}Ra is above the 10^{-6} risk ADL value (0.0031 pCi/m^3) . The sum of the fractions for the 10^{-4} risk factor (note that the AAL values taken from Tables 8A and 8B are used to calculate the sum of the fractions and *not* the ADL values) is:

$$\begin{aligned} \text{Sum} &= (0.55/\ 110) + (0.0051/0.44) + (1.6\times10^{-3}/29) \\ &= 0.0050 + 0.1159 + 0.000055 = 0.13 \end{aligned}$$

Filter 7 follows the flow at Step 9. Filter 8 is evaluated at Step 18 at some time in the future. *It is Day 24, 0230 hours.*

Step 9, Filter 7. The analyst has checked that all analyses have been completed and the results have been compared to their respective 10^{-4} ADL values. (Sum of the fractions at 10^{-6} risk level does not need to be verified because ^{226}Ra already exceeds the 10^{-6} risk.)

Step 10, Filter 7. Only ^{137}Cs and ^{226}Ra have been identified in this sample. The result compares favorably with the original laboratory gross activity measurement, and is between the 10^{-4} and 10^{-6} risk AAL. However, the gross alpha and beta results do not compare favorably with the final sum of the radionuclide activities determined, and the sum of the fractions does not exceed the 10^{-4} risk AAL. The gross alpha measurement at Step 5 was 0.097 pCi/m^3 and the final result was 0.0051 pCi/m^3. The radionuclide results are within the range of 0.5 to 2 times the gross alpha count measurement, but just barely. The data reviewer decides to investigate (Step 21).

Step 21, Filter 7. The data are reviewed by the data validator who notices that the gross alpha counts on the digestate from Step 5 are so close to background that the gross result is significantly affected by the background count rate. Even though the final result is much lower than the screen, it would be difficult in this sample to distinguish between real radium counts and background counts. It is

[20] See Appendix VI for a discussion of critical level.

decided that this discrepancy is within the bounds of the analysis uncertainty at this level, and it will be reported in the comments section of the final report. Go to Step 22.

Step 19, Filter 8. Filter 8 is below the 10^{-6} risk factor ADLs for the radionuclides determined. Go to Step 20.

Step 20, Filter 8. The radionuclide-specific results are consistent with the gross analyses.

Step 21, Filter 8. As all results corresponded to the initial laboratory gross screening, no further action is needed.

Step 22, Filters 7, 8, and 9. Results for Filter 9 are reported immediately after ascertaining that ^{226}Ra and ^{137}Cs are above the 500-mrem ADLs, and thus above the AAL (see Step 10 Filter 9). The discrepancy between the gross alpha and sum of alpha emitters is noted. Results for Filters 7 and 8 are reported about 24 hours later. For Filter 7, the 10^{-6} risk AAL for ^{226}Ra has been exceeded. For Filter 8 all radionuclide concentrations analyzed for are less than the 10^{-6} risk AAL values. *It is Day 24 at 0400 hours.*

Step 23, All final sample test sources. The final sample test sources and any residual solution from the sample dissolution should be archived in case additional analyses are required.

APPENDIX IV. Example of Air Particulate Filters With Known Radiological Contaminants (Radioanalytical Scenario 3)

The number of samples have been minimized and the screening processes have been simplified in this example. In an actual event, the number and complexity of samples will be much greater than identified here.

Description

Air samples have been taken in the vicinity of an event in which a radioactive aerosol is suspected to have been sprayed from an airplane. Initial field readings show indications of alpha activity although no definite identification of radionuclides has been made. The sequence of events in the laboratory assumes a single analyst following the analytical process chart, under conditions of a single sample process stream.

Event Sequence

The incident response team has established a field office for coordinating the response efforts, including a laboratory project manager who reports to the Incident Commander (IC). At *1200 hours of Day 1*, the incident response team sends three air particulate samples and three iodine cartridge samples to the laboratory. These samples are from areas they believe to have the highest concentrations of airborne particulate radionuclides based on the field measurements of these samples. These first samples arrive at the laboratory 6 hours later. While the first samples are en route to the laboratory, the field sampling personnel are taking new samples.

Analysis Paths

When the laboratory receives the first set of samples, they begin by using the Scenario 1 flowchart. By *Day 2 1500 hours*, results of radiochemical analyses indicate that ^{241}Am is present together with a lower amount of ^{238}Pu. The samples have no detectable gamma emitters or radioiodines.

The laboratory calibrates its survey and GPC instruments with ^{241}Am knowing that this is the primary radionuclide. When the second batch of samples arrive at the laboratory, the chain-of-custody form shows that the samples were taken at a flow rate of 20 cfm for 24 hours, for a total of 815 m^3. The laboratory now knows that it will be using the Scenario 3 analytical flow on the next group of samples. The second batch arrived at the laboratory on *Day 2 at 1900 hours*.

A survey meter with a thin window alpha probe calibrated using ^{241}Am for gross alpha measurements is used to make the measurements on the filters noted in the tables below. Also noted are the lab measurements made when they arrived at the laboratory with similar instrumentation. The IC has decided to establish the extent of the spread of the radioactive contamination and wants the lowest activity samples analyzed first to the 5×10^{-6} risk AAL values.

> NOTE: The values for the 1×10^{-6} risk values in Tables 8A and 8B must be multiplied by 5 to generate values for 5×10^{-6} risk ADL.

The IC also has been given evidence to support the presence of ^{238}Pu as well as ^{241}Am, but at lower concentrations than the ^{241}Am. The IC therefore wants ^{238}Pu analysis performed as the laboratory's

second priority. The ADL values for ^{241}Am and ^{238}Pu are 1.2×10^{-2} and 8.5×10^{-3}, respectively. Although the tables for 1×10^{-6} risk are based on radionuclide-specific methods, in this instance they are used for screening purposes to help prioritize these samples, because an unknown component (^{238}Pu) may be present.

Filter ID	Gross Alpha, cpm (Field)	Gross Alpha, cpm (Lab)	Gross Beta, cpm (Field)	Gross Beta, cpm (Lab)
A	682	610	1530	420
B	710	700	1510	415
C	715	720	1485	495
Background air filter sample*	680	600	1505	420

*This represents the routine ambient sample count rate from samples taken at this location prior to this event with similar delivery times to the laboratory.

Step 1. All Filters. The α path is chosen because the principal radionuclides specified by the IC for analysis are both alpha emitters (although ^{241}Am is a gamma emitter, gamma spectrometry would require very long count times at the concentrations expected in the samples).

Step 2α. All Filters. Samples are to be screened using GPC analysis where the instrument is calibrated with ^{241}Am. It is *Day 2 1930 hours.*

Step 3α. All Filters. The laboratory analysis using GPC has determined that the sample with the lowest activity is A. The B and C filters will be processed subsequent to the analysis of filter A. *Day 3 0330 hours*

Step 4α_1. Filter A. Filter A is digested and then americium-specific separations are performed. The value determined for ^{241}Am based on alpha spectrometry is 5.5×10^{-5} pCi/m^3. It is *Day 3 0530 hours.*

Step 5α. Filter A. The same aliquant of the digestate from the filter is used for determination of plutonium by sequential separation steps when the ^{241}Am was performed. Analysis for ^{238}Pu is performed using alpha spectrometry. The value determined is 1.2×10^{-5} pCi/m^3. It is *Day 3 0700 hours.*

Step 6α. Filter A. The scaled ADL values for ^{241}Am and ^{238}Pu at the 5×10^{-6} risk ADL based on Table 8A are 1.2×10^{-2} and 8.5×10^{-3} pCi/m^3, respectively. The scaled u_{MR} values are 2.1×10^{-3} and 1.5×10^{-3} pCi/m^3, respectively. (The 1×10^{-6} risk ADL values are multiplied by 5 to get the 5×10^{-6} risk ADL values.)

Step 7. Filter A. Both values are less than their respective ADL values *(at 5×10^{-6} risk)* and the final concentrations agree with the initial gross alpha activity measurements (i.e., such a low activity would not be detected at count rates higher than the background using screening equipment).

Step 8. Filter A. The sum of the fractions for ^{241}Am and ^{238}Pu (based on 10^{-4} AAL values from Table 8A divided by 20) are:

Sum $= (5.5\times10^{-5} / 1.6\times10^{-2}) + (1.2\times10^{-5} / 1.2\times10^{-2})$

= 0.0034 + 0.001
= 0.0044

This is less than 1.0.

Step 9. Filter A. Results are reported to the IC. Final analysis of Filters B and C is performed at the direction of the IC. It is *Day 3 0830 hours.*

APPENDIX V. Representative Analytical Processing Times

The vertical position of the milestones depicted in the following three figures correspond to the elapsed time on the timelines to the right or left. The timelines are approximate and assume the use of rapid analytical separation methods (versus traditional methods) for environmental levels of the analytes represented in this document.

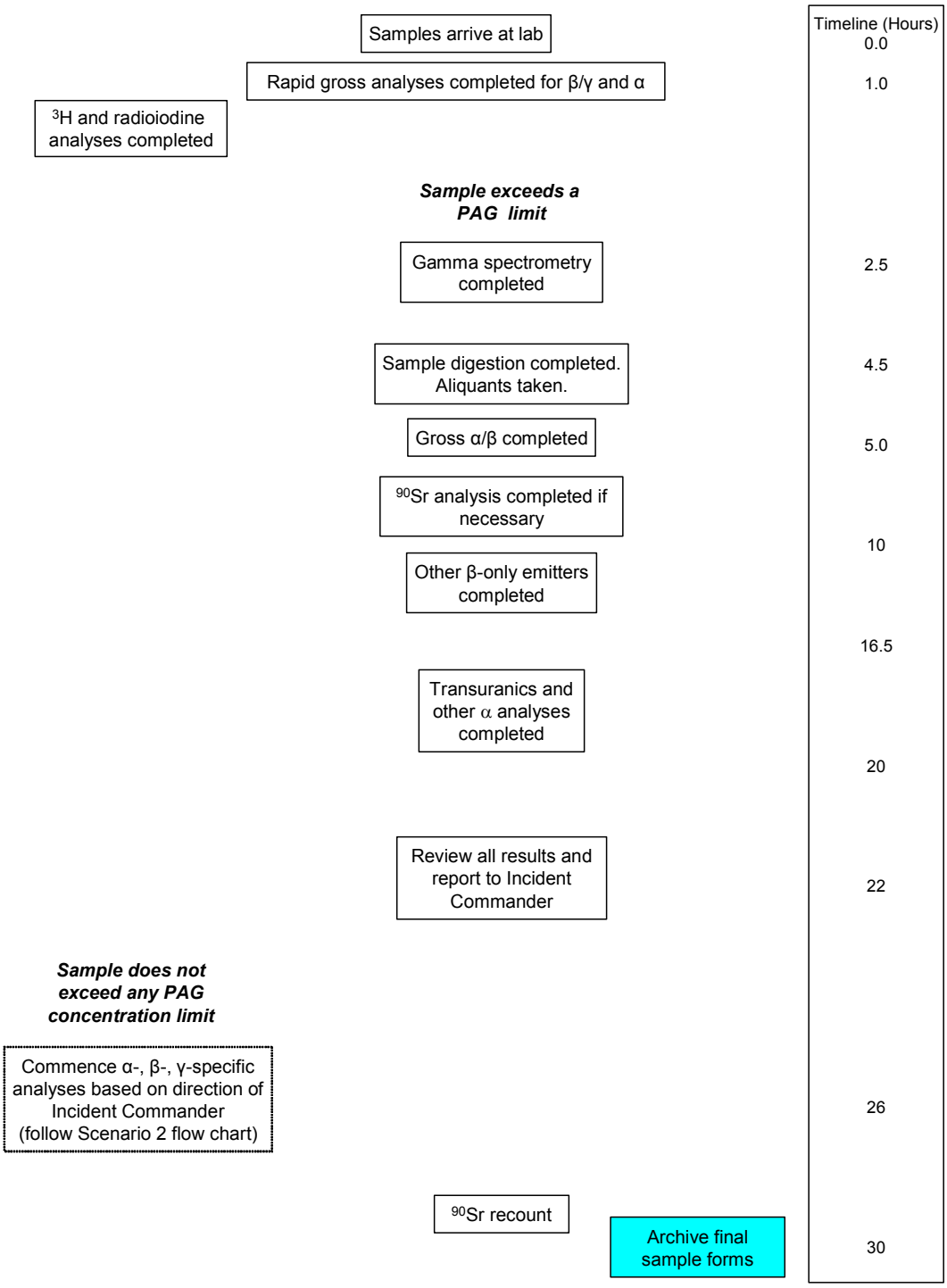
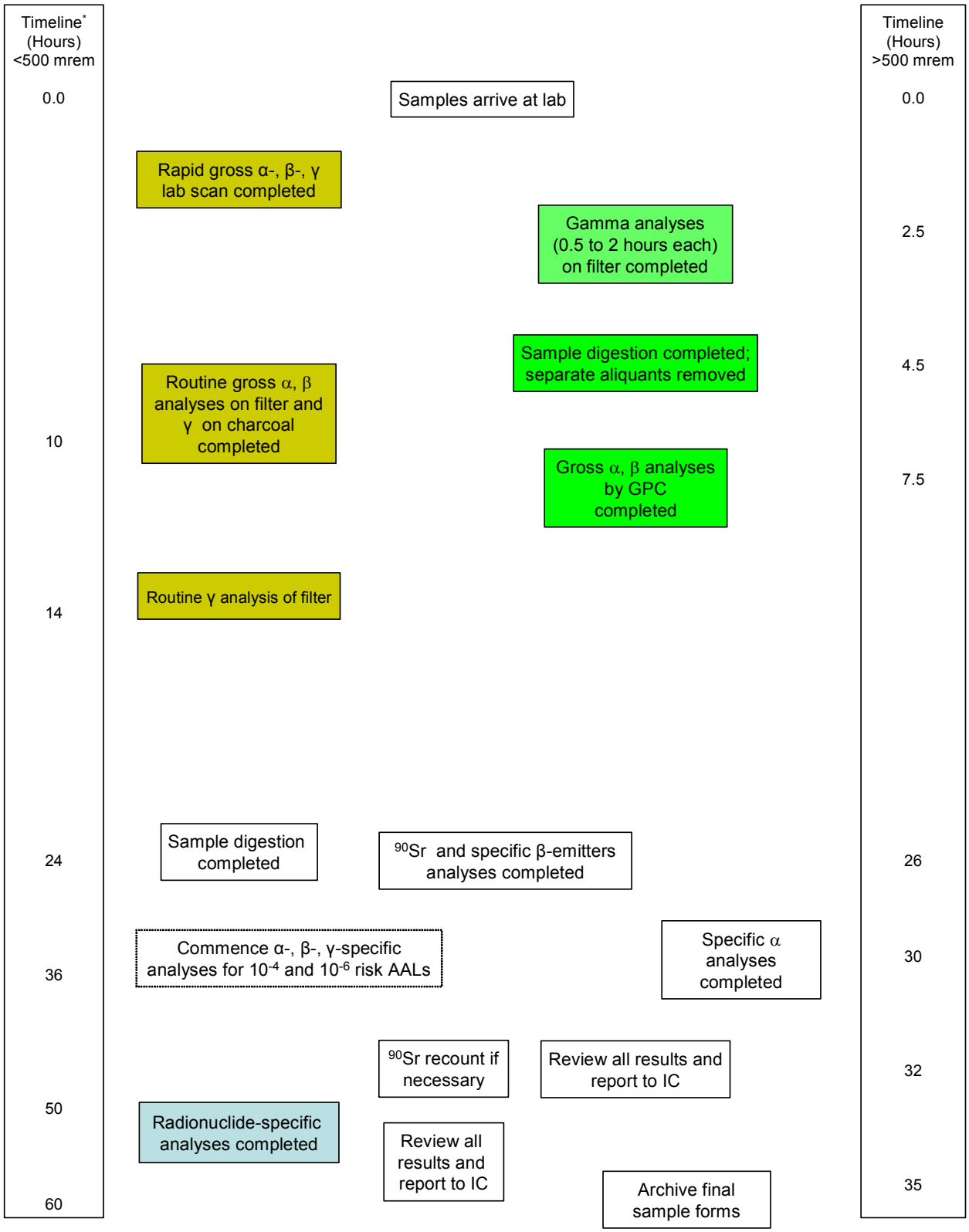


Figure 5 – Approximate Timeframe for Radiochemical Analyses (Radioanalytical Scenario 1)



*The <500-mrem timeline assumes that high priority samples are GPC-counted after digestion before any lower-priority samples.

Figure 6 – Approximate Timeframe for Radiochemical Analyses (Radioanalytical Scenario 2)

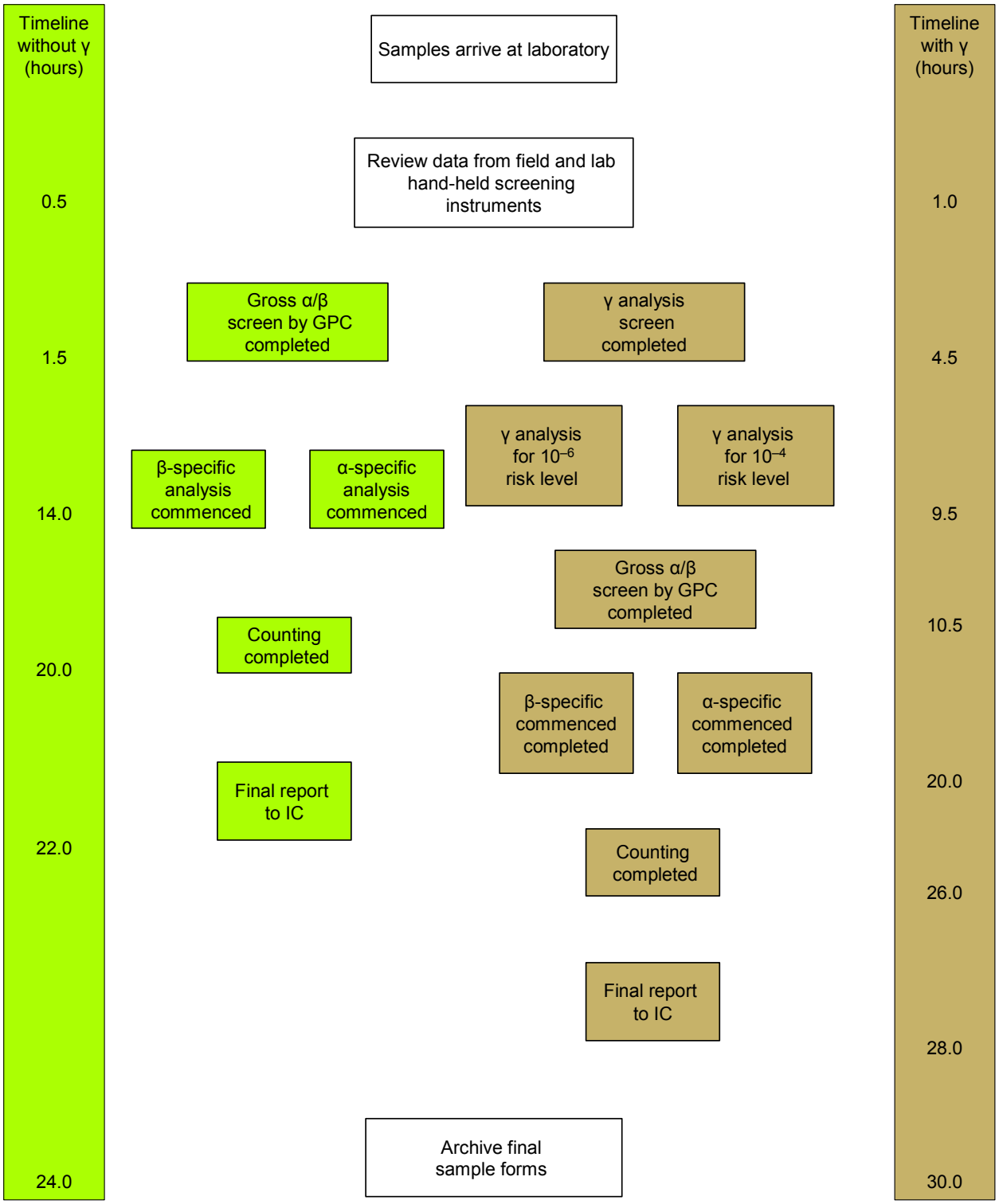


Figure 7 – Approximate Timeframe for Radiochemical Analyses (Radioanalytical Scenario 3)

TABLE 9 – Air Monitoring: Air Filter Counting Times for Various PAGs and Sampling Rates and Durations

PAG/ RISK	Flow Rate (cfm)	Sampling Duration	Volume Collected (m^3)	Counting Instrument	Alpha Screening Counting Time (Minutes) for Detectability†‡	Beta Screening Counting Time (Minutes) for Detectability†
2 rem/y	40	1 h	68	GPC*	~1	<<<1
	40	5 m	5.7	GPC	~20	<<<1
	2	10 h	34	GPC	~2	<<<1
	2	1 h	3.4	GPC	<30	<<<1
	2	10 m	0.57	GPC	~300	<<1
500 mrem/y	40	24 h	1631	GPC	<1	<<<1
	40	1 h	68	GPC	~4	<<<1
	2	1 h	3.4	GPC	<200	<<<1
	2	8 h	27	GPC	<10	<<1
10^{-4} Risk	40	24 h	1631	GPC	<1	<<<1
	40	8 h	544	GPC	<1	<<<1
	2	24 h	82	GPC	~2	<<<1
	2	7 d	571	GPC	<1	<<<1
10^{-6} Risk	40	24 h	1631	GPC/GPC	~10	<<<1
	40	7 d	11,420	GPC/GPC	~2	<<<1
	40	24 h	1631	α AS**/GPC	~10	<<<1
	2	24 h	82	α AS**/GPC	~120	<<1
	2	7 d	571	GPC/GPC	~40	<<1
	2	7 d	571	α AS**/GPC	~20	<<1

† Counting time to have net count rate equal to 3 times the net count rate uncertainty.

‡ Counting times presented for ^{239}Pu. Counting times for the other alpha-emitting nuclides of interest are similar or shorter except for ^{228}Th and ^{210}Po which are much longer.

* gas proportional counter: Alpha detection efficiency/background—10% / 0.05 cpm; beta detection efficiency/ background—30% / 1 cpm.

** Alpha spectrometry counting after radiochemistry processing assuming 100% yield; detector efficiency background—22% / 0.005 cpm.

- To calculate counting times to reach a relative 10% net count rate uncertainty, multiple the counting times in the table by 11.
- The "~" symbol is used for count times because the efficiency will vary slightly from detector to detector. The "<" symbol indicates that the count times are less than the stated value regardless of the efficiency.

APPENDIX VI. Establishing DQOs and MQOs for Incident Response Analysis

Three distinct radioanalytical scenarios are presented for air particulate filters potentially contaminated with radionuclides. The first two assume that the mixture of radionuclides in the sample is unknown. The third situation, a shortened version of the first two, assumes that the radioactive contaminants are known. In each scenario there is special emphasis on the implementation of the decision trees presented within that scenario for prioritizing sample processing by the laboratory. This emphasis on the decision trees is to support timely decision making by the IC regarding actions to protect human health for the first two cases, and in the third case, to expedite analysis so that areas suitable for reoccupation may be identified. Specific MQOs associated with the flow diagrams in Figures 2, 3, and 4 are given in Tables 11, 12, and 13.

This appendix covers single-sample screening measurement decisions by the laboratory. The IC may need to make decisions based on the final radionuclide-specific concentrations based on the mean of the set of samples taken from an area. Measurement quality objectives (MQOs) would need to be developed separately for this case. The required method uncertainty (u_{MR}) should be smaller in this case compared to the laboratory's screening decisions, perhaps by a factor of three (see MARLAP Appendix C).

The flowcharts depicted in this document contain decision points. There are three basic symbols on these flowcharts: rectangles, which represent activities or tasks; decision point diamonds, which represent decision points; and arrows, which represent flow of control. In these flow diagrams, there are many diamond-shaped decision points. Most often they are of the form shown in Figure 8. This is the general form of a theoretical decision rule as discussed in Step 5 of the data quality objectives (DQO) process. The parameter of interest usually is the "measurand" of the radiochemical analysis being performed (e.g., concentration of a radionuclide, total activity, etc.). The AALs will have been set according to criteria involving the appropriate PAGs. The arrows specify the alternative actions to be taken.

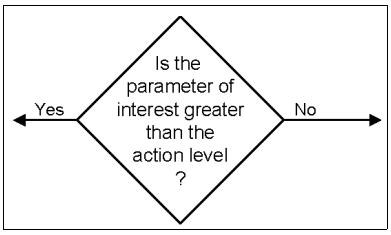


FIGURE 8 – A Decision Point in a Flowchart

The DQO process may be applied to all programs involving the collection of environmental data with objectives that cover decision making activities. When the goal of the study is to support decision - making, the DQO process applies systematic planning and statistical hypothesis testing methodology to decide between alternatives. Data quality objectives can be developed using the Guidance in EPA (2006) *Guidance on Systematic Planning Using the Data Quality Objectives Process (EPA QA/G-4)*. The DQO process is summarized in Figure 9.

Table 10A summarizes the DQO process. From this, MQOs can be established using the guidance in MARLAP. The information in this table should be sufficient to enable the decision maker and laboratory to determine the appropriate MQOs. The output should include an AAL, discrimination limit, gray region, null hypothesis, analytical decision level (ADL, referred to in MARLAP as "critical level"), and required method uncertainty at the AAL. A table summarizing DQO process for each decision point diamond can be prepared in advance and summarized as shown in Tables 11A and 11B.

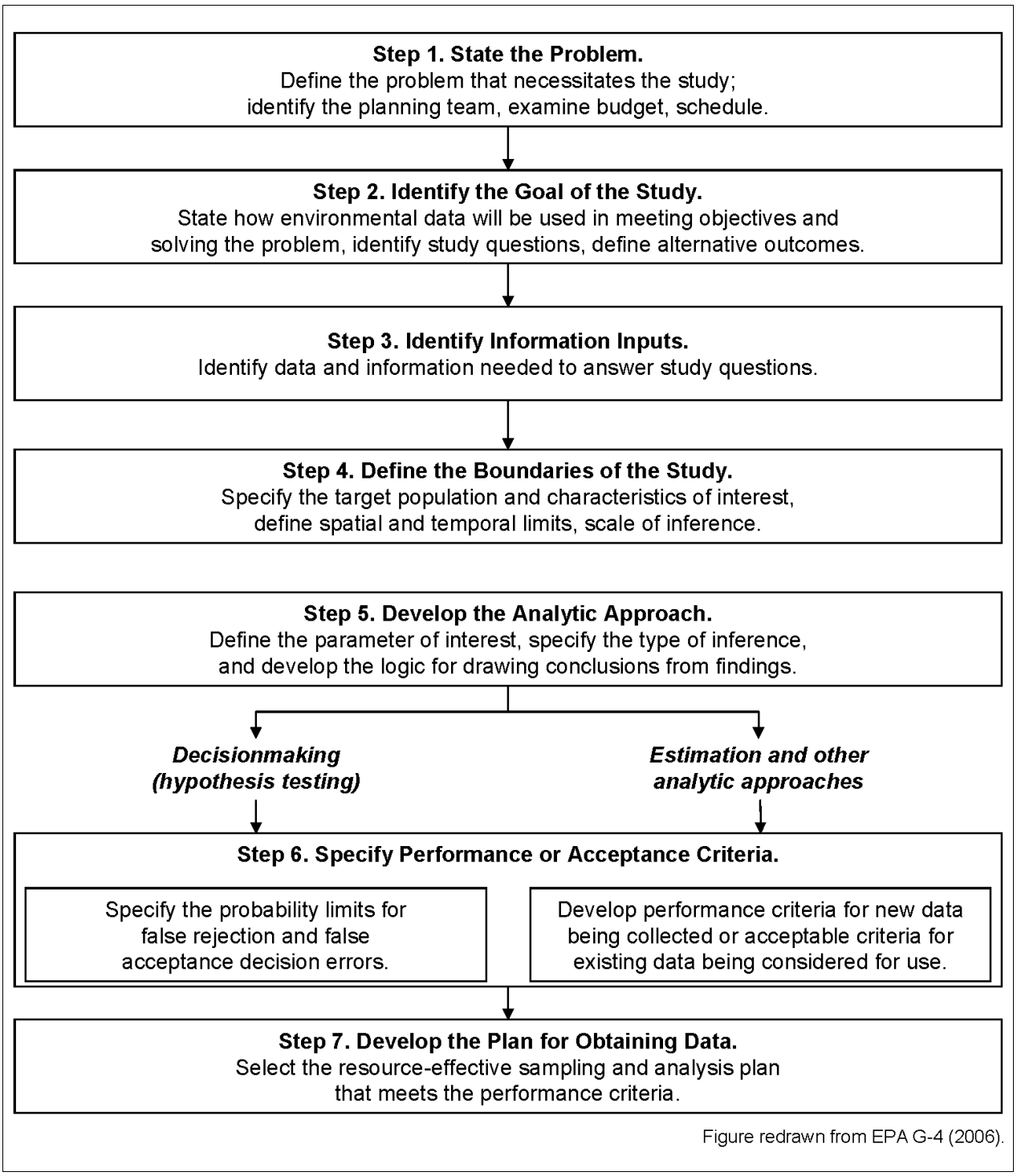


Figure 9 – The Data Quality Objectives Process

TABLE 10A – The DQO Process Applied to a Decision Point

STEP	OUTPUT
Step 1. Define the problem	… with a preliminary determination of the type of data needed and how it will be used; identify decision maker.
Step 2. Identify the decision	…among alternative outcomes or actions, and a list of decision statements that address the problem.
Step 3. Identify information needed for the decision	Analytical action levels that will resolve the decision and potential sources for these; information on the number of variables that will need to be collected; the type of information needed to meet performance or acceptance criteria; information on the performance of appropriate sampling and analysis methods.
Step 4. Define the boundaries of the study	Definition of the target population with detailed descriptions of geographic limits (spatial boundaries); detailed descriptions of what constitutes a sampling unit timeframe appropriate for collecting data and making the decision or estimate, together with any practical constraints that may interfere with data collection; and the appropriate scale for decision making or estimation.
Step 5. Develop a decision rule ***This defines the decision point diamond.***	Identification of the population parameters most relevant for making inferences and conclusions on the target population; for decision problems, the "if..., then...else..." theoretical decision rule based upon a chosen AAL.

The theoretical decision rule specified in Step 5 can be transformed into statistical hypothesis tests that are applied to the data. Due to the inherent uncertainty with measurement data, there is some likelihood that the outcome of statistical hypothesis tests will lead to an erroneous conclusion, i.e., a decision error. This is illustrated in Table 10B.

TABLE 10B – Possible Decision Errors

	True Value of the parameter of interest	
Decision Made	**Greater than the action level**	**Less than the action level**
Decide that the parameter of interest is greater than the action level	Correct decision	*Decision Error*
Decide that the parameter of interest is less than the action level	*Decision Error*	Correct decision

In order to choose an appropriate null hypothesis (or baseline condition), consider which decision error should be more protected against. Choose the null hypothesis which if falsely rejected would cause the greatest harm. Then the data will need to be convincingly inconsistent with the null hypothesis before it will be rejected, and the probability of this happening (a Type I error) is more easily controlled during the statistical design.

Failing to detect a sample that exceeds the AAL could have consequences to public health. But screening additional samples will slow the overall process and therefore also may impact the public health. The probability that such decision errors occur is defined as the parameters α and β in Steps 6.1 and 6.2 in Table 10C. Values of alpha and beta should be set based on the consequences of

making an incorrect decision. How these are balanced will depend on the AAL, sample loads, and other factors as specified by the IC.

The most commonly used values of alpha and beta are 5%, although this is by tradition and has no sound technical basis. These values may be used as a default, but should be optimized in Step 7 of the DQO process according to the actual risk of the decision error being considered.

TABLE 10C – The DQO Process Applied to a Decision Point

STEP	OUTPUT
Step 6. Specify limits on decision errors	

Step 6.1 Determine analytical action level (AAL) on the gray region boundary and set baseline condition (null hypothesis, H_0)	Which is considered the worse: decision error (a) deciding that the parameter of interest is less than the AAL when it actually is greater, or (b) deciding that the parameter of interest is greater than the AAL when it actually is less? Case (a) is usually considered to be a conservative choice by regulatory authorities, but this may not be appropriate in every case.
	
	If (a), the AAL defines the upper boundary of the gray region. The null hypothesis is that the sample concentration is above the AAL. (All samples will be assumed to be above the AAL unless the data are convincingly lower.) A desired limit will be set on the probability (α) of incorrectly deciding the sample is below the AAL when the sample concentration is actually equal to the AAL.
	
	If (b), the AAL defines the lower boundary of the gray region. The null hypothesis is that the sample concentration is below the AAL. (All samples will be assumed to be below the AAL unless the data are convincingly higher.) A desired limit will be set on the probability (α) of incorrectly deciding the sample is above the AAL when the sample concentration is actually equal to the AAL.

6.2 Define the discrimination limit (DL)	If (a), the discrimination limit defines the lower boundary of the gray region.[1] It will be a concentration below the AAL where the desired limit will be set on the probability (β) of incorrectly deciding the sample is above the AAL.
	
	If (b), the discrimination limit defines the upper boundary of the gray region.[2] It will be a concentration above the AAL where the desired limit will be set on the probability (β) of incorrectly deciding the sample is below the AAL.

6.3 Define the required method uncertainty at the AAL	According to MARLAP Appendix C, under either case (a) or case (b) above, the recommended required method uncertainty is: $$u_{MR} \le \frac{UBGR - LBGR}{z_{1-\alpha} + z_{1-\beta}} = \frac{\Delta}{z_{1-\alpha} + z_{1-\beta}}$$ where $z_{1-\alpha}$ and $z_{1-\beta}$ are the $1-\alpha$ and $1-\beta$ quantiles of the standard normal distribution function.
Step 7. Optimize the design for obtaining data	Iterate Steps 1–6 to define optimal values for each of the parameters and the measurement method required.

NOTES:

[1] The DL is the point where it is important to be able to distinguish expected signal from the AAL. When one expects background activity, then it might be zero. If one expects activity near the AAL, however, it might be at 90% of the AAL.

[2] The DL is the point where it is important to be able to distinguish expected signal from the AAL. If the AAL is near zero, the DL would define a concentration deemed to be too high to be undetected. Thus, the DL may be set equal to the MDC. If one expects activity near the AAL, however, it might be at 110% of the AAL.

Figures 10 and 11 illustrate the concepts above for case (a) and case (b) respectively.

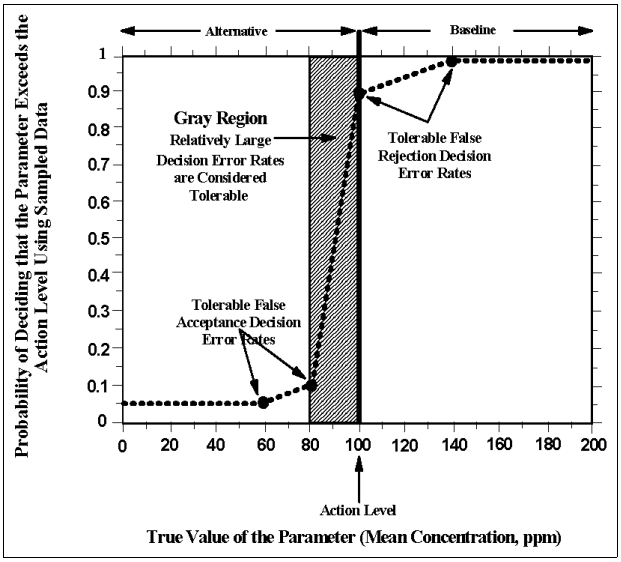


Figure 10 – Example Illustrating Case (a). Baseline Condition (null hypothesis): Parameter Exceeds the Analytical Action Level

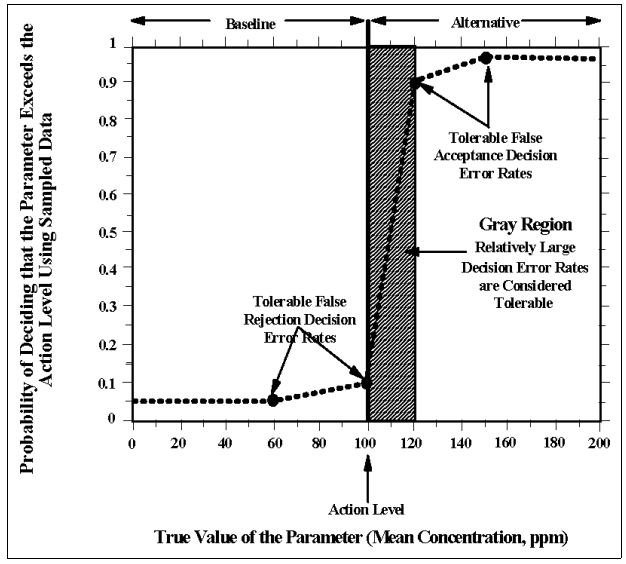


Figure 11 – Example Illustrating Case (b). Baseline Condition (null hypothesis): Parameter Does Not Exceed the Analytical Action Level

Figures taken from EPA G-4 (2006)

In Figure 10, the AAL = 100, the DL = 80, $\Delta = 100 - 80 = 20$ $\alpha = \beta = 0.1$ and

$$u_{MR} \le \frac{\Delta}{z_{1-\alpha} + z_{1-\beta}} = \frac{20}{1.282 + 1.282} = 7.8.$$

In Figure 11, the AAL = 100, the DL = 120, $\Delta = 120\text{-}100 = 20$ $\alpha = \beta = 0.1$ and

$$u_{MR} \le \frac{\Delta}{z_{1-\alpha} + z_{1-\beta}} = \frac{20}{1.282 + 1.282} = 7.8.$$

Table 10D – Values of $z_{1-\alpha}$ (or $z_{1-\beta}$) for Some Commonly Used Values of α (or β)

α or β	$z_{1-\alpha}$ (or $z_{1-\beta}$)
0.001	3.090
0.01	2.326
0.025	1.960
0.05	1.645
0.10	1.282
0.20	0.842
0.30	0.524
0.50	0.000

The concentration that indicates the division between values leading to rejecting the null hypothesis and those that do not is termed the "critical level." Possible values of the concentration can be divided into two regions, the acceptance region and the rejection region. If the value of the concentration comes out to be in the acceptance region, the null hypothesis being tested is not rejected. If the concentration falls in the rejection region, the null hypothesis is rejected. The set of values of a statistic that will lead to the rejection of the null hypothesis tested is called the critical region. Critical region is a synonym for rejection region.

In the context of analyte detection, the *critical value* (see MARLAP Attachment 3B.2[21]) is the minimum measured value (e.g., of the instrument signal or the *analyte* concentration) required to give confidence that a positive (nonzero) amount of *analyte* is present in the material being analyzed. The critical value is sometimes called the *critical level*.

In case (a), the critical value will be UBGR – $z_{1-\alpha}\, u_{\mathrm{M}}$, where u_{M} is its combined standard uncertainty of the measurement result, x. Only measurement results less than the critical value will result in rejecting the null hypothesis that the true concentration is greater than the AAL. This process can be completed for each diamond in each flowchart to fill in Tables 11A, 11B, 12A, 12B, and 13. In these tables, values have been rounded to 2 or 3 significant figures.

In case (b), the critical value will be LBGR + $z_{1-\alpha}\, u_{\mathrm{M}}$, where u_{M} is its combined standard uncertainty of the measurement result, x. Only measurement results greater than the critical value will result in rejecting the null hypothesis that the true concentration is less than the AAL.

In the following tables, MQOs were determined for screening using a discrimination level of zero and Type I and Type II error rates of $\alpha = \beta = 0.05$. These are the MQOs usually associated with developing MDCs and result in a relative method uncertainty of 30% at the AAL, and an ADL value of 0.5 times the AAL.

For radionuclide-specific measurements the requirements are more stringent, using a discrimination level of one-half the AAL and Type I and Type II error rates of $\alpha = 0.01$ with $\beta = 0.05$. This results in a relative required method uncertainty of 13% at the AAL and an ADL value of 0.71 times the AAL.

Note that gamma spectrometric measurements using an HPGe are always radionuclide-specific, and therefore have the more stringent MQOs

[21] In this appendix, we use the term *critical value* to be consistent with MARLAP terminology. It should be noted that the *critical value* in the context of this document refers to the ADL value.

TABLE 11A – DQOs and MQOs for Radioanalytical Scenario 1. Laboratory Prioritization Decisions Based on Screening (Gross α, β, or γ Measurements), Tritium and Iodines[1]

Measurement Rectangle	Decision Point Diamond	Type of Analysis, α, β, or γ	Analytical AL (pCi/m^3)	Null Hypothesis H_0 Choose > AAL or <AAL i.e., case (a) or case (b)	DL DL < AAL in case (a) and DL > AAL in case (b)	Δ = UBGR-LBGR	Type I error rate α	Type II error rate β	u_{MR}	φ_{MR}	Analytical Decision Level (Critical Level) (pCi/L)	Source of AAL
1	1a	α	0.7	a	0	0.7	0.05	0.05	0.21	0.30	0.35	2-rem α screening AAL
1	1a	β/γ	420	a	0	420	0.05	0.05	130	0.30	210	2-rem β screening AAL
1b	3b	^{3}H	2.6×10^{5}	a	0	2.6×10^{5}	0.05	0.05	7.8×10^{4}	0.30	1.3×10^{5}	2-rem ^{3}H AAL
1c	3b	^{125}I	1.3×10^{4}	a	0	1.3×10^{4}	0.05	0.05	3.9×10^{3}	0.30	6.5×10^{3}	2-rem ^{125}I AAL
1c	3b	^{129}I	1.9×10^{3}	a	0	1.9×10^{3}	0.05	0.05	570	0.30	950	2-rem ^{129}I AAL
1c	3b	^{131}I	9.1×10^{3}	a	0	9.1×10^{3}	0.05	0.05	2.7×10^{3}	0.30	4.6×10^{3}	2-rem ^{131}I AAL
2	3a	α	0.7	a	0	0.7	0.05	0.05	0.21	0.30	0.35	2-rem α screening AAL
2	3a	β/γ	420	a	0	420	0.05	0.05	130	0.30	210	2-rem β screening AAL
2	3a	γ	see Table 12B	a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	2-rem AAL from Table 7B
2	3a	^{125}I	1.3×10^{4}	a	0	1.3×10^{4}	0.05	0.05	3.9×10^{3}	0.30	6.5×10^{3}	2-rem ^{125}I AAL
2	3a	^{129}I	1.9×10^{3}	a	0	1.9×10^{3}	0.05	0.05	570	0.30	950	2-rem ^{129}I AAL
2	3a	^{131}I	9.1×10^{3}	a	0	9.1×10^{3}	0.05	0.05	2.7×10^{3}	0.30	4.6×10^{3}	2 rem ^{131}I AAL
	6 [2]											
13	14	γ	see Table 12B	a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	500-mrem AAL from Table 7C
13	14	α	0.17	a	0	0.17	0.05	0.05	0.051	0.30	0.085	500-mrem α screening AAL
13	14	β	110	a	0	110	0.05	0.05	33	0.30	55	500-mrem β screening AAL

Notes:

[1] Rounded to two significant figures.

[2] Mathematically computed from data obtained earlier in measurement rectangles 2 and 5.

TABLE 11B – DQOs and MQOs for Scenario 1. Values Reported to the Incident Commander Based on Radionuclide-Specific Measurements

Measurement Rectangle	Decision Point Diamond	Type of Analysis, α, β, or γ	Analytical AL (pCi/m^3)	Null Hypothesis H_0 Choose > AAL or < AAL i.e. case (a) or case (b)	DL DL < AAL in case (a) and DL > AAL in case (b)	Δ = UBGR-LBGR	Type I error rate α	Type II error rate β	u_{MR}	φ_{MR}	Analytical Decision Level (Critical Level) (pCi/L)	Source of AAL [2]
9	11	α	See Tables 11A and 11B	a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL[1]	2 rem AAL
7,8	11	β		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	2 rem AAL
10	11	γ		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	2 rem AAL
9	11	α		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	500 mrem AAL
7,8	11	β		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	500 mrem AAL
10	11	γ		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	500 mrem AAL

Notes:

[1] In case (a), the critical value is UBGR – $z_{1-\alpha}\, u_M$ = AAL – $z_{1-0.01}$ [$\Delta/(z_{1-0.01} + z_{1-0.05})$]

= AAL – 2.326 [(AAL–0.5 AAL)/(2.326 + 1.645)]

= AAL – 2.326 (0.13×AAL) ≈ 0.71 × AAL.

Specific values for the ADL are listed in Tables 7C and 7D.

[2] When following a green pathway in the flow diagram for Scenario 1, use the 500-mrem AAL MQOs. When following a red pathway in the flow diagram for Scenario 1, use the 2-rem AAL MQOs.

TABLE 12A – DQOs and MQOs for Radioanalytical Scenario 2. Laboratory Prioritization Decisions Based on Screening (Gross α, β, or γ Measurements) and ^{131}I

Measurement Rectangle	Decision Point Diamond	Type of Analysis, α, β, or γ	Analytical AL (pCi/m^3)	Null Hypothesis H_0 Choose > AAL or <AAL i.e., case (a) or case (b)	DL DL < AAL in case (a) and DL > AAL in case (b)	Δ = UBGR-LBGR	Type I error rate α	Type II error rate β	u_{MR}	φ_{MR}	Analytical Decision Level (Critical Level) (pCi/m^3)	Source of AAL
1,5	2,6	α	0.17	a	0	0.17	0.05	0.05	0.051	0.30	0.085	500-mrem α screening AAL Table 7A
1,5	2,6	β/γ	110	a	0	110	0.05	0.05	33	0.30	55	500-mrem β screening AAL Table 7B
3	6	γ	see Table 12B	a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71 ×AAL	500-mrem AAL from Table 7B
7,8,21	10 [1]											
15,16, 17	18,19, 20 [2]											
11	12	α	0.33	a	0	0.33	0.05	0.05	0.099	0.30	0.16	10^{-4} risk α screening AAL from Table 8A
11	12	β	29	a	0	29	0.05	0.05	8.7	0.30	14	10^{-4} risk β AAL from Table 8B

Notes:

All numbers rounded to two significant figures.

[1] Mathematically computed from data obtained earlier in measurement rectangles 2 and 5.

[2] Mathematically computed from data obtained earlier in measurement rectangles 2, 7, and 8.

TABLE 12B – DQOs and MQOs for Scenario 2. Values Reported to the Incident Commander Based on Radionuclide-Specific Measurements

Measurement Rectangle	Decision Point Diamond	Type of Analysis, α, β, or γ	Analytical AL (pCi/m^3)	Null Hypothesis H_0 Choose > AAL or < AAL i.e. case (a) or case (b)	DL DL < AAL in case (a) and DL > AAL in case (b)	Δ = UBGR-LBGR	Type I error rate α	Type II error rate β	u_{MR}	φ_{MR}	Analytical Decision Level (Critical Level) (pCi/m^3)	Source of AAL [2]
11	12	^{131}I	640	a	320	320	0.01	0.05	42	0.13	570	10^{-4} risk ^{131}I AAL
11	12	γ	see Table 8B	a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	10^{-4} risk AAL from Table 8B
15	18,19	α	See Tables 8A and 8B	a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL [1]	10^{-4} risk AAL
16	18,19	β		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	10^{-4} risk AAL
13, 17	18,19	γ		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	10^{-4} risk AAL
15	18,19	α		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	10^{-6} risk AAL
16	18,19	β		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	10^{-6} risk AAL
13, 17	18,19	γ		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	10^{-6} risk AAL
13, 15,16, 17	20 [3]	*These are regulatory derived values.*										

Notes:

[1] In case (a), the critical value is UBGR – $z_{1-\alpha}\, u_M$ = AAL – $z_{1-0.01}$ [$\Delta/(z_{1-0.01} + z_{1-0.05})$]

= AAL – 2.326 [(AAL–0.5 AAL)/(2.326 + 1.645)]

= AAL – 2.326 (0.13×AAL) ≈ 0.71 × AAL.

Specific values for the ADL are listed in Tables 8a and 8B.

[2] When following a green pathway in the flow diagram for Scenario 2, use the 500-mrem MQOs. When following a yellow pathway in the flow diagram for Scenario 2, use the 10^{-4} risk MQOs.

[3] Mathematically computed from data obtained earlier.

TABLE 13 – DQOs and MQOs for Scenario 3. Values Reported to the Incident Commander Based on Radionuclide-Specific Measurements.

Measurement Rectangle	Decision Point Diamond	Type of Analysis, α, β, or γ	Analytical AL (pCi/m^3)	Null Hypothesis H_0 Choose > AAL or < AAL i.e. case (a) or case (b)	DL DL < AAL in case (a) and DL > AAL in case (b)	Δ = UBGR-LBGR	Type I error rate α	Type II error rate β	u_{MR}	φ_{MR}	Analytical Decision Level (Critical Level) (pCi/m^3)	Source of AAL
2μ	3μ	α,β, γ	See Tables 8A and 8B	a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	10^{-4} risk AAL from Table 8A or8 B
2α	3α	α		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	10^{-4} risk α screening AAL from Table 8A
2β	3β	β		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	10^{-4} risk screening β AAL from Table 8B
4α	4α2	α		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL [1]	10^{-4} risk AAL
4β	4β2	β		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	10^{-4} risk AAL
4μ	4μ2	α,β, γ		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	10^{-4} risk AAL
4α	4α1	α		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	10^{-6} risk AAL
4β	4β1	β		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	10^{-6} risk AAL
4μ	4μ1	α,β, γ		a	0.5AAL	0.5AAL	0.01	0.05	0.13×AAL	0.13	0.71×AAL	10^{-6} risk AAL
5μ, 6μ	7,8 [2]											
5α, 6α	7,8 [2]											
5β, 6β	7,8 [2]											

Notes:

[1] In case (a), the critical value is UBGR – $z_{1--\alpha}\, u_{MR}$ = AAL – $z_{1-0.01}$ [Δ/($z_{1-0.01}$ + $z_{1-0.05}$)]

= AAL – 2.326 [(AAL–0.5 AAL)/(2.326 + 1.645)]

= AAL – 2.326 (0.13×AAL) ≈ 0.71 AAL.

Radionuclide-specific ADL values are listed in Table 8.

[2] Mathematically computed from data obtained earlier in measurement rectangles 4 and 5.

Estimated counting times for a filter sample on a gas proportional counter to reach an alpha detection limit and a 10% count rate uncertainty for low- and high-volume air samples at 500-mrem derived air concentrations are given in Table 16.

TABLE 14 – Estimated Counting Times for a Filter Sample Analyzed on a Gas Proportional Counter To Reach an Alpha Detection Limit and a 10% Count Rate Uncertainty for Low- and High-Volume Air Samples at 500-mrem AAL Values

Radionuclide	500-mrem AAL (pCi/m^3)	Low Volume (3.4 m^3) [1]			High Volume (1,631 m^3) [1]		
		Filter Activity (pCi)	Counting Time for Detection Limit (min) [2] [3]	Counting Time for 10% Uncertainty (min) [2]	Filter Activity (pCi)	Counting Time for Detection Limit (min) [2] [3]	Counting Time for 10% Uncertainty (min) [2]
Am-241	0.17	0.58	120	1400	280	<1	~2
Cm-242	2.8	9.5	4.5	50	4,600	<1	~1
Cm-243	0.24	0.82	77	860	390	<1	~1
Cm-244	0.29	0.99	60	670	470	<1	~1
Np-237	0.34	1.2	49	540	560	<1	~1
Po-210	3.9	13	3	35	6,400	<1	<1
Pu-238	0.15	0.51	150	1700	240	<1	~2
Pu-239	0.14	0.48	170	1800	230	<1	~2
Pu-240	0.14	0.48	170	1800	230	<1	~2
Ra-226	1.8	6.1	7 w/o DP	79 w/o DP	2,900	<1	<1
Th-228	0.42	1.4	37	420	690	<1	~1
Th-230	0.17	0.58	120	1400	280	<1	~2
Th-232	0.15	0.51	150	1700	240	<1	~2
U-234	1.8	6.1	7	79	2,900	<1	<1
U-235	2.0	6.8	6	71	3,300	<1	<1
U-238	2.1	7.1	6	67	3,400	<1	<1

Note: Values in table have been rounded.

[1] Low volume= 2 ft^3/minute for 60 minutes; total volume 3.4 m^3. High volume= 40 ft^3/minute for 24 hours; total volume 1,631 m^3.

[2] Assume the typical GPC detector efficiency and background count rate and alpha branching ratio of 1.

[3] Detection limit for this example is 3 times uncertainty = net count rate.

APPENDIX VII. Glossary

***accuracy*:** The closeness of a measured result to the true value of the quantity being measured. Various recognized authorities have given the word "accuracy" different technical definitions, expressed in terms of bias and imprecision. Following MARLAP, this document avoids all of these technical definitions and uses the term "accuracy" in its common, ordinary sense.

aerosol: A suspension of fine solid or liquid particles within a gaseous matrix (usually air).

***aliquant*:** A representative portion of a homogeneous *sample* removed for the purpose of analysis or other chemical treatment. The quantity removed is not an evenly divisible part of the whole sample. An aliquot, by contrast, is an evenly divisible part of the whole.

***analyte*:** See *target analyte*.

analytical action level (AAL): The value of a quantity that will cause the decision maker to choose one of the alternative actions. The *analytical action level* may be a derived concentration level (such as the *derived air concentration* in this document), background level, release criteria, regulatory decision limit, etc. The AAL is often associated with the type of media, *target analyte*, and concentration limit. Some AALs, such as the release criteria for license termination, are expressed in terms of dose or risk. MARLAP uses the term "action level." See *total effective dose equivalent (TEDE)* and derived air concentration (DAC).

analytical decision level (ADL): The minimum measured value for the radionuclide concentration in a sample that indicates the amount of radionuclide present is equal to or greater than the *analytical action level* at a specified *Type II error* rate (assumes that *method uncertainty* requirements have been met). Any measurement result equal to or greater than the applicable ADL is considered to have exceeded the corresponding *analytical action level*. MARLAP uses the term "*critical level*."

***background (instrument)*:** Radiation detected by an instrument when no *source* is present. The background radiation that is detected may come from radionuclides in the materials of construction of the detector, its housing, its electronics, and the building, as well as the environment and natural radiation.

***background level*:** A term that usually refers to the presence of radioactivity or radiation in the environment. From an analytical perspective, the presence of background radioactivity in samples needs to be considered when clarifying the radioanalytical aspects of the decision or study question. Many radionuclides are present in measurable quantities in the environment.

***bias (of a measurement process)*:** A persistent deviation of the mean measured result from the true or accepted reference value of the quantity being measured, which does not vary if a measurement is repeated.

***blank (analytical or method)*:** A *sample* that is assumed to be essentially free of the *target analyte* (the "unknown"), which is carried through the radiochemical preparation, analysis, mounting, and measurement process in the same manner as a routine sample of a given matrix.

***calibration*:** The set of operations that establishes, under specified conditions, the relationship between values indicated by a measuring instrument or measuring system, or values represented by a material measure, and the corresponding known value of a parameter of interest.

***calibration source*:** A prepared *source*, made from a *certified reference material*, that is used for calibrating instruments.

***certified reference material*:** A radioactive material, accompanied by an uncertainty at a stated level of confidence, with one or more values certified by a procedure that establishes its traceability to accepted standard values. A "standard reference material" is a certified reference material issued by the National Institute of Standards and Technology (NIST) in the United States. NIST certifies a standard reference material for specific chemical or physical properties and issues it with a certificate that reports the results of the characterization and indicates the intended use of the material.

***chain of custody*:** Procedures that provide the means to trace the possession and handling of a sample from collection to data reporting.

***check source*:** A material used to validate the operability of a radiation measurement device, sometimes used for instrument quality control. See *source, radioactive*.

critical level: Termed *analytical decision level* in this document in the context of evaluating sample results relative to an *analytical action level*. In the context of analyte detection, *critical level* means the minimum measured value (e.g., of the instrument signal or the radionuclide concentration) that indicates a positive (nonzero) amount of a radionuclide is present in the material within a specified probable error. The critical level is sometimes called the *critical value* or *decision level*.

***data quality objective* (*DQO*)**: Qualitative and quantitative statements that clarify the study objectives, define the most appropriate type of data to collect, determine the most appropriate conditions from which to collect the data, and specify tolerable limits on decision error rates. Because DQOs will be used to establish the quality and quantity of data needed to support decisions, they should encompass the total *uncertainty* resulting from all data collection activities, including analytical and sampling activities.

derived air concentration (DAC): The concentration of a radionuclide, in pCi/m^3, that would result in exposure to a specified dose level. Generally refers to a *protective action guide* or other specified dose- or risk-based factor expressed in equivalent radionuclide concentration and referred to in this document as an *analytical action level*. Thus, the "500-mrem AAL for ^{239}Pu" is the derived air concentration of ^{239}Pu, in pCi/m^3, that would result in an exposure of 500 mrem and would refer to the 500-mrem PAG. The DAC is radionuclide-specific

derived radionuclide concentration (DRC): General application term used in discussions involving both of the terms *derived air concentration* and *derived water concentration*.

discrimination limit (DL): The DL is the point where it is important to be able to distinguish expected signal from the *analytical action level*. The DL limit is one of the boundaries of the *gray region*.

***dose equivalent*:** Quantity that expresses all radiations on a common scale for calculating the effective absorbed dose. This quantity is the product of absorbed dose (*grays* [Gy] or rads) multiplied by a quality factor and any other modifying factors (MARSSIM, 2000). The quality factor adjusts the absorbed dose because not all types of ionizing radiation create the same effect on human tissue. For example, a dose equivalent of one *sievert* (Sv) requires 1 Gy of beta or gamma radiation, but only 0.05 Gy of alpha radiation or 0.1 Gy of neutron radiation. Because the sievert is a large unit, radiation doses often are expressed in millisieverts (mSv). See *total effective dose equivalent* and *roentgen*.

***gray (Gy)*:** The International System of Units (SI) unit for absorbed radiation dose. One gray is 1 joule of energy absorbed per kilogram of matter, equal to 100 *rad*. See *sievert*.

***gray region*:** The range of possible values in which the consequences of decision errors are relatively minor. Specifying a gray region is necessary because variability in the analyte in a population and imprecision in the measurement system combine to produce variability in the data such that the decision may be "too close to call" when the true value is very near the *analytical action level*. The *gray region* establishes the minimum distance from the *analytical action level* where it is most important to control *Type II decision errors*.

***incident of national significance (INS)*:** An actual or potential high-impact event that requires a coordinated and effective response by an appropriate combination of federal, state, local, tribal, nongovernmental, or private-sector entities in order to save lives and minimize damage, and provide the basis for long-term community recovery and mitigation activities.

***measurement quality objective* (*MQO*):** The analytical data requirements of the *data quality objectives*, which are project- or program-specific and can be quantitative or qualitative. These analytical data requirements serve as measurement performance criteria or objectives of the analytical process. MARLAP refers to these performance objectives as MQOs. Examples of quantitative MQOs include statements of required analyte detectability and the *uncertainty* of the analytical protocol at a specified radionuclide concentration, such as the *analytical action level*. Examples of qualitative MQOs include statements of the required specificity of the analytical protocol (e.g., the ability to analyze for the radionuclide of interest [or *target analyte*] given the presence of interferences).

***method uncertainty*:** The predicted *uncertainty* of the result that would be measured if the method were applied to a hypothetical laboratory *sample* with a specified analyte concentration. Although individual measurement uncertainties will vary from one measured result to another, the *required method uncertainty* is a target value for the individual measurement uncertainties and is an

estimate of uncertainty before the sample is actually measured. See also *uncertainty*, *required method uncertainty*, and *required relative method uncertainty*.

***method validation*:** The demonstration that the method selected for the analysis of a particular analyte in a given matrix is capable of providing analytical results to meet the project's *measurement quality objectives* and any other requirements in the analytical protocol specifications.

***minimum detectable concentration (MDC)*:** An estimate of the smallest true value of the analyte concentration that gives a specified high probability of detection.

***nuclide-specific analysis*:** Radiochemical analysis performed to isolate and measure a specific radionuclide.

***null hypothesis (H_0)*:** One of two mutually exclusive statements tested in a statistical *hypothesis test* (compare with alternative hypothesis). The null hypothesis is presumed to be true unless the test provides sufficient evidence to the contrary, in which case the *null hypothesis* is rejected and the alternative hypothesis (H_1) is accepted.

***performance evaluation (PE) program*:** A laboratory's participation in an internal or external program of analyzing proficiency-testing samples appropriate for the analytes and matrices under consideration (i.e., PE program traceable to a national standards body, such as NIST). Reference-material samples used to evaluate the performance of the laboratory are called performance-evaluation or proficiency-testing samples or materials. See *certified reference material*.

***precision*:** The closeness of agreement between independent test results obtained by applying the experimental procedure under stipulated conditions. Precision may be expressed as the standard deviation. Conversely, imprecision is the variation of the results in a set of replicate measurements.

protective action guide (PAG): The radiation dose to individuals in the general population that warrants protective action following a radiological event. In this document, PAGs limit the projected radiation doses for different exposure periods: not to exceed 2-rem *total effective dose equivalent (TEDE)* during the first year, 500-mrem TEDE during the second year, or 5 rem over the next 50 years (including the first and second years of the incident). See *total derived water concentration* and *analytical action level*.

***quality assurance (QA)*:** An integrated system of management activities involving planning, implementation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and expected. Quality assurance includes *quality control*.

***quality control (QC)*:** The overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the project; operational techniques and activities that are used to fulfill requirements for quality. This system of activities and checks is used to ensure that

measurement systems are maintained within prescribed limits, providing protection against out-of-control conditions and ensuring that the results are of acceptable quality.

reference material: See *certified reference material*.

***rem*:** The common unit for the effective or equivalent dose of radiation received by a living organism, equal to the actual dose (in rads) multiplied by a factor representing the danger of the radiation. Rem is an abbreviation for "roentgen equivalent man," meaning that it measures the biological effects of ionizing radiation in humans. One rem is equal to 0.01 Sv. See *sievert* and *dose equivalent*.

***required method uncertainty* (u_{MR}):** *Method uncertainty* at a specified concentration. A key *measurement quality objective*. See also *required relative method uncertainty*.

***required relative method uncertainty* (φ_{MR}):** The *required method uncertainty* divided by the *analytical action level*. The *required relative method uncertainty* is applied to radionuclide concentrations above the *analytical action level*. A key *measurement quality objective*.

roentgen (R): A unit of exposure to ionizing radiation. It is that amount of gamma rays or X-rays required to produce ions carrying one electrostatic unit of electrical charge in one cubic centimeter of dry air under standard conditions. The unit of exposure rate is roentgens per hour (R/h). For environmental exposures, the typical units are microroentgens per hour (μR/h), or 10^{-6} R/h. In SI units, 1 R = 2.58×10^{-4} C/kg (coulombs per kilogram).

***sample*:** (1) A portion of material selected from a larger quantity of material. (2) A set of individual samples or measurements drawn from a population whose properties are studied to gain information about the entire population.

***sample test source*:** The product of a chemical or physical process prepared for the purpose of activity determination (ASTM D7282). Also considered to be the final form in a geometry that will be counted by a radiation detector.

***screening method*:** An economical gross measurement (alpha, beta, gamma) used in a tiered approach to method selection that can be applied to *analyte* concentrations below an *analyte* level in the *analytical protocol specifications* or below a fraction of the specified *action level.*

***sievert (Sv)*:** The SI unit for the effective dose of radiation received by a living organism. It is the actual dose received (*grays* in SI or rads in traditional units) times a factor that is larger for more dangerous forms of radiation. One Sv is 100 *rem*. Radiation doses are often measured in mSv. An effective dose of 1 Sv requires 1 gray of beta or gamma radiation, but only 0.05 Gy of alpha radiation or 0.1 Gy of neutron radiation.

***source, radioactive*:** A quantity of material configured for radiation measurement.

***source term radionuclide*:** A radionuclide that is a significant contaminant in an environmental sample and results in dose contributions that will be important in decisionmaking.

sum of the fractions: A calculated value to determine whether the summed contributions to dose by all radionuclides in a sample, divided by their respective dose limits, exceeds 1.0. For purposes of this calculation, the actual *analytical action level* (*derived air concentration* or *protective action guide*) is used rather than an *analytical decision level*.

***swipe*:** A filter pad used to determine the level of general radioactive contamination when it is wiped over a specific area, about 100 cm^2 in area. Also called smears or wipes.

***target analyte*:** A radionuclide on the list of radionuclides of interest or a radionuclide of concern for a project.

***total effective dose equivalent*:** The sum of the effective dose equivalent (for external exposure) and the committed effective dose equivalent (for internal exposure), expressed in units of Sv or rem. See *dose equivalent*.

***Type I decision error*:** In a hypothesis test, the error made by rejecting the null hypothesis when it is true. A Type I decision error is sometimes called a "false rejection" or a "false positive."

***Type II decision error*:** In a hypothesis test, the error made by failing to reject the null hypothesis when it is false. A Type II decision error is sometimes called a "false acceptance" or a "false negative."

***uncertainty*:** A parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand. See *method uncertainty*.