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Guide for Radiological Laboratories for the Control of Radioactive Contamination and Radiation Exposure

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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 need to ensure adequate laboratory infrastructure to support response and recovery actions following a major radiological or nuclear 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, EPA has established the Environmental Response Laboratory Network (ERLN) to address chemical, biological, and radiological threats during nationally significant incidents (www.epa.gov/erln/). EPA is the RFA for monitoring, surveillance, and remediation of radiological agents. EPA will share responsibility for overall incident response with the U.S. Department of Energy (DOE).

This document is one of several initiatives by EPA's Office of Radiation and Indoor Air designed to provide guidance to radiological laboratories that will support EPA's response and recovery actions following a radiological or nuclear incident, such as the detonation of an improvised nuclear device (IND) or a radiological dispersal device (RDD) ("dirty bomb"). During the response to such an incident, a radiological laboratory may need to process much greater numbers of samples, some of which are likely to have higher levels of radioactivity than the laboratory is accustomed to handling. This guide describes the likely radioactive contamination control and challenges that would face personnel at the laboratory following such an incident, and offers suggestions for preparing for these challenges.

Advance planning by the laboratory to control radioactive contamination and radiation will be critical to ensure the rapid delivery of radioanalytical results that meet the required data quality objectives associated with the protection of human health and the environment.

This guide identifies key topics for consideration by the laboratory and presents various suggestions on which the laboratory may base its decisions regarding the establishment of operational protocols. Specifically, the guide discusses the need to prepare the laboratory to participate in the incident response by defining and establishing discreet work areas and operational guidelines for the various laboratory activities, based primarily on the levels of radioactivity being processed and the flow of radioactive material through the laboratory, and by establishing customized laboratory-specific protocols for the key activities that are likely to have a significant impact on contamination and radiation control.

As with any technical endeavor, the establishment of effective contamination and radiation control for radiological or nuclear incident response in a radiological laboratory will require each laboratory to develop practices and protocols that address the unique needs of its facility. This guide provides examples of practices and descriptions of work areas that are intended to serve as

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

a starting point for the laboratory to consider in the development of its own solutions to the issues presented. The guide does not address a complete catalog of control methodologies or potential situations.

This document[2] 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 analysis of 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 Laboratories – Identification, Preparation, and Implementation of Core Operations for Radiological or Nuclear Incident Response* (EPA 402-R-10-002, June 2010)
- *A Performance-Based Approach to the Use of Swipe Samples in Response to a Radiological or Nuclear Incident* (EPA 600-R-11-122, October 2011)
- *Uses of Field and Laboratory Measurements During a Radiological or Nuclear Incident* (EPA 402-R-12-007, August 2012)
- *Radiological Laboratory Sample Analysis Guide for Radiological or Nuclear Incidents – Radionuclides in Soil* (EPA 402-R-12-006, September 2012)

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[2] All the documents in this series are available at www.epa.gov/erln/radiation.html and at www.epa.gov/narel/incident_guides.html.

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DEDICATION

This report is dedicated to the memory of our friend and colleague, David Garman. Dave administered nearly three dozen separate contracted radiochemistry projects for EPA dating back nearly 17 years, beginning with the *Multi-Agency Radiological Laboratory Analytical Protocols* (MARLAP) in 1994. Dave put up with countless changes of prime contractors, priorities, subcontractors, and budgets, all with good cheer, diligence, and all while keeping up with his "day job" as counting room lead for alpha-spectrometry analysis at NAREL.

Dave started with EPA's National Air and Radiation Laboratory in 1992. He left many friends throughout EPA and the radioanalytical community, and he will be greatly missed.

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ACRONYMS, ABBREVIATIONS, UNITS, AND SYMBOLS

(Excluding chemical symbols and formulas)

α .....alpha particle
α .....probability of a Type I decision error
AA.....atomic absorption (spectrometry)
AAL .....analytical action level
AAL(*C*) .....analytical action level for contamination control analyses
AAL(*S*).....analytical action level for field sample analyses
ADL .....analytical decision level
ADL(*C*) .....analytical decision level for contamination control analyses
ADL(*S*).....analytical decision level for field sample analyses
ALARA.....As Low As Reasonably Achievable
AMTLD .....area monitoring thermoluminescent dosimeter
ASHRAE.....American Society of Heating, Refrigerating, and Air-Conditioning Engineers
β .....beta particle
β.....probability of a Type II decision error
Bq.....becquerel (1 dps)
CFR.....*Code of Federal Regulations*
Ci.....curie
CSU.....combined standard uncertainty
d.....day
DL .....discrimination level
DOE .....United States Department of Energy
DOT .....United States Department of Transportation
dpm .....disintegrations per minute
dps.....disintegrations per second
DQO.....data quality objective
DRP.....discrete radioactive particle
EPA.....United States Environmental Protection Agency
ERLN .....Environmental Response Laboratory Network
γ.....gamma ray
g.....gram
GC/MS .....gas chromatograph/mass spectrometer
G-M.....Geiger-Müller
GPC.....gas-proportional counting/counter
Gy.....gray
h.....hour
HEPA .....high efficiency particulate air [filter]
HPGe.....high purity germanium [detector]
HVAC .....heating, ventilation, air conditioning [system]
ICLN .....Integrated Consortium of Laboratory Networks
ICP .....inductively coupled plasma
IND .....improvised nuclear device (i.e., a nuclear bomb)
IRP .....Incident Response Plan
L .....liter
LSC .....liquid scintillation counting/counter

μCi .....microcurie (10^{-6} Ci)
μR.....microroentgen (10^{-6} R)
m .....meter
MARLAP.....*Multi-Agency Radiological Laboratory Analytical Protocols [Manual]*
MARSAME .....*Multi-Agency Radiation Survey and Assessment of Materials and Equipment [Manual]*
MDC .....minimum detectable concentration
mg .....milligram (10^{-3} g)
min .....minute
mrem .....millirem (10^{-3} rem)
MQO .....measurement quality objective
NaI(Tl) .....thallium-activated sodium iodide detector
NEPA .....National Environmental Policy Act
NRC .....United States Nuclear Regulatory Commission
φ_{MR}.....required relative method uncertainty
$\varphi_{MR}(C)$ .....required relative method uncertainty above the AAL(*C*) for contamination control analyses
$\varphi_{MR}(S)$ .....required relative method uncertainty above the AAL(*S*) for field sample analyses
PAG.....protective action guide
pCi.....picocurie (10^{-12} Ci)
PPE.....personal protective equipment
PT.....proficiency testing
QC.....quality control
R.....roentgen
rad .....radiation absorbed dose
RCP.....Radiological Controls Program
RCRA.....Resource Conservation and Recovery Act
RDD .....radiological dispersal device (i.e., “dirty bomb”)
rem .....roentgen equivalent: man
RFA.....responsible federal agency
RPP .....radiation protection program
RSO.....radiation safety officer
s.....second
SI.....International System of Units
SOP .....standard operating procedure
Sv .....sievert
TEDE .....total effective dose equivalent
TLD.....thermoluminescence dosimeter
u_{MR} .....required method uncertainty
$u_{MR}(C)$ .....required method uncertainty at or below the AAL(*C*) for contamination control analyses
$u_{MR}(S)$ .....required method uncertainty at or below the AAL*(S)* for field sample analyses
y.....year
Z .....atomic number

RADIOMETRIC AND GENERAL UNIT CONVERSIONS

To Convert	To	Multiply by	To Convert	To	Multiply by
years (y)	seconds (s)	3.16×10^{7}	s	y	3.17×10^{-8}
	minutes (min)	5.26×10^{5}	min		1.90×10^{-6}
	hours (h)	8.77×10^{3}	h		1.14×10^{-4}
	days (d)	3.65×10^{2}	d		2.74×10^{-3}
disintegrations per second (dps)	Becquerels (Bq)	1	Bq	dps	1
Bq	picocuries (pCi)	27.0	pCi	Bq	3.70×10^{-2}
Bq/kg	pCi/g	2.70×10^{-2}	pCi/g	Bq/kg	37.0
Bq/m^3	pCi/L	2.70×10^{-2}	pCi/L	Bq/m^3	37.0
Bq/m^3	Bq/L	10^{-3}	Bq/L	Bq/m^3	10^{3}
microcuries per milliliter (μCi/mL)	pCi/L	10^{9}	pCi/L	μCi/mL	10^{-9}
disintegrations per minute (dpm)	μCi	4.50×10^{-7}	pCi	dpm	2.22
	pCi	4.50×10^{-1}	μCi	dpm	2.22×10^{6}
cubic feet (ft^3)	cubic meters (m^3)	2.83×10^{-2}	m^3	ft^3	35.3
gallons (gal)	liters (L)	3.78	L	gal	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 the International System of Units (SI). Conversion to SI units will be aided by the unit conversions in this table.

1. INTRODUCTION

Every radiochemical laboratory with a radioactive materials license must implement a radiation protection program (RPP) that controls and minimizes radiation exposure and radioactive contamination.[3] The primary purpose of the RPP is to protect laboratory personnel and the public from the effects of radiation resulting from laboratory activities. This guide assumes that such a program is in place and is designed to address issues related to the routine operations of the laboratory.

In the event of a radiological or nuclear incident, however, it is likely that many radiological laboratories will be called upon to perform sample analyses in support of the various response efforts taking place, and that the radioactivity concentrations of some of these samples may be well in excess of those to which the laboratory is routinely accustomed. The numbers of samples and the total quantity of sample material are also likely to be significantly increased. In addition, the increased radioactivity levels in the standards and tracers required for analysis, waste produced during analyses, sample test sources, and quality control (QC) samples will all contribute to the increased radioactivity and radiation levels in the laboratory.

Elevated radioactivity levels in the laboratory may increase the risk of occupational radiation exposure, may impact the quality of radioanalytical measurements by increasing instrument background count rates, may increase the possibility of cross-contamination among samples, and may become a potential source of laboratory and environmental contamination. The laboratory should make advance preparations for receiving and handling the samples in order to minimize radiation exposure and radioactive contamination.

> This section refers to both *radiological* and *radioanalytical* contamination.
>
> The general term *radioactive contamination* refers to the contamination of the laboratory facilities or personnel from radioactive materials. In some cases, radioactive contamination may occur at levels that pose a *radiological* health and safety concern.
>
> The specific term *radioanalytical contamination* refers to contamination of the sample material, instrumentation, or laboratory facility that leads to sample cross-contamination or otherwise negatively impacts radioanalyses.
>
> While the laboratory's surveillance and control measures for personnel protection and for the prevention of radioanalytical contamination may frequently overlap, the goals are sufficiently different that they may be discussed separately in this guide, when it becomes important to make the distinction.

These advance preparations should be clearly outlined in the RPP and in relevant standard operating procedures (SOPs). The advance preparations for a radiological or nuclear incident should include an assessment of the configuration of the laboratory, the resources available for the incident response, and the sample and waste handling and contamination control procedures to be implemented during the incident response.

In addition, the laboratory staff should be adequately trained to implement these measures efficiently and effectively during a radiological or nuclear incident. These preparations, the RPP,

[3] 10 CFR 20.1101, *Radiation Protection Programs*.

the laboratory SOPs, and the necessary training are essential components of an effective Radiological Controls Program (RCP).[4]

An effective Radiological Controls Program should eliminate, or at least minimize, the effects of increased radioactivity and radiation levels on laboratory facilities, personnel, and data quality. This may be accomplished through the development of procedures and practices to:

- Control the radioactive materials being handled in the laboratory. This includes the accurate assessment (screening) of the nature of the material and the establishment of well-defined and effective procedures that will guide the physical handling of the material and the movement of the material through the laboratory.[5]
- Actively monitor radioactive contamination and radiation exposures, and establish quantitative limits for contamination of surfaces, instruments, and personnel.
- Proactively address the decontamination and shielding of laboratory personnel to minimize occupational exposures and to prevent exceeding established quantitative limits.
- Programmatically address the decontamination of laboratory surfaces and equipment to prevent the exceedence of established quantitative limits, thereby reducing instrument backgrounds, and minimizing cross-contamination.

As with all other aspects of the laboratory's incident response activities, an RCP should anticipate the unique challenges associated with various radiological or nuclear incident scenarios and allow for rapid assessment of, and adjustments to, changing laboratory conditions.

IMPORTANT NOTE

This guide contains numerous examples of procedures for the control of radioactive contamination and radiation exposure. These examples are intended to provide guidance to the laboratory in the formulation of its own Radiological Controls Program. Users are strongly cautioned, however, that these are only examples, which may be used by the laboratory to assess its own operations and to formulate procedures that address the conditions and operations that may be unique to that specific laboratory. The examples are not intended to be prescriptive or to address every situation that the laboratory might encounter.

[4] A broader discussion of effective Radiological Controls Programs is provided in the companion document *Guide for Laboratories – Identification, Preparation, and Implementation of Core Operations for Radiological or Nuclear Incident Response* (EPA 2010).

[5] More detailed guidance for sample screening considerations is provided in the companion document *Radiological Laboratory Sample Screening Analysis Guide for Incidents of National Significance* (EPA 2009b).

1.1 Purpose and Scope

The purpose of this guide is to assist the laboratory in developing specific parts of an RCP that would enable the laboratory to safely and effectively participate in the response to a radiological or nuclear incident. Specifically, this document provides guidance that is intended to assist in the assessment of the physical layout of the laboratory, and to assist in the consideration of potential changes in the laboratory design and work flow to prevent the incoming sample material from compromising the analytical capabilities of the laboratory or exposing personnel to elevated levels of radiation.

This guide and its appendices also provide examples of procedures for sample handling; for the surveillance, prevention, and control of radioactive contamination throughout the laboratory; and for the control of radiation exposure both inside the laboratory and in the areas immediately outside the laboratory that may be affected by laboratory operations. These examples are intended to be illustrative of typical laboratory operations and to serve as suggestions with which the laboratory might develop its own procedures.

This guide is separated into the following sections:

- Section 2.0 (*Preparing the Laboratory*) describes potentially significant planning steps that (a) define the types of operational areas that a laboratory might typically employ; (b) establish acceptable radioactivity and radiation levels for those areas; (c) establish appropriate protective equipment for those areas; and (d) give consideration to the laboratory layout and process flow for radioactive materials. Other miscellaneous but important planning considerations are also discussed.
- Section 3.0 (*Radioactive Contamination Control*) addresses specific radioactive contamination control measures that may be taken for both personnel protection and radioanalytical control. As mentioned above, these two aspects of contamination control frequently overlap, and control measures are taken with both goals in mind. Where particular recommendations are intended to specifically address one over the other, clarification is provided.
- Section 4.0 (*Exposure Control and Radiation Shielding*) presents the protective measures of time, distance, and shielding in the context of incident response activities in the laboratory, with the primary emphasis on personnel protection. Some additional discussion of the prevention of adverse instrument response from elevated activity and transient sources in the laboratory is also provided.
- The guide concludes with numerous appendices that may be useful by providing specific examples for implementing the various recommendations. The laboratory is strongly cautioned, however, that these are only examples. These examples are not intended to be prescriptive or to limit the scope of the laboratory's preparation for an event, but are intended to help the laboratory identify, select, and devise contamination control measures that are tailored to its specific needs. Decisions regarding the designation of area types, activity levels, appropriate personal protective equipment (PPE), work flow, and protocols are decisions that must be made internally, on a case-by-case basis, specific to each laboratory.

The examples are, however, intended to be applicable to a broad range of radiological laboratories: large, small, streamlined, and complex. The specific procedures that a laboratory develops to address contamination and exposure control will depend largely on the available space, staffing, and other resources of the laboratory. In addition, those procedures may need to be periodically reassessed and revised, depending on the changing nature of the incident response efforts.

1.2 Limitations and Regulatory Considerations

In the event of a radiological or nuclear incident involving releases of significant quantities of radioactive materials to the environment, only those laboratories already having the necessary facilities and procedures will be capable of responding to the anticipated demand for analysis of samples. Laboratories that either intend to develop segregated contamination and radiation areas in their laboratories, or already have them and wish to evaluate them, may find the recommendations for physical layout and organizational procedures for laboratories contained in this report useful. Laboratories with limited physical infrastructure or a very narrow scope of operations may not be able to effectively support the incident response without additional preparation and the development of alternate techniques, modified to accommodate their specific circumstances.

This guide addresses important considerations in the surveillance and control of radioactive contamination and radiation exposure. It is possible that samples related to a nuclear or radiological incident may also pose additional risks from other chemical, biological, or physical hazards. While it is beyond the scope of this document to address such non-radiological hazards, the laboratory should have procedures in place for the assessment of, and response to, these additional potential risks.

This guide does not purport to address specific regulatory compliance issues, including the laboratory's adherence to possession limits and other conditions of its Radioactive Materials License. In no way does the content of this guide obviate or relieve the laboratory of its regulatory compliance responsibilities in the areas of employee health, safety, or hazardous and radioactive materials handling, transportation, or disposal.

This guide is intended to provide planning guidance in preparation for the response to a radiological or nuclear incident, not replace or supersede existing laboratory safety or quality plans, such as a Radiation Safety Plan or Laboratory Quality Manual. This guidance may also be useful in the laboratory's review of the existing Radiation Safety Plan or Laboratory Quality Manual to ensure the laboratory's readiness to respond to a radiological or nuclear incident.

This guide contains numerous examples of radioactivity and exposure limits and their use in the control of laboratory contamination and radioanalytical integrity. The values used in the examples are for illustrative purposes and should not be taken as specific requirements for the laboratory. This guide cannot address every conceivable situation; each laboratory must develop its own activity and exposure limits that are appropriate to the particular laboratory environment and operational goals.

Additional discussion regarding regulatory considerations is provided in the companion document *Guide for Laboratories - Identification, Preparation, and Implementation of Core Operations for Radiological or Nuclear Incident Response (EPA 2010)*.

2. PREPARING THE LABORATORY

As in any operation, a radiological laboratory will have routine practices and procedures that have been established over time to meet the needs of the laboratory, based on the type and volume of work typically performed. These practices and procedures may not be sufficient or adequate for the laboratory's participation in the response to a radiological or nuclear incident. This section describes some key preparations that should be made prior to the acceptance of samples related to a radiological or nuclear incident.

Any laboratory that handles and analyzes radioactive materials should have areas of the laboratory designated for specific processes (e.g., sample screening, low-level counting, etc.). These processes should be segregated by the potential level of radioactivity expected to be present and the likelihood of the material to cause a laboratory contamination issue.

In laboratories that are accustomed to handling only low-level or environmental samples, the segregation of these processes is often overlooked because the entire facility is dedicated to handling samples of the same general activity level. Consequently, the laboratory may be at significant risk of being rendered unusable by the inadvertent mishandling of high-activity material if such material is introduced to the laboratory as part of an incident response effort. Similarly, a laboratory that is accustomed to working with higher levels of radioactivity may be unprepared for the demands of analyzing very low-activity level samples in the recovery stage of the event efforts.

When preparing a laboratory to accept unaccustomed activity levels, the receipt, processing, storage, and disposal of higher levels of radioactive materials should be carefully considered before allowing work to begin. Likewise, careful consideration should be made of the laboratory’s ability to analyze very low-level materials related to the radiological or nuclear incident, prior to acceptance of those samples.

Another concern facing many laboratories is that their routine practices may not be directed toward the handling of very large numbers of samples. Laboratories that typically handle only small numbers of samples may be unprepared for the high throughput demands of an incident. The laboratory’s preparations, prior to receipt of samples from an incident, should include consideration of these and other potentially limiting factors.

The laboratory should make advance decisions related to: a) the definition of the different types of operational areas in the laboratory; b) the establishment of acceptable levels of radiation and radioactive materials for the different types of areas; c) the specific requirements for PPE in those areas; d) the configuration of the laboratory, including the layout and the flow of work that would best minimize contamination risks; and e) the procurement, allocation, placement, and use of additional physical resources, such as frisking stations, decontamination equipment, and shielding material. These topics are discussed below, in this section.

The establishment of protocols for sample handling; movement between areas of the laboratory; surface and personnel contamination surveillance, prevention, and control; and the appropriate use of shielding are discussed in Sections 3.0 and 4.0 of this guide.

2.1 Defining Types of Operational Areas and Other Areas Affected by Laboratory Operations

Prior to an incident, the laboratory should consider carefully defining the various types of segregated areas in a laboratory that may be used during the incident response and that may potentially be affected by radioactive contamination and elevated levels of radiation. The following list of areas is intended as an example for the laboratory's consideration. This list may not be inclusive of all the area types that an individual laboratory might identify and consider.

2.1.1 Unrestricted Public Areas

Unrestricted Public Areas include areas open to any individual who is not under the operational control of the laboratory. Some areas, such as roads, sidewalks, parking lots, reception and office areas, and hallways may be open to members of the general public. Other areas, such as adjacent businesses, may be secured from members of the general public but are still accessed by individuals who are not responsible to, or under the direction of, the laboratory. These should all be considered unrestricted public areas.

The laboratory is responsible for ensuring that radiation doses to the general public from laboratory operations do not exceed regulatory limits, such as those found in 10 CFR 20 (or Agreement State regulations). When considering the effects of laboratory operations on radiation doses to the general public, the laboratory must also ensure that all sources of radiation are properly accounted for. Wastewater effluents, fume hood exhausts, and radioactive and non-radioactive waste will need to be carefully monitored.

2.1.2 Buffer Zones

Buffer zones are generally areas outside the operational areas of the laboratory, but still under control of the laboratory and used to insulate the general public from unnecessary risk. For example, a building which houses a laboratory operation may be situated on a property, set back some distance from the boundary of the property. The area between the building itself and the boundary of the property (sometimes referred to as the "owner controlled area") is not used to handle or store radioactive materials, but may be used advantageously to keep members of the general public at a safe distance from sources of radiation within the building.

These buffer zones are not generally at risk of becoming contaminated with radioactive materials during laboratory operations, but do pose the potential risk of radiation exposure to persons within the buffer zone. When used in this protective capacity, the buffer zones should be fenced, or otherwise configured to restrict access, and should be monitored frequently enough to ensure that changing conditions in the laboratory do not lead to an unacceptable dose to the public.

In addition to unoccupied buffer zones, the laboratory may wish to establish the traffic areas immediately outside the receiving area and at the public entrance of the building as buffer zones, with the acknowledgement that there may be high-volume traffic through those areas, necessitating frequent exposure monitoring and possibly contamination monitoring.

2.1.3 Operational Areas

Of primary concern to this guide are operational areas (see inset), which are secure areas that are within the boundaries of the facility and are under the direct and immediate control of the laboratory. These areas may be used to handle, process, or store radioactive materials, or may be administrative areas that are not used for such purposes but which could inadvertently become contaminated. These areas are generally within the confines of a building but could be located outside, as in routes between buildings or storage areas for samples and waste.

Posting Radioactive Materials Areas

Any operational area in which radioactive materials are used, stored, or handled, must be appropriately posted, per 10 CFR 20.1902(e) or other Federal or State regulation.

Operational areas should be further considered according to the levels of radiation, types of work being performed, the potential for contamination or exposure, and the flow of radioactive material through the laboratory.

The generalized operational areas of the laboratory are considered below in the order that the radioactive material flows through the laboratory.

2.1.3.1 Receiving Areas for Incoming Radioactive Materials Packages

A designated Receiving Area for the laboratory should be established for the receipt of radioactive materials, including samples. The area should facilitate the:

- Receipt and inspection of incoming packages, including the determination of radiation exposure rates from the shipment;
- Assessment of the shipper's compliance with pertinent transportation regulations;
- Assessment of the integrity of the shipping containers;
- Assessment of potential contamination of the container and its contents; and
- Routing of the contents of the package to the appropriate area of the laboratory.

The Receiving Area should be set up with consideration that all samples and other radioactive reagents and supplies will be initially inspected, both visually and with survey instrumentation, in this area. The continuing integrity of the incoming materials depends upon the correct assessment of the condition of the material upon receipt, and the prevention of cross-contamination from one sample or reagent to another. No sample bottle or other primary container of radioactive material should be opened in the Receiving Area; this should be done in

a separate "Screening Area" as described below. The Receiving Area should be solely for the external assessment of the characteristics of the shipment.

In some cases, the physical constraints of the facility may require that the receiving and screening process be carried out in the same room. In this case, care should still be taken to establish separate "areas" for these processes, clearly posted and controlled to prevent the spread of radiological contamination. Work tables, washable partitions, and laboratory fume hoods may serve as appropriate means to isolate the different processes.

Receiving Areas for incoming radioactive materials packages should also be sufficiently separated, or appropriately shielded, from other areas of the laboratory in which radioactive materials are processed, stored, or analyzed. This will facilitate more accurate surveys of the incoming packages, and will minimize the potential impact of those incoming packages on radiation measurements being performed in the laboratory. The area should, at a minimum, be equipped with the following:

- A staging area for incoming materials. Initial exposure rate measurements and removable surface contamination surveys of the outside of the package may be performed in this area.
- A means for containing and sealing a shipment, sample, or other item that has broken or been contaminated in shipping or during handling in the laboratory. Containment bins, large durable trash bags, sealable freezer bags, etc., are useful items to have on hand for such an incident.
- An appropriately configured laboratory fume hood[6] or other exhaust ventilation system for unpacking the shipment. Initial inspection and inventory of the contents, exposure rate measurements, and removable surface contamination surveys should be performed in the ventilation hood, to protect the workers from contamination in the event that a sample container is broken or otherwise compromised in shipment.
- A means for containing spilled liquids. This may include a supply of absorbent spill recovery material, or in the case of larger volumes, a spill containment curb around the work area. The laboratory should ensure that it has sufficient spill recovery capacity immediately on hand to adequately contain the volume of sample material in any one shipment, and that additional supplies are readily available, if needed.
- The appropriate equipment and supplies for segregating and decontaminating containers that have been potentially contaminated by spilled radioactive material. The area should have ready access to the sample screening area, the High-Level Work Areas, and the Routine-Level Work Areas, which are described below.

Minimum recommended procedures for receiving radioactive materials, including samples, are detailed in Section 3.1, *Sample Handling Protocols*.

[6] Guidance for determining appropriate laboratory fume hood specifications and configurations may be found in the following standards: ANSI/AIHA Z9.5, American National Standards for Laboratory Ventilation; ASHRAE, HVAC Applications Handbook; NFPA-45, Standard on Fire Protection for Laboratories Using Chemicals; SEFA 1.2, Laboratory Ventilation.

2.1.3.2 Screening Areas for Incoming Samples

The Sample Screening Area should be established where the samples are initially opened, initial sample conditions such as preservation are verified, and an aliquant is potentially removed for screening analyses. Consequently, the risk of contamination to personnel, laboratory surfaces, and other samples is potentially high. The area should be designed to facilitate the preparation and screening of distinct samples or batches/shipments of samples, while minimizing the risk of contamination to unrelated samples or other areas of the laboratory.

The Sample Screening Area should be a distinct and dedicated area, separate from the sample Receiving Area whenever possible, but adjacent to and with direct access from the Receiving Area. The Sample Screening Area should be designed, whenever possible, as a self-contained preparation and screening analysis laboratory. The area should be equipped with the same facilities required in other laboratory areas, such as a fume hood, basic laboratory equipment, screening instrumentation, adequate storage for the immediate access to reagents and supplies, and adequate utilities, communication systems, and safety and emergency response equipment.

The area should also be equipped with adequate decontamination and survey equipment and supplies to facilitate the rapid cleanup and release of the work areas for the preparation and screening of other samples.

As with the Receiving Area, this area should have ready access to both the high- and routine-level work and storage areas without the need to traverse one to get to the other, if possible. Minimum recommended procedures for opening sample containers and sub-sampling the material are detailed in Section 3.1, *Sample Handling Protocols*.

2.1.3.3 High-Level Work Areas, and 10 CFR 20 "Radiation Areas"

In the following discussion, "High-Level Work Area" is a term defined specifically for this document and should not be confused with, or used interchangeably with, the terms "Radiation Area" or "High Radiation Area," which are described in 10 CFR 20.

High-Level Work Areas are designated areas for processing, storing, and in some cases analyzing samples that present an elevated risk of sample cross-contamination, or contamination or exposure to the employees and the facility.

In evaluating these risks, the laboratory should consider both the activity concentration and the total amount of activity in the sample. Elevated activity concentrations

10 CFR 20 Radiation Areas

Activity concentrations or exposure rates in excess of the upper limit for High-Level Work Areas will likely require the establishment of a **Radiation Area**. Radiation Area is a regulatory term that is used in 10 CFR Part 20.1003 (or equivalent state regulations) to describe areas "accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.005 rem (0.05 mSv) in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates."

The establishment of Radiation Areas, and other requirements of 10 CFR Part 20, include very specific radiation protection measures, which are outside the scope of this document, but with which the laboratory should be familiar as a condition of its radioactive materials license.

increase the risk of contamination or exposure, but this risk may be somewhat mitigated when only small amounts of the sample are handled. Conversely, even moderate activity concentrations may pose an elevated risk of contamination or exposure when the volume of sample is very large. These concepts are discussed further in Section 2.2, *Establishing Acceptable Levels of Radioactivity and Radiation*. In either case, high-activity concentrations in samples or high levels of activity in sample aliquants may interfere with the laboratory's ability to meet the measurement quality objectives (MQOs) for the project. The risks associated with these types of samples may be further increased when the contaminants are potentially volatile, or are potentially associated with fine or dry particulates that may become airborne during handling.

The following design items and practices should be carefully considered when establishing a High-Level Work Area:

- Areas designated for the processing or storage of high-activity samples and waste should be directly accessible from the receiving and screening areas, but should be as remote as feasible from the lower-level work areas and especially from any analytical instrumentation that may be affected by either radiation exposure or by inadvertent laboratory contamination.
- The area should be clearly posted as a High-Level Work Area at all entryways and boundaries between other areas. Access should be restricted to essential personnel only.
- High-activity samples should be stored and processed in these areas, without the need to travel through other parts of the lab, if possible.
- Consumable materials and other laboratory supplies and equipment should be unpacked, to the extent feasible, prior to being moved into the High-Level Work Area. This will minimize the risk of contamination from the removal of unnecessary packaging and extraneous material from the High-Level Work Area.
- Where the analysis of high-activity level samples may pose an elevated risk of contamination to the routine radiation detection instrumentation, or where the movement of prepared samples through other areas of the laboratory is not desirable, specific instrumentation may need to be procured and dedicated for use only in the High-Level Work Area.
- The layout of the area should include particular consideration for minimizing radiation exposure to personnel. This may include optimizing the distance between the accumulated radioactive materials and the personnel work stations, as well as installing additional shielding materials.

Negative Room Air Pressure

Establishing a negative pressure gradient from higher-level to lower-level areas in the laboratory will minimize the movement of airborne radioactivity in the laboratory. Thus, areas with the highest activities should be maintained at the lowest pressure level. The pressure should then be successively increased through the mid- and low-level areas, and into uncontrolled areas so that the movement of airborne contamination is always from low to high. *While this may be accomplished with the existing ventilation system, a qualified industrial hygienist and health physicist, working with the laboratory's heating, ventilation, and air conditioning (HVAC) contractor, should always be consulted before making even minor modifications to the laboratory air handling system.*

- If possible, High-Level Work Areas should employ negative air pressure (relative to adjacent areas) to keep airborne radioactive material inside the room.
- Laboratory fume hoods in the High-Level Work Areas may need to be equipped with high efficiency particulate air (HEPA) filters to reduce the level of radioactive contaminants in the exhaust air. In addition, the laboratory may need a program for monitoring the filters, to ensure worker protection and to facilitate proper handling and disposal.
- Personnel working in these areas should be thoroughly trained in the laboratory's contamination prevention, assessment, and control procedures, and should undergo routine retraining periodically and when the scope of the activities changes significantly. If possible, they should participate in practical exercises to supplement the training.
- To the extent possible, contamination response procedures for these areas, including decontamination efforts, should depend first on the personnel working in that area, in order to minimize unnecessary traffic through that area during the response to a contamination event.
- An integral part of contamination control training for laboratory personnel in these areas should be to recognize when the nature of a contamination event is outside their expertise or ability to control and therefore when to seek additional assistance.
- The area should be designed to facilitate the support of contamination control procedures from adjacent areas. Whenever possible, the area should be designed to allow additional decontamination supplies and equipment to be passed into the laboratory area without risk of spreading contamination and without constraining the movement of personnel into or out of the area. The use of pass-through cabinets or material air locks is useful in this regard and should be employed whenever feasible.
- The area will require a more rigorous egress policy than other areas of the lab, with additional frisking and decontamination resources as described in Section 3.2, *Movement Between Laboratory Areas (Entry/Egress).*

Other design considerations for these areas will not differ significantly from other laboratory areas.

2.1.3.4 Routine-Level Work Areas

Routine-Level Work Areas, as the name implies, are designated for sample radioactivity levels that fall into the normal scope of work to which the laboratory is routinely accustomed, and for which the laboratory has historically demonstrated an ability to achieve the applicable MQOs. In most environmental radiological laboratories, the sample activity levels for these areas will likely correspond to "normal environmental levels," as defined by the laboratory. These areas should not require changes in safety and contamination control protocol beyond those already in place in the laboratory.

Routine-Level Work Areas should be accessible from the sample receiving and/or screening areas, as well as from the High-Level Work Areas, if possible, following proper egress protocols from those areas.

The Routine-Level Work Areas should also have ready access to the nuclear measurements instrumentation that will be used in the analysis of samples prepared in those areas, although the instrumentation area should be situated as far as practical from the Sample Receiving Area and High-Level Work Areas.

The laboratory may choose to include the instrumentation area as a part of the Routine-Level Work Areas, in which case the instrumentation area should still be maintained as a separate area with appropriate entry protocols. It is recommended, however, that the instrumentation area be designated as a Low-Level Work Area, with the descriptions and considerations shown below.

As discussed above, the sample screening and high-level work areas may need to be equipped with their own dedicated instrumentation; uncharacterized sample material and high-activity level samples should not be analyzed on instrumentation dedicated to routine- or low-level work.

2.1.3.5 Low-Level Work Areas

In some cases, it may be advantageous to the project for the laboratory to establish Low-Level Work Areas, which restrict the flow of radioactive materials and general laboratory traffic in order to achieve MQOs that may be well below those to which the laboratory is accustomed. The laboratory may also find it useful to designate the instrumentation areas as Low-Level Work Areas, in order to maintain the integrity of the instrumentation and the laboratory's ability to meet the project MQOs.

The following design items and practices should be carefully considered when establishing a Low-Level Work Area:

- Areas designated as Low-Level Work Areas should not be directly accessible from the receiving and screening areas, or from the High-Level Work Areas.
- The area should be clearly posted as a Low-Level Work Area, with access restricted to essential personnel only.
- The location and layout of the area should include particular consideration for a) minimizing general background radiation to the instrumentation from other parts of the laboratory, particularly from sample storage areas and High-Level Work Areas, which can elevate the measurement uncertainty and detection capability of radioanalytical techniques; and b) minimizing transient variations in the background radiation levels, from the movements of samples and waste through the laboratory, which can result in significant biases in the net analytical results, especially at low sample activities.
- Only those samples that are necessary for the immediate task at hand should be stored in this area. Upon verification of successful analysis, residual sample volumes and prepared samples should be promptly removed from the area and transferred to an appropriate storage location outside the counting/instrumentation room.

- If possible, the area should employ positive air pressure (relative to adjacent areas) to keep airborne radioactive material outside the room. *As mentioned above, a qualified industrial hygienist and health physicist, working with the laboratory's HVAC contractor, should always be consulted before making even minor modifications to the laboratory air handling system.*

Other design considerations for these areas will not differ significantly from other laboratory areas.

2.1.3.6 Administrative and Public Areas

It is also necessary for the laboratory to recognize those administrative areas occupied by non-radiation workers, and those areas that allow for general public access, which may include areas not under the direct control of the laboratory.

These areas will not require any special equipment or supplies, but may require periodic monitoring for contamination of the areas and for exposure levels to the occupants of those areas. In addition, exiting any of the laboratory areas directly into administrative or public areas will require appropriate egress protocols.

2.2 Establishing Acceptable Levels of Radioactivity and Radiation

Once the various types of operational areas are identified, the laboratory should establish acceptable levels of radioactivity and radiation exposure and dose rates that will further define the areas.

The laboratory should be mindful that the ultimate purpose of establishing limits on the levels of radioactivity and radiation, and for pursuing a Radiological Controls Program in general, is to ensure that the laboratory can perform the necessary radioanalytical work while minimizing both personnel exposure and the radioanalytical effects of laboratory contamination and sample cross-contamination.

Acceptable levels of radioactivity and radiation in the different areas might be based on the initial condition of the lab, the type of work routinely performed, and the type of work expected from the radiological or nuclear incident. These acceptable levels should reflect the laboratory's assessment as to what maximum activity and radiation levels should be allowed so that the risk to personnel, project MQOs, and the overall integrity of the laboratory's radioanalytical processes are not compromised.

The *Multi-Agency Radiological Laboratory Analytical Protocols* Manual (MARLAP 2004, Chapter 2) provides guidance for pursuing a "directed planning process," such as the data quality objective (DQO) process, for setting well-defined objectives and developing reliable sampling and analysis plans that support decisionmaking processes. This directed planning approach will be useful in the laboratory's selection of acceptable levels of radioactivity and radiation, and for establishing laboratory-specific protocols for contamination monitoring that support decision-making at those levels.

2.2.1 Action Levels: AAL, Required Method Uncertainty, and ADL

Portions of this guide rely heavily on the use of the terms "analytical action level" (AAL), "required method uncertainty" (u_{MR}), "required relative method uncertainty" (φ_{MR}), and "analytical decision level" (ADL) in characterizing the desired levels of performance of screening and analysis methods and the radioanalytical results for use in decisions regarding the exceedence of established levels of radioactive contamination and radiation exposure. These terms may be used to describe the MQOs for the analysis of field samples related to a nuclear or radiological incident, as well as the analysis of internal samples related to the surveillance of contamination in the laboratory. Each combination of sample type and analytical method may have an AAL, $u_{MR,}$ φ_{MR}, and ADL specific to the requirements of the pertinent MQOs.

The term "analytical action level" (AAL) is used as a general term denoting a radioactivity or radiation level at which some action must be taken. In the context of laboratory contamination control, action is taken by the laboratory to reduce the impact of radiological contamination or radiation in and around the laboratory. This action may include surface decontamination, sample segregation, emplacement of shielding, increased monitoring frequency, or other actions determined by the laboratory. The AALs should correspond to the laboratory's assessment of risk to the radioanalytical processes or to personnel. In making these assessments, the laboratory should incorporate what it considers to be acceptable error rates in its decisions as to whether personnel or analytical processes are impacted to an unacceptable degree. Assessments of acceptable risk and the corresponding radioactivity and radiation levels, and decisions regarding acceptable decision error rates, will be specific to individual laboratories and incident response activities. These assessments should include significant input from qualified technical resources, such as senior analytical, health and safety, and radiation protection personnel.

The selection, validation, and use of a particular analytical method or screening technique rely on the ability of that method or technique to provide a result with a specified required method uncertainty, u_{MR}, at the AAL, and a corresponding required relative method uncertainty, φ_{MR}, for results above the AAL. This condition ensures that the quality of the measurement will be adequate for making decisions, considering the acceptable decision error rates discussed above. Whenever the reported activity or exposure rate exceeds a pre-defined level (the ADL), the AAL can be assumed to have been exceeded and appropriate action is warranted. The derivation and use of AAL, u_{MR}, φ_{MR}, and ADL are discussed in this section and in other companion guides in this series.

While closely interrelated, it is important to note that the use of AAL (and the associated u_{MR} and φ_{MR}) and the ADL represent distinct concepts; they must not be used interchangeably but rather should be interpreted and applied according to these guidelines and those of the related companion documents.

The values for AAL, u_{MR}, φ_{MR}, and ADL will depend on the laboratory area under consideration and the analytical processes being performed. This guide offers examples of AALs, u_{MR}, and φ_{MR} values, and ADLs, with examples of the processes used to derive these values. These examples are provided for illustrative purposes only and should not be used verbatim, but should be

considered as guidance for the laboratory to develop its own action levels and criteria by which to make contamination and exposure control decisions.

It should be understood that the terms AAL, u_{MR}, φ_{MR}, and ADL are also applicable to the MQOs assigned to the laboratory analysis of field samples from incident response activities. In fact, the AALs, u_{MR}, φ_{MR}, and ADLs that apply to the laboratory contamination control measurements might be derived from the AALs, u_{MR}, φ_{MR}, and ADLs that apply to the analysis of field samples.

Where it becomes necessary in this document to distinguish field sample MQOs from contamination control MQOs, the parentheticals (*S*) and (*C*) will be added as needed for clarity:

AAL(*S*) = Analytical action level for field sample analyses
$u_{MR}(S)$ = Required method uncertainty at or below the AAL(*S*) for field sample analyses
$\varphi_{MR}(S)$ = Required relative method uncertainty above the AAL(*S*) for field sample analyses
ADL(*S*) = Analytical decision level for field sample analyses

AAL(*C*) = Analytical action level for contamination control analyses
$u_{MR}(C)$ = Required method uncertainty at or below the AAL(*C*) for contamination control analyses
$\varphi_{MR}(C)$ = Required relative method uncertainty above the AAL(*C*) for contamination control analyses
ADL(*C*) = Analytical decision level for contamination control analyses

Other guides in this series (see Preface) provide additional discussion and examples for deriving and applying these values in a variety of scenarios using both external, incident-derived DQOs and internal, laboratory-specified DQOs.

The following sections, 2.2.2 through 2.2.4, provide an example of the process and associated calculations that a hypothetical laboratory might follow to derive AAL(*C*), u_{MR}(*C*), and finally ADL(*C*) for swipe sample measurements.

Additional examples describing the determination of AAL(*C*), u_{MR}(*C*), and ADL(*C*) values for sample screening activity, and exposure rate monitoring are provided in Appendix J, *Establishing MQOs for Sample Screening Measurements*, and Appendix K, *Establishing MQOs for Sample Exposure Rates*.

2.2.2 Establishing Analytical Action Levels for Contamination Control — AAL(*C*)

Consider an example scenario in which the laboratory wants to establish limits for removable alpha-emitting radioactive contamination on surfaces in a particular laboratory area. In this case, MQOs for contamination control measurements, i.e., AAL(*C*), u_{MR}(*C*), and ADL(*C*), will be directly related to the required MQOs for incident response sample analyses, AAL(*S*), u_{MR}(*S*), and ADL(*S*).

In this example scenario:

- The laboratory area is used for the preparation of samples that are required to meet MQOs that apply to the majority of sample analyses performed by the laboratory. Consequently, this area is considered a "Routine-Level Work Area."
- The most stringent MQO states that the required method uncertainty, $u_{MR}(S)$ (i.e., the combined standard uncertainty (CSU) estimated by the laboratory) is not to exceed 1.5 pCi/g at the specified AAL(*S*), which is 10 pCi/g.
- Sample activity measurements below 10 pCi/g are also limited to the required method uncertainty, $u_{MR}(S)$, of 1.5 pCi/g and measurements above 10 pCi/g are limited to a required relative method uncertainty, $\varphi_{MR}(S)$, of 15% of the measured activity.
- The current analytical method in use in the laboratory employs a sample aliquant of 2 grams and has the capability to produce a CSU of 1.3 pCi/g (13%) at an activity concentration of 10 pCi/g, before sources of potential laboratory contamination are considered.

The laboratory, therefore, has a method that currently limits the CSU to 1.3 pCi/g at the prescribed AAL(*S*) of 10 pCi/g and wishes to determine what maximum level of potential contamination would increase the method uncertainty, $u_{MR}(S)$, to 1.5 pCi/g.

- In the analysis of field samples, and the related uncertainty calculations, this maximum level of potential contamination would be considered an additional contribution to the method uncertainty because it introduces a potential bias to the final result, which may then be added in quadrature to the CSU.
- In the laboratory's contamination control measurements, however, that maximum level of potential contamination would be considered the analytical action level, or AAL(*C*).

The required method uncertainty for field sample analyses, $u_{MR}(S)$, may therefore be estimated by the laboratory by the following equation:

$$u_{MR}(S) = \sqrt{\mathrm{CSU}^2 + \mathrm{AAL}(C)^2}$$

or

$$\frac{1.5\mathrm{pCi}}{\mathrm{g}} = \sqrt{\left(\frac{1.3\mathrm{pCi}}{\mathrm{g}}\right)^2 + \mathrm{AAL}(C)^2}$$

Solving for AAL(*C*) shows that the maximum tolerable level of potential contamination, AAL(*C*), would be equal to 0.75 pCi/g in the field sample analysis.

Since each sample analysis employs an aliquant of 2 g, the maximum tolerable level of alpha contamination in each 2 g sample aliquant is:

$$0.75\ \mathrm{pCi/g} \times 2\ \mathrm{g} = 1.5\ \mathrm{pCi}.$$

The AAL(*C*), expressed in activity units of pCi, is therefore 1.5 pCi alpha activity.[7]

Following this assessment, the laboratory technical personnel are consulted, the sample preparation process is reviewed, and potential sources and mechanisms of contamination are identified. Based on the available information, and perhaps based in large part on the technical judgment of the staff, it is estimated that surficial contamination from approximately 10 cm^2 of laboratory workbench surfaces could potentially enter the analytical process and result in radioanalytical contamination. This estimate may come from empirical task assessments or from general observations of how much a technician inadvertently touches the benchtop, etc. Again, note that the values in this example are for illustrative purposes only. Each laboratory will need to assess its own processes and situations on a case-by-case basis. In all cases, however, the potential contamination should be limited to a level that does not significantly impact the required sample analysis method uncertainty, $u_{MR}(S)$.

Limiting potential contamination from laboratory workbench surfaces to 1.5 pCi (as determined above) per 10 cm^2 surface area gives a maximum allowable contamination level of

$$1.5 \text{ pCi} / 10 \text{ cm}^2 = 0.15 \text{ pCi/cm}^2.$$

A removable surface contamination swipe, covering a standard area of 100 cm^2, should therefore have no more than:

$$0.15 \text{ pCi/cm}^2 \times 100 \text{ cm}^2 = 15 \text{ pCi alpha activity per swipe sample.}[8]$$

The AAL*(C)*, therefore, is 15 pCi of alpha activity per swipe sample, expressed in terms of activity units per swipe sample.

In this example, the laboratory estimates that limiting the potential contribution from sources of laboratory contamination to 1.5 pCi would effectively limit the CSU in the reported sample results to:

- the required method uncertainty (u_{MR}) of 1.5 pCi/g at the 10 pCi/g AAL, and
- the required relative method uncertainty (φ_{MR}) of 15%, at activities above the AAL.

Modifying the Plan

Any modifications to the area type definitions, acceptable activity levels, laboratory layout, or usage of a given area should be accompanied by a thorough review to ensure that the protection of health, safety, and the environment, and the prevention of laboratory and sample contamination have been adequately addressed.

Because the maximum allowable removable surface contamination has been estimated at 0.15 pCi/cm^2, the maximum allowable removable surface contamination would be 15 pCi per 100 cm^2 swipe. The laboratory's contamination control analytical action level, AAL(*C*), for alpha activity on a removable surface contamination swipe in Routine-Level Work Areas is therefore 15 pCi (33 dpm) per swipe. The

[7] In this and other examples in this guide, results are rounded to two significant figures, per MARLAP (2004), Section16.6.3.

[8] In this example scenario, the transfer efficiency of the swipe sampling procedure and the potential contamination transfer "efficiency" to the field sample are considered to be the same. Therefore, the swipe removal factor does not need to be considered in this specific application. For more detailed discussion regarding swipe removal factors and other important considerations in swipe sampling and analysis, see the companion document *A Performance-Based Approach to the Use of Swipe Samples in Response to a Radiological or Nuclear Incident* (EPA 2011).

determination of the required method uncertainty, $u_{MR}(C)$, and analytical decision level, ADL(C), in the laboratory's contamination control measurements are discussed later in this section.

The laboratory may then consider similar scenarios for the various processes and work areas, and generate a list of AAL(C) values beyond which the levels of radioactivity or radiation will be considered too high, which will be the laboratory's indication that some response, or corrective action, is warranted. These AAL(C) values should guide the development of analytical methods to be used for making contamination and exposure control decisions in the different work areas.[9]

These values should be periodically reviewed and may need to be occasionally modified. If possible, a focal review and any necessary adjustments should be made after reviewing the available information about a radiological or nuclear incident and the MQOs for the project, and before receiving samples from the incident.

The laboratory, at a minimum, should establish those levels of radioactivity and radiation that define High-Level Work Areas. The laboratory should distinguish those areas from "routine" work areas that represent the type of work to which the laboratory is accustomed and that are already governed by the laboratory's existing Radiation Protection Program or Radiation Safety Manual. It is recommended, however, that a more thorough classification of potential activity and exposure levels be considered. An example of the scope of classifications and activity levels segregating the different area types is shown in Table 1, *Laboratory AALs for Contamination and Exposure Control: An Example of Maximum Sample Activity, Exposure and Dose Rate, and Radioactive Contamination by Area Type.*

Note that the values shown in Table 1 include the AAL of 33 dpm per 100 cm^2 swipe for removable surface alpha contamination, as determined in the example above.

While the classifications and values shown in Table 1 may be based in part on practical experience in a variety of radiological laboratories, *they should be considered only as examples* and are intended simply to provide conceptual guidance for the laboratory to establish its own criteria. Each individual laboratory should evaluate the requirements of a specific project and the type of work typically performed at that laboratory and in the various work areas, and assign area types and activity levels that are appropriate to the project at hand.

Table 1 describes example AALs for three general aspects of radiological laboratory operations. Analytical action levels for radioactive contamination, sample activity concentrations, and exposure and dose rates are provided for each area type, such as "High-Level," "Routine-Level," etc. Sample activity and contamination AALs are further classified by alpha, beta, and gamma activity levels. In some cases, a distinction is made between lower- and higher-energy beta activity because the required limits of detection and necessary instrumentation may differ significantly for low-energy beta-emitters, such as ^{3}H and ^{14}C.

[9] When assessing appropriate AAL(C) values for radioanalytical contamination control, the laboratory should consider the impact that different types of contamination have on the various processes that are affected. For example, alpha spectrometry analyses may be significantly affected by very small amounts of alpha-emitting contaminants. Alternately, pure beta-emitting contaminants, such as Sr-90, may have little radioanalytical impact on that analysis. The type of radiation and the impact on the desired MQOs should be carefully considered.

Table 1 – Laboratory AALs for Contamination and Exposure Control: An Example of Maximum Sample Activity, Exposure and Dose Rate, and Radioactive Contamination by Area Type

	AREA DEFINITIONS				
	Public Access	Admin. & Buffer	Low Level	Routine Level	High Level
	CONTAMINATION LIMITS				
Maximum Removable Contamination (net dpm/100 cm^2)					
alpha	<5	<5	5	33	200
beta/gamma	<20	<20	20	350	2,000
beta <150 keV	<25	<25	50	350	2,000
Maximum Fixed Contamination (net dpm/100 cm^2)					
alpha	<20	<20	20	175	350
beta/gamma	<100	<100	100	850	2,000
	SAMPLE ACTIVITY LIMITS				
Maximum Screening Activity Concentrations per Matrix					
Solids (pCi/g)					
alpha	na	na	4	100	1 E+04
beta >150 keV	na	na	8	200	2 E+04
beta <150 keV	na	na	20	500	5 E+04
gamma	na	na	8	200	2 E+04
Liquids (pCi/L)					
alpha	na	na	40	100	1 E+04
beta >150 keV	na	na	75	200	2 E+04
beta <150 keV	na	na	400	1,000	1 E+05
gamma	na	na	70	200	2 E+04
Air Filters (pCi/filter)					
alpha	na	na	4	100	1 E+04
beta >150 keV	na	na	8	200	2 E+04
beta <150 keV	na	na	20	500	5 E+04
gamma	na	na	8	200	2 E+04
Alternate Total Activity per Aliquant (pCi)					
alpha	na	na	500	5,000	1 E+07
beta >150 keV	na	na	1,000	10,000	2 E+07
beta <150 keV			2,500	25,000	5 E+07
gamma	na	na	1,000	10,000	2 E+07
	EXPOSURE AND DOSE RATE LIMITS				
Maximum Sample Exposure Rate (µR/h at surface of container)			100	5,000	100,000
Maximum Area Ambient Exposure Rate (µR/h)	2× bkg	2× bkg	2× bkg	500	1,000
Maximum Estimated Dose Rate, TEDE (mrem/h) per 10 CFR 20*	0.01	0.01	0.50	2.50	5.0

* 10 CFR 20 limits the maximum dose rate to the public and to workers. 0.01 mrem/h is the value that is approximately equivalent to the annual public limit 100 mrem/y; 2.5 mrem/h is the value that is equivalent to the 5,000 mrem annual dose limit to radiation workers working 2,000 hours per year; 5 mrem/h is the maximum dose rate allowed before establishing a "Radiation Area"; the value of 0.50 mrem/h for Low-Level Work Areas has no regulatory basis, but rather may reflect the laboratory's desire to further limit the radiation in that area.

2.2.3 Limiting the Method Uncertainty, u_{MR}

In the example scenario provided above, the laboratory has determined the actual levels of radioactive contamination or radiation exposure that should trigger responsive action in the laboratory to mitigate the effects of such levels of contamination or exposure. The laboratory must then select a method for sampling and analyzing the parameter of interest, which in this case is removable surface contamination by alpha-emitting radionuclides.

If the laboratory had a method that would definitively measure that parameter with absolute precision, it would be a simple matter of comparing the measurement results directly to the AALs derived above. Of course, this is not the case for any analytical method, and the uncertainty of the method must be taken into account when comparing the measurement result to the established AALs.

In order to make effective decisions regarding the presence or absence of radioactivity or radiation at a specified level, a careful assessment should be made of the maximum uncertainty that should be tolerated in the sampling and analysis method. The companion document, *A Performance-Based Approach to the Use of Swipe Samples in Response to a Radiological or Nuclear Incident* (EPA 2011), provides a detailed example for calculating the required method uncertainty in a swipe sampling and analysis scenario. Other guides in this series, including *Radiological Laboratory Sample Analysis Guide for Incidents of National Significance – Radionuclides in Air* (EPA 2009a), *Radiological Laboratory Sample Screening Analysis Guide for Incidents of National Significance* (EPA 2009b), and *Guide for Laboratories – Identification, Preparation, and Implementation of Core Operations for Radiological or Nuclear Incident Response* (EPA 2010), provide additional examples that are pertinent to other situations that might be encountered.

In general, the required method uncertainty, u_{MR}, at activity levels equal to the AAL is calculated as:

$$u_{MR} \leq \frac{AAL - DL}{z_{1-\alpha} + z_{1-\beta}}$$

Where

AAL = analytical action level
DL = discrimination level[10]
$z_{1-\alpha}$ and $z_{1-\beta}$ are the $1-\alpha$ and $1-\beta$ quantiles of the standard normal distribution function, where α and β are the respective probabilities of making a Type I or Type II error.

In the example scenario, the analytical action level for alpha activity in removable surface contamination swipes, AAL(C), has been established as 33 dpm per 100 cm^2 swipe sample. Other AALs are shown in Table 1.

The DL is the point where it is important to be able to distinguish the expected measurement result from the AAL. When one expects the instrument response to a sample to be at the

[10] Careful distinction should be made between the discrimination level (DL) and the analytical decision level (ADL). These terms have quite different meanings and are not to be used interchangeably.

background response rate for that instrument, then the DL might be zero. If one expects an instrument response near the AAL, however, the DL might be closer to the AAL. In the example scenario, the AAL(C) for removable alpha activity in Routine-Level Work Areas (33 dpm per swipe) is expected to be distinguishable from the AAL(C) for Low-Level Work Areas, so the DL is set to 5 dpm per swipe.[11]

The z-factor of 1.645 is selected from a standard table of cumulative normal distributions, corresponding to α and β probabilities of 0.05.

Under these conditions, the required method uncertainty for the contamination control analysis, $u_{MR}(C)$, at the AAL will be:

$$u_{MR}(C) = \frac{\text{AAL - DL}}{z_{1-\alpha} + z_{1-\beta}} = \frac{33-5}{1.645+1.645} = 8.5 \text{ dpm per swipe}$$

It is now incumbent upon the laboratory to identify sampling and analysis conditions that satisfy the required method uncertainty. This may be as simple as adjusting swipe sample count times on an instrument or as involved as developing entirely new sampling or analysis protocols to control the overall result uncertainty. Once these sampling and analysis conditions are identified, they should be recorded and actively associated with the specific AAL, preferably in the form of a laboratory's SOP. If the laboratory ultimately cannot satisfy the required method uncertainty, a careful assessment should be made by experienced technical personnel of the impact on the analysis of field samples and the risk of failing to meet those MQOs in the event of laboratory contamination. The Incident Commander, as well as the laboratory's management and quality assurance personnel, should be immediately notified of any potential failure to meet incident MQOs.

Required method uncertainties should then be determined for each AAL, and the appropriate sampling and analytical protocols documented, once again based on laboratory-specific conditions.

2.2.4 Determining the Analytical Decision Level

After determining the required method uncertainty (u_{MR}) for the contamination analysis, the laboratory can then determine the ADL, which is the calculated radioanalytical value that is to be used in making decisions as to whether the AAL is likely to have been exceeded.[12]

[11] In general, the DL for a given scenario may be selected as the AAL for that category in the next lower activity level area, with DL=0 for low-level work areas and administrative areas. DLs should be evaluated by each laboratory for each AAL on a case-by-case basis.

[12] Specific application of u_{MR} to the AAL, to determine the appropriate ADL, will depend on which decision error the laboratory would consider to be worse; deciding that the sample activity is below the AAL when it is not, or deciding that the sample activity is above the AAL when it is not. A detailed discussion addressing both situations is provided in Section 4 of the companion document, *A Performance-Based Approach to the Use of Swipe Samples in Response to a Radiological or Nuclear Incident* (EPA 2011).

In the example scenario introduced above, the laboratory establishes an ADL that is below the AAL to minimize the risk of incorrectly deciding that the true swipe alpha activity is below the AAL, when it is actually above the AAL. Consequently, the ADL(C) would be calculated as:

$$\begin{aligned} \text{ADL}(C) &= \text{AAL}(C) - z_{1-\alpha} \times u_{MR}(C) \\ &= 33 - (1.645 \times 8.5) = 19 \text{ dpm per swipe} \end{aligned}$$

ADLs should then be calculated for each AAL in Table 1 and its corresponding u_{MR}. It may be convenient for laboratory personnel to list the AAL, u_{MR}, ADL, and the sampling and analytical conditions (i.e., pertinent SOPs) required to achieve these MQOs, for each area type that might be encountered. The example values provided in Table 1 have been reduced to the values pertinent to the Routine-Level Work Area, and supporting information for each parameter has been added.

Selected ADL values are presented below in Table 2. The laboratory may find it useful to include similar information in the training of personnel working in this area, and to post this information in the Routine-Level Work Areas so that it is readily available when needed.

Additional examples describing the determination of AAL(C), $u_{\text{MR}}(C)$, and ADL(C) values for sample screening activity, and exposure rate monitoring are provided in Appendix J, *Establishing MQOs for Sample Screening Measurements*, and Appendix K, *Establishing MQOs for Sample Exposure Rates*.

2.2.5 Establishing Appropriate Corrective Action when the ADL(C) is Exceeded

When the ADL(C) is exceeded for any given measurement, the laboratory should respond quickly and decisively in order to prevent the uncontrolled spread of contamination and to maintain the integrity of its radioanalytical processes. The laboratory should have formalized procedures describing the appropriate response and corrective action to be taken for each type of exceedence.

At a minimum, the corrective action should include the return of the laboratory environment to its previous condition, and the performance of follow-up measurements to verify the effectiveness of the laboratory's response.

To continue the example presented above, if a removable contamination survey is performed in a Routine-Level Work Area, and the survey result for gross alpha activity exceeds the ADL(C) of 19 dpm per swipe, some corrective action must be taken. The laboratory's corrective action plan may require:

Table 2 – Laboratory ADLs for Contamination and Exposure Control: An Example of Routine-Level Work Area MQOs

	MQOs for ROUTINE-LEVEL WORK AREAS				
	AAL	u_{MR} [1]	Sampling SOP[2]	Analysis SOP	ADL
	CONTAMINATION LIMITS				
Maximum Removable Contamination (net dpm/100 cm^2)					
alpha	33	8.5	SOP#	SOP#	19
beta/gamma	350	100	SOP#	SOP#	190
beta <150 keV	350	91	SOP#	SOP#	200
Maximum Fixed Contamination (net dpm/100 cm^2)					
alpha	175	47	SOP#	SOP#	98
beta/gamma	850	230	SOP#	SOP#	480
	SAMPLE ACTIVITY LIMITS				
Maximum Screening Activity Concentrations per Matrix					
Solids (pCi/g)					
alpha	100	29	SOP#	SOP#	52
beta >150 keV	200	58	SOP#	SOP#	100
beta <150 keV	500	150	SOP#	SOP#	260
gamma	200	58	SOP#	SOP#	100
Liquids (pCi/L)					
alpha	100	18	SOP#	SOP#	70
beta >150 keV	200	40	SOP#	SOP#	140
beta <150 keV	1,000	180	SOP#	SOP#	700
gamma	200	40	SOP#	SOP#	140
Air Filters (pCi/filter)					
alpha	100	29	SOP#	SOP#	52
beta >150 keV	200	58	SOP#	SOP#	100
beta <150 keV	500	150	SOP#	SOP#	260
gamma	200	58	SOP#	SOP#	100
Alternate Total Activity per Aliquant (pCi)					
alpha	5,000	1,400	SOP#	SOP#	2,800
beta >150 keV	10,000	2,700	SOP#	SOP#	5,500
beta <150 keV	25,000	6,800	SOP#	SOP#	14,000
gamma	10,000	2,700	SOP#	SOP#	5,500
	EXPOSURE AND DOSE RATE LIMITS				
Maximum Sample Exposure Rate (µR/h at surface of container)	5,000	1,500	SOP#	SOP#	2,600
Maximum Area Ambient Exposure Rate (µR/h)	500	150	SOP#	SOP#	260
Maximum Estimated Dose Rate, TEDE (mrem/h)	2.50	0.6	SOP#	SOP#	1.5

[1] The calculation of u_{MR} in this table assumes a z-factor of 1.645, related to α and β probabilities of 0.05.

[2] The Laboratory Sampling and Analysis SOPs have been omitted, as actual method parameters are not used to generate these specific example values. In an actual DQO summary, these columns would be completed with the laboratory method references that correspond to the stated MQOs.

- notification to the area supervisor or Radiation Safety Officer (RSO);
- surface decontamination, following established protocols;[13]
- follow-up survey to verify that the removable surface contamination is now below the ADL(*C*); and
- filing of a brief incident report to the area supervisor or RSO documenting the incident, the corrective action taken, the results of the follow-up measurements, and the necessary approval to resume work.

The laboratory's response to area exposure rate ADL(*C*) excursions may be to move nearby samples to remote storage. Sample activity concentration ADL(*C*) excursions might be addressed by processing the sample material in a higher-activity area or by sub-sampling to limit the total amount of activity being handled, which is discussed in more detail below. The laboratory should develop individual requirements for immediate response, corrective action, and the resumption of work, for each contamination control measurement in each area type.

2.3 Additional Comments Regarding Radioactivity and Exposure Limits

Limits on sample activity concentrations are intended to allow the use of sample screening data to segregate radioactive samples to a particular part of the laboratory for processing. In some laboratories, however, it may not be possible to have both a "High-Level" and "Routine-Level" facility for every process. For that reason, Alternate Total Activity limits are provided to allow for the segregation of a small representative sample aliquant (portion of a high-activity sample) in the higher-activity level area. That reduced aliquant may then be brought into a lower-activity level area for further processing.

EXAMPLE 1: The screening analysis results from a 500-g solid sample indicates beta activity of approximately 5,000 pCi/g, for beta-emitters with emission energies >150 keV. While the laboratory has facilities for the gross handling and digestion of high-activity samples, there are no separate facilities for chemical separation or counting. What is the largest sample aliquant allowed for processing in the Routine-Level Work Areas?

In this case, the sample exceeds the 100 pCi/g activity concentration ADL for this category of beta activity. A small representative aliquant may be processed in the Routine-Level Work Area, provided that the total beta activity does not exceed the 5,500 pCi total sample activity ADL, as determined by the screening results. Consequently, 1.1 g of material may be segregated in the High-Level Work Area and brought into the Routine-Level Work Area for further processing: (5,500 pCi limit) / (5,000 pCi/g sample activity) = *1.1 gram sample limit*.

EXAMPLE 2: In the same scenario, how much sample material may then be transferred into the instrumentation laboratory for analysis, if that area is considered a Low-Level Work Area and the corresponding ADL for total beta activity per sample is 500 pCi?

[13] See Appendix I, *Decontamination of Laboratory Surfaces and Equipment*, for a general example of a decontamination protocol.

> The representative 1.1-g sample aliquant that was brought into the Routine-Level Work Area for processing should be further reduced to the equivalent of no more than a 0.1-g aliquant, prior to being brought into the instrumentation lab: (500 pCi limit) / (5,000 pCi/g sample activity) = *0.1 gram sample limit*.

Additional discussion regarding the handling and sub-sampling of higher-activity samples is given in Section 3.1, *Sample Handling Protocols*.

The limits on exposure and dose rates in Table 2 are intended to allow the laboratory to specify protective measures for the employees based on the type of area, and to control the impact of radiation on the analytical instrumentation in the various areas. Similarly, contamination limits allow the laboratory to control the potential impact of laboratory operations on the ability of the laboratory to achieve certain MQOs, as well as allowing the laboratory to further target protective measures to specific work areas.

Note that the values given in Table 2, and in the examples above, *are provided for guidance only* and are intended to illustrate possible limits that may be used for controlling radioactivity and radiation levels in the various parts of the laboratory. These values will need to be adjusted based on specific laboratory operations. For example, in areas performing gross α/β analyses, the AAL and corresponding ADL values may be considerably higher than those that might be acceptable for areas in which alpha spectrometry analyses are performed. These decisions must be carefully considered on a case-by-case basis.

When establishing operational limits to the measured radioactivity and radiation levels in the different parts of the laboratory, a significant concern will be the potential effect of that radioactivity and radiation on the laboratory's ability to perform sample measurements that meet the MQOs that have been established for the radiological or nuclear incident response. For example, a laboratory might limit sample activity concentrations in an area based on an estimation of the level of cross-contamination among samples that is likely for some particular process, such as soil grinding or the vigorous boiling of water samples. The laboratory may wish to limit the radioactivity associated with such potential cross-contamination to an amount that will not have a significant impact on the incident response decisionmaking process.

In a similar example, the laboratory may wish to limit the fluctuations in nearby counting instrumentation by estimating the exposure rate that would be required from a batch of samples transiting the laboratory, to cause such a response in the instrument. This maximum allowable exposure rate might be distributed among several samples to determine a maximum allowable exposure rate, per sample.

In each example, the AAL established by the laboratory is the level of radioactivity or radiation that is expected to negatively impact laboratory operations. As this true sample value cannot be measured with absolute precision, the uncertainty of the measurement method (u_{MR}) as well as an acceptable level of decision error rate, are also considered when determining an ADL, which is the measurement value beyond which it is understood that the AAL is likely to have been exceeded.

2.4 Determining Appropriate Levels of Personal Protective Equipment

Once the acceptable levels of radioactive materials and radiation are established for the various areas, the laboratory must designate required PPE that is appropriate for the activity levels, chemical hazards, and the type of work being performed.

It is not possible, within the scope of this document, to determine appropriate levels of PPE for the unique situations encountered in each laboratory. As with the designated activity concentrations, and contamination and exposure levels shown in Table 1, this document provides only examples for the laboratory to consider in its determination of appropriate levels of PPE. These examples are shown in Table 3, *Suggested PPE for Operational Areas*.

Table 3 – Suggested PPE for Operational Areas

	Work Area Definitions			
	Low Level	Routine Level	High Level	
Long sleeves, pants.	×	×	×	Important Note: Example requirements for respiratory protective equipment have been intentionally omitted from Table 3, as the selection, training, and use of respiratory protective equipment are complex and well outside the scope of this guide. These matters should be carefully considered by the laboratory's health and safety professionals, in light of the type of samples, activity levels, methodologies, and engineering controls to be used, and should be thoroughly documented in the laboratory's Radiation Protection and Respiratory Protection Programs. Qualified health physicists and industrial hygienists should be consulted prior to designating the use of this equipment.
Closed, flat work shoes.	×	×	×	
Safety Glasses	×	×	×	
Lab Coat	×	×		
Disposable Gloves	×	×	×	
Head Covering			×	
Disposable Lab Coat/Smock			×	
Disposable Shoe Covers (Booties)			×	
Disposable Cuffs			×	
Disposable Gloves (2nd Layer)			×	
Disposable Coveralls			×	
Respiratory Protection (see note)				

It is important to note, however, that most standard laboratory PPE does not provide adequate protection from external exposures to gamma or high-energy beta activity. PPE is primarily designated as protection against chemical hazards, heat/cold and other physical hazards, and as a mechanism for controlling worker and laboratory contamination. Protection against ionizing radiation is discussed further in Section 4.0, *Exposure Control and Radiation Shielding*.

2.5 Laboratory Layout and Process Flow

A key element of laboratory contamination control is the specific and dedicated use of different areas in the laboratory, with proper consideration to how the activity levels in the various areas are related and how materials and staff will move from one area to another.

The laboratory should be configured, whenever possible, to reflect the logical flow of operations and to minimize the impact of potential contamination events. Dedicated work spaces can

minimize the risk that contamination in one area will impact other processes. The laboratory should also establish contingency plans for handling out-of-control events, such as sample spills or broken containers.

In existing facilities, work areas might be reassigned or rearranged to facilitate a more efficient and controlled environment. In designing new facilities, careful attention should be paid to the physical layout of the laboratory and the anticipated flow of work through the different areas. In some cases, separate facilities may be constructed for handling high-level vs. low-level samples. In combined facilities, it is advantageous to have the low-level processes as remote as feasible from high-level processes. Related processes should be situated close to one another to minimize traffic through the work areas, and the flow of work through the laboratory should be smooth, logical, and efficient. These factors will help minimize incidental contamination issues and help contain the contamination when it does occur. Appendix A, *Planning Considerations for Laboratory Layout and Process Flow*, provides a more detailed discussion of the various considerations for separating high-level and low-level sample processing areas in a single laboratory facility. The examples are intended to be illustrative and may be applicable to a wide variety of laboratory configurations.

Additional information about laboratory configuration, process flow, and other critical elements in the preparation of a laboratory for response to a radiological or nuclear incident is provided in the *Guide for Laboratories – Identification, Preparation, and Implementation of Core Operations for Radiological or Nuclear Incident Response* (EPA 2010).

2.6 Additional Planning Considerations

In addition to defining operational areas in the laboratory, establishing acceptable levels of radioactivity and radiation for those areas, determining appropriate levels of PPE, and considering the layout and process flow in the laboratory, several other important planning considerations are briefly introduced below.

2.6.1 Controlled Entry/Egress Points

When planning the various work areas in the laboratory, consideration should be made for existing traffic paths and entryways, as these may be limitations to the intended layout of the work areas.

Each distinct area type, examples of which are provided in Section 2.1, should have limited and controlled access and egress points. Further, the points of entry should be distinct and distant from the points of egress, whenever possible.

2.6.2 Step-Off Pads

The strategic placement and liberal use of adhesive step-off pads or mats will significantly decrease the risk of laboratory contamination resulting from the migration of radioactive materials from foot traffic. Step-off pads should be changed frequently to maintain their effectiveness and should be surveyed prior to removal and disposal so that potential

contamination issues may be identified and corrected. The proper use of step-off pads is discussed in Appendix F, *Egress Into a Lower-Activity Area*.

2.6.3 PPE Donning/Doffing Areas

Sufficient space should be allotted at the area entry points for the storage of, and access to, the PPE that is required in that area. Consideration may also need to be given to space for benches, tables, or other ancillary furniture that will facilitate easy and efficient donning of the required PPE.

The efficient removal (doffing) of PPE, in a manner that helps prevent laboratory contamination, should be facilitated by the placement of PPE doffing stations at the controlled egress points. Doffing areas should include step-off pads, frisking stations, and used PPE and waste receptacles, as well as ready access to personnel decontamination equipment and a phone or intercom to summon assistance, if needed.

2.6.4 Frisking Stations

Frisking stations are locations that provide ready access to hand-held survey equipment. The survey equipment to be used at these stations may be incident-specific. Geiger-Müller probes, exposure rate meters, etc., should be selected with consideration of the radionuclide and type of radiation encountered in the specific incident as well as the detection sensitivity of the instrument and the ability to meet the operational objectives established by the laboratory. Frisking stations should be planned for strategic areas throughout the facility, including egress points and laboratory areas where sample containers, work surfaces, or personnel should be frequently monitored for contamination.

The layout and location of a frisking station should facilitate the task it is intended to accomplish:

- Frisking stations should be located so as to intercept the movement of potentially contaminated materials or personnel through the lab. It is necessary to place frisking stations at the controlled egress points from an area of higher activity to an area of lower activity, so that personnel and materials can safely move to the lower-activity area. It may also be desirable to place additional frisking stations within a work area to monitor the movement of radioactivity within the lab.
- Except for the necessary frisking stations at controlled egress points, locating a frisking station in a high traffic area such as a hallway may increase the risk of contamination to passing personnel and equipment since potentially contaminated materials are deliberately brought to the frisking station for survey. Having a frisking station in a high traffic area may also discourage a thorough survey if the traffic impedes or interferes with the surveying process. Whenever possible, if a frisking station is to be located in a high traffic area, it may be advisable to create a small alcove for that purpose, or to allow sufficient room for traffic to keep well clear of the frisking process.
- Frisking stations should be equipped with a table or other surface for placing materials to be surveyed. The table should be covered with plastic-lined, absorbent, disposable

laboratory paper, which should be changed frequently. The surface should be divided into two areas, one for staging "incoming" materials to be surveyed and the other for "clean" materials that have been successfully surveyed. If any item is determined to be contaminated, the item and the "incoming" area should be decontaminated and the laboratory paper replaced. Consequently, frisking stations should be designed with ready access to decontamination equipment and supplies, a receptacle for potentially contaminated waste, and ready access to a phone or intercom system to summon assistance, if needed.

- Frisking stations at controlled egress points should be equipped with hand-held survey probes necessary for surveying clothing, materials, and other surfaces. In addition, stationary hand-and-foot monitors may expedite traffic through the area.

2.6.5 Personnel Decontamination Stations

Personnel decontamination stations need not be elaborate or take up significant space beyond a normal laboratory configuration. A typical decontamination station should be equipped with a sink for routine hand-washing as well as a shower or drench hose with eyewash station. The laboratory should ensure that the decontamination area is adequately supplied with:

- Hand soap and a chelating detergent;
- Disposable sponges, scrub brushes (such as fingernail brushes), and paper towels;
- Temporary clothing, such as paper coveralls and booties, in the event that the employee's clothing must be removed;
- A temporary modesty screen, to encourage the disposal of potentially contaminated clothing prior to leaving the area; and
- Receptacles for potentially contaminated clothing and supplies.

The laboratory's Radiation Protection Program should provide additional detailed guidance on personnel decontamination that is tailored to the specific facilities and to the radioactive materials and processes in use. These laboratory-specific details are outside the scope of this document.

2.6.6 Spill Response/Surface Decontamination Equipment

As with personnel decontamination stations, laboratory spill response and surface decontamination preparedness need not be overly burdensome to the laboratory. Many needed supplies and equipment will already be on hand for response to chemical spills and decontamination.

Supplies to address minor decontamination events, such as sample bottles or laboratory bench surfaces, should be kept in the individual laboratory area and should include:

- A chelating detergent in a spray or squeeze bottle;
- Disposable wipes;
- Paper towels;
- A supply of secondary containment bags or bins; and

- Access to a receptacle for potentially contaminated waste.

Equipment and supplies for larger events involving the response to radioactive materials spills and surface decontamination should be readily available at strategic locations throughout the laboratory. The primary equipment and supplies will be preferably located on a cart, so that the materials can be easily brought to the location of the spill/contamination. The cart and its contents should be clearly marked for use only in spill or contamination response, to prevent their use in normal housekeeping tasks. The cart and its contents should be frequently inspected, preferably using a check-off/sign-off document to ensure that adequate supplies are readily available when needed.

2.6.7 Contamination Follow-Up Protocol

Following a sample spill or other contamination event, it will be necessary to verify that the affected surfaces, materials, and equipment have been properly decontaminated before they are approved for use in the laboratory. The laboratory should have established guidelines for re-surveying potentially contaminated surfaces, etc., documenting the results of those follow-up surveys, and in some cases obtaining the approval of the RSO or other safety staff before resuming normal operations.

2.6.8 Additional Shielding Material

The laboratory should establish fixed radiation shielding in those areas where protection from elevated exposure to beta and gamma radiation is needed. These areas may include the sample and waste storage areas for high radioactivity materials, selected work stations in the high-level and routine areas, and the radiation measurement instrumentation area.

In addition to fixed shielding, the laboratory should keep on hand a variety of temporary and portable shielding devices that will accommodate activity sources that were not anticipated in the initial planning or the laboratory layout. These devices may include:

- Lead bricks or sheets;
- Lead pigs or other containers for transporting samples; and
- Polycarbonate or acrylic sheets, to be used for beta shielding.

In planning for the laboratory to respond to a radiological or nuclear incident, the availability, location, and transportation of these additional shielding materials within the laboratory should be considered. A more thorough discussion of shielding requirements is found in Section 4, *Exposure Control and Radiation Shielding*.

2.6.9 Glove Boxes

In some cases, high-activity samples and samples that present a high risk of airborne contamination should be processed in a glove box. Whether it is a permanent structure or a temporary glove box located inside a fume hood, the laboratory should ensure that it is large enough for the intended purpose and properly equipped with all required sample handling and

decontamination equipment, and that the personnel are adequately trained in the transfer of material into and out of the box, and the associated surveillance and decontamination practices.

If the laboratory intends to install a glove box, qualified engineering and health physics professionals should be consulted. The engineering and safety requirements related to the selection and use of glove boxes are complex and beyond the scope of this guide.

2.7 Changing the Work Area Designation During an Incident Response

The modification of a work area's designation with respect to activity levels, particularly the change from a higher-level work area to a lower-level work area (e.g., the conversion of a High-Level Work Area to a Routine-Level Work Area) should generally be discouraged during an incident response due to the potential for allowing unobserved contamination to remain in the newly designated lower-level work area. Nonetheless, it is recognized that some modification of the laboratory's processes may be necessary under certain circumstances.

Prior to allowing an area's designation to be changed from a higher-level work area to a lower-level work area, a detailed plan should be created by the laboratory that addresses:

- which areas will be affected;
- how the flow of work through the laboratory will be affected;
- which equipment and surfaces in the area under consideration will remain and which will be removed;
- what decontamination protocols will be used on both the remaining equipment and surfaces, and those to be removed;
- which contamination control ADL(*C*)s will be applicable to the new area (i.e., what the area-type designation of the new area shall be);
- the number and type of surveys that will be necessary to change the area-type designation; and
- the requirements for documentation and approval prior to allowing the work area to be placed into service under the lower-level designation.

Similarly, the conversion of a lower-level work area to a higher-level designation should require a plan that addresses the same considerations described above, except that decontamination and surveillance prior to changing the area-type designation are not necessary in that case.

Any plan for converting laboratory areas should include consideration that materials and equipment being moved through the laboratory in preparation for the conversion are likely to be moved through other lower-level work areas, for which lower contamination and exposure limits apply. Consideration should also be made for the ultimate re-use or disposal of equipment or materials being removed from higher-level work areas, and for the ultimate return of a newly-designated higher-level work area to its former lower-level status. Finally, the frequent or repetitive change of area-types should not be allowed as a routine practice and should not be considered a reasonable substitute for having sufficient laboratory space and infrastructure to properly respond to a radiological or nuclear incident.

3. RADIOACTIVE CONTAMINATION CONTROL

After preparing the physical laboratory to respond to a radiological or nuclear incident, as described in Section 2.0, the laboratory should consider establishing operational protocols that provide task-specific instruction to personnel for controlling radioactive contamination and radiation exposure.

The protocols in the associated appendices are provided as generalized templates only, and are not intended to prescribe specific requirements for the laboratory. Some of the example protocols provide great detail simply to illustrate the benefit of a careful and systematic approach to sample handling. Each laboratory will need to make its own decisions regarding the need for specific protocols, and the content of those protocols it decides to implement in order to accommodate the unique layout and established procedures in the laboratory.

These protocols should address the areas of concern related to the handling and control of elevated levels of radioactivity in samples, waste, and other laboratory materials and the processing of the large numbers of samples that may be expected during the response to a radiological or nuclear incident. These areas of concern include:

- The appropriate handling of radioactive samples, including the initial receipt of samples, the proper handling of opened sample material, the isolation of small amounts of material for further processing, and modified procedures for chemical separations.
- The establishment of dedicated equipment for high-activity samples and the use of detector QC measurements to control and monitor low-level radioanalytical contamination.
- The proper movement of materials and personnel through the laboratory to prevent the migration of radioactive contamination.
- The systematic monitoring and removal of radioactive contamination.

Brief discussions regarding these specific topics are presented below. Example protocols are presented in the associated appendices.

In establishing protocols for the control of radioactive material, the laboratory may find it useful to require that additional personnel are readily available to support the primary employee by providing supplies, recording data, and performing other tasks as needed. This may help to minimize the number of collateral tasks being performed by the person handling the samples and other potentially contaminated materials, thereby minimizing the likelihood of laboratory contamination.

In addition, the establishment of specific protocols will generally require the measurement of radiation and a comparison of the measurement results to the analytical decision level, as discussed in Section 2.2. The laboratory should be familiar with the concepts related to MQOs, ADLs, AALs, etc. Familiarity with the companion guides[14] in this series and MARLAP (2004)

[14] See Preface.

Appendix C, *Measurement Quality Objectives for Method Uncertainty and Detection and Quantification Capability*, will significantly aid in the understanding and application of these concepts.

3.1 Sample Handling Protocols

The laboratory should develop protocols for receiving and screening potentially radioactive materials. Elevated activity samples should be segregated from low-level samples as soon as they are identified, ideally at the point where they are shipped from the field and before they reach the laboratory. The laboratory should communicate with the field personnel, where possible, and make arrangements for segregated shipments, whenever possible. Advance notification from field personnel regarding the expected delivery of samples, including the number, field screening information, and a copy of the chain of custody, may assist the laboratory in its preparations for sample receipt. Samples should be screened as part of the sample receipt process and separated into low-level and high-level streams, as early as practicable, but prior to their release to the laboratory for analysis. Field screening results may be considered in the laboratory's initial receipt of the samples but should not replace laboratory screening protocols. In some cases, extremely elevated activity levels may necessitate that a sample be rejected for receipt by the laboratory, or routed to another location for additional processing or sub-sampling prior to acceptance by the laboratory. Guidance on sample screening, including examples, can be found in the companion document, *Radiological Laboratory Sample Screening Analysis Guide for Incidents of National Significance* (EPA 2009b).

The laboratory should develop protocols for opening, transferring, sub-sampling, and aliquanting sample material. These protocols should incorporate screening data proactively to ensure appropriate handling of elevated activity samples, including the isolation of small sample fractions for processing in lower-activity areas, if necessary.

Sample preparation practices should be reviewed to ensure that they minimize the risk of laboratory contamination and sample cross-contamination, and incorporate contamination monitoring and control techniques, where possible. The analytical procedures should ensure that the risk of detector contamination is minimized, and that such contamination is rapidly identified and corrected, when it does occur.

3.1.1 Initial Receipt of Radioactive Materials

Upon receipt of sample material or radioactive sources, it is extremely important that an external dose rate measurement and a survey of the removable surface contamination from the shipping package be performed. These surveys may be required by federal and applicable state regulations for certain radioactive materials packages, but they are strongly recommended for the receipt of all shipments that could potentially contain radioactive materials. In addition, the contents of the package should be surveyed for removable surface contamination prior to distribution in the laboratory. Finally, the inside of the package and any packing material may need to be surveyed prior to disposal, where the survey of the contents indicates potential contamination.

The laboratory should consider establishing a specific protocol that would be appropriate for the general receipt of radiological material, with activity and exposure limits that reliably ensure identification of materials that may compromise the laboratory's established contamination and exposure limits. An example of a sample receipt protocol is provided in Appendix B, *Initial Receipt of Radioactive Materials*. In addition to the limits selected by the laboratory, the laboratory should be familiar with the requirements of 10 CFR 20, 10 CFR 71, 49 CFR 173, and other applicable regulations regarding the transportation, receipt, and handling of radioactive materials packages.

It is recommended that the laboratory develop a standardized form, to be completed with each shipment, which guides the technician through the various steps of receiving a package. The form should document the measurements performed and include or reference appropriate action levels, and instructions for responding to measurements above the action levels. An example of this type of form is shown in Figure 8, *Example of Radioactive Materials Shipments Initial Survey Results,* in Appendix B.

3.1.2 Opening, Transferring, and Aliquanting Sample Material

The opening of the sample container and the removal of sample material present a significant risk of laboratory contamination, particularly when handling dusty or friable samples, or when the samples contain discrete radioactive particles (DRPs), also referred to as "hot particles," which may become electrostatically charged and therefore difficult to control. Upon receipt in the laboratory, the sample container may need to be opened and sample material removed for screening analysis to determine gross activity levels. Decisions regarding the appropriate storage areas and work locations for the sample should be based on those screening measurements.

The laboratory might consider a protocol that addresses the staging and opening of the sample containers, the removal of sample material, and the transfer of that material to an appropriate container for further processing. Issues such as the dedicated use of work areas for specific tasks, the screening of sample containers, the proper disposal of waste materials, and the ultimate destination for the removed sample material should be addressed.

An example protocol for this phase of sample handling is provided in Appendix C, *Opening, Transferring, and Aliquanting Sample Material*. As in all the examples provided in this guide, suggestions are offered for the laboratory's consideration, but the laboratory will need to make its own decisions about the establishment and content of specific protocols.

The example provided in Appendix C is somewhat simplified and is very specific to the transfer and aliquanting of soil material. It is intended to illustrate particular points regarding the flow of work, the organization of the work area, suggested practices to control dust and to minimize laboratory contamination, and surveillance practices to identify contamination events if they occur. Other laboratory procedures and steps should be examined in the light of these points to control contamination.

3.1.3 Isolating Reduced Fractions for Transfer to Lower-Level Work Areas

As discussed in Section 2.2., the laboratory will benefit from designating specific areas for the handling of sample materials with pre-set activity ranges. Nonetheless, it is recognized that not all laboratories will be able to establish redundant facilities in multiple areas for all tasks. Where laboratory facilities are limited, it may be helpful in some cases to isolate a small, representative aliquant of a highly radioactive sample to be brought into the lower-level work areas for processing. This may be done in a small High-Level Work Area in the laboratory, or may even be done in a remote facility, separate from the analytical laboratory.

If the desired target aliquant is large enough that it can be taken directly from the bulk sample and an accurate measurement of a representative subsample may be reasonably expected, the laboratory might allow the procedures described in Appendix C to be followed. If the desired target aliquant is very small, a reliable measurement of the aliquant size may be difficult or the homogeneity of the aliquant may not be assured. In such cases, a larger intermediate aliquant may need to be taken, digested, or diluted, and a fraction of the final digestate/solution then taken that is equivalent to the target aliquant. In these cases, the accuracy of any dilutions performed will be improved and the uncertainty of the final concentration minimized if the initial sample amount and the digestate solution taken for analysis are measured gravimetrically. An example protocol is briefly described in Appendix D, *Isolating Reduced Fractions for Transfer to Lower-Level Areas*, and is carried out in the laboratory fume hood configuration described in Appendix C.

In this relatively simple manner, a larger subsample of the original material may be further divided into much smaller representative aliquants that may contain micrograms or microliters, or less, of the original sample. The reduced aliquant with the associated reduced activity level may then be brought into lower-level work areas for processing.

3.1.4 Sample Preparation and Chemical Separation Processes

Where possible, the laboratory's sample preparation and chemical separation procedures should be flexible enough to allow the laboratory to accommodate both pre-established incident response MQOs and incident-specific MQOs. The laboratory's procedures should incorporate the collection, review, and communication of screening data proactively to ensure the appropriate handling and aliquanting of elevated activity samples. Laboratories with pre-established digestion and dilution protocols that use screening results as "trigger" points will save time during sample preparation. At the same time, this process ensures that the total activity handled during sample processing is decreased and that the subsequent decontamination of labware, equipment, and detectors is minimized.

If a sample must be processed to separate and purify radionuclide(s) of interest, measures should be taken to detect and minimize cross-contamination. While specific measures taken should reflect the needs and vulnerabilities of each operation, examples of typical measures could include:

- Minimizing the levels of activity, based on screening results, that may be handled in any area or specific operation;

- Grinding solid samples using equipment such as paint shakers or ball mills, which minimize the release of particulates into the air;
- Maximizing the use of disposable labware for high-level work, and segregating labware and equipment for low-level work from that for high-level work;
- Providing dedicated facilities for cleaning low- and high-activity labware and equipment;
- Making provisions to test the effectiveness of cleaning/decontamination, such as analyzing rinse waters or performing equipment blanks;
- Establishing a system to identify equipment used and the sequence in which samples were prepared to facilitate corrective action whenever unexpected high activity is identified later in the process;
- Using plastic-backed, bench/hood absorbent paper liners in preparation areas;
- Pre-treating fume hoods or other surfaces with a strippable coating, which proactively enables effective decontamination;[15] and
- Identifying housekeeping expectations and responsibilities and setting a schedule for keeping work areas clean.

3.1.5 Instrumentation and Radioanalytical Controls

The purpose of radioanalytical contamination control is to protect the quality of the results and to ensure that the required radiochemistry MQOs are met. The levels of contamination that significantly affect the quality of the data are generally much lower than those needed to protect the health of laboratory personnel. Effective radioanalytical contamination control will, by default, minimize personnel contamination and simplify decontamination efforts, both of which have significant impacts on the sample throughput and laboratory staff morale.

The starting point for effective radioanalytical contamination control is good laboratory practices. However, good laboratory practices which may be sufficient for routine operations may not be sufficient when high-level activity samples are processed. Contamination control measures, initiated during the receipt and processing of the samples, should be continued during the analytical process to maintain the integrity of the laboratory.

Such measures should be proactive, and the initiation of corrective actions should take place before contamination becomes a detrimental factor to laboratory processes and jeopardizes the reliability of the data. Implemented measures should reflect the needs and vulnerabilities of each operation. Examples of measures to protect the integrity of the counting instrumentation and the resulting measurements include:

- Logging sample IDs in the order of preparation for non-disposable equipment (e.g., grinders, glassware, etc.) to facilitate investigation of potential cross-contamination;
- Protecting gamma-ray detectors by bagging samples, detectors, or both;

[15] Additional information on the use and efficacy of strippable coatings may be found in Section 3.2 of the companion document, *A Performance-Based Approach to the Use of Swipe Samples in Response to a Radiological or Nuclear Incident* (EPA 2011).

- Swipe-testing certain sealed sample test sources, such as bagged gamma test sources or liquid scintillation vials, prior to their transfer to the nuclear instrumentation room, to verify the lack of removable surface contamination;
- Screening sample test sources to identify excessively high-activity samples prior to introduction into detectors;
- Designating detectors for low and high-activity samples;
- Designating detectors for specific analytes, especially those analytes that are susceptible to interference from the residual effects of other analyses performed in the same detectors (e.g., americium and plutonium results by alpha spectrometry may be biased by the residual effects of short-lived uranium and thorium progeny contamination on the detector);
- Establishing AALs, MQOs, and ADLs for investigation and corrective action (e.g., sample count rate or final sample activity exceeds pre-established criteria);
- Removing high-activity samples from gas proportional counters and alpha spectrometers as soon as the count is finished;
- Checking detector background after exposure to high-activity samples, after first defining "high activity" as it pertains to levels that may cause radioanalytical concerns;
- Periodically performing removable surface contamination surveys on gamma detectors to assess contamination from non-gamma-emitting radionuclides (e.g., ^{90}Sr, ^{239}Pu) on sample containers and other laboratory surfaces; and
- Increasing emphasis on tracking and trending of detector background count rates and method blank results.

In some cases, the laboratory may perform periodic cleaning of certain detector components, such as alpha or gamma spectrometer detectors. The laboratory should establish acceptable protocols for the periodic maintenance of detector systems. In addition, the laboratory should ensure that appropriate quality control checks are performed prior to cleaning and maintenance, to support the data acquired prior to any potential changes to the detector system, as well as ensuring that new background calibrations are performed after cleaning but prior to resuming sample analyses.

3.2 Movement Between Laboratory Areas (Entry/Egress)

After the laboratory defines and delineates the various types of work areas, as described in Section 2.1, it is recommended that protocols be established for movement between the areas. These protocols should be designed to minimize the risk of contamination to personnel, samples, supplies, and equipment, and to facilitate the isolation and removal of such contamination, if it occurs.

Entrance and egress points should be well defined and, whenever possible, separate. It is recognized, however, that separate entrance and egress points are not always possible in all laboratory settings, and that a single entryway or doorway will often need to serve both purposes. When moving between areas of different activity levels, precautions should be taken to protect both the workers and the materials from contamination. In specifying these precautions, the laboratory should ensure that the employees are well trained in the protocols and that those

protocols are thorough, but not unnecessarily burdensome. Overly burdensome guidelines, whose purpose is not immediately obvious, may be circumvented or ignored by the staff.

When providing training for entry and egress protocols, the following points should be emphasized:

- Individuals should be mindful that entry into an area of higher radioactivity will necessitate the eventual exiting from that area, with the associated egress protocols, and that entry is always easier and faster than egress.
- Any movement from an area of higher radioactivity to an area of lower radioactivity entails the risk of contamination to the personnel, samples, supplies, and equipment in the lower-activity area. Consequently, any transition should be carefully considered and planned to minimize the number of trips and the unnecessary movement of materials into (and out of) an area.
- No material should be removed from a higher-activity area to a lower-activity area unless it has been surveyed and determined to meet the entrance criteria for the lower-activity area and decontaminated, if necessary.
- Where possible, additional equipment should be procured in order to minimize the need to move equipment between different types of areas, especially where the risk of contamination to the equipment or the area is high.
- As there is no effective decontamination for sample material, any sample material processed in a higher level area may need to be screened or sub-sampled in order to allow its entry into a lower-activity area. This is time consuming and should be avoided whenever possible. Sample materials transiting an area should remain properly sealed.

Having noted the preceding points, the laboratory may wish to develop specific protocols to guide personnel in their entry to and egress from specific areas in the laboratory.

3.2.1 Entry Into a Higher-Activity Area

When entering a higher-activity area from a lower-activity area, as when moving from the instrumentation laboratory to sample preparation lab, the primary concern should be the protection of the employee and the materials being moved from the potential sources of contamination in the higher-activity areas. There is little concern that the materials or supplies entering the higher levels area will contaminate that area because they begin in the lower level areas, and it is assumed that the materials have met the criteria for those areas. Consequently, entering a higher level area from a lower level area need not entail contamination surveillance, such as screening or frisking practices, or decontamination protocols.

It may be helpful for the laboratory to ensure that the entry area, immediately outside the higher-activity area access point, is equipped with the following items:

- Lockers, cubbies, bins, or other containers for storing personal items that are not to be transported into the area;

- An ample supply of PPE items required for entry. This may include a selection of gloves, shoe covers, disposable coveralls, etc.; and
- A table or other surface for staging materials.

When entering the higher level area, the materials being moved into that area should be carefully considered. The number of trips back and forth should be minimized and no unnecessary items, such as redundant supplies or unneeded packing materials, should be taken into the area as these items present an unnecessary contamination risk.

Appendix E, *Entry Into a Higher-Activity Area*, provides an example of the type of protocol a laboratory may establish for transiting from a lower-activity area to a higher-activity area. Each laboratory should specify the entry protocol for each area, which will depend greatly on how the area types are defined, what activity levels are specified, and what type of PPE is required.

3.2.2 Egress Into a Lower-Activity Area

When leaving a higher-activity area, the primary concerns should be the containment of any radioactive materials being moved, and the assessment and control of contamination on the employee and the materials being moved. The goal is to prevent the migration of any potential contamination into the lower-activity area, which would expose lower level sample materials, laboratory facilities, and unprotected employees to the contamination source.

The protocols for egress from a higher-activity area will necessarily be more complex than the entry protocols. It may be useful to ensure that additional personnel are available to assist the egress process, including decontamination activities, if needed. An example protocol for moving personnel and materials from a higher level area to a lower level area is provided in Appendix F, *Egress Into a Lower-Activity Area*. As with other example protocols, this is based on a hypothetical laboratory operation, under very specific operating conditions, and is intended only as an example on which a laboratory might choose to base its own protocols.

The egress area should have provisions for contamination surveillance, removal of PPE, and the effective decontamination of items that are identified as contaminated. An example layout for an egress area is shown in Figure 11 of Appendix F.

3.3 Laboratory Contamination Monitoring and Control

In order to detect, control, and prevent the spread of radioactive contamination in the laboratory, a fully functional Radiological Controls Program should be implemented. This program must address low levels of radiological contamination that also present *radioanalytical* problems for the laboratory.

In some cases, the spread of cross-contamination as low as 0.25–1 pCi for beta/gamma-emitting nuclides and 0.1 pCi for alpha-emitting nuclides could lead to the reporting of erroneous results for low-level environmental samples and allow low levels of contamination to escape outside of the radiologically controlled area.

A laboratory's established radiological monitoring program should provide for adequate monitoring during normal operations and should include additional provisions for monitoring when handling samples that contain concentrations of radioactive contaminants well above those normally processed. These additional provisions could include increasing the frequency of surveys as a function of the activity level and number of samples processed, and expanding the areas of concern to include:

- Hallways, sample receipt area (inside and outside), and even administration areas;
- Inaccessible areas, such as laboratory hoods (including ductwork, fans, and exhaust stacks), floor drains, sink drains, and traps;
- Hood filters, and hood scrubber waste water; and
- Building external locations, such as the roof, loading and receiving docks, and the nearest sanitary or storm drains into which building liquid discharges are directed.

Surveys can be performed using portable survey meters, taking swipe samples, or taking grab samples, if appropriate. Additional information regarding contamination and dose can be obtained from ambient air monitoring of sample receipt and high-activity sample processing areas and from samples of mop water and step-off pads.

It is important to establish baseline activity values for these measurements under current laboratory conditions. Because some of these surveys may not be performed during routine operations of the laboratory, it may be necessary to develop and implement documented procedures to identify critical areas, and approaches to performing non-routine surveys. This also means that data should be collected for all sample locations, so that a baseline and an action level are established for each type of measurement and location. Any data collected during the incident response period should be evaluated against this baseline, assessed quickly, and followed with appropriate response, such as additional surveys or cleanup to minimize exposure, protect the integrity of samples and radioanalytical measurements, and prevent laboratory contamination or releases of radioactive materials to the environment.

Radiological monitoring of designated areas should take place at specified frequencies,[16] with specified sampling and measurement techniques, using pre-determined MQOs. Examples of these important components of a radiological monitoring program are provided in Appendix G, *Active Radiological Monitoring Program for Contamination Control*. Specific procedures for surveillance and decontamination of laboratory surfaces, equipment, and personnel are discussed in the following sections.

[16] Guidance on strategies for establishing survey frequencies was issued by the U.S. Nuclear Regulatory Commission (NRC, 1999: NUREG 1556, vol. 11), but each laboratory should develop its own program. The approach should also keep in mind that the NUREG document is focused primarily on human health concerns, although much lower levels of radioactive contamination may be of concern in radioanalytical facilities where measurements of low-level radioactivity are being performed.

3.3.1 Surveillance of Laboratory Surfaces and Equipment

Surveillance of laboratory surfaces and equipment should employ both hand-held survey equipment and laboratory swipes. Section 2.2 and Appendix G discuss the need to establish acceptable levels of fixed and removable contamination[17] and associated survey MQOs in the various area types prior to accepting samples from a radiological or nuclear incident. Note that in the transfer of materials from a higher-activity area to a lower-activity area, the contamination limits must satisfy the requirements of the lower activity before the materials leave the higher-activity area.

3.3.1.1 Fixed Contamination Surveys

Fixed contamination surveys, using hand-held survey instruments, should be required on all potentially affected surfaces that present a risk of exposing laboratory workers to radiation above the limits specified in the area descriptions or causing elevated or unstable background levels that may adversely affect instrumentation. Laboratory surfaces should be surveyed periodically and after any necessary decontamination efforts. All materials, such as laboratory equipment, paperwork, samples, etc., that are being moved from a high-activity level area to a lower-activity level area should also be surveyed. In some instances, it may be useful to survey sample test sources that have been prepared in a high-activity level area, prior to transferring those samples to a lower-activity level area.

"Fixing" Contamination In Place

The use of paints, epoxies, and other coatings to affix contamination to a surface permanently or semi-permanently may be a viable option for alpha and low-energy beta contamination in cases where the fixed-in-place radionuclides pose no external dose risk to personnel. These techniques can be especially useful when the contaminated surface is difficult to clean (e.g., porous concrete, wood, etc.) but replacement costs are prohibitive. Careful records must be kept to assist any eventual decommissioning activities in the facility, and fixed contamination areas should be clearly identified in the laboratory.

The laboratory should ensure that the hand-held survey instrument selected for use is appropriate to the type of radiation expected in the samples from the incident. If the type of potential contamination is uncertain or if the samples from the incident involve multiple types of radiation, the surface may need to be surveyed repeatedly using the different instrument types. When possible, survey equipment should be calibrated with the radionuclide of interest or an appropriate conversion factor should be determined. Additional guidance on the calibration and use of hand-held survey equipment is provided in *Radiological Laboratory Sample Screening Analysis Guide for Incidents of National Significance* (EPA 2009).

While the laboratory will have established procedures for the calibration and use of hand-held survey equipment, the actual implementation of these procedures can be highly technique-

[17] For purposes of this document, "fixed" contamination refers to the portion of contamination that remains attached to a surface after reasonable attempts to clean or decontaminate that surface. Contamination that is fixed to the surface is usually of concern only as a source of external exposure unless it becomes loose and is redistributed. "Removable" contamination is transferrable by contact, inhalation, or ingestion. The amount of removable contamination usually is determined by obtaining swipe samples (EPA 2011).

dependent, and the instrument results can vary significantly from one user to another. The response of any hand-held survey instrument, particularly those measuring alpha and beta radiation, to a radioactive source is dependent on the orientation and distance of the probe to the surface being measured, which may be different for each person unless steps are taken to ensure uniformity in the use of these instruments. Instrument check sources, therefore, should be measured by each technician daily or prior to use. The frequent measurement of check sources and the comparison of the results to established acceptance criteria by each individual technician performing the surveys may help to ensure consistency in the use of the instruments.

3.3.1.2 Removable Surface Contamination (Swipe) Surveys

The collection and analysis of swipes is intended to identify removable surface contamination. In general, a swipe survey is performed by selecting an appropriate swiping material, such as a paper or glass fiber filter. The swipe may be used dry or may be wetted with an appropriate agent, and is then drawn across a pre-determined area of the potentially contaminated surface. The swipe is then analyzed with an appropriately calibrated instrument, such as a gas proportional counter, liquid scintillation counter, or gamma spectrometer. Results are usually reported in activity units per swipe or per unit area swiped.

Swipes specifically designed for radiological surveys are commercially available, in a variety of materials, with or without adhesive backing for planchet mounting, and soluble in liquid scintillation cocktail, if desired.

The laboratory should develop and validate procedures for performing swipe surveys that are specifically suited to the surfaces and the type of radiological material in use. Those procedures should be specifically designed to meet the MQOs of the survey, which are in turn based on the type of area being surveyed and the activity levels employed there. Those procedures should be sufficiently clear and straightforward to ensure that appropriately trained personnel responsible for performing a survey for radioactive contamination can properly select and use the survey equipment and other necessary instrumentation.

Additional information and suggestions for the implementation of radiological surveys, including example forms for recording survey data, are included in Appendix H, *Surveillance of Laboratory Surfaces and Equipment*.

Due to the wide variety of survey equipment, swipe materials, and swipe analysis techniques, this guide does not address the use of specific equipment or the performance of specific analytical practices. Where specific techniques are discussed in Appendix H, they are provided only as examples and should be carefully reviewed by the laboratory technical management staff to determine applicability to the specific laboratory conditions.

Detailed guidance for performing swipe surveys is provided in the companion document *A Performance-Based Approach to the Use of Swipe Samples in Response to a Radiological or Nuclear Incident* (EPA 2011) and in the *Multi-Agency Radiation Survey and Assessment of Materials and Equipment* Manual (MARSAME 2009).

3.3.2 Decontamination of Laboratory Surfaces and Equipment

Decontamination procedures for surfaces in the laboratory will generally be limited to non-porous surfaces that can be readily cleaned with conventional methods. It is therefore important that the laboratory restrict the use of absorbent or porous materials, such as fabric or unfinished wood, to those absolutely necessary to the laboratory operations. Absorbent or porous surfaces are difficult, and frequently impossible, to decontaminate to acceptable levels after a contamination incident. These items must then be disposed of as radioactive waste, which may be difficult and expensive. If such items or surfaces must be used, they should be coated to the extent possible with a non-absorbent covering. For example, if a wood pallet is needed to bring new equipment into the hot zone, the pallet may be covered with Tyvek to reduce the risk of contaminating the pallet.

Appendix I, *Decontamination of Laboratory Surfaces and Equipment*, is an example protocol intended to provide guidance for the decontamination of laboratory surfaces. In developing its own protocols, the laboratory will consider the types of surfaces, work areas, etc., that may be unique to that facility.

3.4 Personnel Contamination Monitoring and Control

Personnel contamination monitoring and control are critical to the control of radioanalytical contamination in the laboratory, and should be a significant component of the existing radiation protection program. The three major components of personnel contamination control are prevention, monitoring for personnel contamination, and the effective decontamination of personnel should contamination occur. Depending on the existing contamination control practices in place in the laboratory, some of the measures listed below might already be in place, while others should be planned prior to, and implemented during, incident response activities. In any case, all routine practices and any additional personnel contamination control practices that might be put into effect during incident response situations should be accompanied by detailed and clearly written SOPs. The laboratory staff should be trained in these procedures, and the training should be documented.

3.4.1 Personnel Contamination Prevention

The spread of very low-level radioanalytical contamination as a result of staff activities can occur easily and is difficult to detect. Very often, practices that have no serious consequences in a laboratory used for the analysis of stable metals or environmental organic contaminants may significantly impact the quality of radioanalytical data. For example, uncontrolled movement of personnel or materials from one area to another may result in spread of contamination and, even in very low amounts, may increase the instrument background and adversely affect detection limits. It may be advisable to consider limiting staff to specific functions and work areas. To continue the example, analysts working with open sample containers who are thus potentially exposed to radioanalytical contamination should be precluded from entering the instrumentation area, where the sample test sources are counted and where maintaining low background is most critical.

Some of the additional recommended practices listed below are not intuitive, and others are simply "good laboratory practices," but all need to be considered when planning for incident response activities involving samples with increased levels of radioactivity:

- Single use of disposable gloves when handling samples;
- Removal and disposal of gloves when moving from a hood area to a laboratory bench area;
- Frisking of laboratory coats prior to and after use;
- Frequent change of laboratory coats (and subsequent laundering or disposal depending upon the laboratory situation);
- Proper use of laboratory coats (i.e., keeping them buttoned and with sleeves rolled down and used only when not compromised);
- Careful placement of contaminated materials into disposal containers (as opposed to dropping them in or overfilling) to avoid spread of contamination through release of particulates into the air;
- Removal of gloves and frisking of hands before touching non-contaminated items (e.g., telephones, computers, cabinets, drawers, doorknobs, reference texts, etc.);
- Review of personal hygiene and taking appropriate protective measures, such as tying back or covering loose hair with disposable caps, removing threadbare or compromised garments, removing loose jewelry, wearing appropriate footwear, and covering wounds securely; and
- Identifying the procedures and having equipment in place for a rapid decontamination of personnel, clothing, and other items.

3.4.2 Personnel Contamination Surveillance

Contamination survey procedures for personnel are identical to those used for fixed contamination surveys of laboratory surfaces, described above. Additional procedural guidance is recommended, however, to ensure that the individual surveying him/herself does not inadvertently contaminate the survey equipment.

Radiological surveys of laboratory personnel should be conducted after handling radiological material, before leaving the work area. In addition, surveys of the hands, arms, or other pertinent areas may be performed frequently during the handling of radiological material to detect and prevent the spread of contamination during the process. Frequent personnel surveys may also help maintain control of radiological material within a small work area such as a fume hood, where the integrity of low-activity zones within the hood itself may be important for radioanalytical contamination control.

While the laboratory will develop its own personnel surveillance protocols, those found in Appendix F, *Egress Into a Lower-Activity Area*, may be helpful.

Specific requirements for personnel contamination monitoring depend on the level of activity expected and the potential for radiation exposure during handling. These requirements should be considered for every staff member and every visitor and must be identified in the RPP. In incident response situations accompanied by the potential of increased exposure, additional considerations might include:

- Implementation or increased frequency of monitoring of external exposure using thermoluminescence dosimeters (TLDs) and finger rings, including potential use of real time dosimetry when working with significantly elevated levels of radiation.
- Implementation or increased frequency of monitoring of internal exposure using techniques such as in-vivo and in-vitro bioassay and air sampling. An arrangement with an outside laboratory specializing in in-vivo and in-vitro radiobioassay analyses may be necessary, unless in-house capability is available.
- Increased frequency of exposure reporting. In addition to more timely warnings of increased worker exposure, this may have the added benefit of providing frequent reminders to workers that work habits impact exposure control.

Additional personnel contamination surveillance information can be found in the U.S. DOE *Radiological Control Manual* (DOE, 1994).

3.4.3 Personnel Decontamination

Any instance of personnel contamination should be reported immediately to the laboratory's Radiation Safety Officer, or other qualified response personnel identified by the laboratory. In general, personnel decontamination efforts consist of removing the contaminated article of PPE or personal clothing, as appropriate. In cases where the employee is found to be directly contaminated, the decontamination procedure may be similar to that used for chemical decontamination of personnel. A discussion of typical equipment and supplies for personnel decontamination stations is provided in Section 2.5.

The procedure should consider whether movement to another area or decontamination in place is most appropriate. In some situations, the employee's movements through the work areas should be restricted to prevent the spread of contamination through the laboratory, unless there is urgent need to move the employee to another location, such as a chemical shower. In other cases, moving the employee to a contained decontamination area may be the most effective way to protect the laboratory and other personnel and to facilitate decontamination of the affected individual(s).

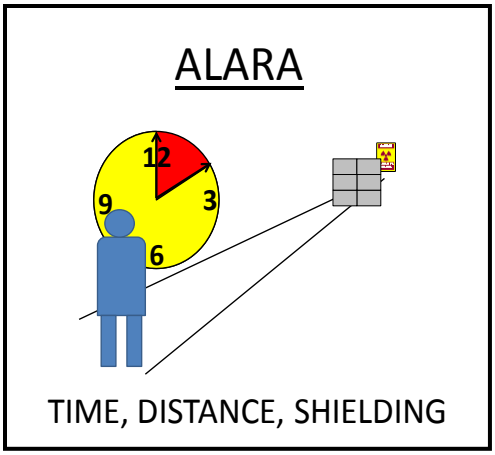
The laboratory should develop protocols for personnel decontamination that address the specific sample materials, reagents, and radionuclides involved in the incident response. The combined issues of radiological and chemical exposures, and medical treatment and surveillance are beyond the scope of this guide. A qualified health physicist, industrial hygienist, and occupational medical professional, as appropriate, should be involved in the development of personnel decontamination protocols.

Hospital and Emergency Medical Treatment

In the event that radiologically contaminated personnel require urgent medical attention, emergency response and hospital workers will need to treat and transport those contaminated personnel. The laboratory should coordinate, in advance, with hospital and emergency room personnel to ensure that those facilities are willing and prepared to receive and treat contaminated personnel. In some cases, the laboratory may need to provide decontamination and surveillance support at the hospital.

4. EXPOSURE CONTROL AND RADIATION SHIELDING

The information in this section assumes a basic understanding of the physical properties of alpha, beta, and gamma radiation. Federal regulations[18] require that laboratory personnel receive sufficiently detailed training in these and related issues, prior to being allowed to work in a radiologically controlled area, such as the laboratory areas described in this guide. Nonetheless, a complete and detailed discussion of the subject of radiation protection and dose reduction is complex and well beyond the scope of this guide, and should be referred to a qualified health physicist, particularly in cases where elevated activity levels are encountered and a measurable radiation dose may be received by laboratory personnel.



4.1 ALARA Principles

In all cases, a worker's exposure to radiation and radioactive materials should be kept As Low As Reasonably Achievable (ALARA). Any shielding techniques employed by the laboratory should be considered in this broader context of ALARA, which should take into account practices that *maximize the distance* between the source of radiation and the worker or equipment affected, and that *minimize the amount of time* spent in proximity to the source of radiation. These time and distance factors should be considered and optimized prior to making decisions about shielding requirements.

4.2 General Shielding Information

Despite the detailed level of training that a laboratory worker may receive prior to handling radioactive materials, the subject of shielding radioactive sources to prevent exposure to personnel is conceptually complex due to the various interactions between the primary radiation and the material through which it travels. This often results in additional, secondary sources of radiation that should also be considered. Consequently, the laboratory should be initially content with a simplified first-order approximation of the shielding requirements, and then be prepared to make minor adjustments based on actual survey measurements performed during the initial

[18] 10 CFR 20 and 29 USC 654,(b)(1), § 5(a)(1).

phases of the project. This empirical approach will expedite the initial setup of the laboratory and facilitate improved responsiveness to changing laboratory conditions.

In the selection of shielding materials, the laboratory should ensure that all shielding material is of sturdy construction and impervious to penetration by the radiological sample material, and that the outer surfaces are able to be easily decontaminated. Fabric, paper, cardboard, and similar materials, though capable of providing adequate shielding from alpha and beta radiation, should not be used because they cannot be effectively decontaminated.
The effectiveness of any shielding measures will be determined primarily by performing area surveys with hand-held survey meters. The employees must be adequately trained in the use of hand-held survey meters and the interpretation of the results.

When considering shielding requirements in the laboratory, the source and type of radiation should be carefully considered. Improperly shielded beta activity can actually increase the risk of exposure to the workers and the laboratory equipment, and unnecessary gamma shielding can be expensive and unwieldy. A thorough knowledge of the details of the radiological or nuclear incident and continuous vigilance in the performance of laboratory radiation surveys will help in the selection and use of shielding that is appropriate to the project.

In determining appropriate shielding requirements for different types of radiation, two relatively simple concepts are typically employed. The first is that of the "range" of particle radiation, which is the average distance that a particle will travel through a specific type of shielding. The range of an emitted particle is dependent on the type of particle, its emission energy, and the material used to construct the shielding. Most alpha particles, for example, have a limited range of less than 10 centimeters in air. The second concept is the "half-value layer," which will be applied to gamma radiation. Simply stated, the half-value layer is the thickness of a given material that will reduce the intensity of the gamma radiation to one-half of its original value. These values are entirely dependent on the gamma emission energy and the type of shielding employed. For example, if ^{137}Cs is the source term radionuclide in a radiological or nuclear incident, the intensity of the resulting 662 keV gamma emissions from the sample material will be reduced to one-half of its original value by using a 6.3-mm thick layer of lead shielding. The half-value layer and other analogous measures, such as the $1/10^{th}$ value layer, are commonly used to decide the thickness of shielding material needed to provide adequate protection.

An additional consideration in the design and implementation of radiation shielding is the occupancy of the personnel, or the amount of time that an individual spends in close proximity to the radiation source. Areas with a low occupancy, such as waste storage areas, may require less shielding than areas in which a worker spends the majority of his/her time, although these low occupancy areas still require appropriate posting and dose rate monitoring.

The examples provided below are intended to illustrate possible solutions to shielding requirements in the laboratory. Every actual laboratory situation, however, is likely to be unique and will require solutions that are tailored to those specific laboratory conditions.

4.2.1 Alpha Shielding

Shielding against alpha radiation is not a concern in a radiological laboratory. The range of any alpha particle through a solid material, such as a glass or polypropylene sample container, will be much less than the thickness of the container. For stored materials, the sample, waste, or source container provides adequate shielding against alpha radiation. For in-process materials, where the primary health concern is the inhalation or ingestion of alpha-emitting radionuclides, worker protection is ensured by the use of appropriate engineering controls such as the laboratory fume hood as well as PPE. Nearby instrumentation is unaffected because the instrument housing effectively blocks all alpha radiation.

4.2.2 Beta Shielding

Beta shielding should address two primary concerns: protection against the effects of the beta particle itself and protection from the bremsstrahlung (photon) radiation that is produced when the velocity of a beta particle is changed suddenly, as when thin sheets of metal are used for shielding. Whenever possible, primary beta shielding should minimize the production of bremsstrahlung radiation by employing material of a low atomic number (Z), such as polycarbonate, instead of high-Z material such as lead. Even in low-Z material, however, the production of bremsstrahlung radiation may be high enough to require secondary shielding. In these cases, a high-Z secondary shielding material, such as lead, is placed between the primary shielding and the area to be shielded. When handling and storing beta-emitting radionuclides, careful surveillance of both the beta and gamma field near the material is required, even when the radionuclide is known to be only a beta-emitter, with no associated gamma emissions, such as ^{90}Sr/Y.

The storage conditions should be considered when determining the need for shielding beta-emitting materials. Most beta particles will have a range of less than 100 cm in air, and a much smaller range of less than 1–2 cm in solid materials. The laboratory should have on hand an adequate supply of conveniently sized 0.25–0.5-cm thick plastic panels, to be used for additional beta shielding, as needed.

If the storage conditions are such that—

- The beta-emitting material is stored in durable glass or plastic containers;
- Sufficient distance is maintained between the radiological material and the laboratory personnel and equipment; and
- The employee presence in the storage area is minimal —

it may be preferable to avoid the use of additional shielding material in very close proximity to the samples. This may reduce the production of bremsstrahlung radiation and avoid the need for additional shielding material.

Beta shielding for work in progress should consist of a low-Z material, such as polycarbonate sheets or an enclosure such as a glove box. The material should be clear to allow the sample to

be seen during handling and should be configured to allow necessary access of the hands while protecting the rest of the worker's body, particularly the face and any other exposed parts. In some cases, when shielding high energy beta sources results in the production of excessive bremsstrahlung radiation, an additional layer of leaded glass may provide sufficient protection while maintaining visibility and access to the sample.

Shielding the hands of the individual handling the sample material, although often neglected, can be readily achieved with a second layer of durable gloves, such as butyl rubber.

Radiation detection instrumentation rarely requires additional beta shielding for the same reason that alpha shielding is not required. For most beta particle measuring instrumentation used in the laboratory, the detector's housing generally reduces or eliminates external beta radiation.

The need for beta shielding in any given situation will be difficult to predict, due to the self-absorption by the samples and their containers, and should be determined by empirical measurement of the beta radiation in the area. In addition, gamma radiation measurements should be performed regularly, after the beta sources and shielding are in place, to determine the need for additional shielding of the resulting bremsstrahlung radiation.

4.3 Gamma Shielding of Storage Areas

Gamma radiation is, by far, the most likely type of radiation that will require additional shielding measures due primarily to the penetrating nature of gamma photons. Gamma shielding, which necessarily consists of massive material such as lead bricks and panels, is not always easily moved and may be in limited supply in the laboratory.

Prior to accepting samples from a radiological or nuclear incident, the laboratory should make an initial estimate of the amount of shielding that is likely to be required. This estimate should account for the volume of space to be shielded; the placement, number, and activity levels of the sample material; and the projected waste streams. The laboratory may want to enlist the assistance of a qualified health physicist to perform this estimate.

Due to the expense and the difficulty in moving some shielding materials, some generalized considerations for designing gamma shielding for storage areas are discussed below.

4.3.1 Use of Buffer Zones and Other Unoccupied Spaces

Figure 1 shows an example of sample and waste storage areas in a laboratory diagram excerpted from Appendix A, *Planning Considerations for Laboratory Layout and Process Flow*. The large arrows represent the exposure gradient that might be expected, based on the amount of shielding provided, with the darker areas representing areas of high gamma exposure and the lighter areas representing lower levels. Notice that the less shielding provided, the more distance is required for the gamma field to be reduced to lower levels.

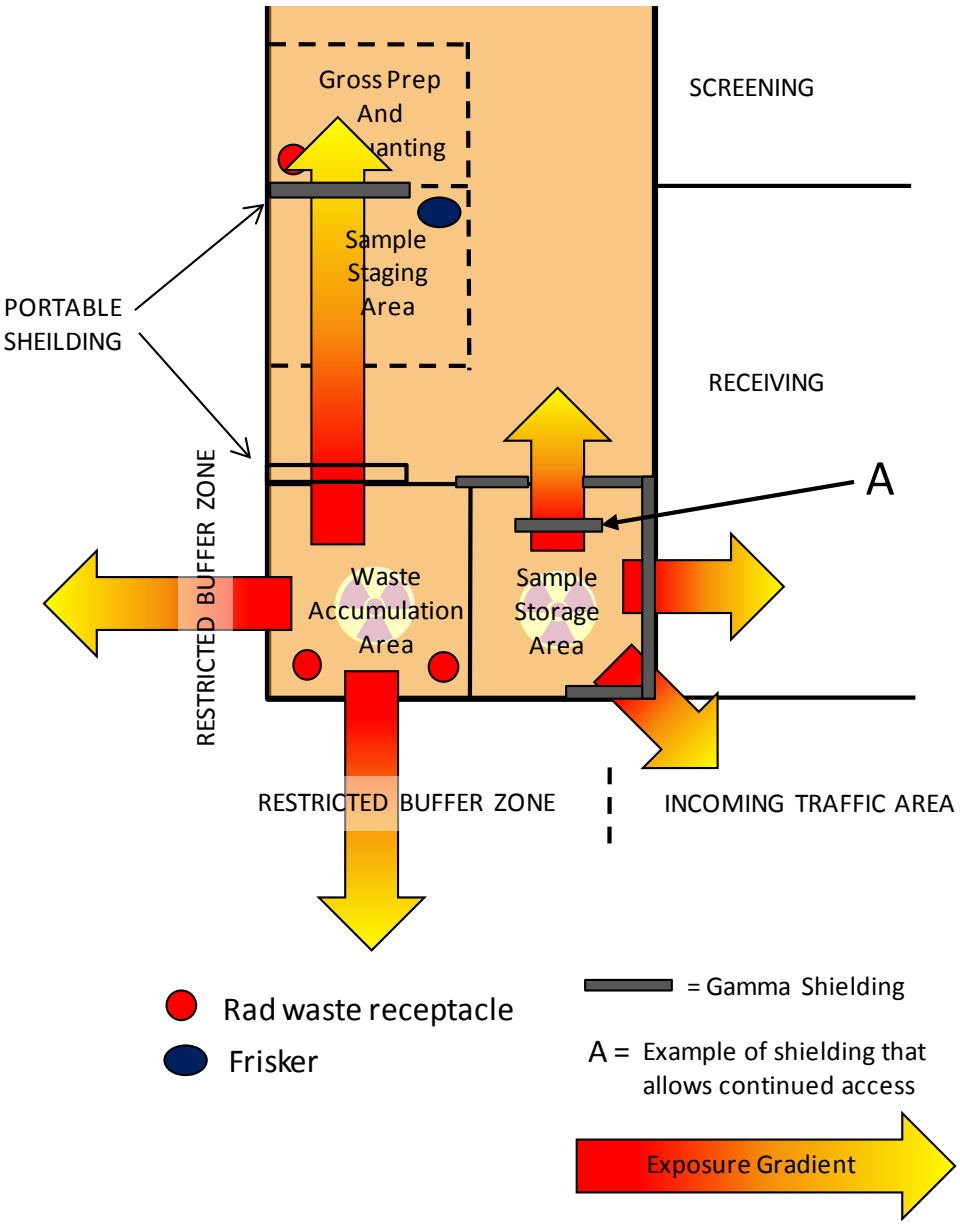


Figure 1 – Example of Shielding Considerations in Sample and Waste Storage Areas

4.3.2 Consideration of the Occupancy of Affected Areas

Inside the building, the laboratory may consider the occupancy factor expected in adjacent areas. In the example shown in Figure 1, it is assumed that the sample staging area is a transitional holding area for samples that are about to be processed, and that the time the workers spend in this area is minimal. Consequently, shielding requirements for this area may be reduced. These areas, however, still require appropriate posting and dose rate monitoring.

Similarly, shielding inside the storage areas has been kept to a minimum in this example, on the assumption that the time any worker spends inside the actual storage areas is limited. In some

instances, however, this may not be the case. For example, if the laboratory employs a sample custodian whose primary responsibilities are to manage the samples inside the storage areas, additional shielding may be required inside the storage area to protect the worker during the considerable time spent inside that area.

Unlike the unoccupied buffer zones or areas with low occupancy, the sample receiving area may be continually occupied and must be adequately shielded from the radiation in the adjacent room. The effect of occupancy may be considered arithmetically. First, assign an occupancy factor that is equal to the fraction of time that the area in question is occupied. In the above example of the sample staging area, the area is occupied only 20 percent of the time, which is equal to occupancy factor of 0.20. Next, determine the acceptable level of exposure in that area by dividing the usual acceptable exposure level by the occupancy factor. The application of any occupancy factor less than 1.0 to allow exceptions to the acceptable exposure levels in any area should be reviewed and approved by the laboratory's RSO or health physicist.

4.3.3 Strategic Placement of Gamma Shielding Materials

After considering buffer zones and pertinent occupancy factors, shielding should be placed as needed to prevent exceeding the maximum exposure levels stated in the laboratory's area definitions. The placement of shielding should also optimize the stability of the background levels in nearby instrumentation.

In some cases, it may be more convenient to place the shielding outside the area. Figure 1 shows additional shielding material added immediately outside the Sample Storage Area, in the hallway.

In some cases, the cost to the laboratory for permanent shielding materials may be reduced, and the laboratory's ability to respond to changing conditions within the facility may be increased, by the judicious use of portable shielding, such as the panel shown in Figure 1 between the Sample Staging Area and the Gross Preparation and Aliquanting area. Such portable shielding may be used to address a sudden influx of samples in the Staging Area during an incident response. Caution should be used in this approach, however, because the placement of shielding further from the source of radiation allows for less overall protected work area due to the reduced shielding angle. Reliance on reduced occupancy factors in the unshielded areas should be controlled to minimize worker exposure. In addition, portable shielding may be secured or controlled in a manner similar to an electrical "Lock Out/Tag Out" program to prevent unintended worker exposure by movement of the shielding by unauthorized personnel.

Figure 1 also shows a particular situation in which the entryway to the Sample Storage Area must be shielded to protect the workers immediately outside, while still allowing access to the area. In this example, the shielding inside the door (labeled "A") is stationary and personnel walk around it to access the sample storage area. This is just one example of a technique that might be employed for shielding traffic lanes.

4.3.4 Consideration of Multi-Level Facilities

Not shown in Figure 1 is consideration of multi-level facilities that house radiological laboratories. It should be understood that radiation extends in three dimensions and that in such facilities, it may be necessary to evaluate areas on adjacent levels and to potentially shield the work areas above and below the sources of radiation exposure.

4.4 Gamma Shielding of In-Process Materials

When radioactive materials are handled directly by the employees performing radioanalytical processes on the materials, additional shielding and other precautionary measures may need to be taken, since the sample material is now in very close proximity to the employees and may be open to the environment. In addition, changes in background associated with the movement of elevated levels of radioactivity in the laboratory may compromise measurements performed within the changing radiation field. Appropriate shielding may help minimize changes in the background.

Sensitive instrumentation is readily shielded in the same manner and with the same materials as storage areas. Lead bricks or panels placed strategically between the source of radiation and the instrumentation are simple and effective shielding solutions.

Shielding the employees who must handle the radioactive material is not always as straightforward. Small amounts of highly radioactive material (in an appropriate sample container) may be placed inside a lead pig, to be opened only as needed to remove small aliquants. Larger quantities of material should be staged inside small lead enclosures until needed, then minimally handled to perform the necessary laboratory functions.

When providing gamma shielding for samples undergoing laboratory procedures, particular care should be taken to evaluate potential exposures in all directions. These considerations are often overlooked in laboratories that are unaccustomed to higher levels of radioactivity. Figure 2 demonstrates the need to evaluate gamma shielding in three dimensions. The worker should be adequately protected from "gamma shine." This includes direct irradiation by the sample material, as well as scattered gamma photons and induced X-rays from the surrounding materials.

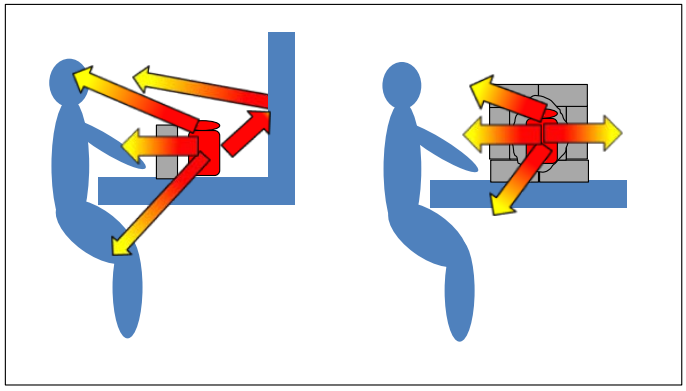


Figure 2 – Three-Dimensional Shielding Considerations

In some situations, workers may be shielded effectively from gamma radiation emitted from a relatively localized source by placing the shielding in close proximity to the source, as shown in Figure 3a. This configuration maximizes the shielded work area with a minimum amount of shielding.

In situations involving sources that are distributed over a larger area and where limited shielding is available, it may be preferable to shield the worker from gamma radiation in the same manner that instrumentation is shielded. That is, the shield is placed in close proximity to the work station in such a way that it protects only the specific worker or area, rather than shielding a larger work area, which might require significantly more shielding material. This alternate shielding configuration is shown in Figure 3b. This configuration may conserve shielding material in some situations and may provide additional flexibility and responsiveness to the laboratory in its efforts to respond to a radiological incident. This configuration may also have the added benefit of potentially reducing exposure due to scattered gamma photons, which can increase the shielding requirements.

Caution is needed in this approach, since it assumes a low occupancy factor for the unshielded parts of the work area. As with such consideration in storage areas, discussed above, incorporating low occupancy factors in the determination of shielding requirements should be approved by the laboratory's Radiation Safety Officer or Health Physicist.

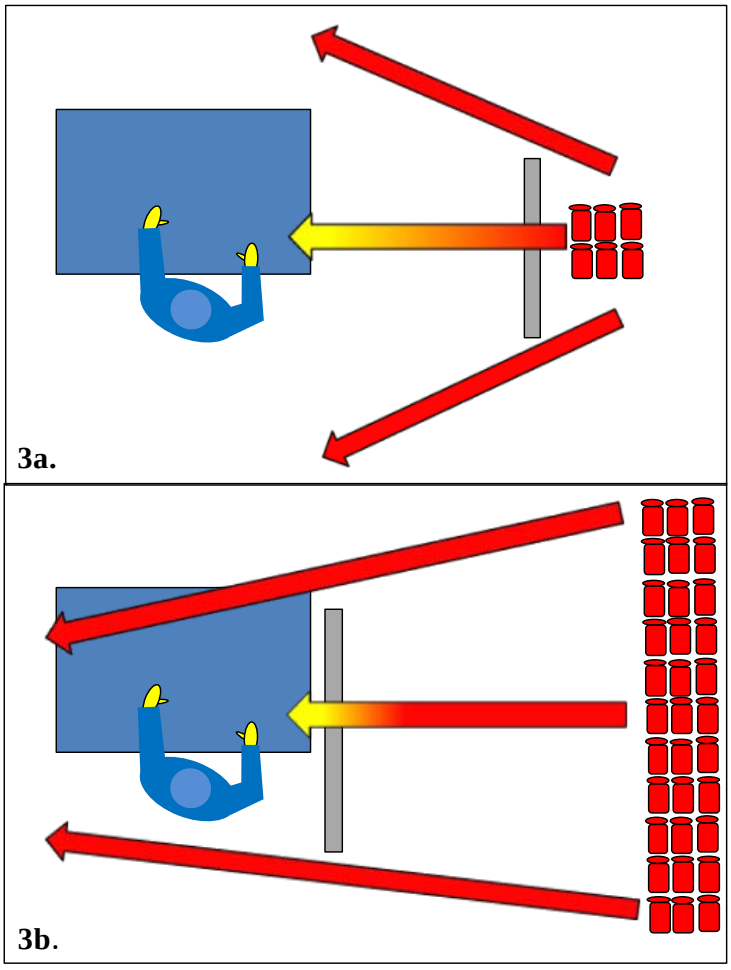


Figure 3 – Alternate Shielding Configurations

5. SUMMARY

A laboratory preparing to support the response to a radiological or nuclear incident will anticipate a dramatic increase in the number of samples received, the range of activity levels in those samples, and the associated analytical and human health risks of radiological laboratory contamination and increased radiation.

To minimize those risks, the laboratory should consider taking a number of tangible preliminary steps that may help prevent, identify, and control potential contamination and exposure challenges when the samples arrive at the laboratory.

- The laboratory should plan and prepare for the arrival of the incident samples and the associated analytical work by deciding what type of work will be performed in the different laboratory areas and what operational constraints will apply to that work. These decisions should take into consideration the physical layout of the laboratory facilities, the expected flow of work through the facility, the levels of radioactivity and radiation that can be expected to be safely and properly handled in each area, and the resources that will be required to maintain those operations.
- The laboratory should establish operational protocols for the new and different procedures and situations that are likely to be encountered and provide training for personnel who will be affected by the change in laboratory operations. These protocols will necessarily be tailored to each individual laboratory and will depend greatly on the specific circumstances of each laboratory.

These preliminary steps can be taken by any laboratory, regardless of size, resources, organizational affiliation, or type of work currently performed. If these preliminary steps are properly addressed, it simply remains to execute the established protocols and remain vigilant against laboratory contamination and exposure problems. By carefully considering the measures recommended in this guide, the laboratory will be better able to participate in the incident response, preserve the ongoing analytical integrity of the laboratory, and resume normal operations after the event.

The intention of this guide is not to prescribe specific practices for the laboratory to follow, but to provide pertinent topics for the laboratory to consider in its own efforts to preserve and enhance its analytical capabilities, to preserve the health and well-being of its personnel, and to assist in a significant national effort to protect the public health.

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APPENDIX A: PLANNING CONSIDERATIONS FOR LABORATORY LAYOUT AND PROCESS FLOW

Once the acceptable activity levels and required PPE for the various types of work areas have been defined by the laboratory, as discussed in Section 2, the physical areas in the laboratory corresponding to the area types should be delineated. A plan view or map of the facility may be a useful planning tool, as shown in the following example.

The proposed layout of the laboratory should take into consideration the flow of work and the paths that various radioactive materials will take through the laboratory. The physical constraints of the building and the likely need to establish controlled entrance and egress points to specific areas should also be considered.

Figure 4 depicts a simplified example for a suggested layout of laboratory and administrative areas in a laboratory operation. Discussion of the flow of work through these areas follows the diagram. It is important to note that every laboratory has a different physical design, performs different types of analytical work, and uses different systems to perform the necessary work. Each laboratory must evaluate its own operation and determine the best work area layout and work flow for its facility.

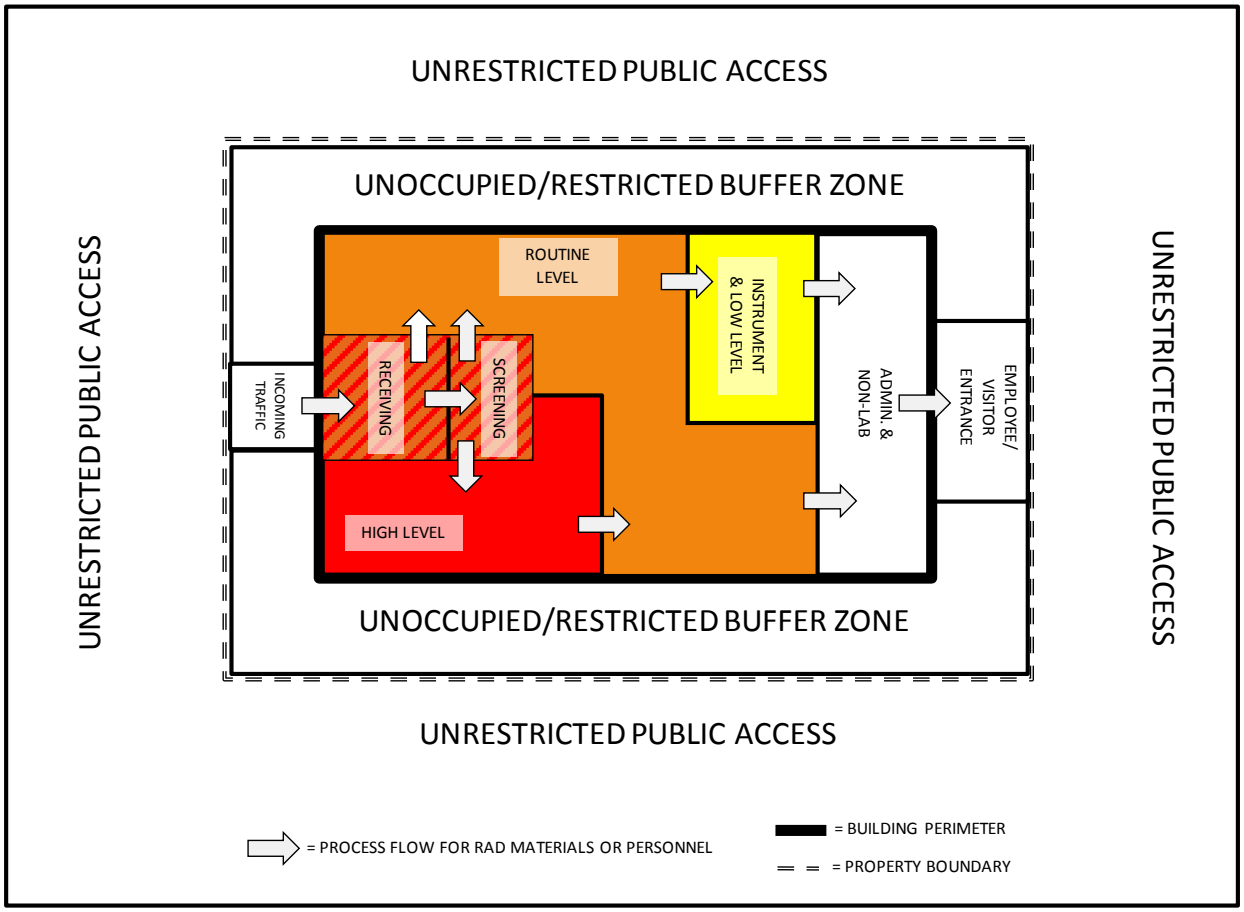

Figure 4 – Conceptual Layout of the Laboratory and Associated Areas

Incoming Traffic Buffer Zone

Samples entering the laboratory generally arrive via courier or public delivery service and are brought to the designated sample receiving area through the incoming traffic buffer zone. The laboratory should recognize that this zone may become contaminated and should be surveyed periodically.

Outgoing packages should be screened prior to release, and processed in a segregated staging area, to minimize the risk of contamination from incoming packages. Ideally, the shipment of material out of the facility should occur from a location other than that used for receiving samples.

Receiving Area for Incoming Radioactive Materials Packages

Incoming radioactive materials packages are delivered directly to the designated sample receiving area. No other area of the laboratory should be used to accept delivery of potentially radioactive materials. Instead, such deliveries should be redirected to the appropriate receiving area. Incoming packages will contain a variety of samples, with potentially unknown physical and chemical characteristics, and a broad range of radioactivity concentrations from very low to very high levels. It may be useful for the laboratory to employ high-level gamma monitors in the sample receiving area, which may automatically sound an alarm when pre-set gamma exposure levels are exceeded, thereby providing the laboratory with an early warning of high gamma activity samples.

The physical flow of samples within the receiving area should be organized logically so that initial processes, such as acceptance of delivery, collection of external swipes, and exposure measurements, are performed nearer to the delivery entrance than later processes. Packages should then be moved into subsequent processing areas, such as a fume hood designated for unpacking, to physically separate the different receiving steps as much as possible. The laboratory's processes should be designed to create a linear, one-way path for material through the various areas. In the event of a contamination issue, this will help the laboratory to isolate the potentially contaminated work surfaces and equipment. Figure 5, *Process Flow in the Sample Receiving Area*, shows a generalized view of one possibility for the one-way flow of radioactive materials through the area.

In the sample receiving areas and all subsequent areas, the laboratory should consider identifying specific decontamination areas (labeled "Decon Area" in Figure 5) for sequestering and isolating material identified as potentially contaminated. These areas should be separate from those used for the regular flow of samples, i.e., in no case should material identified as contaminated be returned to the process flow where it could potentially contaminate otherwise uncompromised material, until the contamination issue has been addressed. Additional information regarding radiological decontamination is provided in Appendix I, *Decontamination of Laboratory Surfaces and Equipment.*

Necessary materials and supplies for the work being performed in an area should be situated close at hand, but preferably out of the direct flow of sample traffic. After being properly

screened for external exposure rates[19] and removable surface contamination,[20] the unopened contents of the radioactive materials packages should be routed directly to the sample screening lab. Consequently, the receiving area should have direct access to the Sample Screening Area whenever possible. This will minimize the risk of contamination associated with moving uncharacterized samples through the laboratory.

Certain equipment and supplies may need to be routed directly between the receiving area and the various work areas, and it may be both unnecessary and undesirable to move these materials through the Sample Screening Area. It may, therefore, also be desirable to enable ready access to the routine laboratory areas from the receiving area. Clear protocols should be established that define the acceptable movement of materials, supplies, and samples.

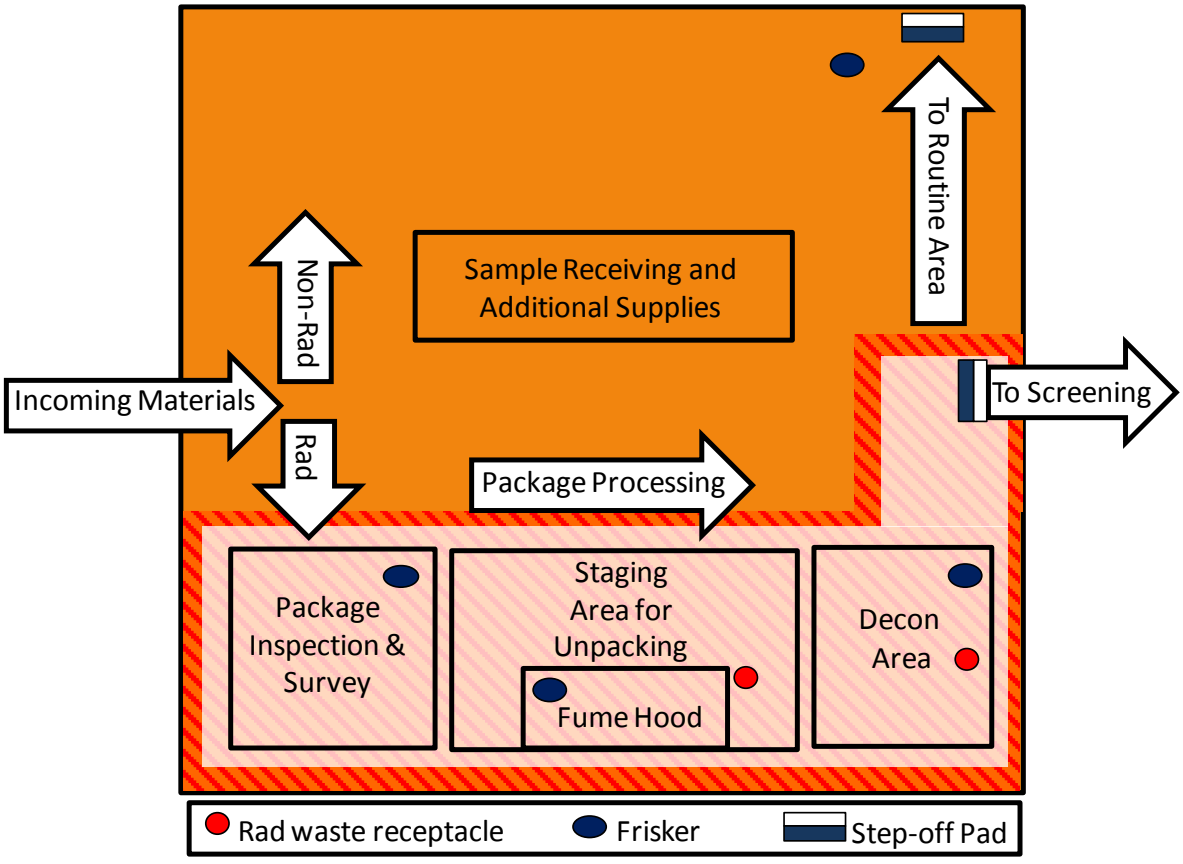

Figure 5 – Process Flow in the Sample Receiving Area

Screening Areas for Incoming Samples

As with the Sample Receiving Areas, Screening Areas for Incoming Samples will process a variety of sample types, with a wide range of activity concentrations. Whenever possible, it may

[19] See *Radiological Laboratory Sample Screening Analysis Guide for Incidents of National Significance* (EPA 402-R-09-008, June 2009)

[20] See *A Performance-Based Approach to the Use of Swipe Samples in Response to a Radiological or Nuclear Incident* (EPA 2011)

be useful for the laboratory to consider establishing separate screening areas, or separate workstations within a single area, for samples of known or expected activity ranges. For example, samples that exceed preset decision levels for external exposure readings or for which reliable field screening data indicate elevated activity may be processed for screening in one area while samples that fall below those decision levels, or samples that are not expected to contain elevated activity levels, may be processed in another. This may reduce the risk of sample cross-contamination.

In any case, the screening areas should be set up to accommodate the flow of work, moving the samples from the receiving area entrance in a linear path toward the exit to sample storage and processing areas whenever possible. Figure 6a shows a generalized view of the one-way flow of radioactive materials through this area. In this view, the incoming samples are initially processed near the entrance and then moved to the instrumentation areas, which are close to the exits. Reagents and supplies that must remain clean and uncontaminated are stored close at hand but out of the flow of the samples.

In some laboratory areas, there may be either a single entrance to the room or other conditions that prevent the linear flow of materials through the laboratory area. In these cases, the path into and out of a work area may be through the same doorway or aisle-way. In these situations, the flow of work might be organized with the preliminary steps closer to the entrance and the later steps, such as screening measurements, further inside the room. During a contamination event, which is most likely to occur in the earlier handling steps, this configuration may minimize the spread of contamination to the analytical areas by restricting traffic to the necessary cleanup areas near the door. Again, the consumable supplies, etc., should be stored out of the flow of the samples but still readily available. In this type of situation, the layout shown in Figure 6a is still applicable with the separate exits to the High Level and Routine areas removed, as shown in Figure 6b, so that entrance to and egress from the area is through Sample Receiving.

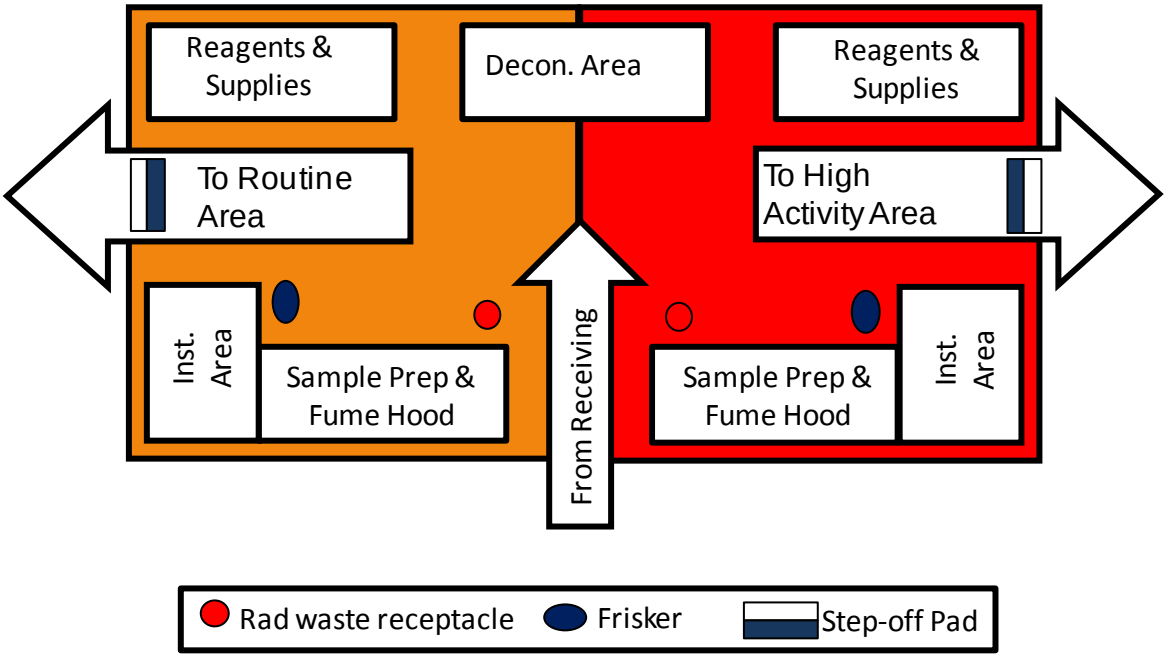

Figure 6a – Process Flow in the Screening Areas

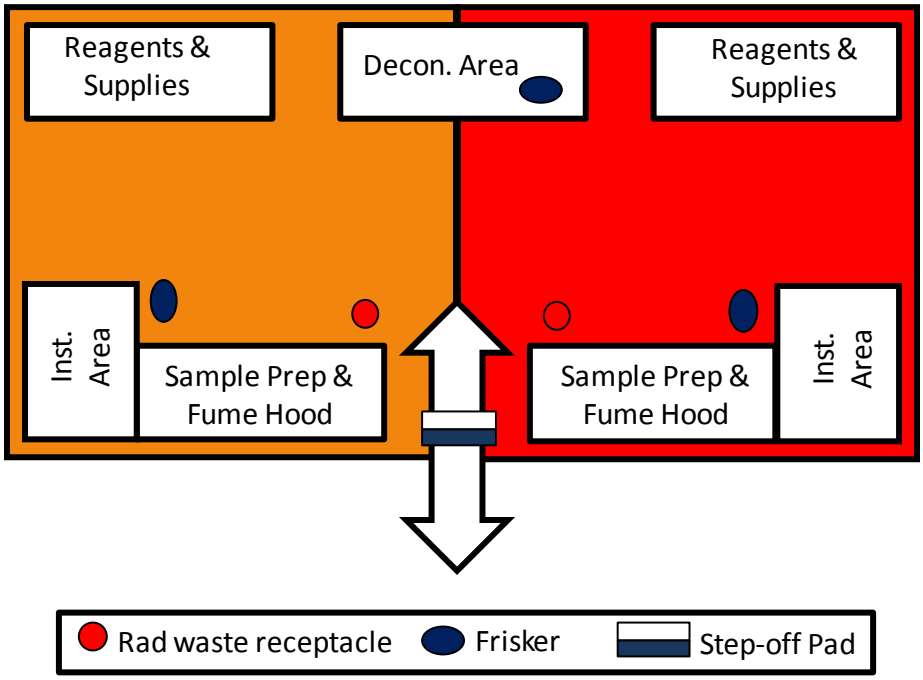

Figure 6b – Process Flow in the Screening Area with a Single Entryway

Other Laboratory and Storage Areas

As in the Sample Receiving and Screening Areas, the flow of radioactive materials through the general laboratory areas, including the High-Level, Routine, and Low-Level Areas, should follow a path that closely matches the flow of work.

Figure 7 demonstrates one possible layout for a typical laboratory area. For clarity, Figure 7 shows only the Routine-Level Work Areas in the example laboratory. Work flow may be routed into other types of laboratory areas, such as the High-Level and Low-Level work areas, and the following suggestions are generally applicable to all types of laboratory areas:

- Storage of large numbers of samples or samples with elevated activity should be located near the entrance of the area, furthest away from instrumentation or personnel activities. This configuration will minimize exposure to the workers and provide lower and more stable background radiation levels for the instruments.
- Areas for the initial gross preparation (such as drying, grinding, filtering, etc.) and aliquanting of the sample material are established next.
- In some cases, it may be helpful to then establish an area for the digestion of solid materials. After this point, the sample material will be in a liquid form, which is generally easier to contain and handle, may be further sub-sampled, and is much less likely to cause a laboratory contamination issue. Undigested solid materials, other than those in a sealed container that will remain unopened (such as for gamma spectrometry), should not be brought further into the laboratory than this point.

- Samples are then moved further along the preparation process and, consequently, further into the laboratory areas. The final steps of chemical purification and preparation of the sample to be presented to the instrumentation area are performed in closer proximity to the instrumentation area than the previous steps.
- Ancillary areas for storage of (non-radioactive) supplies and equipment should be strategically located between potential sources of radiation and the instrumentation and administrative areas, in order to provide an additional buffer zone and to separate people as much as possible from the High-Level Work Areas.

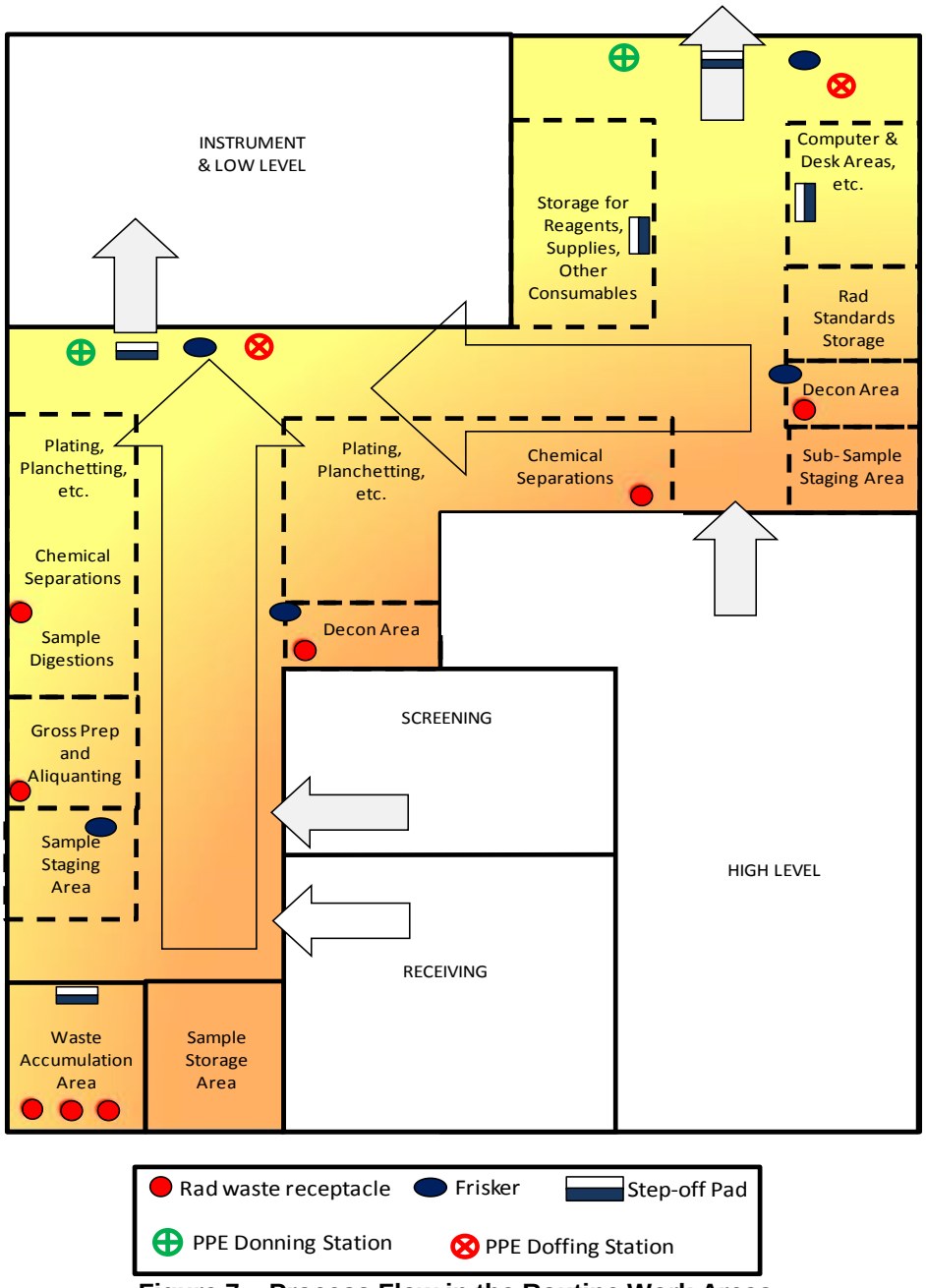

Figure 7 – Process Flow in the Routine Work Areas

Administrative and Public Areas

Personnel exiting the laboratory areas should carefully follow the laboratory's exit protocols. An example of laboratory egress protocols is given in Appendix F: *Egress Into a Lower-Activity Area*. There should be absolutely no flow of sample material or potentially contaminated equipment or materials from the laboratory into the administrative or public areas.

APPENDIX B: INITIAL RECEIPT OF RADIOACTIVE MATERIALS

The following is a suggestion for a protocol that might be used for the general receipt of radiological material. Appropriate PPE is required for all steps.

EQUIPMENT AND MATERIALS

- Exposure rate meter
- Removable surface contamination swipes
- Spill kit
- Secondary containment bins
- Plastic-backed laboratory bench paper
- Laboratory trays and carts for staging samples and supplies
- Radioactive Materials Shipment Initial Survey Results form

PROCEDURE

1. Immediately upon receipt, inspect the package for visible signs of damage or leakage of the contents. DO NOT OPEN THE PACKAGE until preliminary administrative, visual, and radiological checks have been completed (Steps 1.1 through 3).
   1.1. If the package appears to be undamaged and intact, place it in the staging area for incoming radioactive materials and proceed to Step 2.
   1.2. If the package appears to be damaged or leaking, immediately contain the package in a durable plastic bag, secondary containment bin, or other suitable containment material to prevent the spread of radioactive material. If it is possible to move the contained package into a fume hood without risking the spread of radioactive material, do so, then immediately contact the RSO and wait for further instructions.
   1.3. Take a preliminary measurement of the package exposure rate, in μR/h, near the package surface. If the measurement of the package dose rate exceeds 2,600 μR/h,[21] shield personnel, notify the RSO, and wait for further instructions.
2. Initiate a Radioactive Materials Shipment Incoming Survey Results form, completing the first section and noting the date and time of receipt of the shipment. See Figure 8, *Example of Radioactive Materials Shipments Initial Survey Results.*
3. Perform external surveys of the package.
   3.1. Measure the instrument background response and record that value on the survey results form. *Be sure to perform this initial measurement in an area that is well removed from potential sources of radiation exposure, in order to obtain an accurate background reading.*
   3.2. Measure the exposure rate, in μR/h, at a distance of 30 cm from the surface of the package and record the value on the survey results form.[22]

[21] Referring to the example in Section 2.2., Table 2, 2,600 μR/h is the ADL for exposure rate measurements in Routine-Level work areas. The ADL described the measurement result that should trigger a decision that the 5,000 μR/h AAL may have been exceeded and that additional steps should be taken, such as those described in Step 1.3, above.

3.3. Measure the exposure rate, in μR/h, at the external surfaces of the package and record the highest measured value on the survey results form.

3.4. Perform a swipe survey of 300 cm^2 of the outside surface of the package. Count the swipe on the appropriate instrumentation and record the alpha and beta activity values on the survey results form.

3.5. Record the date and time that the surveys were completed on the results form.

3.6. If any of the ADLs[23] shown on the form are exceeded, initiate the appropriate corrective action, as described on the survey results form. If all results are below the prescribed ADLs, proceed to the Step 4.

> Note that the ADLs shown on the form in Figure 8 are taken from Table 2, in Section 2.2., and are derived from the example AALs for contamination and exposure control in Routine-Level Work Areas.

[22] While the characterization of the exposure rate at a distance of 30 cm from the surface of the package is consistent with the requirements of 10 CFR 20 for the establishment of a Radiation Area, the laboratory may select other internal requirements that address the specific needs and operational conditions of the work area.

[23] As in other places in this guide and the various companion documents, these ADLs describe the measurement result that should trigger a decision in the laboratory to take additional steps. In this example, the hypothetical laboratory ADLs correspond to AALs that are based on federal regulations, such as 40 CFR 173.421 and 173.403.

XYZ Laboratories, Inc.

RADIOACTIVE MATERIALS SHIPMENTS
INITIAL SURVEY RESULTS

Shipper: _____ Client: _____

CoC ID: _____ Project: _____

Delivery Date & Time: _____ Cooler ID: _____

Nuclide(s): _____ ☐ (check if unknown)

Other Info: _____

Instrument Background Exposure Rate _____ µR/h

Exposure Rate @ 30 cm from package surface
ADL* = 1,000 µR/h _____ µR/h

If ADL is exceeded, report to Radiation Safety Officer.

Max. Exposure Rate @ package surface
ADL = 2,600 µR/h _____ µR/h

If ADL is exceeded, report to HazMat Shippng Officer and Radiation Safety Officer

External Removable Contamination Survey _____ alpha dpm/swipe

_____ beta dpm/swipe

Perform 300 cm^2 swipe on outside of package.

ADL = 1.1 dpm/cm^2 (330 dpm total) alpha
11 dpm/cm^2 (3300 dpm total) beta

If Action Level is exceeded, report to HazMat Shippng Officer and Radiation Safety Officer.

External Survey Completion Date & Time: _____

Removable Contamination Survey of Contents

Item #	Description	alpha dpm/swipe	beta dpm/swipe
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

Perform 100 cm^2 swipe on inner container of source.

ADL = 0.1 dpm/cm^2 (10 dpm total) alpha, per Lab Radiation Protection Plan.
1 dpm/cm^2 (100 dpm total) beta, per Lab Radiation Protection Plan.

If ADL is exceeded, secure the package and the receipt area and report to Radiation Safety Officer.

Approved By: _____

Date: _____

*ADL = Analytical Decision Level

Figure 8 – Example of Radioactive Materials Shipments Initial Survey Results

4. Unpack the shipping container.

4.1. Prepare a clean laboratory fume hood by lining the bottom with plastic-backed absorbent laboratory paper. The fume hood, similar to most work areas for radiological materials, will have a "hot" zone on one side, a "warm" zone in the middle, and a "cool" zone on the other side. In the example shown in Figure 9, the "hot" zone is to the left and the "cool" zone is to the right.

> In this section and elsewhere in this guide, certain techniques may suggest the use of one hand (or one side of a work surface) over the other. This preference is generally arbitrary, or in some cases indicated by the "handed-ness" of the person performing the task. The primary purpose of such techniques is to maintain a "clean" hand (or work area), considering the other to be "potentially contaminated." In all cases, the specific configuration should be determined by the most effective contamination-control practices, which may include consideration of individuals involved.

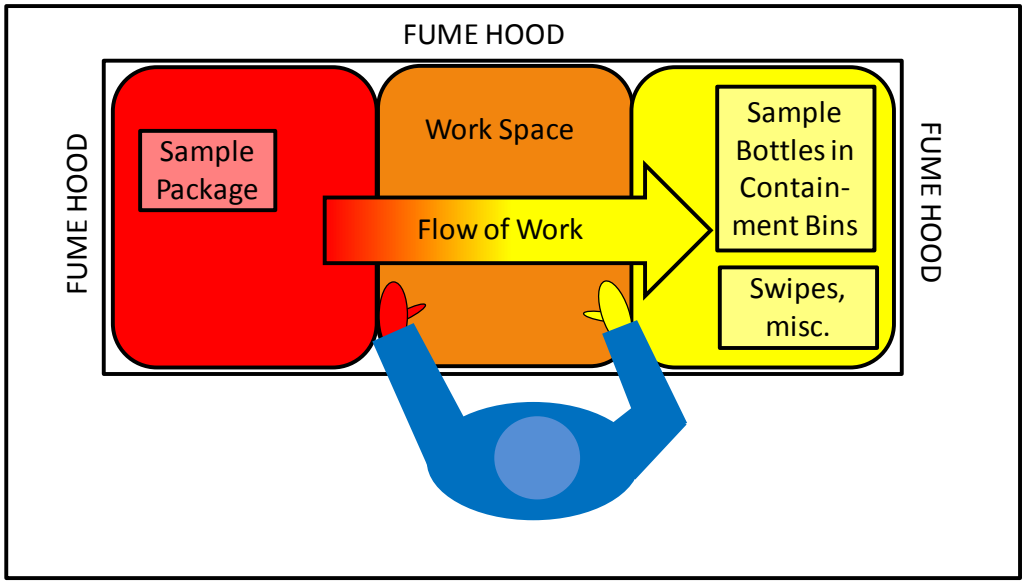

Figure 9 – Work Flow Inside Fume Hood; Unpacking Samples

4.2. On the right side of the hood, preferably on a laboratory tray, lay out enough swipes to survey each sample container expected in the shipment and enough supplies to mount and label each swipe.

4.3. Move the shipping container to the far left side of the fume hood.

4.4. Carefully open the container. Treat all packing material, enclosed paper work, and any other contents as potentially contaminated until verified to be below the release limits designated in the RPP. Before removing the contents, inspect the inside of the container for signs of spilled material or other damage to the contents. If a sample container has broken, or sample material has spilled inside the shipping container, immediately close the shipping container, notify the RSO, and wait for further instructions.

4.5. If the samples appear intact, carefully remove them one at a time, swipe them, and place them in a secondary containment bin. Other control checks, such as sample temperature,

are not described here but may be incorporated into individual laboratory procedures, as necessary.

4.5.1. Remove the sample from the shipping container with the left hand. This hand will be used only to handle the individual sample containers, if possible.

4.5.2. Take a new swipe in the right hand (it may be useful to have another person hand the swipes over, in such a way as to avoid transferring contamination to the helper), swipe the sample container, and place the swipe on a pre-labeled planchet.

4.5.3. Place the sample container in a secondary containment bin or other suitable laboratory storage container.

4.5.4. As each sample container is placed in the secondary containment bin, record the field ID and other appropriate information on a laboratory chain-of-custody or other suitable form. The laboratory's internal ID labels may be affixed to the samples at this time, if necessary.

4.5.5. Cover the containment bin and move it, along with the shipping container, to a suitable holding area until the swipes are analyzed.

4.6. Survey the shipping container, enclosed documentation, packing material, hood liner, hood surfaces, and personnel, following the prescribed ADLs for the area, as shown in the example in Section 2.2., Table 2.

4.7. Count the swipes. The instrument and count parameters should be carefully chosen to address the laboratory's predetermined contamination limits. Record the results and transfer the samples to the designated storage area.

4.7.1. If the results of the removable surface contamination surveys of the sample containers are below the established limits, the samples may be transferred to the appropriate sample storage area. The shipping container and packing materials may be disposed in the sanitary trash or returned to service if the project allows.

4.7.2. If any of the results of the removable surface-contamination surveys are above the AAL, the samples, packing material, and shipping container must be returned to the fume hood or other appropriate location, and decontaminated. Following decontamination, return to Step 4.5 and re-survey the containers to verify that the decontamination was successful. If decontamination is not feasible, the RSO should be notified and the material disposed according to the laboratory's Radioactive Waste Management Plan.

4.8. Review and approval of the survey results should be performed by qualified personnel. If any AALs are exceeded, the RSO should review and approve of the decontamination process and the final survey results.

4.9. Upon completion of the survey, the survey results form should be included with the sample chain of custody and other laboratory documentation of the sample receipt.

APPENDIX C: OPENING, TRANSFERRING, AND ALIQUANTING SAMPLE MATERIAL

This protocol is generally applicable for the opening of sample containers and the removal of either the entire sample or a fraction of the sample, from the perspective of minimizing the risk of laboratory contamination. This may be applicable to samples arriving in the screening area as well as samples being processed in the radiochemistry laboratory areas.

In this example protocol, samples are staged outside the hood, waiting for processing. Single samples are brought into the hood, opened, and an aliquant removed. If further processing is to immediately follow in the hood, as may be the case in the screening lab, the sample aliquants are staged inside the hood for further processing. If sample aliquants are to be returned to the storage area for processing at a later time, the aliquant is sealed in an appropriate container, the outside of the container is cleaned, and both fractions of the sample (the original and the new aliquant) are returned to storage. A generalized view of the work area for this procedure is shown in Figure 10.

This appendix also provides an example in which multiple aliquants are removed simultaneously in anticipation of multiple analyses being performed on the sample. In this example, one aliquant is removed for a primary analysis and the other "reserve" aliquant is held for contingent analysis. Careful planning will determine the number and size of the sample aliquants that may ultimately be needed, including any additional aliquants required for further screening or for reserve/ contingent analyses. In some cases, this approach may minimize handling and the associated risk of laboratory contamination, and may also optimize sample throughput. While the example uses a soil sample, analogous procedures could be used for other types of samples. The laboratory may also consider that, while the process of aliquanting a sample and preparing the aliquant for screening may be amenable to a single laboratory hood space, it may still be advisable to break up the process into stages (e.g., aliquanting all samples, then digesting all sample aliquants, then planchetting all samples), rather than trying to perform the complete cycle on each sample in turn. This approach may facilitate the rapid handling of large numbers of samples and minimize the amount of equipment and supplies in the work area at one time, thereby reducing the risk of accidents and other potential contamination issues. These are all issues for the individual laboratory to decide.

1. Prepare a clean laboratory fume hood for the sample handling process by lining the bottom with an underlayment of plastic-backed, absorbent laboratory paper and assembling the necessary equipment, which will be dependent on the type of samples and the sub-sampling technique.
2. Establish a staging area for samples to be processed outside of the hood, but in close proximity to the "hot" side of the hood. Establish another staging area outside the hood, but in close proximity to the "cool" side of the hood, for necessary supplies.

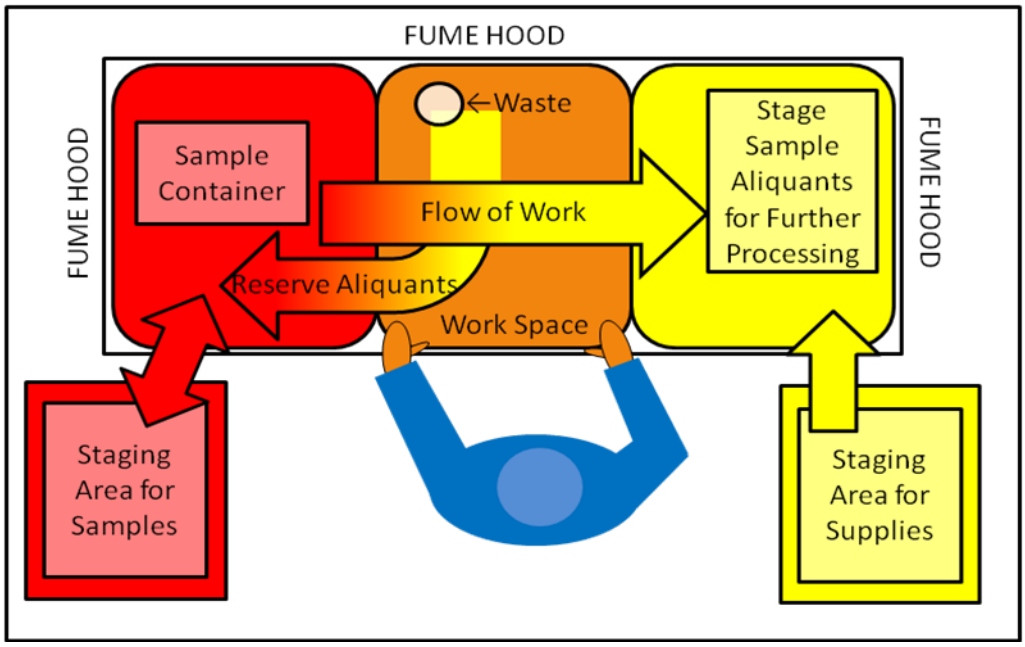

Figure 10 – Opening, Transferring, and Aliquanting Sample Material

3. Determine what supplies will be needed for processing each sample and assemble those supplies in the hood, as needed. The use of disposable or single-use laboratory supplies is strongly encouraged to minimize the risk of cross-contamination. Examples of supplies needed to aliquant a soil sample would be:
    - Single sheet of plastic-backed laboratory bench paper (approximately 45cm × 45cm), spread out on the center work area;
    - Disposable spatulas;
    - Disposable vessels, with lids, or other suitable, sealable containers, pre-weighed (with lid) and labeled;
    - Containment bin or tray for processed samples;
    - Spray bottle of decon solution;
    - Paper towels or disposable wipes;[24] and
    - Survey meters to periodically monitor hands, sample containers, work areas, and swipes during the process.
4. Bring one sealed sample container from the staging area outside the hood into the "hot" area of the hood. Only one sample should be processed at a time.
5. Open the sample container, remove the aliquant(s), then close the sample container and the new aliquant container.
    5.1. Open the sample container carefully, holding the sample container in one hand and removing the lid with the other.

[24] The distinction is made here between "wipes," which are used for cleaning purposes and which may be surveyed prior to disposal as an indication of contamination, and "swipes," which are used solely to measure removable surface contamination.

5.2. Keep the sample container in the one hand and put the lid down, top side down, to the left side of the bench paper square.

5.3. Survey the gloved right hand and the inside of the container lid and for indications of unexpected levels of activity, or levels that would require segregation of the sample in the high activity work areas.

5.4. Place two pre-weighed, labeled disposable vessels on the bench paper, one designated for the primary analysis and the other designated as a "reserve" aliquant.

5.5. Using a disposable spatula and working over the bench paper, carefully transfer the desired representative aliquants from the sample container to the aliquant vessels. Minimize the agitation of the sample or any aggressive motions that may cause dust, splashing, or other loss of the sample material to the work area.

> Although removal of "representative" aliquants of the sample is important, and effort to homogenize the sample should be taken prior to removing an aliquant, aggressive agitation of open material increases the risk of laboratory contamination. The requirements for sample homogenization and representative sub-sampling should be clearly stated in the project DQOs and should be reflected in the laboratory's sample handling and contamination control protocols.

5.6. Place the spatula in the waste receptacle inside the hood.

5.7. Replace the cover on the original sample container and put the sample down in the hood. Survey gloved hands before proceeding.

5.8. Carefully seal the aliquant vessels. Place the sample aliquant designated for screening in the aliquant staging area inside the hood, designated for further processing.

5.9. Place the sample aliquant to be reserved for future testing on the other side of the hood, with the original sample. This aliquant will be returned to storage with the original sample container.

6. Clean the containers with a damp disposable wipe before moving them.

6.1. Pick up sample/aliquant containers in one hand only.

6.2. Use the other (clean) hand to spray containers and wipe them clean.

6.3. After cleaning, place the damp wipe on the bench paper square, to be surveyed in the next step, grasp the container with a clean wipe and move it to the staging location. The staging location may be outside the hood, for samples to be returned to storage, or inside the hood, for samples to be further processed.

6.4. Survey the gloved hands and the wipes to determine removable surface contamination levels on the sample container.

6.5. Where multiple containers are provided for a sample, repeat for each container.

7. Dispose of consumables and prepare the work area for another sample.

7.1. Gather any potentially contaminated consumables and other waste (spatulas, etc.) onto the bench paper square, fold the waste up into the paper, and place the bundle of contained waste into the designated waste receptacle inside the hood.

7.2. Replace gloves.

7.3. Replace the bench paper square and consumable supplies and proceed with the next sample, from Step 3.

8. Continue sample processing.

8.1. The original sample container and the reserve aliquant are sealed and cleaned and may be returned to the appropriate sample storage area. The reserve aliquant may be taken, en route, to a balance station to obtain a gross container weight for use in the anticipated analysis.

8.2. Likewise, the aliquant designated for the screening analysis may also be weighed. The sample preparation process can then proceed, according to the laboratory's SOP.

9. After appropriate aliquants have been removed from all samples, and the samples have been removed from the hood, the plastic-backed bench paper should be removed, and the hood should be cleaned and surveyed in preparation for processing other samples.

APPENDIX D: ISOLATING REDUCED FRACTIONS FOR TRANSFER TO LOWER-LEVEL AREAS

This protocol provides a strategy for isolating a very small, yet representative amount of high-activity sample material when it is necessary to bring that material into a lower-activity-level work area for processing or analysis. This is particularly applicable to laboratories without separate low-level and high-level facilities for all processes.

The laboratory should first recognize the inherent challenges in obtaining representative subsamples from any field sample, particularly from solid matrices such as soil, debris, or particulate air filters. The project DQOs and the laboratory's sample handling protocols should clearly address the requirements and specific techniques for sample homogenization and representative sub-sampling, including minimum allowable aliquant sizes that may be considered representative and acceptable practices and equipment for measuring sample aliquants. In addition to these established protocols, unusual or difficult samples or samples that might be expected to be heterogeneous should be evaluated by qualified laboratory personnel to determine the limitations of direct sub-sampling techniques.

The examples provided here are not intended to give specific guidance on the aliquant sizes to be used or the acceptable techniques for sample homogenization, but are simply intended to illustrate a possible technique for reducing a representative aliquant to a manageable size, with particular emphasis on controlling radioactive contamination in the laboratory. The actual aliquant sizes used by the laboratory will be determined by the sample screening results, the analytical method to be performed, the analytical requirements for homogeneity and sub-sampling, and the laboratory's specific contamination control practices.

Once the laboratory's protocols for sample homogenization and representative sub-sampling are addressed, an "intermediate" aliquant is taken from the sample material and the aliquant size is measured. Liquid samples may be initially measured volumetrically, if volumetric reporting units are required. Solid samples may be weighed, then digested to facilitate further sub-sampling. Gravimetric dilutions of all samples are then performed, in series if necessary, to minimize laboratory contamination and to allow accurate measurement of very small aliquants.

The selection of equipment for volumetric and gravimetric measurements should reflect the incident response analytical requirements; the uncertainty of the measurement should be controlled at a level that is consistent with the project MQOs and should be reflected in the combined standard uncertainty that is reported with the analytical results. In the following procedure, the inclusion of specific equipment, such as volumetric pipettes and analytical balances, is for illustrative purposes only.

1. Before proceeding, estimated target aliquants should be determined based on the sample screening results and the ultimate "target activity" that should be isolated. The target activity is the amount of activity that is desired for subsequent procedures. These values are based on the established limits for sample activity, determined in Section 2.2., *Establishing Acceptable Levels of Radioactivity and Radiation*.
2. Remove an "intermediate" aliquant, *s*, by the same technique described in Appendix C, *Opening, Transferring, and Aliquanting Sample Material,* and place the aliquant in a pre-

weighed, labeled vessel, such as a specimen cup, beaker, crucible, etc., that can be tightly covered or sealed to appropriately contain the sample. The type of vessel used will depend on the sample material, the target radionuclides for which the sample is to be analyzed, and the digestion or dilution technique used.

2.1 For liquids that are to be analyzed on a volumetric basis (results reported as activity per volume of sample), remove the intermediate aliquant with a calibrated pipette and record the volume, *v*, of the aliquant.

2.2. For filters and swipes, record the fraction, *f*, of the sample taken, such as 0.5 filter or 0.25 filter. It is preferable, whenever possible and without compromising the requested analyses, to digest the entire filter, in which case the intermediate aliquant sample size is 1.0 filter. Where the filter is physically cut or split, a preliminary survey may provide early indication of inhomogeneity or "hot particle" activity.

2.3. For solids that are to be analyzed on a gravimetric basis (results reported as activity per mass of sample):

2.3.1. Seal the samples to allow transport outside the hood.

2.3.2. Where indicated by the sample screening results or other laboratory contamination control protocols, perform a removable surface contamination swipe survey on the container prior to removing it from the fume hood.[25] This step should be performed for all samples, where necessary, whenever the sample container is removed from the fume hood.

2.3.3. Transport the samples to the weighing station, record the gross mass of the sample and the container, and determine and record the net mass, *m*, of the intermediate aliquant.

2.3.4. Return the sealed samples to the fume hood.

2.4. Perform the required digestion or dilution of the sample material. Quantitatively transfer each solution to a new pre-weighed container. Seal the containers and transport them to the weighing station to determine the net total mass, m_t, of the solution. Return the samples to the fume hood.

2.5. Before proceeding, it may be desirable to perform another screening measurement on the sample solution to confirm the appropriate aliquant size for analysis.[26]

2.6. With a disposable transfer pipette, remove an approximate aliquant that is representative of the final target aliquant and transfer it to another pre-weighed, labeled container.

2.7. Seal the sample containers to allow transport outside the hood.

2.8. Weigh the container with the final aliquant for analysis and determine the net weight, m_a, of the final target aliquant of the solution.

2.9. The final sample aliquant, *a*, is calculated as

[25] See Appendix H, *Surveillance of Laboratory Surfaces and Equipment*, and Section 2.2., *Establishing Acceptable Levels of Radioactivity and Radiation*.

[26] See *Radiological Laboratory Sample Screening Analysis Guide for Incidents of National Significance* (EPA 2009b).

$$a = s \times \frac{m_a}{m_t}$$

where s = the intermediate sample size, v, f, or m, depending on the sample type, from Step 2.1, 2.2, or 2.3, above.

2.10. Where very small aliquant sizes are required, additional serial dilutions may be necessary. These may be performed by repeating steps 2.6 through 2.9, above. In this case, the final dilution factor, $\frac{m_a}{m_t}$ in the previous step, is replaced with

$$\frac{m_{a1}}{m_{t1}} \times \frac{m_{a2}}{m_{t2}} \times \ldots \times \frac{m_{an}}{m_{tn}}$$

where $\frac{m_{ai}}{m_{ti}}$ is the dilution factor for each serial dilution performed.

In this relatively simple manner, an aliquant that is equivalent to very small amounts of the original sample (e.g., µg, µL, etc.) may be sequestered from the bulk sample. The reduced aliquant, and the reduced activity level that results, may be brought into lower-level work areas for processing.

APPENDIX E: ENTRY INTO A HIGHER-ACTIVITY AREA

1. Plan all work in advance to help minimize the movement of materials and the number of trips into and out of the room. In many cases, pre-job planning meetings will help to ensure the involvement of all affected personnel and facilitate planning for various contingencies.
2. Evaluate the materials being moved into the higher level areas and remove all non-essential items.

   2.1 Personal items, such as jewelry, watches, etc., should be removed. These items may be difficult to decontaminate and may need to be discarded if a significant contamination event occurs.

   2.2. Common items (such as pens, notepads, etc.) should be available in the destination area and should not be transported back and forth between the areas.

   2.3. The movement of paperwork or other documentation from higher-activity areas should be minimized, as these items are difficult and time consuming to assess for contamination. The use of fax machines and document scanning technology and the electronic management of information may significantly reduce the risk of laboratory contamination.

   2.4. Extraneous packaging materials that will simply be discarded should not be moved into the higher-activity area. Otherwise, these materials must be surveyed, and potentially decontaminated or classified as radioactive waste, prior to removal. This presents an additional burden to personnel and additional contamination risk to the laboratory.
3. Secure/seal materials, if appropriate.

   3.1 Some materials, such as necessary documents, exposure meters, and samples that are only transiting the area en route to another processing area, should be effectively sealed against contamination in a locking plastic bag or other container.
4. Remove PPE designated for use only in the lower-level area. For example, a laboratory coat designated for use in the “routine-level” areas should not be worn in the “high-level” areas.
5. Don the required PPE. The laboratory SOP should provide the explicit list and the order in which it must be donned. For example:
   - Scrubs;
   - Head cover;
   - Nitrile gloves;
   - Tyvek coveralls;
   - Shoe covers; and
   - Second pair of Nitrile gloves.
6. Gather any materials being brought into the area and enter.

APPENDIX F: EGRESS INTO A LOWER-ACTIVITY AREA

The following egress protocol is provided only as an example. Each laboratory must specify the egress protocol for each area, which will depend greatly on how the area types are defined, what activity levels are specified, and what type of PPE is required.

In this protocol, the egress area consists of two step-off pads, with a buffer zone between them. The first, or "primary," step-off pad is used for the removal of PPE that was worn in the higher-activity level area. Once that PPE is removed, the worker moves to the buffer zone and proceeds to don any PPE necessary to enter the lower-activity level area. The worker then surveys the materials being transferred to the lower-activity level area and enters that area after using the "secondary" step-off pad as an additional precaution against the migration of radioactive contamination through the laboratory.

Disposable PPE and other consumable supplies that exceed the pre-determined survey limits for a given area are placed in the "Rad Waste Container" for disposal as radioactive contaminated waste. Otherwise, the item is placed in the "Potentially Contaminated Waste Container" for further characterization prior to final disposal.[27]

In this protocol, the egress area is equipped with the following items:

- A primary step-off pad;
- A table or other appropriate surface for staging materials;
- Adequate decontamination supplies;
- A frisking station with the appropriate survey instrument for the types of radiation being processed in the area[28]; the survey meter probe should be positioned face-up and ready to perform an initial survey of the worker's gloved hand, without the need to handle the probe before the initial survey is complete;
- A receptacle for positively contaminated PPE;
- A receptacle for potentially contaminated PPE;
- A supply of any PPE that is required to enter the lower-activity area;
- Ready access to a phone, intercom, or other means of summoning assistance, if needed;
- Ready access to a personnel decontamination station; and
- A secondary step-off pad.

[27] The laboratory should have a detailed Waste Management Plan, or similar document, that clearly identifies the accumulation, characterization, and ultimate disposal of laboratory waste.

[28] Stationary hand and foot monitors are useful for monitoring personnel contamination, and they may facilitate the rapid movement of personnel through controlled egress points. They are not, however, a complete replacement for hand-held survey equipment, which is useful for surveying clothing and other items.

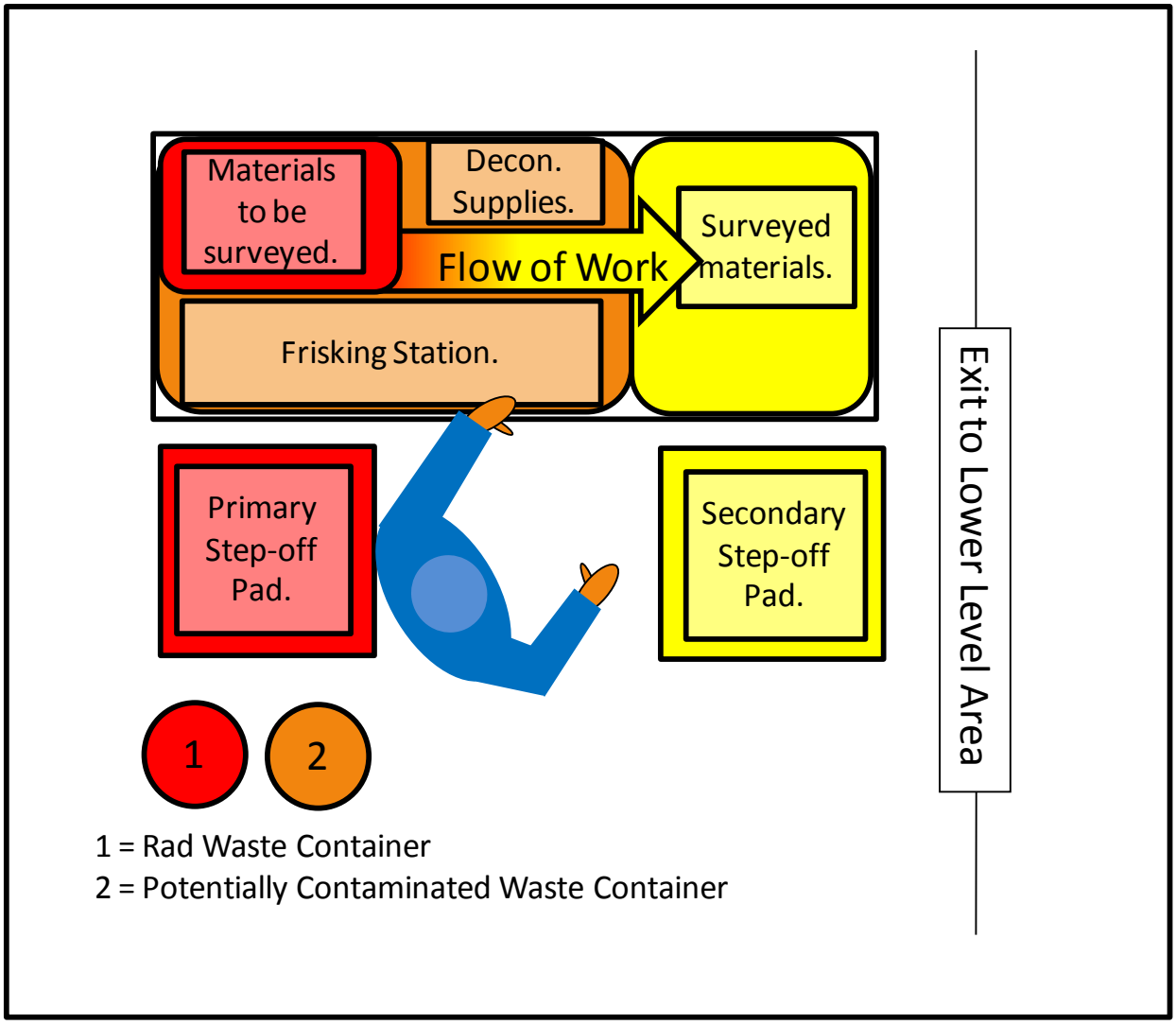

Figure 11 – Example Layout of the Egress Area

1. Stage the items to be removed from the higher level work area.
   All items to be moved into the lower-activity area should be initially placed on a table, or other suitable staging area, adjacent to the frisking station. Any tools or equipment that are potentially contaminated should be thoroughly cleaned and surveyed/swiped before being placed in the staging area.
2. Step on to the primary step-off pad.
   Enter the egress area by stepping onto the primary step-off pad. While standing on the primary step-off pad, remove the PPE as described below, starting at the head and working down to the feet.

Disposable PPE and other consumable supplies that exceed pre-determined survey limits are placed in the "Rad Waste Container." Otherwise, the item is placed in the "Potentially Contaminated Waste Container." All laboratory waste and related materials should be characterized and disposed of according to the laboratory's Radiation Protection Program and Waste Management Protocols.

At each step, the item to be removed is surveyed prior to removal and is placed in the appropriate waste receptacle. Particular attention should be paid to the areas that are prone to contamination, such as the front and cuffs of the laboratory coat or coveralls, and the bottom of the shoes and shoe coverings.

3. Survey and remove outer gloves.
   When removing outer gloves, the exposed side of the outer layer is considered "dirty" and the inner glove is considered "clean." Contact of a clean surface should be made only by another clean surface.
   3.1 As discussed above, the survey meter probe should be positioned face-up, ready to allow the worker to perform an initial survey of the gloved hands without picking up the probe. Survey both gloved hands.
   3.2. Grasp the outside of one glove, near the wrist, using the other gloved hand.
   3.3. Peel the glove away from the hand, turning it inside out as it is removed.
   3.4. While holding the removed glove with the remaining "dirty" gloved hand, insert the "clean" tip of one finger underneath the edge of the remaining "dirty" glove at the wrist opening.
   3.5. Peel the second outer glove off, turning it inside out as it is removed.
   3.6. Keep holding the first glove until the second glove envelopes the first and both are contained in a single package, with both gloves inside out, one inside the other.
   3.7. Place the gloves into the appropriate waste receptacle.
   3.8. Survey the inner gloves before proceeding to ensure that they have not been contaminated and that the survey probe may now be handled without becoming contaminated.
4. Survey and remove disposable coveralls.
   4.1 After surveying the coveralls, push the hood back off the head, taking care not to allow contact between the gloved hand and the face or head.
   4.2. Unzip the coveralls.
   4.3. Peel the coveralls away from the body, starting at the top and turning them inside out as they are removed. During this step, minimize contact between the gloved hands and the outside of the suit, and do not allow the outside of the suit to contact the inner layer of protective clothing (e.g., scrubs).
   4.4. With the coveralls rolled inside out, place them in the appropriate waste receptacle.
5. Survey and remove shoe covers.
   5.1 After surveying the bottom of each shoe cover, place the survey probe on the table, face up.
   5.2. Grasp the outside of the shoe cover, at the back, above the heel, with one gloved hand.
   5.3. With the other gloved hand, grasp the outside of the same shoe cover, on the top side, near the toe.
   5.4. Slide the shoe cover off the shoe and step the exposed shoe down on the floor past the primary step-off pad, not back onto the primary step-off pad.

5.5. Place the shoe cover into the appropriate waste receptacle.

5.6. Survey the gloved hands before proceeding.

5.7. Remove and discard the second shoe cover in the same manner, stepping completely off the primary step-off pad when the second shoe cover is removed.

6. Don a laboratory coat or other required PPE indicated for the area being entered.
7. Survey the materials being removed from the area. Decontaminate, if necessary. Place items that pass the survey acceptance criteria into the staging area for survey materials. Instructions for performing the surveys and decontamination are provided in Appendix I, *Decontamination of Laboratory Surfaces and Equipment*.
8. Survey the gloved hands, bottom of shoes, the laboratory coat, pant legs, and any other exposed surfaces of the employees clothing.
9. Put the survey probe down, face up. The instrument should be ready to perform a new survey without being handled.
10. Remove inner gloves using the same procedure described in Step 3, survey the hands, and don a new pair of gloves, if required for the new area or for subsequent work.
11. Collect surveyed items and proceed into the lower level area, using the secondary step-off pad on the way.

APPENDIX G: ACTIVE RADIOLOGICAL MONITORING PROGRAM FOR CONTAMINATION CONTROL

In order to detect and prevent the spread of radioactive contamination from a higher-level sample processing area to lower-level sample processing and administrative areas, a fully functional radiological monitoring program for the laboratory facilities should be implemented. In some cases, the spread of contamination with activity as low as 0.25–1 pCi for beta/gamma-emitting nuclides and 0.1 pCi for alpha-emitting nuclides[29] could lead to cross-contamination of samples and the reporting of erroneous results for low-level environmental samples. Detecting contamination at these low levels cannot be accomplished with typical health physics contamination control program applications. A survey meter may be useful for the detection of higher levels of contamination in the high-level processing and sample storage areas, and as a "go/no-go" measurement when moving materials from the high-level areas to the routine-level areas, for example. Other more sensitive techniques will be required to detect lower levels of contamination that may cause radioanalytical problems for the laboratory.

The first element that should be considered is the development of a contamination control plan, followed by a contamination control implementation program. The following elements should be considered in developing a plan:

- Personnel responsible for developing and implementing the program;
- Suggested changes to the laboratory layout;
- Laboratory/building areas to monitor;
- Methods and frequency of monitoring;
- Action levels and corresponding analytical decision levels[30] for each type of contamination and monitored area; and
- Documentation.

Personnel Responsible for Developing and Implementing the Program

Generally, key radiochemistry, quality assurance, and radiation protection personnel have different concerns and perspectives and should therefore all be involved in the development and implementation of the contamination control plan. Certain work functions needed for the implementation of the program (swipes, surveys, sample analysis, floor mopping, etc.) can be carried out by technicians, analytical staff, and other appropriately trained support personnel.

[29] These values are examples only, based on experience in specific laboratory settings with specific MQOs. Each laboratory should determine its own AAL(C), $u_{MR}(C)$, and ADL(C) values, based on the individual laboratory environment and the project MQOs being addressed. See section 2.2, Establishing Acceptable Levels of Radioactivity and Radiation, for more detail.

[30] See Appendix VI in *Radiological Laboratory Sample Analysis Guide for Incidents of National Significance – Radionuclides in Water* (EPA 2008), "Establishing DQOs and MQOs for Incident Response Analysis."

Suggested Changes to the Laboratory Layout for Radiological or Nuclear Incident Response Operations

Appendix A of this guide, *Planning Considerations for Laboratory Layout and Process Flow*, provides general guidance for establishing the physical layout of the laboratory, with consideration for the type of work being done and the levels of radioactivity being handled. Appendix A shows only a simplified, conceptual layout of laboratory areas to be considered for general planning purposes.

In this appendix, a different, more detailed example of a laboratory configuration is considered, in which a variety of analytical functions may be performed, both radiological and non-radiological. In this case, activities related to a radiological or nuclear incident response may require the laboratory to make temporary changes to specific radiochemistry, sample receiving, and storage areas to accommodate the potential influx of higher-activity samples.

Figures 12 and 13 provide specific examples of how laboratory and facility contamination and radiation monitoring controls might change from normal operation to the incident response situation. The suggested changes should be considered only as examples, and a laboratory may have to come up with its own solutions to specific problems. For example, if it is not feasible to install an additional hood (see hood #3 in Figure 13b) in the sample prep area, perhaps a portable fume hood can be purchased and reserved for handling of high-activity samples.

Figure 12a describes a hypothetical environmental laboratory, with the radiochemistry laboratory and the nuclear instrumentation area (the counting room) expanded in Figure 12b. Figure 13 represents the same laboratory modified for radiological or nuclear incident response. Figure 13a includes modifications to the whole laboratory, such as the creation of High-Level Work Areas, additional area monitoring thermoluminescent dosimeters (AMTLDs) in areas normally not monitored for exposure to radiation, and creation of long-term radioactive sample and radioactive waste storage in a remote area of the facility. Figure 13b represents the expanded view of the radiochemistry laboratory and the nuclear instrumentation area modified for incident response. Table 4 summarizes the major changes suggested for this hypothetical laboratory when a radiological or nuclear incident response is taking place and the rationale for each. Once again, these modifications are provided only as examples. They may be examined and subsequently included in the laboratory contamination control plan only after careful consideration of the laboratory's individual needs.

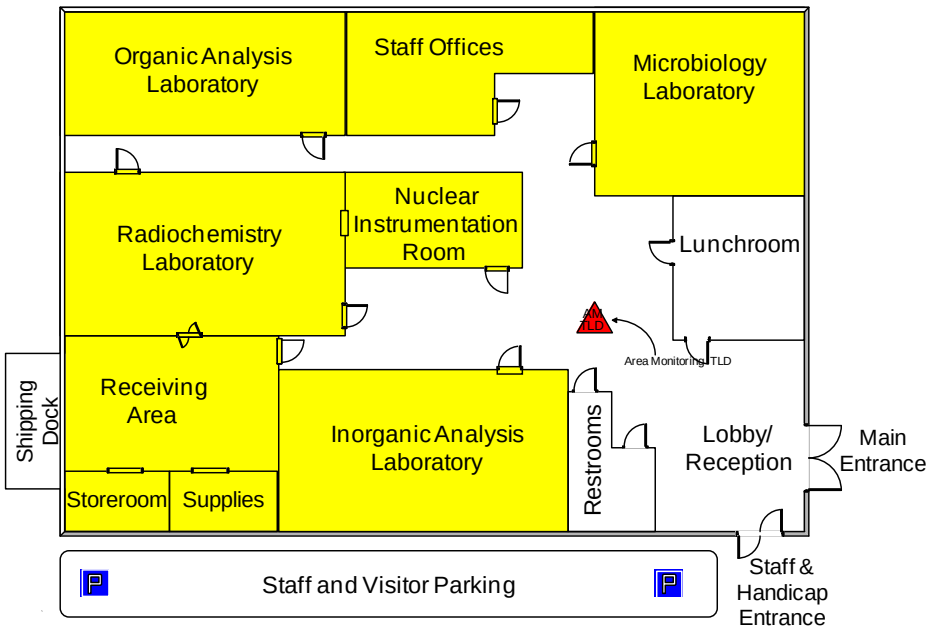

Figure 12a – Hypothetical Environmental Laboratory Operating Under Normal Conditions

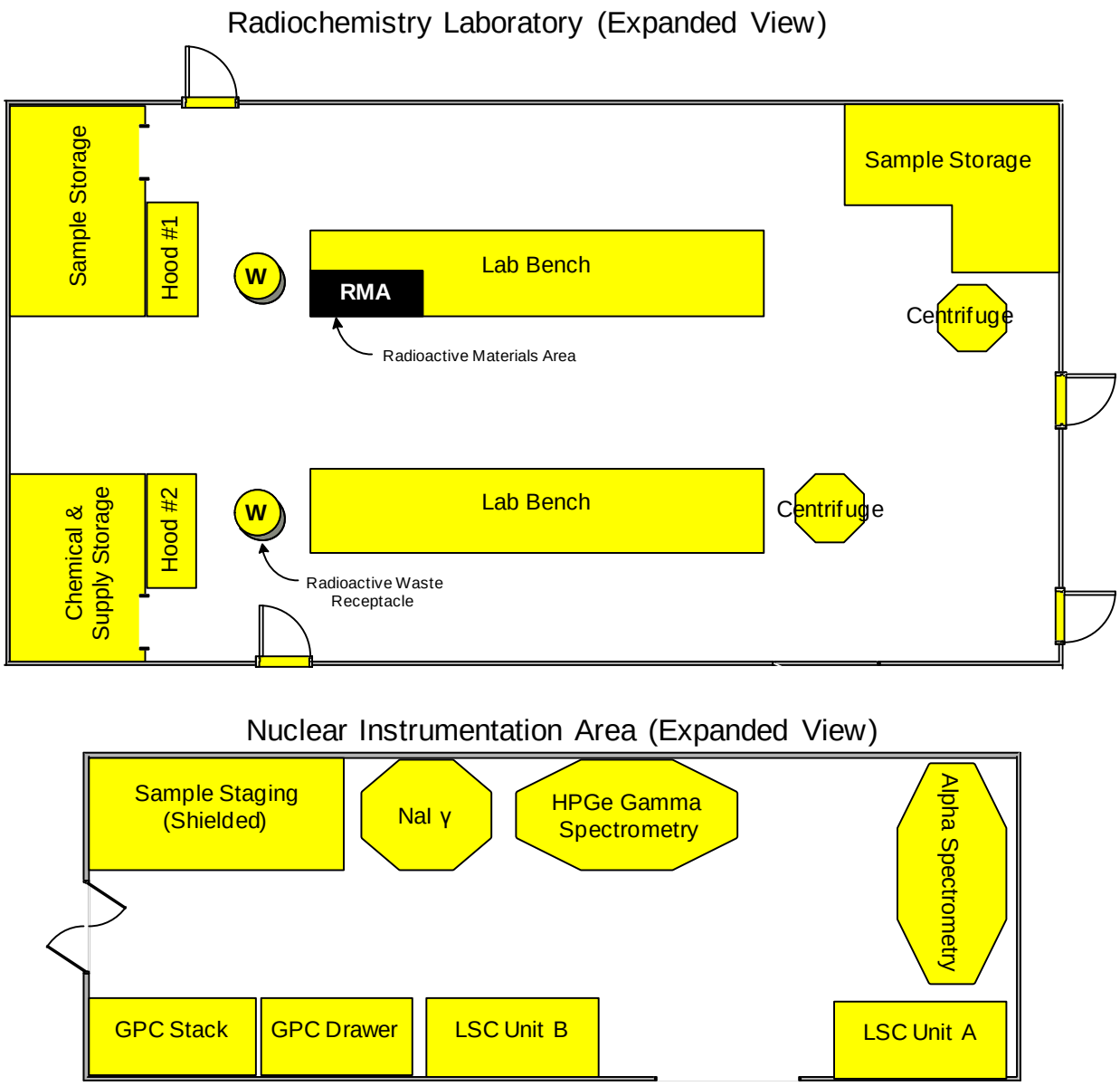

Figure 12b – Hypothetical Environmental Laboratory Operating Under Normal Conditions

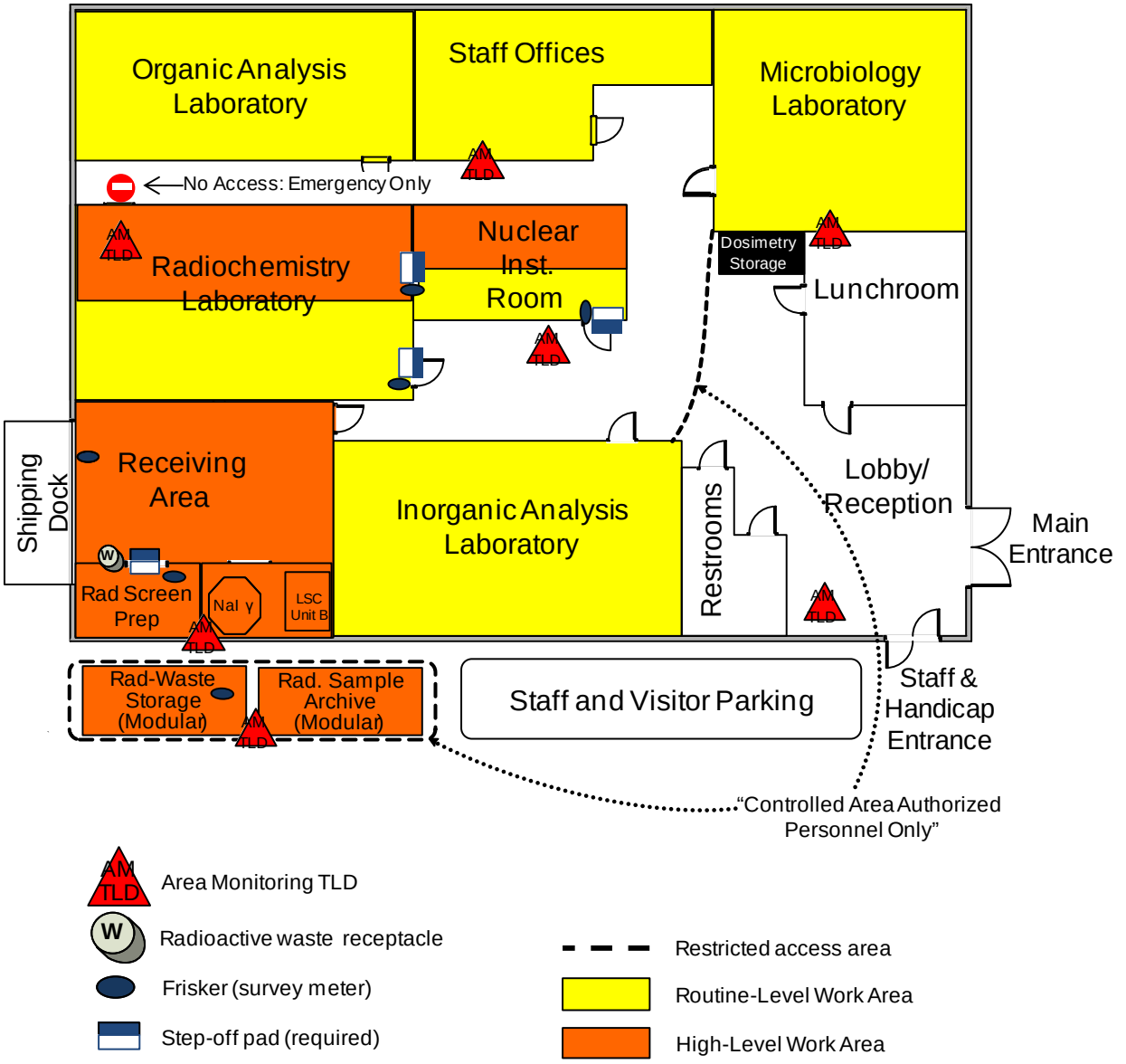

Figure 13a – Hypothetical Environmental Laboratory Operating Under Incident-Response Conditions

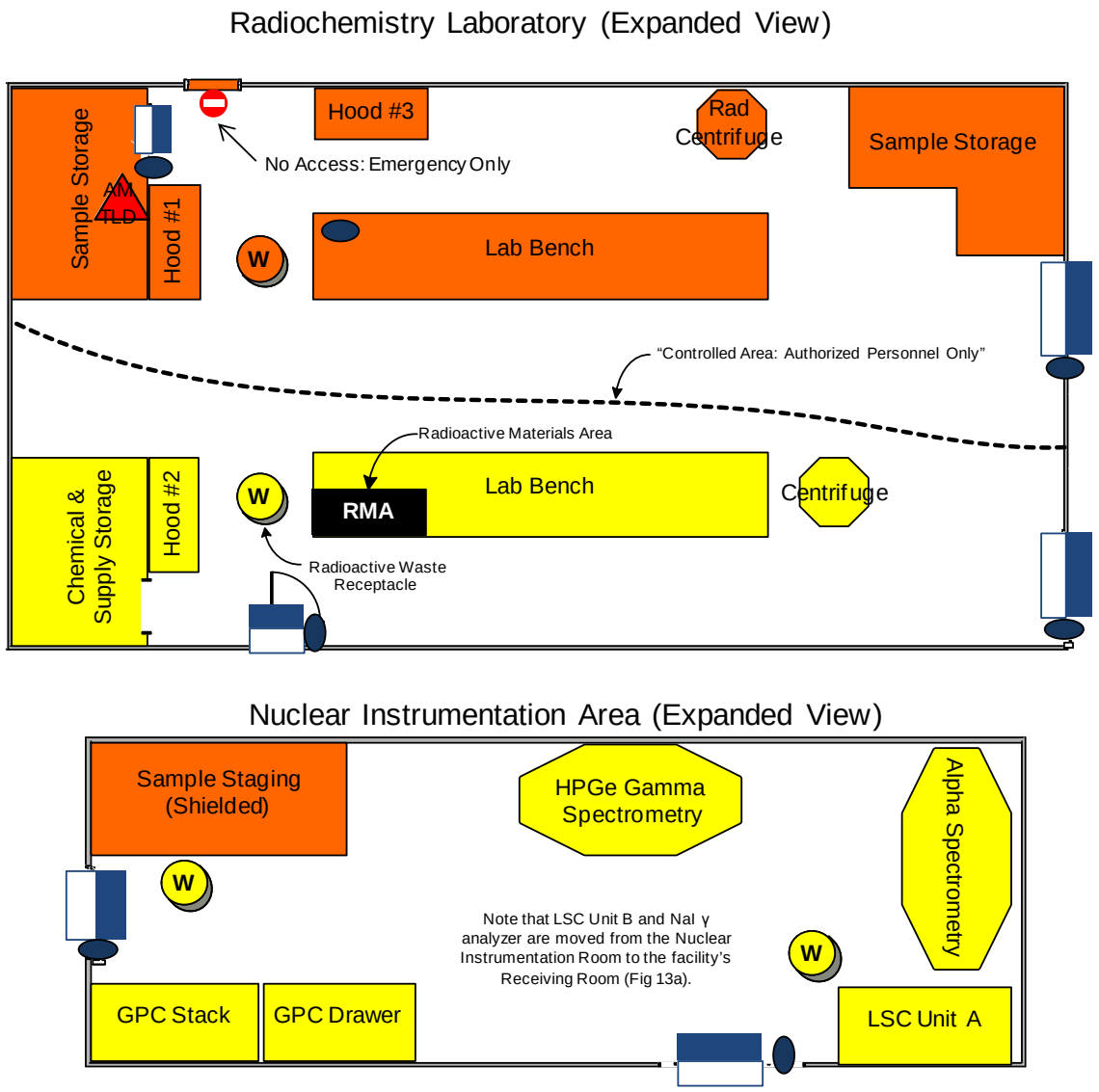

Figure 13b – Hypothetical Environmental Laboratory Operating Under Incident-Response Conditions: Radiochemistry Laboratory Expanded View

Table 4 – Summary of Major Changes Suggested for Radiological or Nuclear Incident Response Operations

Programmatic Issue	Change from Normal Operation	Rationale
Controlled access areas	Access to laboratory areas is limited to authorized personnel only.	The laboratory limits access to work areas to only those persons possessing appropriate, documented training. This will prevent exposure of members of the general public to radioactivity and help ensure use of safe work practices in the laboratory and, thereby, protection of workers.
Isolated preparation area for radiological screening upon receipt	Gross α/β and gross γ screening has been instituted for all incident-related samples that might contain elevated levels of radioactivity. A fully functional preparation area (including a hood and all other necessary equipment, safety equipment, waste containers, step-off pad, etc.) has been set up adjacent to receipt area.	Expanded screening beyond the DOT radiological screens routinely performed supports the contamination control program and permits prioritization of sample analysis according to different activity levels. Isolating the handling of elevated activity samples from routine low-level work minimizes the risk of cross-contamination.
Isolated instrumentation area for rad screening upon receipt	NaI-γ detector and liquid scintillation counters (LSCs) have been transferred from the routine counting area to an anteroom in the receipt area to identify and segregate samples with the elevated activity.	The size of the facility and limited amount of instrumentation prevent identifying a more remote area for sample counting. However, rad screening in a separate area minimizes impact of radioactive samples on low-level counting operations. The laboratory also should institute measures to minimize impact of transient sources of radiation on counting.
Isolated radioactive sample preparation area	A discrete area has been designated for preparing, splitting and screening, and aliquanting samples prior to release to radiochemistry laboratory for chemical separations and source preparation.	Although use of separate areas for handling rad and non-rad samples would be most ideal, due to the small size of the laboratory and limited instrumentation, contamination will be controlled by preparing aliquants of limited known gross activity prior to release to the radiochemistry laboratory.
Designated zones for radioactive sample handling within the radiochemistry area	The laboratory has designated two zones in its radiochemistry laboratory for processing samples containing different activity levels.	Complete segregation is preferable, but facility size precludes multiple areas for chemical separations of samples containing different activity levels. Screened aliquants of limited known gross activity will be prepared and released to the appropriate zone of the radiochemistry laboratory for processing to minimize the risk of cross-contamination.
Step-off pads	Added step-off pads at egress points in areas handling rad samples.	To control personnel contamination and limit the spread of contamination through the laboratory.
Survey meters	Survey meters have been located where significant quantities of radioactive materials are in use.	Survey meters, while limited in their sensitivity, may permit real-time detection of activity and radioactive contamination before it spreads and compromises health and safety or data quality.

Programmatic Issue	Change from Normal Operation	Rationale
Radioactive waste receptacles	Receptacles have been added where incident-related processes will produce rad waste (or potential rad waste, including step-off pads). This is only a temporary waste receptacle and should be emptied daily to a more remote waste storage location.	To capture incident-related wastes per prior evaluation of incident-related procedures.
Dosimetry	Laboratory has instituted use of personnel dosimetry (e.g., TLDs and bioassay).	Personal dosimetry provides measurements of exposure to workers and allows exposures to be kept as low as reasonably achievable. Where high levels of activity are handled, more frequent or even real-time dosimetry may be required.
AMTLDs	Installed AMTLDs wherever significant activity is stored or in use.	To measure highest potential external dose to workers.
AMTLDs	Installed AMTLDs in areas accessible to public.	To measure highest potential external dose to public.
Remote storage of radioactive samples	Storage of samples is limited to in-progress samples. Remote, secure, climate-controlled sample storage and archiving areas are established (e.g., parking lot).	Personnel exposures will be minimized, the risk of contamination reduced, and impact on instrument backgrounds minimized by maintaining only in-process samples in sample storage, laboratory processing, and instrumentation areas.
Remote storage of radioactive waste	Storage of radioactive waste in work areas is limited and radioactive waste is moved to remote storage area on a frequent basis (e.g., daily or weekly) to prevent accumulation of significant amounts of material.	Personnel exposures will be minimized, the risk of contamination reduced, and impact on instrument backgrounds minimized by maintaining only in-process waste in sample storage, laboratory processing, and instrumentation areas.

Areas to Monitor During a Radiological Event

Areas in a laboratory where radioactive materials are used, stored, or transported should be subjected to the most frequent monitoring. The laboratory should carefully consider the physical configuration of the work areas, the flow of work through those areas, and the level of radioactivity being handled in those areas when deciding what areas should be surveyed and with what frequency. Generally, the more activity in use, the more frequent monitoring is required. Areas where radioactive materials are used in an open or uncontained form generally are associated with the highest likelihood of contamination and would require the highest frequency of monitoring. Office areas, lunch areas, and the like are much less likely to be contaminated (generally by transport of contamination from another area) and thus would generally be monitored with the least frequency.

The following laboratory areas are examples of areas that are typically considered for monitoring:

- Sample receiving areas
  The monitoring program for sample receiving areas should be sure to consider any area or surface that is used to process uncharacterized samples, including shipping containers, as well as any surfaces that receiving personnel may come into contact with during sample receipt operations. Other surfaces that may not have direct contact, but may become indirectly contaminated, such as air foils or sink drains, should be carefully and critically evaluated to determine a level of monitoring and control that is appropriate to the specific conditions in that area.

  An abbreviated example of the types of items and surfaces to be considered includes:
  - Incoming samples;
  - Shipping containers and packing materials;
  - Bench tops;
  - Hood surfaces;
  - Floors and loading docks;
  - Keyboards, phones, and other office equipment; and
  - Light switches and doorknobs.

  In this, and in the following examples, the list is provided only to illustrate the types of items and surfaces to be considered. These examples should in no way be considered to be prescriptive or complete. Each laboratory must evaluate its own activities, procedures, and levels of radioactive materials to determine the appropriate items and surfaces, monitoring frequency, action levels, and other content of a radiological monitoring program that is specific to the area being evaluated.

- Sample preparation areas
  This area should include the same types of surfaces and work areas discussed above for the sample receiving areas, but would also incorporate items that are specific to the handling and preparation of open sample material, with consideration of the activity levels, sample matrices, and types of tasks being performed. This includes areas such as the Sample Screening Areas, High-, Routine-, and Low-Level Work Areas. Additional items to consider may include:
  - Labware;
  - Sample and waste storage areas, shelves, etc.;
  - Egress area equipment;
  - Step-off pads;
  - Instrument control panels; and
  - Sinks, floor drains, and traps.

- Nuclear instrumentation rooms, whether they are in High-, Routine-, or Low-Level Work Areas, should also incorporate the ongoing evaluation of analytical equipment, as well as those surfaces and areas listed above that might be applicable:

- Detectors, instrument housing surfaces, shields; and
- Desiccators or other sample storage cabinets.

In addition, the laboratory may wish to incorporate into the Radiological Monitoring Program a real-time evaluation of instrument performance checks and QC control charts, as an indication of emerging low-level laboratory contamination issues.

- General and administrative areas
  Although perhaps less frequently, these areas should be evaluated periodically to ensure that laboratory contamination is contained and controlled, and has not migrated out of the designated radiological areas. These evaluations may include areas and surfaces such as:
  - Hallways and floors;
  - Administrative areas – desks, doorknobs, telephones/switchboards, keyboards;
  - Break room and restroom fixtures;
  - Sinks, traps, and floor drains; and
  - Door handles at the building exits.

While the frequency for these monitoring activities may be less than for the general laboratory areas, the MQOs for the survey measurements should be carefully considered and should be appropriate for the lower levels of acceptable exposure to non-radiological workers and to the general public.

Monitoring Method and Frequency of Monitoring

Once the laboratory has determined what changes may be appropriate to the layout of the laboratory and which areas and items require increased contamination surveillance, the laboratory should then determine which contamination monitoring techniques will be appropriate and how frequently they should be performed.

Ambient exposure and dose rate measurements, fixed and removable contamination surveys, and the analysis of process by-products such as mop water or HVAC air filters all provide information about the various laboratory activities and the specific contamination risks associated with different areas. In all cases, the contamination surveillance measurements should support the laboratory's ability to make decisions regarding the potential for radioanalytical contamination that interferes with the MQOs of the incident response.

An example of target areas to be monitored, techniques used, and minimum frequency recommended is summarized in Table 5.[31] Additional information on the contamination

[31] For all of these measurements, baseline values representing normal routine operations should be established before any incident-related samples are received. General guidance is provided in NUREG 1556, vol. 11, but each laboratory should develop its own program. The approach should also keep in mind that the NUREG document is focused primarily on human health concerns, although much lower levels of radioactive contamination may be of concern in radioanalytical facilities where measurements of low-level radioactivity are being performed.

monitoring of laboratory surfaces and equipment is provided in Appendix H, *Surveillance of Laboratory Surfaces and Equipment*.

Table 5 – Target Areas, Techniques, and Frequency of Radiological Monitoring

Laboratory Area	Item Monitored	Type of Monitoring	Frequency [1]
Sample Receipt	Samples received	Survey meter, swipe	Upon receipt
	Bench top	Survey meter, swipe	Weekly
	Floor	Mop water, swipes	Every two weeks composite
High-Level Screening and Processing Areas	Bench tops, doorknobs	Survey meter, swipe	Daily
	Hoods	Survey meter, swipe	Daily
	Floor	Mop water	Daily
	Labware (non-disposable)	Rinse water	Weekly composite
	Sample and waste storage areas, shelves, etc.	Survey meter, swipe	Weekly
	Entry area	Sticky pad	Weekly
	Egress area	Survey meter – hand and foot monitoring	Upon leaving area
	Sticky pads	Gamma spectrometer	Weekly
Routine-Level Processing Areas	Bench tops, doorknobs	Survey meter, swipe	Every two weeks
	Hoods	Survey meter, swipe	Every two weeks
	Floor	Mop water	Every two weeks
	Labware	Rinse water	Weekly composite
	Sample and waste storage areas, shelves, etc.	Survey meter, swipe	Every two weeks
Long-Term Sample or Waste Storage – High-Level	Shelves	Survey meter, swipe	Weekly
	Floor	Mop water	Weekly
Nuclear Instrumentation Room – High-Level	Detectors, instruments, shields	Swipes	Weekly
	Bench and work areas	Swipes	Weekly
	Computer keyboards	Swipes	Weekly
	Floor	Mop water	Weekly
Nuclear Instrumentation Room – Routine-Level	Detectors, instruments, shields	Swipes	Weekly
	Bench and work areas	Swipes	Every two weeks
	Computer keyboards	Swipes	Every two weeks
	Floor	Mop water	Every two weeks
Hallways	Floors	Mop water	Every two weeks
Administrative	Desks, doorknobs	Swipes	Monthly
Sinks, Traps, and Floor Drains	Sink surfaces, drain elbows, beneath sinks	Swipes and "on-contact" dose rate measurements	Monthly
External Radiation Monitoring	One TLD in areas of high-level samples	Environmental TLDs	Monthly

[1] Monitoring frequencies during the first several days of an incident response may need to be increased until the effectiveness of the laboratory's contamination control measures can be assessed.

Investigation and Action Levels for Each Monitored Area

Within the contamination control plan and program, action levels should be specified which, when exceeded, require some type of intervention.

- For certain analytical methods, such as gamma spectrometry or gas proportional counting, in which the total number of radiation events is integrated over a measurable counting period, each action level should have an associated ADL based on the probability of committing Type I and II errors.[32] When the contamination measurement result is above the ADL, it is assumed that the action level has been exceeded.
- Alternately, for survey techniques such as exposure rate meters or Geiger-Müller (G-M) probes that simply provide an instantaneous dose- or count-rate, an "investigation level" should be established, which would trigger further action when exceeded. This further action may include additional swipe surveys or other definitive analytical techniques. In some cases, these investigation and action levels may correlate to the level of radioactivity typically encountered in the laboratory under routine conditions. In this case, a change in laboratory radioactivity levels can be determined only if an accurate baseline measurement has been previously performed for the specific method being evaluated.

Table 6 provides examples of the types of investigation and action levels that might be considered for the laboratory. These will necessarily vary by the type of area and the specific operations performed in that area.

Table 6 – Example Contamination Investigation and Action Levels

Instrument	Item	Investigation Levels (for survey meters) and Action Levels (for instrumentation)
Survey meters (e.g., exposure rate meters, G-M probes, etc.)	Bench tops, instrument surfaces	3 times ambient background[33]
Gross alpha / beta - GPC	Swipes	1 pCi beta 0.1 pCi alpha
Gamma Spectrometry	Swipes, mats Mop and rinse water	15 pCi gross gamma (ref. ^{137}Cs)

The type of actions triggered by exceeding investigation levels or ADLs may vary from increased monitoring to process stoppage and decontamination of the area to acceptable levels. The investigation and action levels will vary according to laboratory area. A certain amount of contamination that may be tolerable in the high-level sample processing area would not be permissible in the low-level nuclear instrumentation area. The results of the monitoring activities

[32] See Appendix VI in *Radiological Laboratory Sample Analysis Guide for Incidents of National Significance – Radionuclides in Water* for the determination of an ADL as a function of Type I and Type II decision errors.

[33] See the companion documents, *Guide for Laboratories – Identification, Preparation, and Implementation of Core Operations for Radiological or Nuclear Incident Response* (EPA 2010) and *Radiological Laboratory Sample Screening Analysis Guide for Incidents of National Significance* (EPA 2009b) for additional discussion regarding considerations in the appropriate determination of instrument background count rates.

in Table 5 should be compared on a periodic (e.g., weekly) basis to the established investigation and action levels to determine whether an action is needed, and to identify trends that might indicate a developing problem. Action items from the contamination control program should be entered into the laboratory's corrective action program, indicating the date, cause of the action, action to be taken, person responsible for implementation of the action, and the due date for completion of the corrective action.

Documentation

A summary of the results of the contamination control program should be incorporated, as a separate section, into the laboratory's quality assurance program reports and documentation. In addition, the results of the contamination control program should be discussed at quality assurance and safety program staff meetings.

APPENDIX H: SURVEILLANCE OF LABORATORY SURFACES AND EQUIPMENT

1. Fixed Contamination Surveys

1.1 Fixed contamination surveys should be performed:

- On any object or material being transferred from a higher-activity area to a lower-activity area.
- On any surface that has been potentially contaminated by the handling of radioactive material.
- On the hands, feet, and outer garments of any employee exiting a radiological processing area. This includes any employee moving from a higher-activity area to a lower-activity area.

1.2. Survey instrument readings should be recorded in a logbook or on a standardized form to ensure a record of the survey activities, and to allow for supervisory/management review of the survey results. An example form is shown in Figures 14 and 15, which may also be used to record swipe surveys discussed in Section 2 of this appendix. When developing such a form, it is useful for the laboratory to include a map of the facility or area to aid in the survey description. The map should be sufficiently detailed to allow the survey technicians to indicate specific items, such as bench tops and fume hoods.

1.3. Measure and record the instrument background reading.

- Where survey results and/or action levels are referenced to a background level, an appropriate measurement of the instrument background readings must be taken prior to measuring the surfaces.
- Activity measurements (e.g., dpm, pCi, Bq, etc.) are, by definition, net results and should always be appropriately background corrected, which requires a representative measurement of the instrument background readings for the particular measurement geometry.
- For general measurements of surfaces of a variable or unpredictable composition, the background readings for instruments measuring alpha and beta activity can be made by simply removing the survey probe to an acceptable distance from possible sources of contamination.
- When the surfaces being measured are consistent or predictable, such as when measuring swipe samples or direct measurements of walls or floors, the background measurement should be made against an appropriate control surface, such as a clean swipe or a similarly constructed wall or floor outside the work area.
- When measuring the background readings for gamma activity, including exposure and dose rate meters, great care should be taken to ensure that the background reading is performed well away from potential sources of gamma activity, which can travel significant distances in the laboratory.
- The technicians should be aware of their proximity to radioactive materials storage areas, waste collection areas, and any other potential sources of gamma activity. In some cases, the background reading may have to be taken in advance, in another area of the laboratory, to ensure that the determination of net instrument response is accurate.

XYZ Laboratories, Inc.

RADIOACTIVE CONTAMINATION SURVEY REPORT

Date and Time: _____

Technician: _____

Instrument ID: _____

Calibration Date: _____

Check all that apply:

_____ Routine scheduled surveillance
_____ Response to spill or other incident.
_____ Hand-held survey meter
_____ Swipe samples

_____ If response to spill or other incident, the RSO has been notified.

Other notes and comments:

Action Levels (specific to area and type of survey - see Radiation Protection Plan):

Action Level	Units	Circle Type of Radiation/Reading and Measurement Units		
		Alpha	µR/h	cpm
		Beta	mrem/h	dpm
		Gamma	Other:	

If Action Level is exceeded, report to Radiation Safety Officer.

Survey Results: Indicate location on back of form, if necessary.

Item #	Description	gross net (circle one) Survey Result	Units	Type of Radiation
0	Background Measurement (Gross Only)			
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				

Approved By: _____

Date: _____

Figure 14 – Example Survey Report Form, Front

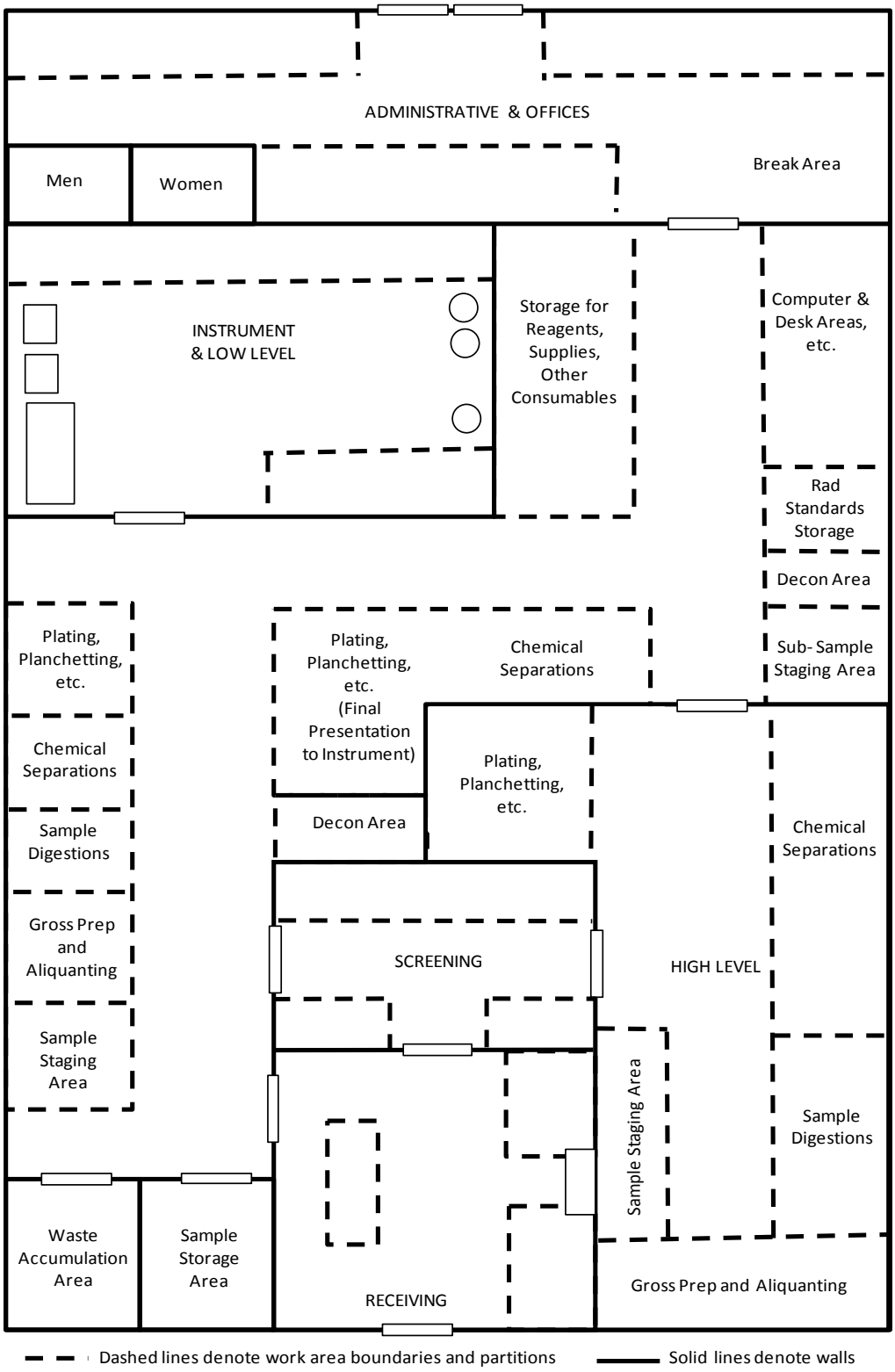

Figure 15 – Example Survey Report Form, Back

1.4. Measurements are made of the potentially affected surfaces. The probe of the survey instrument should be moved across the surface to be surveyed slowly (2-3 inches per second is a customary scan rate) and deliberately to enable detection of discreet areas of contamination. Typically, hand-held probes may be held approximately one inch from the surface and moved approximately 2–3 inches per second. In the event that "hot particles" are suspected, slower scan rates are advisable, as the scanning instrument response may otherwise be too slow to react. Great care should be taken to protect the hand-held survey equipment from contamination by the items being surveyed.

When performing the survey, it is not unusual for the instrument reading to fluctuate somewhat while traversing the areas to be measured. It is acceptable to simply record the highest observed reading. If the survey indicates unacceptable contamination levels on a specific part of the surface, a detailed note should be made accordingly.

1.5. Action levels for surveys should be based on the type of area and the acceptable levels of contamination, as discussed in Section 2.2. Any surface measurement that results in a survey reading above the associated action levels should be confirmed. Portable items should be sequestered until decontamination procedures are completed. Access and use of contaminated laboratory surfaces should be prevented until decontamination is completed.

1.6. Note that the success of any decontamination activities must be confirmed with a new survey prior to releasing the surface or object for use in the laboratory.

2. Removable Surface Contamination (Swipes) Surveys[34]

2.1 Surveys should be required on all potentially affected surfaces that present a risk of transferring contamination to laboratory workers, equipment, or other samples.

2.1.1 Sample containers should be surveyed before moving the containers from a high-activity level area to a lower activity level area.

2.1.2 Laboratory equipment that is being moved from a high-activity level area to a lower-activity level area should be surveyed.

2.1.3 Laboratory surfaces, such as hood interiors, bench tops, floors, etc., should receive regular, periodic surveys. In addition, these surfaces should be surveyed following operations with significantly elevated levels of radioactivity, or after a spill or other release of radiological material, to ensure that the decontamination efforts are successful.

2.2 Swipe survey protocols, in addition to ensuring accurate results, should be developed to facilitate the sampling and rapid analysis of large numbers of swipes. Analysis of the swipes by direct reading instrumentation, without the need for significant preparation or handling, and the use of instrumentation with an automatic sample changer, should be considered whenever possible.

2.3 The swipe material should be rugged enough to remove surficial contamination from the surface of the object being surveyed, without significantly damaging the swipe or leaving swipe material behind on the surface.

[34] Additional detailed information regarding the removable contamination surveys may be found in the companion document, *A Performance-Based Approach to the Use of Swipe Samples in Response to a Radiological or Nuclear Incident* (EPA 2011).

2.4 The decision to wet the swipe, and the selection of a wetting agent, should take into consideration the chemical form of the potential contamination and the degree to which the solution may be compatible with the analytical process.

2.5 As with the use of hand-held survey equipment, the collection of swipe samples may be greatly affected by the technique of the individual collecting the samples. If possible, the number of individuals who collect swipes should be limited to ensure consistency in the final results.

2.6 The survey activities and results should be recorded on a standardized form, such as the one shown in Figure 14, to ensure complete documentation and to facilitate adequate supervisory review of the information.

2.7 The area to be swiped should be as consistent as possible. In some cases, it may be helpful to include a diagram of the standard swipe area, on the form used to record the survey activities, as a reminder to the survey technician.

2.8 When collecting the swipe samples on larger surfaces, or objects on which the potential contamination is not expected to be consistent or homogeneous over the entire surface, multiple swipes may need to be taken to ensure that the final results provide accurate information about the level of contamination on the object.

APPENDIX I: DECONTAMINATION OF LABORATORY SURFACES AND EQUIPMENT

This example is intended to provide guidance for the decontamination of laboratory surfaces. If the contamination is the result of a spill or other release of radiological materials, this guidance is applicable after the general containment and removal of debris and gross materials from the spill.

This is a generalized protocol, provided for example purposes only. The user should evaluate each situation and determine whether these or other measures will be more appropriate and effective.

1. Selection of Decontamination Equipment and Materials

   A ready supply of decontamination equipment and materials should be maintained and kept close at hand in the work areas. These items are separate from, and in addition to, spill response equipment and supplies. Decontamination supplies should be selected based on the surfaces to be cleaned and the type of radiological material being handled in the laboratory, but should include at a minimum:

   - Disposable towels or absorbent wipes;
   - Disposable scrubbing brushes;
   - Spray bottles containing the appropriate decon solution; and
   - Sealable plastic bags or other means of containing and disposing of used decontamination supplies.

   Selection of the appropriate decontamination solution should consider the type of radiological material being handled in the laboratory. Most household cleaning solutions, such as window cleaner or multi-surface cleaners, will be quite effective in removing a wide variety of surficial contamination. The laboratory may also consider commercially available radiological decontamination solutions that contain chelating agents, which are useful in the removal of radionuclides present in ionic form.

2. Decontamination Procedures

   Decontamination procedures for laboratory surfaces are much like any other general cleaning task in the laboratory. Specific care should be taken, however, to deliberately contain and remove the contamination without spreading the radiological material to uncontaminated areas. The laboratory's specific decontamination procedures must address the specific surfaces, type of radiological materials, levels of radioactivity present, potential exposure concerns, waste disposal practices, and release criteria. The following steps are intended only as an example:

   2.1. Identify the area to be decontaminated. Previous surveys should have adequately defined the affected areas and identified the boundaries of the contamination.

   2.2. Stage the decontamination supplies and disposal container within reach of the contaminated area, on top of a disposable piece of laboratory bench paper.

   2.3. Spray the contaminated surface with the appropriate decontamination solution.

   2.4. With a disposable towel or wipe, start at the outer edge of the contaminated area. Maintain a definite boundary between the cleaned and contaminated areas.

2.5. Avoid spreading contamination into the areas already cleaned by working in one direction and frequently disposing of and replacing the cleaning towels.

2.6. Any potentially contaminated supplies should be immediately transferred to a sealable plastic bag, or other container, for disposal.

2.7. After the initial decontamination procedure, repeat from the beginning to ensure adequate removal of the contamination.

2.8. Finally, dispose of all potentially contaminated supplies, including the laboratory bench paper, and place the waste material in the proper waste collection container.

To minimize the risk of further contamination to the facility, the removal of potentially contaminated materials and decontamination supplies from the affected area should take place only after the contamination event has been contained, the materials have been properly secured and surveyed, and not under the “crisis” or “emergency” conditions that may have been created by the contamination incident, if possible.

3. Re-Survey of the Contaminated Surfaces

After completing the decontamination process, the objects or surfaces must not be released for general use until a new survey has been performed to confirm that the decontamination procedure was successful.

APPENDIX J: ESTABLISHING MQOS FOR SAMPLE SCREENING MEASUREMENTS

Section 2.2 of this guide contains an example in which a hypothetical laboratory establishes contamination control MQOs by determining AAL(*C*), $u_{MR}(C)$, and ADL(*C*) values for alpha-emitting radioactive contamination measurements in Routine-Level Work Areas in the laboratory. These contamination control MQOs were based on the AAL(*S*), $u_{MR}(S)$, and ADL(*S*) MQOs that the laboratory is required to meet for sample analyses. This appendix provides an additional example that illustrates how a laboratory might develop similar MQOs for sample screening measurements[35] when those screening results are used to segregate samples into different types of work areas, depending on the sample activity levels.

As in Section 2.2, incident response MQOs will be distinguished from the laboratory's internal screening MQOs by the use of the parentheticals (*S*) for sample and (*C*) for potential cross-contamination from co-processed samples.

1. Determine AAL(*C*)

   Consider an example scenario in which the laboratory wants to establish limits for beta activity in a Low-Level Work Area. As with the previous example, in Section 2.2, MQOs for sample screening results, which may be used as the basis of segregating samples by activity concentration levels, will be directly related to the MQOs for incident response sample analysis.

   Developing MQOs for sample screening measurements in this scenario is very similar to the development of MQOs for removable surface contamination surveys, as discussed in Section 2.2. In both cases, the potential activity from a source of contamination contributes to the uncertainty of the field sample measurement, and the estimate of the maximum tolerable level of contamination is the basis for the Analytical Action Level of the contamination control or sample screening measurement, i.e., AAL(*C*).

   In this example scenario:

   - The laboratory area is used for the preparation of samples that are required to meet MQOs that cannot generally be supported by the "Routine-Level Work Area" contamination surveillance limits described in Table 2. In this scenario, the laboratory has established a "Low-Level Work Area" for the preparation of these samples.
   - The incident response MQO for ^{90}Sr analysis in water samples states that the required method uncertainty, $u_{MR}(S)$ is not to exceed 0.15 pCi/L at the specified AAL(*S*), which is 1.5 pCi/L.
   - Sample activity measurements below 1.5 pCi/L are also limited to the required method uncertainty, $u_{MR}(S)$, of 0.15 pCi/L, and measurements above 1.5 pCi/L are limited to a relative required method uncertainty, $\varphi_{MR}(S)$, of 10% of the measured activity.

[35] Additional detailed information regarding sample screening MQOs, sample processing for screening purposes, instrument calibration considerations, and other key recommendations is provided in the companion guide *Radiological Laboratory Sample Screening Analysis Guide for Incidents of National Significance* (EPA 402-R-09-008, June 2009).

- The current analytical method in use in the laboratory employs a sample aliquant of 0.5 liter and has the capability to produce a CSU of 0.13 pCi/L (8.7%) at an activity concentration of 1.5 pCi/L, before potential sources of sample cross-contamination are considered.

The laboratory, therefore, has a method that currently limits the CSU to 0.13 pCi/L at the prescribed AAL(*S*) of 1.5 pCi/L and wishes to determine what maximum level of potential sample cross-contamination would increase the method uncertainty, $u_{MR}(S)$, to 0.15 pCi/L.

The required method uncertainty for field sample analyses, $u_{MR}(S)$, may be estimated by the laboratory by the following equation:

$$u_{MR}(S) = \sqrt{\mathrm{CSU}^2 + \mathrm{AAL}(C)^2}$$

or

$$\frac{0.15\mathrm{pCi}}{\mathrm{L}} = \sqrt{\left(\frac{0.13\mathrm{pCi}}{\mathrm{L}}\right)^2 + \mathrm{AAL}(C)^2}$$

Solving for AAL(*C*) shows that the maximum tolerable level of potential ^{90}Sr sample cross-contamination, AAL(*C*), would be equal to 0.075 pCi/L in the field sample analysis.
Since each sample analysis employs an aliquant of 0.5 L, the maximum tolerable level of ^{90}Sr cross-contamination in each 0.5 L sample aliquant is:

$$0.075\ \mathrm{pCi/L} \times 0.5\ \mathrm{L} = 0.0375\ \mathrm{pCi}.$$

The AAL(*C*), expressed in activity units of pCi, is therefore 0.0375 pCi beta activity from ^{90}Sr.

Following this assessment, the laboratory technical personnel are consulted, the sample preparation process is reviewed, and potential sources and mechanisms of sample cross-contamination are identified. The volume of sample that may be aerosolized due to vigorous boiling, or whether a technician inadvertently grasps the inside lip of a beaker during sample preparation might be considered. Based on the available information, and perhaps based in large part on the technical judgment of the staff, it is estimated that the ^{90}Sr analysis of a field sample could potentially receive up to 0.5 mL as cross-contamination from other samples being processed concurrently.

> *Note that the values in this example are for illustrative purposes only. Each laboratory will need to assess its own processes and situations on a case-by-case basis. In all cases, however, the potential sample cross-contamination should be limited to a level that does not significantly impact the required sample analysis method uncertainty, $u_{MR}(S)$.*

Limiting the potential activity from sample cross-contamination to 0.0375 pCi (as determined above) per 0.5 mL of sample volume gives the maximum allowable ^{90}Sr activity concentration for samples being prepared in that Low-Level Work Area:

$$0.0375 \text{ pCi} / 0.5 \text{ mL} = 0.075 \text{ pCi/mL}$$
$$= 75 \text{ pCi/L}$$

The AAL*(C)*, therefore, is 75 pCi/L. For screening analyses it is generally faster, more convenient, and analytically conservative to measure gross beta activity, rather than actual ^{90}Sr activity. The AAL(*C*), therefore, is 75 pCi gross beta activity per liter of sample. This value is shown in Table 1 of this guide, under "Maximum Screening Activity Concentrations per Matrix", for "beta > 150 keV" in liquids.

2. Limiting the Screening Method Uncertainty, $u_{MR}(C)$

As discussed in Section 2.2.3, the required method uncertainty, $u_{MR}(C)$, is calculated as:

$$u_{MR} \leq \frac{\text{AAL - DL}}{z_{1-\alpha} + z_{1-\beta}}$$

Where

AAL = analytical action level
DL = discrimination level
$z_{1-\alpha}$ and $z_{1-\beta}$ are the $1-\alpha$ and $1-\beta$ quantiles of the standard normal distribution function, where α and β are the respective probabilities of making a Type I or Type II error.

In this example scenario, the AAL(*C*), has been established as 75 pCi/L. The DL is selected as zero because the screening results for samples being processed in a Low-Level Work Area should be distinguishable from uncontaminated, e.g., zero activity, measurements. The values for $z_{1-\alpha}$ and $z_{1-\beta}$ are both set to 1.645, corresponding to 5% Type I and Type II error rates.

Under these conditions, the required method uncertainty for gross beta screening analyses, $u_{MR}(C)$, at the AAL will be:

$$u_{MR}(C) = \frac{\text{AAL - DL}}{z_{1-\alpha} + z_{1-\beta}} = \frac{75 - 0}{1.645 + 1.645} = 23 \text{ pCi/L}$$

The laboratory, therefore, must identify analysis conditions for sample gross beta screening that satisfy the required method uncertainty of 23 pCi/L.

3. Determining ADL(*C*)

The ADL(*C*) is the screening result that is used to determine whether or not the actual gross beta activity in a sample is likely to exceed the AAL(*C*), determined above. The ADL(*C*) is calculated as:

$$\text{ADL}(C) = \text{AAL}(C) - z_{1-\alpha} \times u_{MR}(C)$$

$$= 75 - (1.645 \times 23) = 37 \text{ pCi/L}$$

4. Summary

   In this example scenario, the laboratory determined the AAL(*C*) for gross beta activity in samples being processed in the Low-Level Work Area. The AAL(*C*) was determined by the MQOs associated with the field sample analyses being performed, and the laboratory's estimate of tolerable levels of sample cross-contamination that would be unlikely to significantly impact the field sample MQOs.

   Once the AAL(*C*) was determined, the laboratory then established constraints on the uncertainty, $u_{MR}(C)$, of the screening method to be employed, then used those values to determine what screening measurement result, ADL(*C*), would cause the laboratory to decide that the AAL(*C*) was likely to have been exceeded, given the screening method uncertainty and the laboratory's tolerance for errors.

   After determining the ADL(*C*) for gross beta sample screening analyses, the laboratory should calculate ADL(*C*) values for other contamination control measurements that will be necessary for that area, as shown in the example for Routine-Level Work Areas in Table 2.

APPENDIX K: ESTABLISHING MQOS FOR SAMPLE EXPOSURE RATES

Section 2.2 of this guide contains an example in which a hypothetical laboratory establishes contamination control MQOs by determining AAL(C), $u_{MR}(C)$, and ADL(C) values for alpha-emitting radioactive contamination measurements in Routine-Level Work Areas in the laboratory. These contamination control MQOs were based on the AAL(S), $u_{MR}(S)$, and ADL(S) MQOs that the laboratory is required to meet for sample analyses. This appendix provides an additional example that illustrates how a laboratory might develop analogous MQOs for exposure rate measurements when those results are used to segregate samples into different types of work areas.

It should be carefully noted that there are significant differences between analytical methods for which the total number of radiation events is integrated over a measurable counting period (e.g., gamma spectrometry, gas proportional counting, etc.), and methods that simply provide an instantaneous dose- or count-rate (e.g., G-M probes, exposure rate meters, etc.).

One primary difference is the statistical basis for decisionmaking based on the probability of committing Type I and Type II errors, which is readily employed in the former type of measurements, and only roughly approximated in the latter.

In this example scenario, MQOs for exposure rate measurements are developed in a manner that is analogous to the development of MQOs for integrated activity measurements. These MQOs may be useful to the laboratory in making decisions regarding the segregation of samples in order to minimize the impact of excessive or transient exposure on the analytical process. The laboratory is cautioned, however, against extending the concepts presented in this example to other applications, such as the measurement of sample radioactivity levels or the reliance on such measurements to support decisionmaking at a proposed statistical confidence interval.

A detailed discussion of the applicability and limitations of hand-held survey equipment is provided in the companion document *Uses of Field and Laboratory Measurements During a Radiological or Nuclear Incident* (EPA 2012).

As in Section 2.2, incident response MQOs will be distinguished from the laboratory's internal exposure rate MQOs by the use of the parentheticals (S) and (C) for potential cross-contamination from co-processed samples.

1. Determine AAL(C)

   Consider an example scenario in which the laboratory wants to establish exposure rate limits for individual samples in a Routine-Level Work Area. As with the previous example, in Appendix J, MQOs for sample exposure rates, which may be used as the basis for segregating samples to different work areas, should be related to the laboratory's ability to achieve the required MQOs for incident response sample analysis.

   Developing MQOs for exposure rate measurements in this scenario is similar to the development of MQOs for removable surface contamination surveys, as discussed in Section

2.2, with some notable differences. In both cases, the potential contribution from a source of radioactive contamination or radiation exposure contributes to the uncertainty of the field sample measurement, and the estimate of the maximum tolerable level of that contribution, is the basis for the Analytical Action Level of the contamination control or exposure rate measurement, i.e., AAL(*C*). In this example, however, the estimate of the impact on the field sample MQOs is based on the transient effect of gamma radiation on the laboratory instrumentation, and the measurement uncertainty is empirically derived, rather than being calculated as a CSU.

In this example scenario:

- The laboratory area is classified as a Routine-Level Work Area and is used for the preparation and analysis of samples that are required to meet MQOs that apply to the majority of sample analyses performed by the laboratory.
- The incident response MQO for ^{137}Cs analysis in air filters states that the required method uncertainty, $u_{MR}(S)$ is not to exceed 5 pCi/filter at the specified AAL(*S*), which is 40 pCi/filter.
- Sample activity measurements below 40 pCi/filter are also limited to the required method uncertainty, $u_{MR}(S)$, of 5 pCi/filter and measurements above 40 pCi/filter are limited to a relative required method uncertainty, $\varphi_{MR}(S)$, of 12.5% of the measured activity.
- The current gamma spectroscopy method in use in the laboratory employs a sample aliquant of 1 filter and has the capability to produce a CSU of 3.5 pCi/filter (8.8%) at an activity concentration of 40 pCi/L, before potential sources of radioanalytical interference from sample exposure rates are considered.

The laboratory, therefore, has a method that currently limits the CSU to 3.5 pCi/filter at the prescribed AAL(*S*) of 40 pCi/filter and wishes to determine what maximum level of sample exposure rate would potentially increase the method uncertainty, $u_{MR}(S)$, to 5 pCi/filter.

In this specific scenario, the sample exposure rate does not actually contribute to the radioactivity in the sample, but is manifested in the field sample analysis results through the transient impact that excess gamma radiation has on the gamma spectroscopy instrumentation in use in the lab. *To assess the potential impact, the laboratory will need to have performed a basic empirical study to quantify that impact.* In this example scenario, *the laboratory is presumed to have determined* a "worst-case" scenario in which samples containing ^{137}Cs, delivered to the instrument room, and having an exposure rate of 1,000 μR/h, introduced an average positive bias of 0.72 pCi/filter in the gamma spectrometry analysis of ^{137}Cs in air filters, under the analytical conditions being considered in this example. The impact of the hypothetical exposure rate on other analytical techniques, such as gross gamma activity analyses or the spectroscopic analysis of other gamma-emitting radionuclides, must be evaluated separately. For this example scenario, the resulting contribution to the bias is:

$$\frac{0.72\text{pCi}}{\text{filter}} \Big/ \frac{1000\mu\text{R}}{\text{h}} = 7.2\times10^{-4}\,\frac{\text{pCi}\cdot\text{h}}{\mu\text{R}\cdot\text{filter}}$$

As previously discussed, the required method uncertainty for field sample analyses, $u_{MR}(S)$, may be estimated by the laboratory by the following equation:[36]

$$u_{MR}(S) = \sqrt{CSU^2 + AAL(C)^2}$$

or

$$\frac{5\text{pCi}}{\text{f}} = \sqrt{\left(\frac{3.5\text{pCi}}{\text{f}}\right)^2 + AAL(C)^2}$$

Solving for AAL(C) shows that the maximum tolerable potential bias to the ^{137}Cs results, AAL(C), which is treated as an additional uncertainty factor in the field sample analysis, would be equal to 3.6 pCi/filter in the field sample analysis.

Converting this AAL(C) from an activity level to an external sample exposure rate,

$$3.6\frac{\text{pCi}}{\text{f}} \Big/ 7.2\times10^{-4}\frac{\text{pCi}\cdot\text{h}}{\mu\text{R}\cdot\text{f}} = 5000\frac{\mu\text{R}}{\text{h}}$$

The AAL*(C)* for sample exposure rate measurements in this particular work area is therefore 5,000 µR/h. This value is shown in Table 1 of this guide, under "Maximum Sample Exposure Rate (µR/h at surface of container)".

2. Limiting the Survey Method Uncertainty, $u_{MR}(C)$

   As discussed in Section 2.2.3, the required method uncertainty, $u_{MR}(C)$, is calculated as:

$$u_{MR} \le \frac{\text{AAL - DL}}{z_{1-\alpha} + z_{1-\beta}}$$

   Where

   AAL = analytical action level
   DL = discrimination level
   $z_{1-\alpha}$ and $z_{1-\beta}$ are the $1-\alpha$ and $1-\beta$ quantiles of the standard normal distribution function, where α and β are the respective probabilities of making a Type I or Type II error.

   In this example scenario, the AAL(C), has been established as 5,000 µR/h. The DL is selected as 100 µR/h, which is the AAL(C) for the Low-Level Work Areas. The values for $z_{1-\alpha}$ and $z_{1-\beta}$ are both set to 1.645, corresponding to 5% Type I and Type II error rates.

[36] This equation, and others in this example scenario, make certain assumptions about the results of the empirical study performed by the laboratory, most notably, that the effects of external exposure on the analytical system are independent, normally distributed contributions to the uncertainty in the reported results of the field samples. This may be a simplification of the actual laboratory conditions, and other statistical treatments of the derivation of AAL(C) may be more appropriate in some cases. Additional information regarding the estimation of uncertainty in various measurement systems, including the treatment of non-normal distributions, is provided in MARLAP (2004), Chapter 19.

Under these scenario conditions, the required method uncertainty for exposure rate measurements, $u_{MR}(C)$, at the AAL will be:

$$u_{MR}(C) = \frac{\text{AAL - DL}}{z_{1-\alpha} + z_{1-\beta}} = \frac{5000 - 100}{1.645 + 1.645} = 1489 \text{ μR/h}$$

$$= 1.5 \times 10^3 \text{ μR/h}$$

The laboratory, therefore, must identify measurement conditions for exposure rate monitoring that satisfy the required method uncertainty of 1,500 μR/h at the AAL*(C)* of 5,000 μR/h.

It should be noted that the "method uncertainty" in this scenario, and for other hand-held survey instrument measurements, cannot be determined by calculating a CSU, as is done routinely with other laboratory instrumentation that integrates the total number of radiation events over a measurable counting period. In the case of instantaneous readout survey instruments, the laboratory may make estimates of the uncertainty of the measurement process by performing empirical studies that incorporate the various contributions to variability in a measured result. For example, multiple measurements of a source might be made under different conditions, by various technicians, and the relative standard deviation of those measurements might be used as an estimate of the "method uncertainty." Measurements should be taken at the AAL*(C)* of 5,000 μR/h.

3. Determining ADL(*C*)

The ADL(*C*) is the screening result that is used to determine whether or not the actual sample exposure rate is likely to exceed the AAL(*C*), determined above. The ADL(*C*) is calculated as:

$$\text{ADL}(C) = \text{AAL}(C) - z_{1-\alpha} \times u_{MR}(C)$$
$$= 5000 - (1.645 \times 1489) = 2550 \text{ μR/h}$$
$$= 2.6 \text{ x } 10^3 \text{ μR/h}$$

4. Summary

In this example scenario, the laboratory determined the AAL(*C*) for sample exposure rates in samples being processed in the Routine-Level Work Area. The AAL(*C*) was determined by the MQOs associated with the field sample analyses being performed and the laboratory's estimate of tolerable levels of instrument interference that would be unlikely to significantly impact the field sample MQOs.

Once the AAL(*C*) was determined, the laboratory then established constraints on the uncertainty, $u_{MR}(C)$, of the survey method to be employed, and then used those values to determine what survey measurement result, ADL(*C*), would cause the laboratory to decide

that the AAL(*C*) was likely to have been exceeded, given the screening method uncertainty and the laboratory's tolerance for errors.

This example scenario makes assumptions about the laboratory's radioanalytical systems and the direct impact of sample exposure rates on the analytical process. In some cases, the laboratory may use exposure rate measurements for other purposes, such as a rapid and easy technique for identifying high-activity samples transiting the laboratory, which may increase the risk of laboratory contamination. Each laboratory should develop its own survey measurement protocols based on the anticipated risks and concerns that may be unique to that laboratory and ensure that the development of AAL, uncertainty, and ADL values appropriately address those unique laboratory conditions.