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Radiological Laboratory Sample Screening Analysis Guide for Incidents of National Significance

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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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Preface

The document describes methods that may be applied by personnel at a radioanalytical laboratory for sample radioactivity screening following a radiological or nuclear incident, such as that caused by a terrorist attack. The methods used for the screening of a large number of contaminated samples, and the decisions regarding sample processing, will change based on the radionuclides involved in the event and the incident priorities. The rapid assessment and prioritization of individual sample activity concentrations for analytical processing require consistent application of the method used for screening the different types of samples that will be generated during such an incident. A quality assurance program that addresses this screening process from instrument calibration through data reporting will also be necessary to provide defensible decisions and data.

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 exist across a core set of laboratories to carry out EPA's designated RFA responsibilities.

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 calibration and screening methods outlined in this document provide guidance in gross sample radioactivity measurements to support the laboratory's efforts to process a large influx of samples rapidly. These methods are based upon the anticipated varied activity levels that incoming samples probably would contain if they were impacted by a radiological dispersion device into the atmosphere, water, or soil.

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

The use of a planned methodology to assess radioactivity levels of samples that contain significant quantities of radioactive materials will ensure that the radioanalytical data produced will be of known quality and appropriate for the intended incident response decisions. This guide will assist laboratories in establishing measurement quality objectives (MQOs) for the screening instruments. This will allow laboratories to have greater confidence in screening measurements as they potentially will be using radionuclides for calibration that are likely to be present in such samples.

As with any technical endeavor, actual radioanalytical projects may require particular methods or techniques to meet specific measurement quality objectives. This document cannot address a complete catalog of analytical methodologies or potential radionuclides nor does it intend to proscribe particular methodologies. Laboratories that have screening techniques using alternative methods or instruments in place to address the protocols identified in this guide should continue to use them if they support the measurement quality objectives required by the incident. Radionuclide-specific 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, which provides detailed radioanalytical guidance for project planners, managers, and radioanalytical personnel based on project-specific requirements. 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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Acronyms, Abbreviations, Units, and Symbols

(Excluding chemical symbols and formulas)

α .....alpha particle
AAL .....analytical action level
ADL .....analytical decision level
AL .....action level
β .....beta particle
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
cpm.....counts per minute
d.....day
DAC .....derived air concentration
DL .....discrimination limit
DOE .....U.S. 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
EPA.....U.S. Environmental Protection Agency
ERLN.....Environmental Response Laboratory Network
FOM.....figure of merit
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
HPGe.....high-purity germanium detector
IC.....Incident Commander [or designee]
ICLN .....Integrated Consortium of Laboratory Networks
IND .....improvised nuclear device

INS .....incident of national significance
keV .....thousand electron volts
L .....liter
LBGR.....lower bound of the gray region
LCS .....laboratory control sample
LEPD.....low-energy photon detector
LS .....liquid scintillation
LSC .....liquid scintillation counter
MARLAP .....*Multi-Agency Radiological Laboratory Analytical Protocols Manual*
MARSSIM .....*Multi-Agency Radiation Survey and Site Investigation Manual*
MCL.....maximum contaminant level
MDC .....minimum detectable concentration
MeV .....million electron volts
mg .....milligram (10^{-3} g)
min .....minute
mL .....milliliter (10^{-3} L)
MQO .....measurement quality objective
mR.....milliroengten (10^{-3} R)
mrem .....millirem (10^{-3} rem)
µg .....microgram (10^{-6} g)
NaI(Tl) .....thallium-activated sodium iodide detector
NORM ..... naturally occurring radioactive materials
φ_{MR}.....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
rem .....roentgen equivalent man
RFA.....responsible federal agency
s .....second
SI.....International System of Units
SOP .....standard operating procedure
STS.....sample test source
Sv .....sievert
$t_{½}$ .....half-life
TAT.....turnaround time
TEDA.....triethylenediamine
TEDE .....total effective radiation 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}	m^3	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 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.

I. INTRODUCTION

Most laboratories do not routinely screen samples under conditions found during an emergency response situation, such as from a radiological or nuclear incident of national significance (INS). Many of these samples are higher in activity and need to be accurately surveyed and prioritized for analysis based on direction from the Incident Commander (IC).[1] This document describes methods that may be applied by personnel at a radioanalytical laboratory for screening of samples for radioactivity. The specific techniques described in this guide may be used to assess the gross α, β, or γ activity in samples that may have been contaminated as the result of a radiological or nuclear event, such as a radiological dispersion device (RDD), improvised nuclear device (IND), or an intentional release of radioactive materials into the atmosphere or a body of water or aquifer, or to terrestrial areas 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 release of radioactivity to the environment likely will occur in three phases that 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). Each phase of an incident response will require different and distinct radioanalytical resources to address the different consequences, management, priorities, and requirements of a phase. Some of the more important radioanalytical laboratory issues germane to an incident response consist of radionuclide identification and quantification capability, sample load capacity, sample processing turnaround time, quality of analytical data, and data transfer capability. This guide emphasizes the laboratory screening of samples from the end of the early phase, through the intermediate phase, and into the recovery phase (but does not address the screening by initial responders).

Although not the focus of this document, 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 the need to provide for *qualitative* identification of radionuclides. During this phase, the Protective Action Guides (PAGs) for radiological emergencies require evacuation of a population if the projected short-term total effective radiation dose equivalent[2] (TEDE) exceeds 1 rem.[3] 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, and the extent of the contamination.

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

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

[2] 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.

[3] 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.

rapidly determined. For 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 or any subsequent 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 potential for more extensive radiochemical analyses at the lowest radionuclide concentrations.

The analytical resources needed during any phase of a radiological event will depend on the radionuclide analytical action level (AAL)[4] developed for the various media that may affect human exposure. The radionuclide AALs, which are derived radionuclide concentrations for the different media types based on the PAGs or risk values, may change depending upon the phase of the event.

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 focus on optimizing sample analyses so that the initial qualitative aspects and concentrations related to the appropriate AALs can be determined quickly (i.e., rapid turnaround of sample results). Radioanalytical screening by laboratories during these phases will include methods for all three radioactive emissions. During the recovery phase, however, the screening techniques used for samples will be more focused because the radionuclides from the event are likely to have already been identified and chemically characterized.

During all phases of an incident response, radioanalytical resources are needed for the gross radiation screening of samples for prioritization of sample processing or for information related to the general level of contamination, identification of the radionuclide source term, and quantification of the radionuclides in a variety of sample media. This document has been developed to provide guidance during an incident on techniques to enhance the ability to differentiate radioactivity in samples near action levels and optimize the calibration of the screening equipment used for gross sample activity measurement. Using these techniques should help laboratories to prioritize samples in a timely fashion based on the request of the IC.

The process of screening samples using a survey instrument can be described in two stages. The first stage deals with the receipt of the bulk sample shipment and assessment of the radiation dose rate (mrem/h) or gross activity (cpm) from the shipment and the individual samples, *prior to opening any samples*. The main purpose in this stage is to identify any immediate radiological hazard to the receipt personnel and sample analysts. This screening measurement typically is made using an instrument that does not discriminate particle energies or assess total dose rate from the sample. For example, an instrument like a Geiger-Mueller (GM) detector is sensitive to

[4] The term "analytical action level" (AAL) is used in this publication series as a general term denoting the radionuclide concentration at which action must be taken by incident responders. The AAL should always correspond to a PAG or risk-based dose.

all gamma and beta particles with enough energy to pass through the container walls without identifying which is which. At this time, no assessment of alpha particle or low-energy beta particle contamination can be made. The measurement should not take more than 5 to 10 seconds to complete per sample. Important aspects of the outcome of this measurement are that the samples can be appropriately shielded and labeled for both radiation protection and prioritization purposes, and that the sample mass and integrity remain unchanged (this is a non-destructive, non-invasive test).

The second stage of screening is more substantive in that it examines the total radionuclide activity for a particular type of particle emitted from the radionuclides contained within the sample. Ideally, if ^{90}Sr, ^{14}C, and ^{99}Tc were all contained in a sample, the instrument used for screening would measure the total contribution as *the sum of the three*, even if it could not identify them individually. Unfortunately, the instruments used for *screening* are not ideal: detector response tends to be proportional to the characteristic energy of the radiation emitted by a radionuclide and the detection is also impacted by sample self-shielding. It is very important to ensure that a screening test will provide a conservative estimate of the total activity of the radionuclides present to ensure that the screen does not underestimate the total amount of a radionuclide present. If the identity of the radionuclides is known, a different response factor should be applied when measuring the medium-to-high energy beta from $^{90}Sr/^{90}Y$ than for the lower energy ^{14}C in samples where mass attenuation may be significant.

Using gas proportional counting (GPC) or liquid scintillation counting (LSC) to perform the screening process has several important consequences. First, when the sample container itself is opened, the potential exists for contaminating both the sample and the laboratory. Second, a portion of the sample may be sacrificed for the screening process, which may require judicious sub-sampling. Third, chain-of-custody must be established for open sample containers and aliquanting prior to actual analysis. This will prevent questions later on regarding the sample integrity.

This document provides technical information and recommendations for a laboratory faced with screening samples received following a radiological INS. Screening samples deals with the detector responses to radiation and the effects of different forms of radiation on different detector types. Three appendices provide detailed scenarios that use the information in the technical section of the document. These scenarios illustrate when to change calibration and screening techniques based upon what is known about the sample's radioactive contaminants and the instrument detection efficiency. The methods demonstrated by these scenarios are:

- Preparation of laboratory screening equipment for an INS event;
- Receipt of samples from an INS event with known radionuclides for which the laboratory screening instruments are calibrated; and
- Receipt of samples from an INS event with known radionuclides, but the laboratory screening equipment must use a detection correction factor because the instruments were not calibrated with radionuclides present in the event samples.

Facility personnel should use these examples as guidance to prepare the screening instruments that are commonly used in their laboratories to analyze gross activity in samples from an INS.

A. Purpose and Objectives

This document describes how to develop laboratory methods to perform gross radioactivity analysis for samples resulting from an INS. It discusses technical issues associated with screening measurements, provides the suggested methodologies to determine correction factors for these instruments, offers a consistent methodology for measuring sample gross activity concentrations, and provides guidance on the calibration of screening equipment commonly used by laboratories.

Although the list of potential threat radionuclides is relatively short, instrument responses to the different particle energies may vary significantly depending upon the type of screening instrument used. It is important to be able to use screening instrumentation to support the overall laboratory process of sample prioritization and analysis that will support decisions to protect the health and safety of the public.

This document provides guidance for a user to select appropriate methods for screening at different points in the analytical process. The critical points in the process are sample receipt, sample prioritization, and rapid feedback to the IC on samples exceeding action levels.

The specific objectives for response personnel to accomplish in preparing their laboratories for such an event include:

- Performance of method validation for each instrument/sample geometry combination used in screening;
- Identification of consistent methods of screening for various media;
- Screening instrument configurations that streamline the screening process;
- Screening measurements that will aid in prioritizing samples for analyses; and
- Methods for calibration of screening equipment that will have the widest applicability to those radionuclides most likely to result from an INS.

B. Scope of DQOs/MQOs for the Screening Process

The use of screening instrumentation to prioritize samples based on the amount of activity in an individual sample should be consistent for *all* laboratories responding to an INS. This should allow the processing of samples and return of results to the IC based on the measurement quality objectives (MQOs) of the event in the timeliest manner. During the early phase of an event when the identity and extent of radioactive contamination are unknown, the screening instrumentation should be calibrated with radionuclides that are routinely used for gross screening calibrations, but in a geometry that should support the best discrimination of activity levels. As the event progresses and the specific radionuclides are identified, either the calibration may be changed to reflect the known radionuclides or an interpolated correction factor for instrument response due to other radionuclides based on energy should be used.

Other guides in this series[5] identify Protective Action Guides (PAGs) as associated concentrations and AALs that are critical measurement limits. The screening instruments used in the laboratory to support the rapid and organized evaluation of sample priority should be calibrated for gross activity measurements at these critical measurement limits in order to achieve the established MQOs stated in the other guides.

Samples that have the potential for considerations in a criminal investigation must be handled separately, and the laboratory should receive information from the Incident Commander on how to process these samples.

C. Measurement Quality Objectives: Relationship of Derived Concentrations, AAL, ADL, Risk Levels, and u_{MR} to Dose

MQOs External to the Laboratory

Gross activity screening of samples is the first step to assessing whether or not a particular sample exceeds a PAG's derived radionuclide concentration for the matrix that is being assessed for radioactive materials. PAGs establish radiation dose limits applicable to different phases of an incident response. The PAG (expressed as a numerical dose level) indicates a level of exposure at which protective action should be taken to prevent, reduce, or limit a person's radiation dose during a radiological incident. The measurements that are made with screening instruments in the radioanalytical laboratory should be correlated to the PAGs expressed as concentrations (or other AALs) for each matrix defined by the incident.

A *derived concentration* of a radionuclide that corresponds to a PAG or risk-based dose in a specific matrix can be calculated and used to facilitate the application of these radioanalytical action levels in the laboratory for decision-making purposes. For example, the derived air concentration (DAC, in units of pCi/m^3) of an individual radionuclide in air corresponds to a radiation dose (PAG) to a specific population. For each matrix that undergoes screening, there should be a derived radionuclide concentration that may be *directed* by regulation or *selected* based on the specific incident.

Screening instruments, when configured properly, can be used to conservatively determine if a sample has or has not exceeded an AAL. However, when the total gross screening activity exceeds an AAL, it may not be possible to determine if the AAL for an individual radionuclide is actually exceeded until radionuclide-specific methods are performed. In cases where it is not possible to determine if an individual radionuclide AAL has been exceeded, screening provides the laboratory with the information to prioritize samples that need to be analyzed first. The priority for sample analyses will be decided based upon the incident phase and the specific needs of the IC. For example, the order of analysis could be based on highest activity first, lowest activity first, gamma response first, or any such logical priority.

[5] See Appendix IV for further references to how measurements are used to make decisions regarding PAGs and action levels.

MQOs Internal to the Laboratory

The laboratory also needs the screening equipment to correlate to MQOs established in the laboratory and thus facilitate sample processing. The screening MQO will likely change as the event progresses and the known concentration of the radionuclides involved becomes more certain and their concentration diminishes due to radioactive decay, dilution, or dispersion. Using *Radiological Laboratory Sample Analysis Guide for Incidents of National Significance–Radionuclides in Air* as an example, four different levels are assessed over the course of an event: 2 rem, 500 mrem, 10^{-4} risk, and 10^{-6} risk. As the event progresses towards samples being analyzed at the level of 10^{-6} risk, the method detection capability may need to improve in order to continually and efficiently prioritize samples. The feedback to the IC will be slowed down because the decreased sample activities will result in longer screening times for samples and longer count times for samples following analytical separations.

The changing MQOs will have a "domino effect" on laboratory QC analyses, such as spikes, duplicates, laboratory control samples (LCSs), and blank samples, processed in a batch. The activity levels for spikes and LCSs may become lower as the event progresses, and the acceptance criteria for the QC samples also may change. Changes to the required measurement uncertainties for these QC samples will require longer counting times and also may slow down reporting to the IC.

The required method uncertainty (u_{MR}) may have default values for each radionuclide and matrix (other guides in this series identify these default values; see references in Appendix IV) or may have incident-driven values. In either case, the laboratory should be prepared to adjust these values when required by the incident MQOs for both the screening instruments and the radionuclide specific methods. The value of u_{MR} and the acceptable error rates for Type I and Type II errors are used to determine the analytical decision level (ADL). The ADL is a value that is less than the AAL. When the ADL is exceeded, it is concluded that the AAL has also been exceeded, guarding against a decision error that would allow a sample exceeding the AAL to go undetected. The ADL concept is also used for both screening instruments and laboratory-specific methods. For more details on these concepts, see Appendix VI to *Radiological Laboratory Sample Analysis Guide for Incidents of National Significance–Radionuclides in Water* (EPA 2008a).

II. RADIONUCLIDES

The list in Table 1 is specifically for an RDD event and the major (non-inclusive) dose-related radionuclides that might be released during the detonation of an IND. 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 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 1 – 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, [X-ray]	^{227}Ac[2]	21.77 y	β, γ
^{242}Cm	163 d	α	^{141}Ce[1]	32.51 d	β, γ
^{243}Cm	29.1 y	α, γ	^{144}Ce[3]	284.9 d	β, γ
^{244}Cm	18.10 y	α	^{57}Co[1]	271.7 d	ϵ, γ, X-ray
^{237}Np	2.14×10^{6} y	α, γ, [γ, X-ray]	^{60}Co[1]	5.271 y	β, γ
^{210}Po [1]	138.4 d	α	^{134}Cs[1]	2.065 y	β, γ
^{238}Pu	87.7 y	α, [γ, X-ray]	^{137}Cs[4]	30.07 y	β, γ
^{239}Pu	2.41×10^{4} y	α, [γ, X-ray]	^{3}H[1]	12.32 y	β only
^{240}Pu	6.56×10^{3} y	α, [γ, X-ray]	^{125}I[1]	59.40 d	ϵ, γ, X-ray
^{226}Ra[2]	1.60×10^{3} y	α, γ	^{129}I[2]	1.57×10^{7} y	β, γ, X-ray
^{228}Th[2]	1.912 y	α, γ	^{131}I[1]	8.021 d	β, γ
^{230}Th	7.538×10^{4} y	α, γ	^{192}Ir[1]	73.83 d	β, γ
^{232}Th	1.405×10^{10} y	α	^{99}Mo[2]	65.94 h	β, γ
^{234}U	2.455×10^{5} y	α	^{32}P[1]	14.26 d	β only
^{235}U	7.038×10^{8} y	α, γ	^{103}Pd[1]	16.99 d	β, γ
^{238}U[3]	4.468×10^{9} y	α	^{241}Pu	14.29 y	β, [α, γ]
U-Nat[3]	---	α	^{228}Ra[2]	5.75 y	β only
			^{103}Ru[2]	39.26 d	β, γ
			^{106}Ru[2]	373.6 d	β only, (β, γ from progeny)
			^{75}Se[1]	119.8 d	ε, γ
			^{89}Sr[1]	50.53 d	β only
			^{90}Sr[2]	28.79 y	β only
			^{99}Tc[1]	2.11×10^{5} y	β only

Notes:
The half-lives of the nuclides are given in years (y), days (d) or hours (h).
[1] No radioactive progeny or progeny not analytically useful.
[2] Radioactive progeny with short half-lives, and the progeny may be used as part of the detection method for the parent.
[3] Radioactive progeny not used for quantification, only screening.
[4] Radioactive progeny used for quantification only, not screening.
Brackets [ ] indicate minor emission probability. If large quantities of these radionuclides are present, these minor emission modes may contribute significantly to any screening measurements made on the sample.

Instruments available for screening should provide a consistent measure of sensitivity[6] to allow detection of as many radionuclides as possible. However, some radionuclides (depending on total activity levels) likely will evade detection with routine screening instrumentation (solid scintillators or gas detectors). Generally, those radionuclides that decay by electron capture, positron emission, or very-low beta particle emission (and no gamma emission) should be analyzed with radiochemical-specific methods to determine their presence. The radionuclides from Table 1 in this group are: ^{3}H, ^{99}Tc, ^{125}I, ^{228}Ra, ^{241}Pu, and ^{106}Ru. However, it should be noted that if liquid scintillation is used as a screening technique, a measurable response to these radionuclides will occur.

III. DISCUSSION

The discussion section of the document is divided into five parts. Part A deals with sample screening and different instruments that are commonly used to make these measurements. This section also provides some insight into technical issues encountered when performing gross sample activity measurements when the radionuclide being measured is unknown.

Part B deals with the calibration of screening equipment and the effects on the calibration process as a function of the particle type emitted by the calibration source and its energy It also discusses the responses of different types of detectors and provides figures demonstrating detector and sample configurations that may be advantageous for screening of samples for gross activity.

Part C deals with the use of screening equipment for prioritizing samples when the radionuclide(s) present are known.

Part D discusses the MQO process, and Part E provides key recommendations for the laboratory in establishing a screening protocol for samples resulting from radiological incidents.

A. Sample Screening and Processing at the Laboratory

Guidance on using both the screening instrumentation and the radiation-specific detectors for emergency response sample screening is discussed in this section.

Gross Activity Measurement Instruments

If the sample screening process at the laboratory is organized properly, it can significantly improve the turnaround time for results and minimize risk of the spread of contamination in the laboratory, as well as the chance for sample cross-contamination.

Gross activity measurements can be made using two general types of instrument—a ratemeter or a scaler.

[6] In this context, sensitivity refers to the ability of the screening equipment to detect different particles.

The ratemeter measures the radiation emission per unit time in real time, but not all instruments have a summation function that would allow total decays to be measured over a defined time period. The overall sensitivity and ability of these instruments to discriminate radiation types are generally low. Although these are portable instruments that are often used for general area surveys, for the purposes of this guide these instruments are used in a fixed geometry relative to the samples. These instruments have time constants whose duration can be changed so that an average response to general radiation measured is more easily determined. A shorter time constant display has more frequent readings with the subsequent result of a "jumpy" needle or scale display when activity levels are close to the background level. By increasing the time constant, these measurements are averaged out internally and the display becomes more constant. This is more of a benefit to the application where the sample and the detector are in a fixed juxtaposition. When using a ratemeter for assessing gross radiation levels, it will be necessary for the laboratory to establish a protocol to determine the measurement value when meter/display readings are not constant (e.g., average the values of the high- and low-meter readings during a 20-second observation).

The scaler measures individual events and records them during a specified time period. Instrument outputs are generally in terms of total counts. The assessment of the gross activity generally takes longer with the scaler than with the rate meter, but the interpretation of the values obtained is somewhat more definitive. Some of these instruments have modest energy discrimination capabilities. However, these capabilities are severely limited when a mixture of radionuclides of varied decay modes is present. Laboratories should have a protocol that describes how to use the gross count data obtained by these types of instruments.

Table 2 identifies general descriptions of gross activity measurement instruments and laboratory screening instruments that can be used for sample screening and specific emission types to which they are most sensitive.

TABLE 2 – Detectors Used for Gross Sample Screening

Type of Detector	Sensitive to:
Geiger-Mueller (GM) Detector [Ionizable Gas]	Gamma (X-rays)
Open-end GM Detector [Ionizable Gas]	Beta, Gamma, X-rays (some high activity alpha)
GM Pancake Style Detectors [Ionizable Gas]	Beta and Gamma (some high activity alpha)
Micro-R meters [NaI(Tl)]	Gamma and X-rays
Cylindrical Probe [NaI(Tl)]	Gamma and X-rays
Thin Window (Alpha Scintillator)	Alpha
Thin Window (Beta Scintillator)	Beta (low response to photons)
Dual Phosphor Detectors First Layer [ZnS] Second Layer [Organic]	Alpha and Beta
Portable Gamma Detectors [HPGe]	Gamma (X-rays)
Small Article Monitors [NaI(Tl)]	Gamma (X-rays)
Small Article Monitors [Organic Scintillator]	Beta and Gamma (X-rays)
Liquid Scintillation [Liquid Fluor]	Beta, Alpha, and Gamma

Instrument Response Characteristic Determination

The first factor to consider when performing a sample survey is the actual response by the instrument to the potential radionuclides plus any decay progeny in the sample. Not only is the response of these instruments different for each type of radiation, but it may also vary in a complex way with respect to the energy of decay. A couple of examples that demonstrate these differences in response are:

- The response of a NaI(Tl) micro-R meter will be different for high-energy photons compared to low-energy photons (i.e., it over-responds to low-energy photons).
- A GM pancake detector will respond to both alpha and beta radiation. However, for equal activities of ^{32}P (beta-emitter) and ^{242}Cm (alpha-emitter), the instrument will yield a greater response (i.e., higher counts per minute) from the betas of ^{32}P.
- An open-end GM detector will respond to both beta and gamma radiation. However:
    - The response to 10 nCi of ^{89}Sr ($E_{\beta max}$ at 1.49 MeV) will be greater than that for 10 nCi of ^{99}Tc ($E_{\beta max}$ at 0.294 MeV).
    - The response to 50 nCi of ^{137}Cs (gamma energy 0.662 MeV) will be smaller than that for 50 nCi of ^{57}Co (gamma energies at 0.136 and 0.122 MeV) because the lower energy gamma rays interact more favorably due to the photoelectric effect.

These examples illustrate that the type and energy of radiation, as well as branching ratios, abundance values, and other physical properties of the radionuclide and the detection system are significant factors in assessing the total activity of a sample during the screening process using survey meters when the exact types of radionuclides present are unknown. Radionuclide-specific detection parameters are explained in detail in Knoll.[7]

Crosstalk: Detector Responses to Radioactive Emissions

In addition to the individual particle energy providing a different response in a particular detector, one type of particle may yield a response indicative of another type of particle. This is particularly true with gross alpha-beta detection devices that rely on pulse size to determine whether an individual event represents an alpha, beta, or gamma detection.

One instance of this type of incorrect identification occurs with measurement of ^{241}Am using a gas proportional detector. Although ^{241}Am is principally an alpha-emitter, it also emits a low-energy photon at 59 keV. A photon of this low energy may yield a response in the beta channel because of the high probability of secondary interaction of scattered radiation with the instrument components (including electronics, detector casing, instrument housing) via the photo-electric and Compton effects. Thus, if the total activity of the ^{241}Am is high, an incorrect assumption regarding beta activity could be made.

Care must also be used to evaluate and interpret the results with respect to possible beta-to-alpha and alpha-to-beta crosstalk effects when screening air filters (or other solid materials) for gross alpha and beta activities by instruments using gas proportional counting. The type of effect

[7] Knoll, Glen F. 1979. *Radiation Detection and Measurement*, New York: John Wiley and Sons, Inc.

depends on the instrument mode of operation, setup, voltage plateaus, and discriminator settings. For most modern gas proportional counting instruments, the mode of operation may include:

1) Simultaneous measurements of alpha and beta activities based on a single operating plateau and beta-to-alpha and alpha-to-beta discriminator settings; or
2) Independent analysis of alpha and beta plus alpha activities on two separate voltage plateaus.

The second mode of operation, for most practical purposes, eliminates the beta-to-alpha crosstalk effect. However, the alpha response on the beta plateau must be estimated and the beta results adjusted accordingly. The remainder of the discussion that follows here will address the simultaneous alpha- and beta-counting mode.

The instrument voltage discriminator setting[8] should be adjusted when operating in the simultaneous alpha and beta counting mode to maximize the alpha detector efficiency and minimize the beta-to-alpha response crosstalk. These settings should be established using a source with matrix characteristics similar to the samples received from the incident response since absorption of the alpha particles in the matrix will decrease the alpha energy available with a proportional decrease in the signal voltage for processing. Typically, nominal instrument settings can be established that allow for an acceptable alpha counting efficiency and a beta-to-alpha crosstalk of <0.1 %. However, depending on the sample matrix and instrument settings, the actual crosstalk value can vary widely from this value. For air filter matrices, the alpha detector efficiency may be as low as 5 to 10%, and the beta-to-alpha crosstalk may contribute significantly to this value.

When evaluating gross alpha and beta activity results of sample analyses for the purpose of sample prioritization (for subsequent radionuclide-specific analyses), it is important to consider the possible effect of the beta-to-alpha crosstalk on deciding if the instrument alpha results have been artificially increased. The beta-to-alpha crosstalk effect may be most important either during the initial phases of an incident (when the radionuclides of interest are unknown) or when the composition of the mixture of alpha- and beta-emitting radionuclides is known. For the latter case, the beta-to-alpha crosstalk effect should be addressed. This can be done, once the radionuclides have been identified, by performing instrument calibrations for crosstalk using the actual radionuclides of concern, and corrections can be made that are both accurate and of known uncertainty.

A general observation of the AALs for those alpha- and beta-emitting radionuclides identified in Table 1 indicates that the AALs for the beta-emitting nuclides are at least a factor of 500 or greater than for the alpha-emitting nuclides. For example, the 500 mrem AALs for ^{90}Sr and ^{137}Cs are 110 and 550 pCi on the air filter for a 68 m^3 air sample. For the same dose and volume sampled, the AALs for ^{241}Am and ^{239}Pu are 0.17 and 0.14 pCi. For gross screening sample prioritization, the AALs for the ^{90}Sr and ^{241}Am should be used. Note that when the actual beta-to-alpha crosstalk discrimination is 0.1%, the alpha response observed from ^{90}Sr activity at the AAL may be > 0.1 cpm. With an alpha detector efficiency of 10%, the reported activity would be

[8]ASTM International (ASTM D7282-06). *Standard Practice for Set-up, Calibration, and Quality Control of Instruments Used for Radioactivity Measurements*, ANNEX X2. West Conshohocken, PA. Available for purchase from: www.astm.org/Standards/D7282.htm.

near the gross alpha screening AAL. Therefore, when evaluating gross alpha results when the beta result is greater than 500 to 1,000 times the alpha result, care must be taken to avoid the false conclusion that the screening alpha AAL has been exceeded. When screening air filters that have a beta-emitting radionuclide whose AAL is greater than the ^{90}Sr AAL, the beta-to-alpha crosstalk effect may be greater (depending on the beta particle energy), and the gross alpha screening AAL may be artificially exceeded more often when the radionuclide beta activity is near its own AAL.

As an example, suppose ^{90}Sr at the 500 mrem AAL (110 pCi/m^3) had deposited on an air filter. The activity would be the sum of ^{90}Sr + ^{90}Y = 220 pCi/m^3 for a 68 m^3 sample[9] (a total activity of 3.32×10^4 dpm). The measured beta activity for a 30% efficient detector would be

$$\text{beta dpm} = 0.3 \times 3.32\times10^4 \text{ dpm beta} = 9.96\times10^3 \text{ cpm}.$$

The alpha response from beta-to-alpha crosstalk would be based on the crosstalk factor, which is relatively small (about 0.1%). Thus, the apparent alpha activity counted would be

$$\text{cpm} = 9.96\times10^3 \times 0.001 = 9.96 \text{ cpm}.$$

Alpha background on a GPC will be small at ~ 0.05 cpm. Thus, with an alpha efficiency of 0.1 (10%), the net count rate for alpha would yield a calculated alpha activity of

$$\text{alpha} = (9.96\text{-}0.05) / (0.1) = 99.1 \text{ dpm} = 44.7 \text{ pCi}.$$

This would yield a false indication of alpha activity when none is present.

Using the same reasoning, example AALs can be applied to the evaluation of air filters with elevated alpha activity. The effects of alpha-to-beta crosstalk (versus beta-to-alpha crosstalk) can be calculated, and the potential impact on artificially exceeding the beta AALs can be determined.

When operating a gas proportional counter in the simultaneous alpha and beta counting mode, the initial adjustment of the voltage discriminators is intended to minimize the beta-to-alpha crosstalk. Crosstalk, however, is more dependent on the specific radionuclide present in the sample and its physical decay and emission properties, than on the instrument discriminator settings. Actual alpha-to-beta crosstalk can vary from less than 3% to more than 30%, depending on the radionuclide and other factors.

Alpha-to-beta crosstalk correction factors should be determined during the initial instrument efficiency calibrations. These factors can be useful in making corrections to the beta count rate, based on the alpha count rate, but only when the radionuclide present has been correctly identified and the instrument has been calibrated accordingly.

[9] The volume of 68 m^3 is used as a reference volume as described in the *Radiological Laboratory Sample Analysis Guide for Incidents of National Significance–Radionuclides in Air* (2009, In Preparation).

When performing gross screening analyses, however, where the radionuclide has not been identified and the instrument has not been appropriately calibrated, making a crosstalk correction based on the initial instrument calibration can result in significant errors in the measurement of the beta activity in the sample. Depending on the project MQOs and event circumstances, it may be preferable to make no crosstalk correction and to potentially overestimate the sample beta activity. Because the beta AALs are typically much higher than the alpha AALs, this overestimate should result in artificially exceeding the beta AALs only when the alpha activity is extremely elevated.

In the previous example for beta-to-alpha crosstalk, the 500-mrem AAL for ^{90}Sr is 110 pCi for a 68 m^3 air sample. An ^{241}Am activity of 2,200 pCi would be required to yield a beta channel signal that would correspond to the 110 pCi activity for ^{90}Sr, or nearly 13,000 times the ^{241}Am AAL. For other alpha-emitting radionuclides, the alpha activity required to cause this beta AAL to be artificially exceeded could be greater than 100,000 times the AAL of that other radionuclide.

In these unusual cases, the apparent beta activity should be confirmed by an appropriate technique, such as recounting the sample with an alpha-attenuating barrier in place and comparing the beta count rates from the two analyses. For screening analyses, however, these techniques assist only in estimating the degree of bias in the results, and do not correct for all sources of crosstalk.

This effect can be illustrated by calculating the quantity of alpha activity from ^{241}Am that would yield an indication of beta activity at the AAL for ^{90}Sr. Given the 10^{-6} risk AAL for ^{90}Sr of 0.29 pCi/m^3 and an assumed sampled air volume of 68 m^3:

- A beta activity from (^{90}Sr + ^{90}Y) on a filter at the AAL would be approximately 88 dpm;
- The beta counts recorded (with a detector efficiency of 30%) would be ~26 cpm beta; and
- A normal beta background of 1 cpm yields a net beta count rate of ~25 cpm.

Assuming 30% alpha-to-beta crosstalk and 10% counting efficiency for ^{241}Am, the alpha activity required to produce alpha-to-beta crosstalk equivalent to the ^{90}Sr AAL would be

$$\text{Alpha activity} = 26/(0.3\times0.1\times2.22), \text{ or approximately 390 pCi.}$$

Thus, an activity of ^{241}Am of 390 pCi can cause an *apparent* beta activity equivalent to the AAL of ^{90}Sr even when there is none present.

Detector Background

A second factor to consider during sample screening is the background. Background can be divided into the categories of instrument (intrinsic or electronic), environmental (laboratory location), and sample container/sample. These should be minimized when possible to achieve the best signal to background ratio for the sample. As will be shown further on in this document, reduction of background is one of the most important limiting factors for detection of low level sample activity during the screening process.

Some examples of potential background concerns are:

- Proximity of one screening instrument to another when samples or groups of samples contain enough activity to have an impact on a neighboring instrument.
- Presence of radionuclides with multiple emissions that can be detected by the instrument.

Since the level of background is crucial to the measurement, the shielding of the detector is an important consideration.

Sample Geometry

The third factor that should be considered when using survey meters is the consistency of the sample-to-detector geometry. The method of calibration of the survey meter and the method used to screen samples using the survey meter should match as closely as possible to obtain the best estimate of absolute activity in the samples.

Finally, sample self-absorption should be evaluated when assessing the results of sample screening. This effect is most critical with alpha- or beta-emitters, but for low-energy photon-emitters it also will be a contributing factor to misidentification of particles. The loss of particle energy as it travels through the sample medium will cause it to yield a smaller ionization pulse in the detection device. As described earlier, this can register a false count for the wrong type of emitted particle.

Each of these three factors will be considered in the sections below that address the calibration of screening detection equipment.

Laboratory Instruments

Hand-held devices are not the only types of instrumentation that can be used for performing a gross radiological screen on a sample. Consideration should also be given to using three mainstays of the radiochemical laboratory for screening analyses. Gas proportional counters (GPC), NaI(Tl) detectors, and liquid scintillation counters (LSC) normally are used for radionuclide-specific analyses, and in such applications radiochemical purity of the sample test source (STS) is imperative. These instruments can be used to assess total activity as well. This may require a modification or re-configuration of laboratory instrumentation to dedicate some portion of the laboratory resources to emergency response rapid screening.

B. Calibration of Instrumentation for Screening Analyses

Detector Type

Examples of different types of gross screening survey meters and laboratory screening instruments are summarized here:

- Gross Alpha
  - ZnS(Ag) scintillation detector with a thin aluminum or Mylar™ window

  - Open-end GM detector
  - Gas-filled pancake probe with a thin window
- Gross Beta
  - Plastic organic scintillator with a thin aluminum or Mylar window
  - Gas-filled GM detector (with slide-window allowing gamma detection in the presence of beta)
- Gross Gamma
  - Gas-filled GM detector
  - Sodium iodide (NaI[Tl]) or cesium iodide (CsI[Tl]) detector (well or flat type crystal) with scaler for open discrimination counting
  - Micro-R meter using NaI(Tl) or CsI(Tl) detector
  - HPGe detector (may be flat or well type) set for gross counts using summation of all channels

It would not be practical to maintain calibrations for each of the radionuclides, or mixtures of radionuclides, shown previously in Table 1. However, a straightforward process can be performed to relate the response of each detector to decay particle energy. While the measurements are not as precise as more extensive laboratory measurements, it allows increased accuracy for a longer list of radionuclides when making an estimate of the total activity. This can be accomplished by selecting at least two (but preferably three or more) radionuclides that emit characteristic decay particles with distinct energies that span the usable range of the instrument. Table 3 identifies a list of radionuclides that can be obtained as standards for calibration of detector energy. Their emissions and energies for calibration are also included.

Table 3 – Radionuclides Spanning the Energy-Calibration Range

Radionuclide	^{57}Co	^{60}Co	^{137}Cs	^{99}Tc	^{90}Sr/^{90}Y	^{230}Th[1]	^{241}Am
Emission Type	γ	γ	γ	β_{max}	β_{max}	α	α
Energy, MeV	0.122, 0.136	1.173, 1.332	0.662	0.29	0.545, 2.28[2]	4.69	5.49

[1] This is the primary alpha for thorium; thorium has progeny that emit alphas as well.
[2] This energy belongs to ^{90}Y, which is in secular equilibrium with the ^{90}Sr.

Next, the net instrument response for each of the radionuclides is measured in a standard configuration (i.e., a "geometry": matched quantities of sample, containers, and position relative to the active volume of the detector). For each type of decay particle and geometry, instrument response should be plotted against the average decay energy[10] of the particle emitted. Using these data, a table of response factors (i.e., efficiencies) is prepared that correlates to each of the radionuclides in Table 1 based on decay type and respective average decay energy. An example of this application can be seen in Figure 1, which shows the energy response to different energy gamma radiation for a halogen quenched GM detector, and in Figure 2 for a NaI(Tl) detector. Note the significant, relative effect that using the GM shield has on the detection of the lower-energy versus the high-energy gamma emitters. This also can be used in a qualitative sense to assess the overall energy profile of the gamma emitters.

[10] See example in Appendix III for ^{192}Ir.

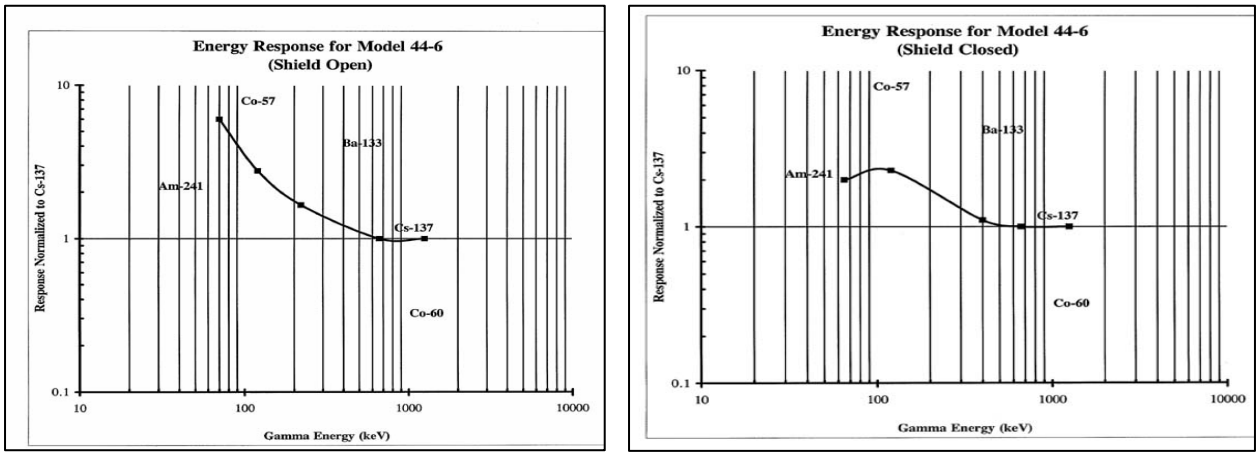

FIGURE 1 – Halogen-Quenched GM Detector Response to Gamma Radiation (A) with Shield Open (B) with Shield Closed

The maximum in detector response for the commonly used NaI(Tl) detector is about 100 keV (see Figure 2). For a comparable sized CsI detector, the response would be more efficient overall, and the maximum in the efficiency curve would be at a slightly higher energy. This is due to the difference in physical properties of the CsI(Tl) crystal material.

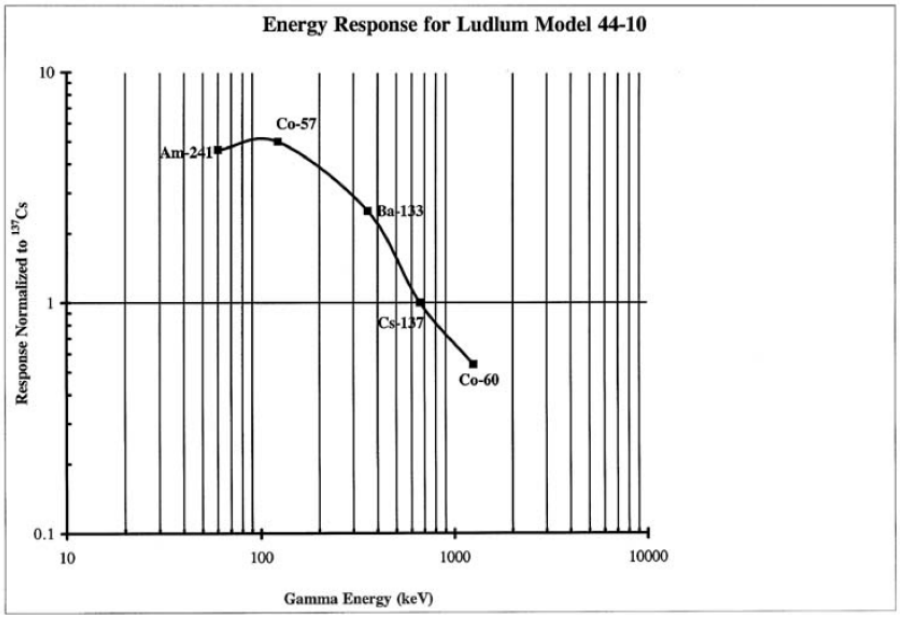

FIGURE 2 – Gamma Energy Response for a Na(Tl) detector

The response for an alpha-beta survey meter,[11] using a halogen quench fill gas and a thin mica window pancake probe, may have the following characteristics:

- Efficiency (2-pi geometry): 5%–^{14}C; 22%–^{90}Sr/^{90}Y; 19%–^{99}Tc; 32%–^{32}P; 15%–^{239}Pu

[11] The response curves and characteristics for these instruments were taken from information provided by Ludlum Measurements, Inc., at www.ludlums.com.

- Sensitivity: Typically 3,300 cpm/mR/h (^{137}Cs gamma)
- Energy Response: Energy dependent

From these few examples, it can be seen that the response of a survey instrument to different types and energies of radiation is a complex function of not only the radiation emitted but also of the survey instrument used.

Geometry

The relative geometry of sample to screening instrument and shielding can take on several different configurations. It is very important to ensure that the sample measurement matches the calibration geometry. Some of the considerations that will affect the optimal configuration of sample to detection device are:

- Shielding (detector). The detection capability of the screening method will be optimized by shielding the detector to reduce ambient background and minimize response to external sources of radiation. The detector and detector shielding configurations should remain fixed so that the background count rate is reasonably constant.
- Shielding (container). The sample container material can be made of glass, polyethylene, Teflon, or other non-reactive material. The effect that these different materials have on shielding the radioactive emissions from the detector varies with particle type and energy. Also, the thickness of the container walls can increase the average distance of the center-of-activity of the sample to the detector. Both of these sample container characteristics can affect the net screening result.
- Volume/shape/density. The sample volume must be consistent with gross measurements made during the calibration of the screening equipment so that the relative configuration of sample-to-detector is maintained. Thus, it is important that the sample container be virtually identical to the container used for calibration purposes. Sample density (or for solids, the degree of compaction) has a significant effect on the potential self-shielding of the sample from the detector. The mass of the calibration source and the sample should be relatively close in value to achieve consistent configuration.
- The figure of merit[12] (FOM) for the configuration of the shielding may need to be optimized (i.e., a larger FOM is better). For example, it may be advantageous to have a relatively large shielded volume with the sample centrally located, versus a shielded volume that exactly fits the sample geometry.
- Location of the sensitive detection area in the screening equipment. The manufacturer's detailed diagram for the specific model of screening equipment should be available so that the optimum position of the detector with the sample can be achieved (See Figure 3).
- Size and shape of the detector with respect to the sample geometry. The sample shape and detector juxtapositioning can have significant effects on the measurement. One measure of this is the FOM.

An example illustrating the effects of the size and shape of the detector on the FOM can be seen in Table 4, which identifies some data taken using NaI(Tl) detectors of various sizes (none of

[12] FOM = [(detector efficiency)^2/background] (Mann et al., 1991).

these were well detectors). The sample container was a 1 liter plastic bottle. The data were recorded using a detector and shielding as shown in Figure 3. The configuration of the detector and shielding actually used in this case was not optimal: In the bottom orientation position, the detector is partially unshielded, and the flat surface of the NaI(Tl) detector can is facing the sample bottle. Figure 3 also shows the side orientation where again the detector is partially unshielded, and the curved detector cover is parallel to the sample. Also, note the actual position of the detector crystal in both cases. It is clear in either case, however, that detector size and positioning with respect to the sample will have a significant effect on the measurement sensitivity (based on the FOM).

TABLE 4 – Response and Figure of Merit for ^{60}Co and ^{137}Cs with Different NaI(Tl) Detector Configurations

Radionuclide	Activity pCi/L	Net cpm			Figure of Merit		
		1"×1"	2"×2"	3"×3"	1"×1"	2"×2"	3"×3"
Background (BO)	–	2.80×10^{2}	1.65×10^{3}	2.4×10^{3}	–	–	–
^{137}Cs (BO)	5.038×10^{5}	2.22×10^{3}	1.34×10^{4}	1.3×10^{4}	6.93×10^{-8}	4.28×10^{-7}	2.77×10^{-7}
^{60}Co (BO)	3.317×10^{4}	5.5×10^{2}	9.5×10^{2}	7.5×10^{2}	1.67×10^{-7}	4.97×10^{-7}	2.13×10^{-7}
Background (SO)	–	2.7×10^{2}	1.1×10^{3}	1.75×10^{3}	–	–	–
^{137}Cs (SO)	5.038×10^{5}	5.03×10^{3}	1.66×10^{4}	1.78×10^{4}	3.69×10^{-7}	9.87×10^{-7}	7.13×10^{-7}
^{137}Cs (SO)	5.038×10^{4}	3.1×10^{2}	9.0×10^{2}	6.0×10^{2}	1.4×10^{-7}	2.90×10^{-9}	8.1×10^{-8}
^{137}Cs (SO)	1.242×10^{4}	1.5×10^{2}	3.0×10^{2}	1.2×10^{2}	5.40×10^{-7}	5.30×10^{-7}	5.33×10^{-8}
^{60}Co (SO)	3.317×10^{4}	5.8×10^{2}	2.2×10^{3}	1.5×10^{3}	1.13×10^{-6}	3.99×10^{-6}	1.17×10^{-6}

Notes:
SO = Side Orientation (see Figure 3)
BO = Bottom Orientation (see Figure 3)
Example Calculation: For the Cs bottom orientation (BO) and the 1"×1" detector
FOM = [net cpm/pCi/L]^2/[Background] = $[2.22\times10^{3}/5.038\times10^{5}]^2/(2.8\times10^{2}) = 6.93\times10^{-8}$

The data indicate that the biggest detector volume does not always give the highest count rate, nor does it always yield the highest value FOM. Thus, it is imperative that the detection equipment used be assessed in a similar fashion to determine which screening equipment is best suited for each combination of matrix and geometry. Two factors to be considered in determining this are:

- Location of the mean sample activity relative to the location of the detector, and
- Shielding (covering) of the screening equipment.

There are different considerations for samples that need to be screened for gamma radiation. An example is using a NaI(Tl) well detector. Many different sample types can be accommodated into this well for screening purposes. For example, a 47-mm air particulate filter may be rolled and inserted into a container, such that the container will fit reproducibly into the well of the NaI(Tl) detector, improving overall efficiency for detection. When doing this, care must be taken to avoid contaminating the detector. That specific geometry for calibrating this style of detector can be accommodated by most laboratories.

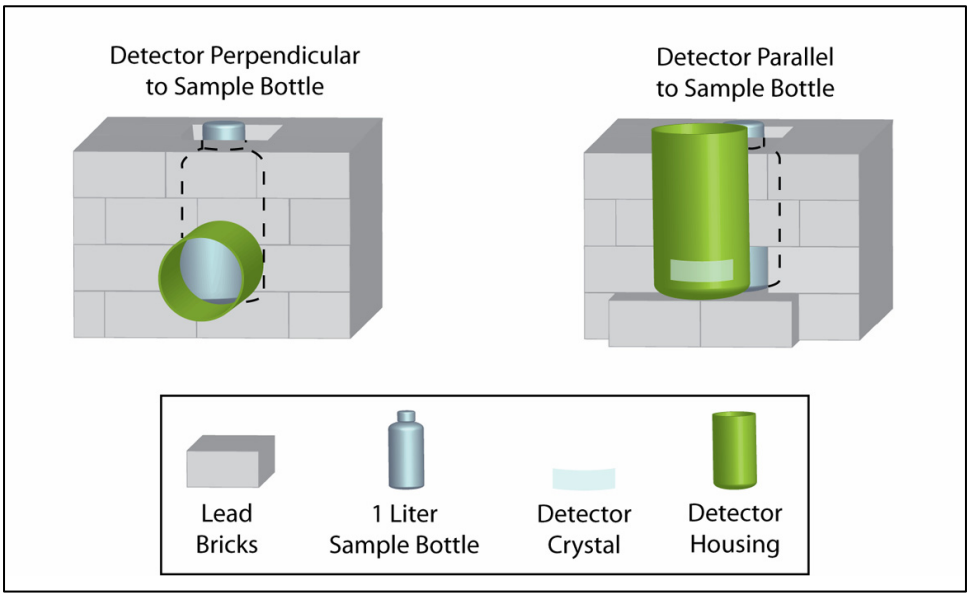

FIGURE 3 – Shown Without Bricks Covering Top of Shielded Geometry. NaI(Tl) Detector Example

Figure 4 shows another way to configure the detector and the sample bottle to achieve a better FOM for the measurement. In this configuration, the active area of the NaI(Tl) detector is inside the shielding and thus has a lower net background from room and ambient background contributions.

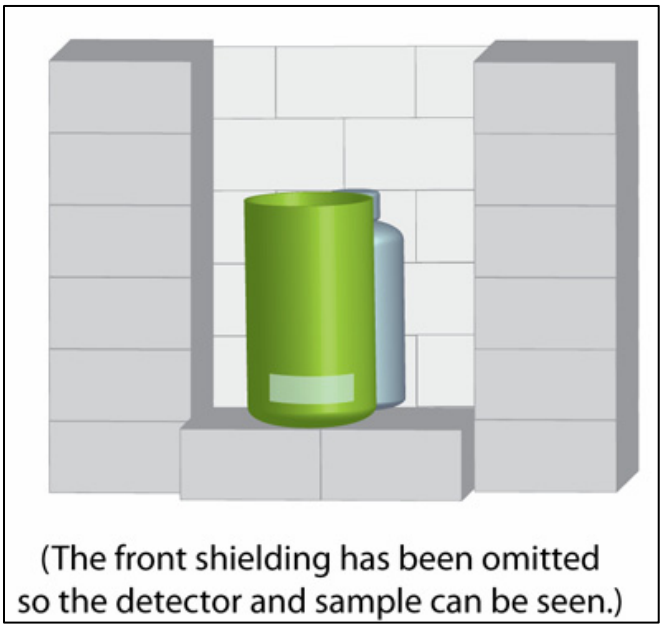

FIGURE 4 – An Improved Orientation for Shielding. Active Detector Area Within Shielding.

Figure 5 shows two different configurations of shielding with respect to the detector that will provide different backgrounds. Note that the thickness of the shielding walls is the same but that the internal cavity in which the detector is held is larger in Figure 5B. The larger volume ultimately leads to a better FOM since any Compton scattering from the shielding in 5B will impinge to a lesser degree on the detector than in 5A solely due to distance. In Figure 5B, a sample stand has been added to put the sample in the middle of the shielded volume, and the detector has been raised slightly to yield the same orientation as in 5A, thus maintaining the same detector efficiency.

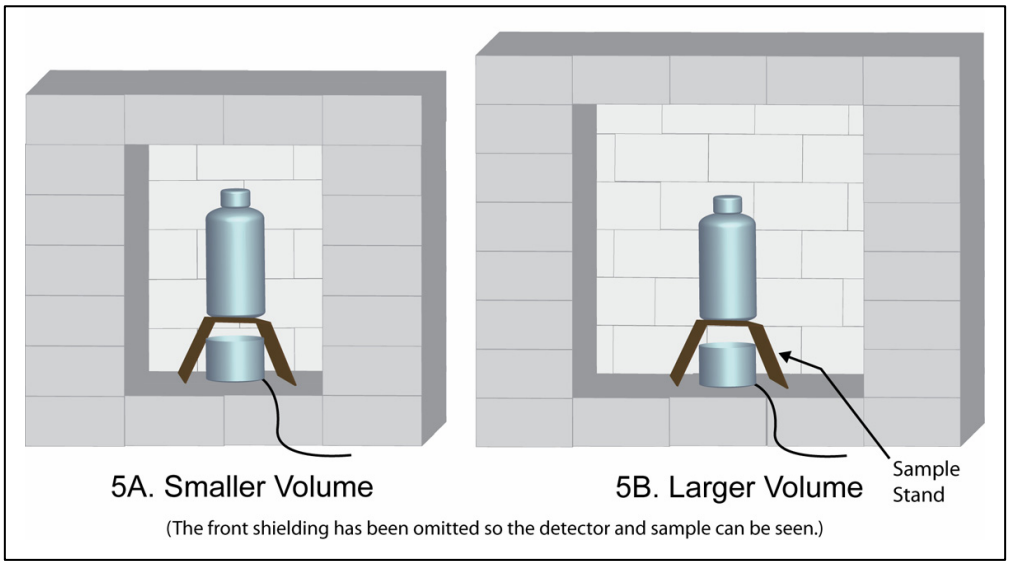

FIGURE 5 – Relative Size of Shielded Volume

Figure 6 shows a configuration for a pancake-style screening instrument (could be gross alpha-beta or beta-gamma). The air particulate filter is slid into place beneath the detector, which is maintained in a fixed position using a small stand. The presence of shielding allows reduction in background for the detector and for the sample, and provides a fixed geometry for consistent results.

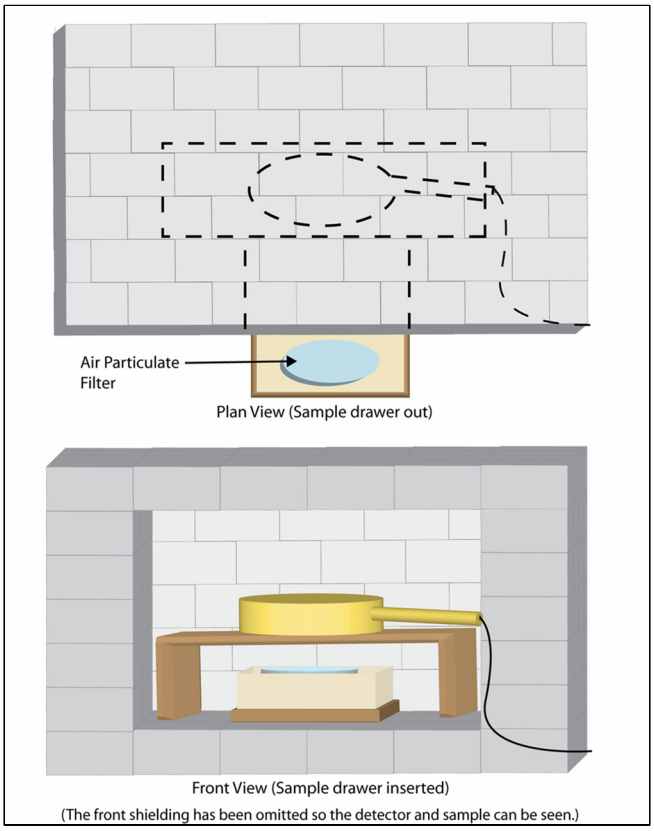

FIGURE 6 – Sample Shielding and Detector Orientations for Gross Screening of Air Particulate Filters Using an Alpha/Beta Pancake Detector

Crosstalk, Dead-Band, and Self-Absorption Factors

The degree of crosstalk as determined under routine instrument calibration conditions may not be significant. However, when the activity being measured is two and three orders of magnitude greater than normal sample test sources, crosstalk that was once obscured in the background may provide a signal that is indicative of a particle type that is absent. Thus, it is important to challenge the screening instrumentation with standards of high activity so that the level of cross-talk can be assessed. One such application involves GPC systems that are simultaneously counting gross alpha and beta activity. An assessment of crosstalk should be made in the beta channel response when the alpha activity is large compared to the beta activity and compared with the same beta activity response with no corresponding alpha activity. The inverse assessment should also be made. These measurements may lead the lab to apply a "dead band" between the lower level beta and upper level alpha discriminator settings that normally would not be used. This dead band would minimize the crosstalk, but would also lower the efficiency for both types of particles. Thus, the use of a dead band should be used judiciously to avoid abnormally long count times when screening time is at a premium.

It should also be recognized that elevated activity of radionuclides that decay only by beta emission may result in counts above background when using a sodium iodide detector for gross count assessment (e.g., as when using a small article monitor). The *bremstrahlung* radiation, emitted as a result of the beta interaction with matter, yields low-energy photons that produce a signal in the sodium iodide detector.

Self-absorption factors are significant for alpha- and beta-emitters. Determining how sample mass affects the efficiency of detection can be estimated using calibration sources and absorbing materials of known areal density (measured in units of mg/cm^2) placed between the sample and the detector. This intervening material would simulate the sample mass when the sample is not ideal (i.e., the sample is not "massless" and will absorb some of the contained radiation). This mass attenuation correction for self-absorption is similar to determining unknown beta particle energy using the Feather Method.[13] For alpha particles, this may mean using a thin film of aluminized Mylar, while for betas, varied thicknesses of aluminum metal may be used. The areal density effect for each detector should be semi-quantitatively identified so that estimates of activity correction can be made when samples of observable mass are measured using detection techniques such as GPC.

Final Instrument Calibration and Method Validation

Once the detectors to be used for screening have been selected and the considerations for sample to detector configuration and efficiency have been assessed, a method should be written. The

[13]A technique that has been used successfully to determine the energy of beta-only emitters is to measure the range of the beta particles in a pure material ("Feather analysis"). The ranges of beta particles in several pure materials (such as aluminum) have already been established. The units of thickness are expressed as areal density, or mg/cm^2. A set of aluminum absorbers of varying thickness is used, and the activity versus the absorber thickness is plotted on a semi-log scale. The linear portion of this curve is then extrapolated to find the "zero" activity thickness. This is then related to the $E_{\beta max}$ of the beta particle, which will be characteristic for a particular radionuclide. A discussion of this technique can be found in Chase, G.D. and J.L. Rabinowitz (1967). *Principles of Radioisotope Methodology*, 3rd Edition. Minneapolis: Chase and Burgess.

method should incorporate the laboratory's best estimate of the potential geometries and plausible radionuclides into the procedure. Specific instructions regarding the receiving and storing of the samples, recording of data, and sample aliquanting for particle-specific screening should be included in this method. Once the method is written, a method validation process that follows the *Method Validation Requirements for Qualifying Methods Used by Radiological Laboratories Participating in Incident Response Activities* (EPA, 2009b) should be followed. The method validation process requires the use of proficiency test samples to validate the detector response to achieve the MQOs established for the project or by the laboratory. Once the method has been validated, the procedure should be implemented routinely for sample processing by all staff members, which will reinforce training on the procedure.

C. Calibration of Screening Instruments when Radionuclide Identities are Known

Screening equipment that is calibrated for overall response to decay particles will have its accuracy challenged if the radionuclide in the sample to be measured has a different particle or energy.

During the initial phases of an emergency, before the identity of the radionuclide(s) associated with the event has been established, a response factor for the screening equipment presumably will be based on a single radionuclide, such as ^{137}Cs. As the radiological event progresses, the radionuclide(s) associated with the event should be identified. For example, if ^{192}Ir is identified, the factor used to convert cpm/sample to pCi/sample should be changed so that the screening equipment more accurately characterizes the sample activity level, and the laboratory will be able to characterize the activity of the samples more accurately. This change in the response factor can be implemented in several ways:

1. The laboratory has already established a response factor on the screening equipment for this radionuclide in this geometry. In this case, receipt instructions need to be updated to include the identity of the radionuclide(s) of concern. For example, consider a beta/gamma survey meter that has been calibrated with a ^{137}Cs source that had a measured response factor for a 1-L liquid sample of 5.1×10^{-4} mR/h per pCi. This factor has been entered into the electronic database for the meter used (identified by serial number). Knowing now that the radionuclide of interest is ^{192}Ir, with a response factor of 2.8×10^{-4} mR/h per pCi, this response factor should replace the ^{137}Cs value currently present in the electronic database .[14] This change will identify more accurately the activity based on gross screening measurements.

2. The laboratory has performed an energy response factor curve for the screening equipment and can interpolate the curve for the effective mean emission energy of the radionuclide present in the sample. For example, this method is demonstrated in Figure 7 for a 47-mm air particulate filter using simulated data.

[14] The date of this change and the reason for the change need to be noted in the instrument data files.

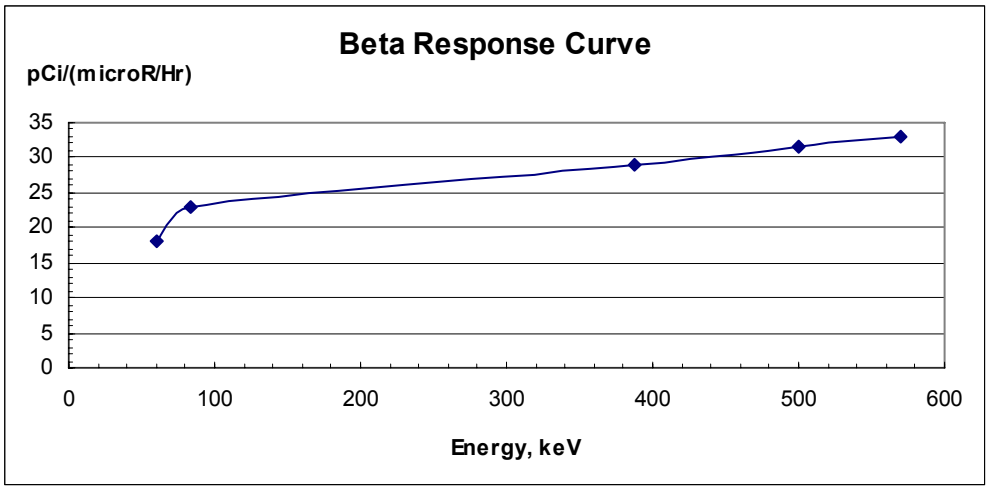

FIGURE 7 – Survey Meter 12345 Energy Open Window Response Curve for Beta Emitters

In Figure 7, the radionuclide energies represented are approximately one-third of $E_{\beta max}$. Thus, as an example, the effective beta particle energy for ^{14}C is 156 keV/3 = 55 keV.[15]

3. The laboratory may take a sample that is to be analyzed, and determine a conversion factor based on a comparison of the screening value and radionuclide-specific analysis results. In this case, it would likely be best to take an average conversion factor from several samples to ensure the most accurate representation of the factor. This is because the factor can be affected by non-uniform distribution in the sample. Consequently, the laboratory should consider the potential for significant uncertainty in this conversion factor, which may be estimated by the standard deviation of the individual measurements used to calculate the average conversion factor.

As an example, a data table like the one below could be constructed. Note that the information shown is not based on actual data but is used for illustrative purposes only.

Table 5 – Screening Instrument Conversion Factor Based on Sample Analysis of a 1-Liter Sample Geometry

Sample	Screening Value, (mR/h)/L	Radionuclide-Specific Analysis Results, ^{137}Cs µCi/L	Conversion Factor [µCi]/(mR/h)	Estimated Conversion Factor Uncertainty [µCi]/(mR/h) [1]
Background	2	–	–	–
Sample 1	55	1,601	30.2	–
Sample 2	78	2,005	26.4	–
Sample 3	41	1,448	37.1	–
Average Conversion Factor: 31 ± 5				

[1] The method used to estimate the screening equipment uncertainty must be decided upon by the laboratory. The column is included here so that it is clear that this should be one aspect of this process.

[15] It is important to note that the use of this type of curve is not necessary for alpha instruments since the alpha response would be mostly independent of energy.

In this example, the samples have already been screened using a micro-R meter. The samples are then analyzed using a radionuclide-specific method, and the values obtained are specifically for ^{137}Cs. The final analytical values for the samples are divided by the original exposure rate measurements to obtain a conversion factor for the radionuclide contained in the event-specific samples. The average conversion factor and the associated uncertainty estimate are rounded to the appropriate number of significant digits. In this case, the conversion factor would allow the laboratory to estimate the concentration of ^{137}Cs in the subsequent samples, based on the micro-R meter screening results. This simplified example uses a single radionuclide with no ingrowth considerations. In cases where one or more radioactive progeny may be present, care must be taken to ensure that the screening conditions, especially the degree of progeny ingrowth, are reasonably consistent. In all cases, the counting geometry for sample screening should be as consistent as possible.

During the latter phases of an event (when the radionuclide content of the samples is expected at the 10^{-4} risk level for air filters and the maximum contaminant levels for drinking water), the screening of lower activity samples may be performed using a different technique. For example, if both alpha- and beta-emitters are present, rather than using GPC to screen the samples for both alpha- and beta-emitters simultaneously, it may be advantageous to perform each screen separately and extend the count time to ensure better discrimination between those samples where analysis is required immediately and those that may be delayed.

D. Measurement Quality Objectives (MQOs) for the Screening Process

Screening of samples as they arrive significantly impacts the laboratory's decisions about which samples to analyze first. The IC should have decided how the samples are to be prioritized and communicated this to the laboratory. The laboratory may confidently screen these samples for gross activity so that they can be processed in a timely fashion based on the needs of the incident.

General guidance on how to establish an MQO for the required method uncertainty can be found in MARLAP (2004) and specifically for radionuclides in water (EPA 2008a, Appendix VI). Additional MQOs for screening should be established by the laboratory based on the type of instrumentation available.

In order to illustrate the typical decisions and actions to be taken by a laboratory for calibration and gross sample screening, three examples using theoretical samples and measurement results are provided in Appendices I-III. These examples demonstrate an acceptable method for the calibration of instruments and measurement of samples, but each example is one of several different possible variations of calibration and measurement techniques. The examples here should not be construed as limiting.

The first scenario (Appendix I) illustrates how a laboratory *may prepare* its screening equipment to be ready to receive samples from a radiological incident. The instrumentation and standards used are limited to what is available to the laboratory, which demonstrates how some basic planning can assist in being prepared for such an event. In the second scenario (Appendix II), the same laboratory *has received* samples from a radiological transportation accident and has been asked to rapidly assess the spread and degree of contamination. The calibration of the screening

equipment is optimized to assess the contamination levels in the samples that have been sent. The third scenario (Appendix III) discusses how instrument calibrations may be adjusted during the latter phases of an event when the radionuclide(s) identity(ies) is (are) known. In this instance, the screening process will be looking at lower overall activity in the samples so that re-calibration with the same radionuclide will enhance the detection capability of the screening equipment.

E. Key Recommendations

Laboratories should be prepared for potential radiological events where large numbers of samples at much higher activity concentrations than normal arrive suddenly. To assist laboratory personnel in promptly receiving, prioritizing, and analyzing samples, the following is a summary of the key recommendations for sample screening:

- Screening equipment should be calibrated with traceable sources that match geometries for anticipated emergency response samples.
- These calibrations should have associated direct reading conversion factors for ease of reporting results in the appropriate units.
- Laboratories should have written procedures (or instructions) for the process of screening emergency response samples.
- Shielding for the screening equipment should be configured to maximize the signal to background ratio, providing the analyst with smaller uncertainties of the measurement.
- A plan that provides for the calibration adjustment of the screening equipment based on the incident radionuclide(s) should be prepared for that time when the activities are much lower, and better discrimination between lower level activities will be required.

Appendix I – Screening Instrumentation Initial Calibration

Background

ABG Laboratory, Inc., has decided to set aside certain instruments for radiological events where sample gross screening will be necessary. A GM pancake detector and an old 3"×3", planar, NaI(Tl) detector with a scaler have separate, shielded geometries for samples of 47-mm filters, a 1-L liquid, and a 250-g solids container. The equipment is to be located near the sample-receiving area of the laboratory facility. Once the equipment is set up, the laboratory staff performs background counts on the instruments while waiting for the new calibration sources to arrive. The calibration sources are ^{99}Tc, ^{90}Sr, ^{241}Am, ^{57}Co, ^{230}Th, and ^{60}Co. Each source has been ordered for each geometry identified above and is traceable to a national standards body, such as the National Institute of Standards and Technology in the United States.

Discussion

The NaI(Tl) detector was set up to accumulate total counts in a two-minute count. The GM pancake detector was set up in rate mode for cpm. The following table identifies the detector background and response from the standards for each of the instruments.

TABLE 6 – Calibration Data for Screening Instrument Response

Detector	Radionuclide Source	Total Background*	Activity pCi	Air Filter, Net Counts	250 g Can, Net Counts	1 L Bottle, Net Counts
NaI(Tl)	^{57}Co	5,840 cpm	8.0×10^{5}	8.88×10^{4}	5.33×10^{4}	2.13×10^{4}
			2.0×10^{5}	2.22×10^{4}	1.33×10^{4}	5.33×10^{3}
	^{60}Co	5,840 cpm	8.0×10^{5}	1.24×10^{5}	9.59×10^{4}	3.66×10^{4}
			2.0×10^{5}	3.11×10^{4}	2.40×10^{4}	8.88×10^{3}
GM				**Air Filter, Net cpm**	**250 g Can (open) Net cpm**	**1 L bottle (closed, side measurement) Net cpm**
Alpha	^{241}Am	0.05 cpm	40	8	0.18	0
			10	2	0.04	0
	^{232}Th	0.05 cpm	32	6.5	0.14	0
			8.0	1.6	0.04	0
Beta	^{99}Tc	0.8 cpm	4.5×10^{3}	509	10	0.1
			1.2×10^{3}	136	2.5	0.03
	^{90}Sr	0.8cpm	300	133	67	20
			80	35.5	18	5.3

*For the sodium iodide detector, background counts were summed over the energy range of 50 to 2500 keV. For the GM detector, the background represents an average measurement performed at several times of the day. Each instrument background measurement was made using an empty sample container in the position for sample measurement, and the sample plus detector were shielded with 4" of lead brick.

The laboratory staff has made separate calibration factors for low- and high-energy gamma-ray emitters. Similarly, for the ^{90}Sr and ^{99}Tc, the efficiency of detection of the ^{90}Sr is much better due to a smaller degree of self-absorption in the sample and better penetration of the GM detector beta shield when used. The response factors for both the ^{241}Am and the ^{232}Th are the same. The laboratory staff has made the following response factor table for its instruments:

TABLE 7 – Response Factors (RF) for Radionuclides with Respective Screening Equipment

Radionuclide	Energy, keV	Abundance Factor*	Air Filter, pCi/cpm	Open Tuna Can, pCi/cpm	Bottle, pCi/cpm
NaI(Tl) Detector, Gamma					
^{57}Co	121, 135	1.003	17.5	29.9	74.8
^{60}Co	1,173; 1,332	2.0	6.45	8.34	22.5
GM Detector, Alpha					
^{241}Am	5,449; 5,440	1.0	5.01	2.25×10^{2}	1.5×10^{5}
GM Detector, Beta					
^{99}Tc,	210	1.0	8.83	4.50×10^{2}	4.50×10^{4}
^{90}Sr	546; 2,280	2.0	1.13	2.25	7.5

*The abundance factor is the number of particles that are produced per decay of the radionuclide and can be detected by the detector listed. The value for ^{60}Co is 2.0 since it yields two gamma rays for each decay (the gamma rays are in full coincidence). For ^{90}Sr, the value is 2.0 since it is in secular equilibrium with its progeny ^{90}Y, also a beta-emitter.

The response factors in the table are calculated as follows:

$$\mathrm{RF} = \frac{\text{Source pCi}}{(\text{net cpm}) \cdot \text{Abundance Factor}}$$

Thus, for the air filter geometry on the NaI(Tl) detector for ^{60}Co:

$$\mathrm{RF}_{\text{Co-60}} = \frac{8\times10^{5}}{(1.24\times10^{5}\ \text{counts}/2\,\text{min}) \cdot 2.0} = 6.45\,\text{pCi/cpm}$$

Appendix II – Radiological Event Screening for ^{241}Am

Background

The date is November 15, and steady winds from the northwest at about 20-25 mph are expected through tomorrow. A truck is carrying used ^{99m}Tc generators[16] and ^{241}Am smoke detectors (as the bulk of its shipment, but other radioactive waste materials of smaller volume were on board). The truck overturns and slides into a rock embankment, bursting into flames along a small two-lane highway between towns, and burns down to the tires. Air sampling equipment has been stationed in several locations in both towns and along several roadsides. Air samples are expected to arrive at the laboratory by 1800 hours this evening (it is currently 1300 hours). Additionally, several hundred soil and crop samples are expected over the next week so that the plume can be tracked.

The IC has requested that the highest activity samples be identified and analyzed first so that the recovery phase can focus on:

- Determining how much material has become airborne, and
- Cleaning up high activity areas first to remove the bulk of the source term.

Discussion

ABG Laboratory, Inc., has been contacted and told to expect the samples shortly. It will be using the calibrations it has made for its screening equipment to accommodate the influx of samples.

Table 8 identifies the sample activity measured for each of the matrices received at ~1800 hours. Knowing the truck's cargo makes use of the calibration factors straightforward. The air particulate filters have been transmitted in glassine envelopes, and the soil samples were stored in solids (tuna) can geometry with a removable lid. The laboratory has verified that these geometries match the geometries it used for its gross screening calibration of the instruments.

The spreadsheet it is using has the following equations for the analysis:

- Air Filters
  - Gross Alpha Activity = (meter reading, cpm – 0.05, cpm)×(5.01pCi/cpm)
  - Gross Beta activity = (meter reading, cpm – 0.8, cpm)×(8.83 pCi/cpm)
  - Gross Gamma Activity[17] = (Total counts – 5,840 cpm)x(17.5 pCi/cpm)
- Solids Can
  - Gross Alpha Activity[18] = (meter reading, cpm – 0.05, cpm)×(225pCi/cpm)
  - Gross Beta activity = (meter reading, cpm – 0.8, cpm)×(450 pCi/cpm)
  - Gross Gamma Activity = (Total counts – 5,840 cpm)×(8.34 pCi/cpm)

[16] Although the ^{99m}Tc ($t_{½}$ = 6 hours) and its ^{99}Mo ($t_{½}$ = 66 hours) precursor have decayed, the progeny ^{99}Tc has a half-life of 2.1×10^{5} y, and will thus be present in the environmental samples exposed during the accident.

[17] Note that the energy of ^{241}Am (59 keV) is somewhat lower than that of ^{57}Co (122 and 135 keV) and will be significantly affected by the aluminum shielding on the NaI(Tl) detector.

[18] The laboratory homogenized the samples by shaking prior to opening and performing the gross screen. The values will be affected due to sample self-shielding.

TABLE 8 – Gross Screening Measurement Results from Transportation Incident

Sample	Alpha GM Detector, cpm	α Gross Screening Estimate, pCi	Beta Open Window Probe, cpm	β Gross Screening Estimate, pCi	NaI(Tl) Detector, cpm	γ Gross Screening Estimate, pCi
Air Filter-1	4.7	**23.3**	1.77	8.57	5,750	-1,580
Air Filter-2	0.085	0.175	**5.82**	44.3	5,900	1,050
Air Filter-3	0.10	0.25	**2.88**	18.4	5,880	700
Soil-1	0.550	**113**	1.46	**297**	6,050	**1,750**
Soil-2	0.16	**24.8**	3.9	**1,395**	8,120	**19,000**
Soil-3	0.07	4.5	0.7	-45	6,000	1,330

The laboratory reports back to the IC that the sample results, bolded above, have the highest concentrations based on gross screening results, and the analyses for ^{241}Am and ^{99}Tc are in progress. The laboratory supervisor queues the samples according to activity. The highest-activity samples are to be analyzed first. The supervisor also notifies the separations chemists about the levels of activity they will find in these samples.

The laboratory protocol has established a limit of 100 pCi per aliquant. Normally, the sample size processed is 2.0 g. However, for Soil-2, there is 250 g of sample, and in order to be less than 100 pCi, only 1.0–1.3 g of sample will be aliquanted for this analysis.[19]

[19] The gross gamma estimate for the entire sample is 19,000 pCi. This gives about 19,000/250g = 76 pCi/g. Taking a 2-g sample would result in 152 pCi, exceeding the laboratory limit. An aliquant of 1.3 g yields 98 pCi.

Appendix III – Screening Instrumentation Response Corrected for Different Radionuclide

Background

A suspected terrorist event involving explosive devices has occurred. Several different radioactive materials suppliers have reported thefts of large quantities of radionuclides in the past three months. The missing radionuclides were ^{210}Po and ^{192}Ir. Preliminary evidence from the scene of the incident identified the presence of radioactive materials. It is suspected that the materials that were reported missing are related to this event.

Radiochemistry Analysts of America has been contacted to screen, then analyze about 200 samples a day for ^{192}Ir and ^{210}Po, and any other radionuclides that may be present. The samples will be air particulate filters (47 mm) and soil (~0.200 kg). It is Day 1 at 1100 hours, and the first sample shipment will arrive at 0600 hours on Day 2. The IC has indicated that the sample priority is to analyze those samples with the highest activity first. The laboratory has neither a ^{210}Po nor a ^{192}Ir source/standard.

Discussion

The laboratory has selected a NaI(Tl) well detector to screen the air particulate filter samples for the ^{192}Ir. Its current calibration factor used ^{60}Co, but it has a response curve based on energy as shown below.[20]

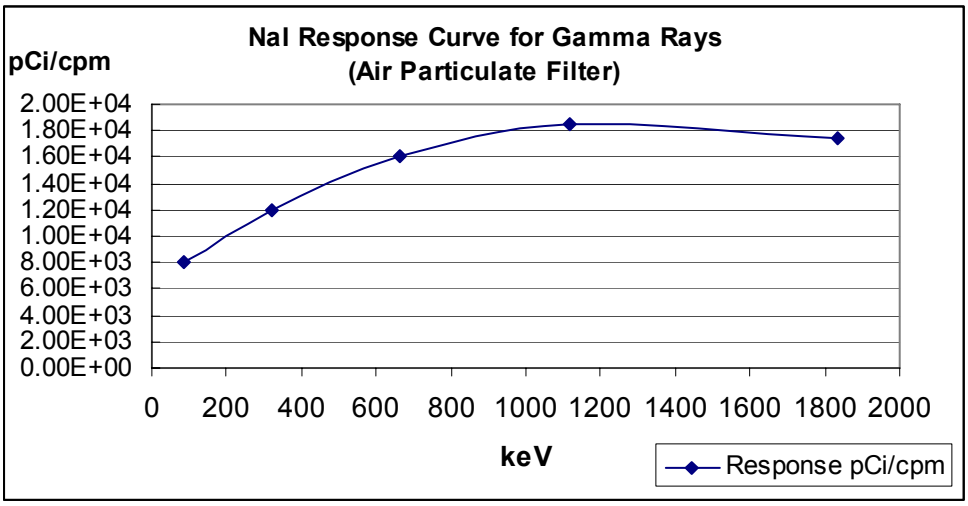

FIGURE 8 – Gamma Energy Response Curve for a NaI(Tl) Detector

The average energy[21] of the ^{192}Ir is approximately 390 keV. This corresponds to a factor of 1.30×10^{4} pCi/(net cpm) as estimated using the curve in Figure 8. A similar curve was made for the solid geometry and a response factor of 6.1×10^{3} pCi/(net cpm) for ^{192}Ir was estimated.

[20] Calibration points for the curve were 88, 320, 662, 1115, and 1836 keV. The standards were counted for 5 minutes each in a shielded geometry. The standards used were individual radionuclides (i.e., *not* a mixed gamma ray source).
[21] Ir-192 has several different gamma rays. The average energy per decay event is approximately 390 keV based on the sum of the gamma ray abundances multiplied by their respective energies.

The laboratory staff is using a GM pancake-style detector for alpha screening of the samples. The corresponding response factors for alpha particles are:

Air filter	Solid, 200 g
5.01	2.25×10^{2}

The following day, several hundred samples are received, and the screening process begins. An example dataset is shown below:

TABLE 9 – Results of Screening Measurement Using Adjusted Response

Sample ID	Air Filter 1	Air Filter 2	Air Filter 3	Soil Sample 1	Soil Sample 2	Background
NaI(Tl), cpm	4,630	4,550	4,480	6,100	4,700	4,500
GM Detector, cpm	2.80	1.56	0.23	0.13	0.14	0.12
Screening Results						
Gross gamma, pCi	1.7×10^{6}	6.5×10^{5}	-2.6×10^{5}	9.8×10^{7}	1.2×10^{6}	–
Gross alpha, pCi	13.43	7.21	0.55	2.25	4.5	–

Based on the results of these screening measurements, air filter 1 and soil 1 have the highest activities and should be analyzed first for ^{192}Ir and ^{210}Po.

Appendix IV – Additional Sources and References

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