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United States
Environmental Protection
Agency

A Performance-Based Approach to the Use of Swipe Samples in Response to a Radiological or Nuclear Incident

Office of Research and Development
National Homeland Security Research Center

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

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A Performance-Based Approach to the Use of Swipe Samples in Response to a Radiological or Nuclear Incident

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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PREFACE

This document describes the various swipe techniques that may be used to sample surfaces contaminated by radioactive materials following an incident such as the detonation of an improvised nuclear device (IND) or a radiological dispersal device (RDD) ("dirty bomb"). While simple in concept, procedures used to take a swipe sample may vary considerably in practice. A standard method or technique for taking swipe samples does not exist. This means the fraction of the total removable radioactive surface contamination transferred to the swipe will also vary depending on the technique used. It is anticipated that a large number of swipes will be taken, so it is essential that the data generated are accurate so that they will be useful for the decisions that need to be made. While some may be counted in the field, others will be sent to laboratories for analysis. This document was developed to provide guidance to those radioanalytical laboratories that will support EPA's response and recovery actions following a radiological or nuclear incident.

The need to ensure an 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 and emerging laboratory networks across the Federal Government. ICLN is designed to provide a national infrastructure with a coordinated and operational system of laboratory networks that will 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 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).

EPA's responsibilities, as outlined in the *National Response Framework*, include response and recovery actions to detect and identify radioactive substances and to coordinate federal radiological monitoring and assessment activities.

As with any technical endeavor, actual radioanalytical projects may require particular methods or techniques to meet specific measurement quality objectives (MQOs). Uncertainties associated with swipe samples can be extremely large. Understanding the components of uncertainty, beginning with the removal factors associated with various combinations of swipe materials, surfaces, chemical forms of radionuclides, and sampling techniques, will provide Incident Commanders and other decisionmakers with a better estimate of the uncertainties in swipe-sample analytical results, how these can affect decisionmaking, and an appreciation of how uncertainties may be reduced if necessary. However, it is clear that additional research is needed to develop better sampling techniques, to quantify the limitations of the various techniques, and to assist in the selection of the technique that is most appropriate to the circumstances.

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

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Detailed guidance on recommended radioanalytical and site survey practices can be found in the *Multi-Agency Radiological Laboratory Analytical Protocols* (MARLAP) Manual and the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM). MARLAP provides detailed radioanalytical guidance for project planners, managers, and radioanalytical personnel based on project-specific requirements. MARSSIM provides information for planning, conducting, evaluating, and documenting building surface and surface-soil final status radiological surveys for demonstrating compliance with dose or risk-based regulations or standards. These documents are available at www.epa.gov/radiation/programs.html. Familiarity with Chapter 10 of MARLAP will be of significant benefit to users of this guide.

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

- *Radiological Laboratory Sample Analysis Guide for Incidents of National Significance – Radionuclides in Water* (EPA 402-R-07-007, January 2008)
- *Radiological Laboratory Sample Analysis Guide for Incidents of National Significance – Radionuclides in Air* (EPA 402-R-09-007, June 2009)
- *Radiological Laboratory Sample Screening Analysis Guide for Incidents of National Significance* (EPA 402-R-09-008, June 2009)
- *Method Validation Guide for Qualifying Methods Used by Radiological Laboratories Participating in Incident Response Activities* (EPA 402-R-09-006, June 2009)
- *Guide for Laboratories – Identification, Preparation, and Implementation of Core Operations for Radiological or Nuclear Incident Response* (EPA 402-R-10-002, June 2010)
- *Uses of Field and Laboratory Measurements During a Radiological or Nuclear Incident* (in preparation)
- *Guide for Radiological Laboratories for the Control of Radioactive Contamination and Radiation Exposure* (in preparation)
- *Radiological Laboratory Sample Analysis Guide for Radiological or Nuclear Incidents – Radionuclides in Soil* (in preparation)

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ACRONYMS, ABBREVIATIONS, UNITS, AND SYMBOLS

(Excluding chemical symbols and formulas)

α .....alpha particle
α .....probability of a Type I decision error
AAL .....analytical action level
ADL .....analytical decision level
AL .....action level
ALARA.....as low as reasonably achievable
AS .....alpha spectrometry
A_R.....activity removed by the first swipe sample
A_T.....total removable activity
β .....beta particle
β.....probability of a Type II decision error
Bq.....becquerel (1 dps)
CFR.....*Code of Federal Regulations*
cm.....centimeter
cpm.....counts per minute
d.....day
DL .....discrimination limit
DOE .....U.S. Department of Energy
DOT .....U.S. Department of Transportation
dpm .....disintegrations per minute
dps.....disintegrations per second
DQO.....data quality objective
$E_{\beta max}$ .....maximum energy of the beta-particle emission
ε_i .....instrument efficiency for radiation type (alpha or beta radiation)
ε_s .....source efficiency
EPA.....U.S. Environmental Protection Agency
ERLN .....Environmental Response Laboratory Network
F.....removal factor
γ.....gamma ray
g.....gram
Ge.....germanium [semiconductor]
G-M.....Geiger-Muller [detector]
GP .....gas proportional
GPC.....gas proportional counting/counter
GS .....gamma spectrometry
GUM .....*Guide to the Expression of Uncertainty in Measurement*
Gy.....gray
h.....hour
H_0 .....null hypothesis
H_1 .....alternate hypothesis
HPGe.....high-purity germanium [detector]
IC.....Incident Commander (or designee)
ICLN .....Integrated Consortium of Laboratory Networks
ICP-MS .....inductively coupled plasma mass spectrometry

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IND .....improvised nuclear device (i.e., a nuclear bomb)
ISO .....International Organization for Standardization
keV.....kilo (thousand) electron volts
KPA.....kinetic phosphorescence analysis
L .....liter
LBGR.....lower bound of the gray region
LS.....liquid scintillation
LSC .....liquid scintillation counter/counting
MARLAP.....*Multi-Agency Radiological Laboratory Analytical Protocols* [Manual]
MARSAME .....*Multi-Agency Radiation Survey and Assessment of Materials and Equipment* [Manual]
MARSSIM .....*Multi-Agency Radiation Survey and Site Investigation Manual*
MDA .....minimum detectable activity
MDC .....minimum detectable concentration
MeV .....mega (million) electron volts
mg .....milligram (10^{-3} g)
min .....minute
mL.....milliliter (10^{-3} L)
MQO .....measurement quality objective
mrem .....millirem (10^{-3} rem)
µg .....microgram (10^{-6} g)
NaI(Tl) .....thallium-activated sodium iodide detector
n_B .....background count
NIST.....National Institute of Standards and Technology
NORM.....naturally occurring radioactive materials
NRC .....U.S. Nuclear Regulatory Commission
φ_{MR} .....relative required method uncertainty
PAG.....protective action guide
pCi.....picocurie (10^{-12} Ci)
QA.....quality assurance
QC.....quality control
rad .....radiation absorbed dose
RDD .....radiological dispersal device (i.e., "dirty bomb")
rem .....roentgen equivalent: man
RFA.....responsible federal agency
ROI.....region of interest
s.....second
S.....surface area
SCP .....sample collection plan
SI.....International System of Units
SIMCON.....simulated contamination
SOP .....standard operating procedure
Sv .....sievert
UBGR .....upper bound of the gray region
u_{MR} .....required method uncertainty
XRF.....X-ray fluorescence
y.....year

RADIOMETRIC AND GENERAL UNIT CONVERSIONS

To Convert	To	Multiply by	To Convert	To	Multiply by
years (y)	seconds (s) minutes (min) hours (h) days (d)	3.16×10^{7} 5.26×10^{5} 8.77×10^{3} 3.65×10^{2}	s min h d	y	3.17×10^{-8} 1.90×10^{-6} 1.14×10^{-4} 2.74×10^{-3}
disintegrations per second (dps)	becquerels (Bq)	1	Bq	dps	1
Bq Bq/kg Bq/m^3 Bq/m^3	picocuries (pCi) pCi/g pCi/L Bq/L	27.0 2.70×10^{-2} 2.70×10^{-2} 10^{-3}	pCi pCi/g pCi/L Bq/L	Bq Bq/kg Bq/m^3 Bq/m^3	3.70×10^{-2} 37.0 37.0 10^{3}
microcuries per milliliter (μCi/mL)	pCi/L	10^{9}	pCi/L	μCi/mL	10^{-9}
disintegrations per minute (dpm)	μCi pCi	4.50×10^{-7} 4.50×10^{-1}	pCi μCi	dpm	2.22 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 International System of Units (SI) units. Protective action guides (PAGs) and their derived concentrations appear in official documents in the traditional units and are in common usage. Conversion to SI units will be aided by the unit conversions in this table.

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1. INTRODUCTION

If a radiological or nuclear device were detonated in the United States, a large number of samples would need to be analyzed to assess and control the spread of fine particulate matter contaminated by radionuclides. This document deals with the analysis of swipe[2] samples from areas that may have been contaminated as the result of a radiological or nuclear event, such as a radiological dispersal device (RDD), improvised nuclear device (IND), or intentional release of radioactive materials. In the event of a major incident that releases radioactive materials to the environment, EPA will turn to radioanalytical laboratories to support its response and recovery activities. In order to expedite sample analyses and data feedback, the laboratories will need guidance on the EPA's expectations. Three response phases are defined by EPA:

- The *early phase*, also known as the *emergency phase*, is the initial reaction to the emergency and can last for a few hours or up to a few days. During this phase, single-point swipes at both random and targeted locations are taken. This information is used to establish contamination controls for areas, structures, and components; to assess decontamination and dose assessment requirements for affected members of the public; and to assess protection factors and respiratory protection requirements for initial responders and for recovery planning.

- The *intermediate phase* initiates when the immediate emergency situation is under control and reliable environmental measurements are available for use as the basis of additional protective actions. This phase may overlap with the other two phases and can last from weeks to months. Swipe data are used to assess the adequacy of—and ongoing requirements for—radiation protection and controls for recovery personnel and for assessing progress of decontamination.

- The *late phase*, also known as the *recovery phase*, begins with recovery actions. Recovery actions are designed to reduce radiation levels in the environment to levels acceptable for unrestricted use. Swipe data are used to assess final radiological conditions with respect to incident goals and limits.

1.1 SCOPE

This document focuses primarily on the intermediate and late phases. Many of the procedures are designed to detect and characterize radiation in potentially contaminated areas. However, as discussed in Section 1.3, "Current Practice," the limitations and potential sources of uncertainty introduced by these procedures will impact the decisionmaking processes in each phase. For example:

- Intermediate phase: False negatives may lead to inadequate worker protection, inadequate decontamination, potential release of contaminated surfaces or components, adverse public and political reactions, and additional costs to recover from each. False positives lead to over-protection for workers and/or excessive decontamination; both resulting in adverse costs and schedule issues.

[2] The terms "swipe," "wipe," and "smear" are often used interchangeably in the literature. In this document, the term "swipes" is used, unless quoting directly from another document

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- Late phase: False positives result in excessive decontamination, extended schedule, and cost impacts, while false negatives again result in potential release of contamination with attendant public/political reactions and recovery costs.

During the long-term recovery phase of incidents involving RDDs or INDs, EPA will lead the radiological environmental characterization and will manage the federal radiological cleanup activities. While field detection capabilities can quickly be used to take action following an incident, more extensive and time-consuming fixed-laboratory analyses will be needed to assess whether the public can resume normal use of the affected areas. Such assessments are intrinsically different from those used, for example at nuclear facilities, to monitor and control the spread of contamination within radiologically controlled areas. A site-specific optimization process that incorporates local needs, health risks, costs, technical feasibility, and other factors will be used to establish cleanup levels. This process is designed to be transparent and involve representative stakeholders in the decisionmaking process. The data upon which these decisions will rely must therefore meet the same quality criteria required in other EPA cleanup activities. In some cases, swipe samples may be a key source of information for these decisions. However, current practice uses swipes often as a tool for qualitatively assessing the presence of removable activity on surfaces. Following an RDD or IND, more quantitative assessments will be needed for recovery phase decisions, and the data will need to be reported with realistic uncertainty evaluations. This new application will present a paradigm shift in how swipes are taken, how the data are analyzed, and how the results are interpreted.

This document is meant for those with a background in ionizing radiation and radioactivity measurements. It is intended to assist in the planning and implementation of surveys using swipe samples to evaluate the amount of radioactivity on surfaces that might be separated from a surface under normal or light abrasive contact. This document provides recommendations for the process of taking swipes and evaluating the results. The objectives of this document are to:

- Review the current practice in obtaining swipe samples;
- Compare direct and indirect methods for assessing surface contamination;
- Provide a framework for evaluating the results;
- Provide general recommendations on the process of taking swipes; and
- Make specific recommendations concerning how swipe samples should be taken and analyzed following an RDD or IND.

1.2 BACKGROUND

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 would not be transferred to the body and is usually of concern only as a source of external exposure, unless it becomes loose and is redistributed. However, it is the removable contamination that is transferrable to humans by contact, inhalation, or ingestion that poses a hazard of internal radiation exposure. The amount of removable contamination is usually determined by obtaining swipe samples. Usually, only a portion of the removable activity is collected on the first swipe, and several swipes are needed to assess the total removable activity. The interpretation of swipe sample results quantitatively is generally difficult because the

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sampling and measurement uncertainties are often not adequately evaluated. However, for an RDD there are some details of the circumstances that will be known soon after the event. These will aid in the interpretation of the results and will reduce the overall uncertainty. The situation for INDs may be more complex due to the increased number of radionuclides likely to be present.

The levels of removable contamination that are of concern may be much lower than those for fixed contamination. The intensity and effective duration of the exposure to radiation from internally deposited radionuclides can result in a committed dose of radiation. These internal doses may be much greater than the external dose that may be received from sources of radiation outside the body. These external doses are delivered only when in the presence of those sources.

The amount of removable surface contamination transferred to a swipe sample will vary according to the:

- Type of swipe material,
- Method used,
- Physical and chemical nature of the contaminated material,
- Surface roughness of the material swiped, and
- Physical and chemical nature of the radionuclide contaminant(s).

In order to determine the extent of surface contamination of materials and the effectiveness of the decontamination processes reliably, the swipe removal factor for the contaminant must be determined for the various materials swiped. The removal factor is the ratio of the activity of the radionuclides removed from the surface by one initial swipe sample to the total removable activity. This swipe removal factor must then be applied when evaluating the radioanalytical results of the swipe samples. Among the many types of swipe materials used are dry swipes that use various dry absorbent materials such as glass and cellulose fibers, and wet swipes used by application of various solvents to the dry swipe to enhance the amount of material removed from the surface.

A recent review of swipe sampling methods for chemical and biological agents (EPA, 2007) documented that, in most cases, cotton or gauze was used as the swipe material. Usually paper, cloth or glass fiber filter materials are used for radioactivity swipes. Although swipes of radioactivity were not covered, some of the conclusions are relevant:

> [I]t is clear that there is not an overwhelming consensus on how to take a [s]wipe sample…from surfaces. Different methods, media, and wetting solvents have been recommended and used by various groups and studies. Many of the compounds…do not even have a specific [s]wipe sampling methodology for their collection. If the goal is to establish a [s]wipe sampling method (or methods) for the compounds discussed in this report, then the next steps in this process must be research[ed] to investigate and fill in the gaps in [s]wipe sampling knowledge that exist, followed by method validation to optimize the methods. (EPA, 2007)

One can come to many of the same conclusions for swipes used to sample surface radioactivity. As an RDD or IND event unfolds, many specifics about the radionuclides, chemical form, and surfaces involved will become available. Applying a consistent swipe sampling method using

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this information will greatly aid in reducing the uncertainty of the results.

References used in this document are listed in Section 9.1. Other sources, including discussions with subject matter experts and additional Internet searches, are listed in Section 9.2. Although there is universal agreement that there are large uncertainties in the results of swipe sampling that may complicate their interpretation, there does not appear to be a lot of active experimental research going on in this field. Many studies exist, but they are not readily generalized to contaminants, solvents, surfaces, and detection methods other than those considered in the specific experiments reported. Appendix A contains a review of Department of Energy (DOE), Nuclear Regulatory Commission (NRC), and Department of Transportation (DOT) regulations and regulatory guidance documents that identify various uses of swipes that might be applicable to incident response activities, especially in the intermediate and recovery phases.

1.3 CURRENT PRACTICE

> Despite their high variability and poor detection limits, [s]wipe tests remain one of the universally accepted techniques for detecting removable radioactive contamination on surfaces. It is often a stipulation of radioactive materials licenses and is widely used by laboratory personnel to monitor their work areas, especially for low-energy radioisotopes that are otherwise difficult to detect with hand-held survey instruments. (Klein et al., 1992, Klein et al., 1997, Campbell et al., 1993).

Swipe samples may be taken over a designated surface area of interior and exterior building surfaces and public/private transportation vehicles, sidewalks, streets, ventilation systems, and various equipment and objects.

For compliance measurements, swipes are taken in a prescribed manner, and the measured activity on the swipe is compared to a limit specified by the cognizant regulatory agency. This in effect *defines* "removable" as what is transferred to a swipe. The removal efficiency or other sampling and analysis factors that may affect the uncertainty in the swipe result do not appear to be examined routinely. However, it is known that generally not all removable activity will be removed on a single swipe. The sum of an exhaustive[3] series of swipe samples should be used. Since this is not often practical, such a series of samples is done only occasionally in order to define a removal factor that is the fraction of the removable activity removed by the first swipe sample.

A good summary of the current state of the art of interpreting swipe samples is given by Frame and Abelquist (1999). Although there appears to be a consensus in the literature that swipe samples provide important information about human exposures to radioactivity in the environment that often cannot be obtained otherwise, there is also agreement that swipe sample results for removable contamination may have a very high uncertainty. Despite this recognition that the uncertainties can be large, the results of swipe sampling are seldom reported with their associated uncertainties. The lack of this information can adversely affect the data usability for decisionmaking. Thus, the procedures for swipe sampling and interpretation may benefit from a reassessment and reevaluation in the context of modern data quality objectives.

[3] "Exhaustive" in this context means swipe sampling until 10% or less of the first swipe's activity is obtained.

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Frame and Abelquist (1999) observe that,

> At a minimum, it may be concluded that removable activity is present when smear [swipe] results exceed the critical level of the smear [swipe] analysis procedure. On the other hand, if a smear [swipe] result indicates that activity does not exceed background levels, it might be inappropriate to conclude that removable activity is not present since the collection efficiency could be near zero.

In essence, if a swipe sample shows contamination, it confirms that there is removable contamination present. However, if a swipe sample does not show contamination, it cannot automatically be concluded that there is no removable contamination present. Note that directly measuring the surface using a field instrument will give an estimate of the sum of the fixed-plus-removable activity. It is also true that this measurement may be influenced by the self-absorption of the material due to surface characteristics. A different concern exists for physical samples of the surface taken for radiochemical analysis. Physical samples taken from the surface for analysis by radiochemical separation also will not provide information regarding the removable versus fixed content of the surface. It should be noted that each approach to the determination of surface contamination (direct measurements, swipes, or physical samples) has its benefits and limitations.

If removable contamination levels are present at low levels, they may not be detectable by use of swipes due to low transfer efficiency. Additionally, such low levels may not be detectable with portable survey instruments where a direct surface measurement is made, due to interference from background activity. The only technique for assessing low levels with a greater degree of certainty would be by use of "grab" sampling[4] of the material with subsequent destructive analysis at a laboratory. Thus, the use of swipes, field monitoring equipment, and grab sampling for laboratory analysis are all important components of assessing the state of radioactive materials contamination of a surface (Figure 1). Field measurements and grab samples generally will result in an estimate of the sum of fixed and removable activity, whereas swipes generally will result only in an estimate of removable activity.

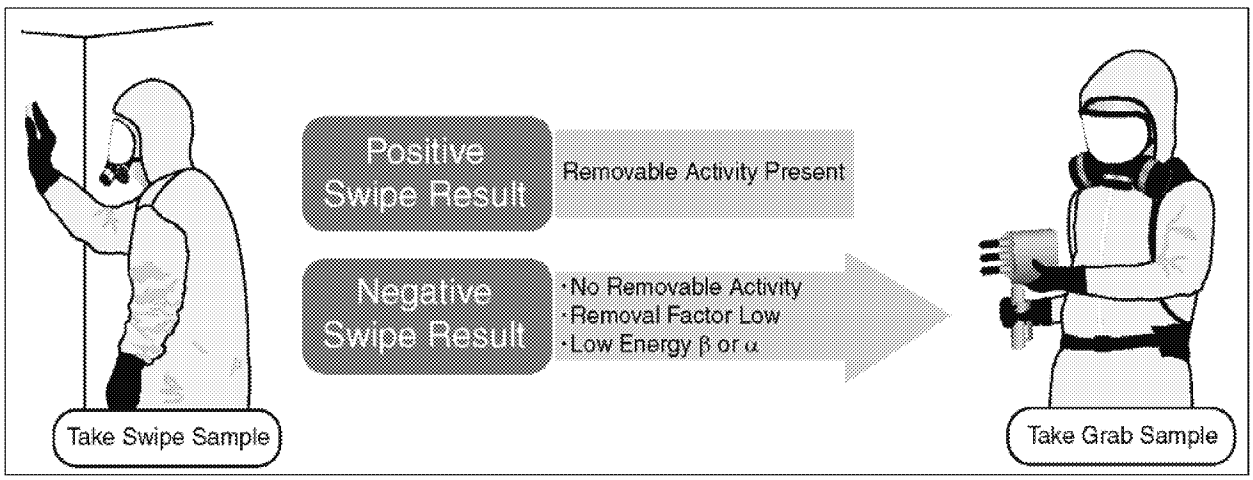

Figure 1 – Is removable contamination present? A negative result does not necessarily

[4] For purposes of this document, a "grab sample" means a single physical sample collected at a particular time and place that represents the composition of the surface under study (www.epa.gov/ocepaterms/gterms.html).

mean there is no removable contamination present.

1.4 A PERFORMANCE-BASED APPROACH

As indicated in the previous section, a key issue is how to interpret swipe measurements that result in a decision that no removable contamination is detected, i.e., the measurement is a "non-detect." Without a statement of the level of removable activity that could have been measured had it been there, such a result contains little useful information. The minimum detectable activity (MDA) is a measurement quality objective (MQO) that specifies the level of removable contamination that can be detected with high probability, if present, with the measurement method being used. It is not enough to report "not detected;" one also must specify how thorough the sampling process must be. Doing this requires developing MQOs for the detection of contamination of a specified type on a specific surface using a particular sampling and analysis protocol. To calculate the MDA, there must be some estimate of the uncertainty in a measurement taken near background. Indeed, the use of any measurement without an accompanying statement of the uncertainty in that measurement is virtually useless for decisionmaking. This is a point that was stressed in the performance-based approach contained in MARLAP, which includes a method for setting MQOs based on project-specific data quality objectives (DQOs). This topic is covered in greater detail in Section 6.1. The connection between DQOs and MQOs is important not just to laboratory measurements, but to any measurement, including those made with field survey instruments. The MARLAP (2004) approach to DQOs and MQOs was extended to cover such measurements in MARSAME (2009), where specific procedures and examples are given.

The fundamental MQO in MARLAP is the required method uncertainty at the action level. In each case, an action level should be specified for the scenario so that it can be determined that the sampling and analysis processes used have the required method uncertainty or sensitivity (e.g., minimum detectable surface activity) to be useful for the decision that must be made on the basis of the data. To advance to a more quantitative interpretation of swipe results, it is necessary to examine the various sources of uncertainty associated with the measurement. Several factors should be considered, including:

- Radionuclide(s) of concern and their chemical form,
- Removal technique (including human factors),
- Removal factor of the surface contamination with the initial swipe, and
- Debris matrix that the specific radionuclide is encapsulated in as part of the swipe.

Applying the uncertainty to the decisionmaking process, including conclusions to be drawn from "non-detects," requires consideration of the:

- Action level,
- Analytical decision level,
- Discrimination level,
- Acceptable error rates, and
- Detection capability.

Specific sources of uncertainty in swipe measurements are discussed in greater detail in Section 3. The subject of specifying requirements for limiting uncertainty is covered in Section 6.1.

Examples of how to evaluate the uncertainty in a swipe sample measurement are given in Sections 6.2–6.4.

The components of uncertainty for each part of the swipe sampling methodology will generally be large. However, when a positive indication of activity is found, the result of that measurement, even though not known with a high degree of accuracy, can provide useful information regarding the type of radioactive materials and the ability of removal techniques to reduce the quantities on the surface. For a specific scenario, such as the case of an RDD scenario with a source term with defined radionuclides and chemical form, it may be possible to produce an uncertainty budget (see Sections 6.3 and 6.4) that can identify the dominant sources of uncertainty for that radionuclide and for specific surfaces. From this, one can determine those sources of uncertainty that may be easily reduced, minimized, or eliminated. Uncertainty budgets may be more complicated for INDs for several reasons, including the increased number of radionuclides likely to be present.

MARLAP (2004) identifies two kinds of questions one commonly asks about samples of radioactivity: (1) is there something there? and (2) how much is there? For swipes, the amount of detail necessary to answer the second question with any confidence is often not available, or not used, even in controlled, non-emergency situations. This has consequences for the usability of this data for making decisions. A major objective of this document is to suggest improvements to the current approach for taking and analyzing swipe data, so that the results can be used with greater confidence for the decisions being made.

The result of a swipe sample analysis generally is used to make a simple detection decision, i.e., MARLAP question (1), is there something there? Answering that question requires the determination of the major sources of uncertainty both near background and at the action level, so that an appropriate MDA can be established for the swipe samples. The first step would be to list all of the potential sources of uncertainty in the swipe measurement, in some way estimate their contribution to the total, and assemble an uncertainty budget as illustrated in the *Guide to the Expression of Uncertainty in Measurement* (GUM; ISO 1995). A swipe sample not showing contamination does not aid the decisionmaking process unless it is accompanied by the uncertainty associated with the measurement. Otherwise, it cannot be concluded that there is no removable contamination present at the action level. A quantitative interpretation of a swipe result, i.e., an answer to MARLAP question (2)—how much is there?—also requires that both the measurement result and its uncertainty be reported. Only then can an objective statement be made about the probability that a given amount of removable contamination is present. This then allows the decisionmaker to assess the chance of a decision error.

2. MEASUREMENTS OF SURFACE CONTAMINATION

As previously mentioned, there are generally considered to be two types of surface contamination: fixed and removable. Removable surface contamination is contamination that may be removed by normal, non-destructive contact with surfaces (a swipe sample is intended to mimic this type of contact), or by reasonable attempts at cleaning and decontaminating. Fixed contamination refers to the portion of contamination that remains.

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There are also two ways to measure surface contamination: directly and indirectly. Direct measurements of surface contamination are made by means of a field survey meter or monitor. A direct measurement estimates the combined fixed-plus-removable contamination, but may also include contributions from interfering radioactivity inherently present in the surface being measured or from ambient sources in the area adjacent to the measurement. An indirect evaluation of removable surface contamination is made by taking and subsequently analyzing a swipe sample or a grab sample.

The contrast between direct and indirect measurements in the context of the evaluation of surface contamination shares some common characteristics with the more general contrast between field and laboratory measurements. A companion EPA report in this series, *Uses of Field and Laboratory Measurements During a Radiological or Nuclear Incident* (in preparation) discusses some of these characteristics.

A swipe is obtained by taking a sample of removable activity by rubbing the surface with dry or wet material. A single swipe will not normally remove all potentially removable contamination.[5]

The removal factor is the ratio of the activity of the radionuclides removed from the surface by one swipe sample to the total removable activity of the surface prior to this sampling. The removal factor, F, is defined by the following relationship:

$$F = A_1 / A_{Sum} \tag{1}$$

where:

A_1 is the activity removed by the initial swipe sample.

A_i is the activity removed by the ith swipe sample.

A_{Sum} is the total activity of the removable surface contamination prior to taking the first swipe sample. It is estimated by summing a set of repetitive swipes, $A_{Sum} = \sum_i A_i$.

The removal factor should be determined experimentally for each set of measurement conditions encountered, using the method of exhaustive removal by repetitive swipe sampling.[6] The sum of the activities removed by repetitive swipes yields an estimate of the total removable activity A_T. This can then be compared to the activity removed by the initial swipe sample, A_1, to yield the removal factor. If it is not possible to determine the removal factor experimentally, a value of $F = 0.1$ is sometimes assumed (see for example 49 CFR 173.443(a)(1)). Depending on what, if any, prior knowledge of the surface characteristics is available, the use of this 0.1 value as a default may introduce a fairly large uncertainty into the result that may not be reflected in the uncertainty reported with the result.

[5] It should be noted that under the influence of natural physical and chemical interactions in the environment, fixed contamination may become removable, or removable contamination may become fixed. The total surface activity may also be reduced by such processes.

[6] If the removal efficiency is very low and the first swipe is the only one that shows significant activity, the removal factor may be erroneously overestimated as 100%.

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2.1 DETERMINATION OF INSTRUMENT EFFICIENCY

The *overall efficiency* for measurements of surface activity is theoretically considered to be the product of two factors: the *instrument efficiency* (ε_i) and the *source efficiency* (ε_S). Thus, the *overall efficiency* is $\varepsilon_i\,\varepsilon_S$.

The *instrument efficiency* is defined as the ratio of the response of an instrument relative to the surface emission rate of a source in a specified measurement geometry. ISO 7503 (1988) defines *surface emission rate* as the number of particles of a given type above a given energy emerging from the front face of the source per unit time. The maximum *instrument efficiency* for a surface measurement is 1. Quantitative measurements of radioactivity are not possible given *instrument efficiency* alone; rather, they require separate determinations of *source efficiency*. Considerations impacting determination of source efficiency are addressed in the subsequent sections below.

The *instrument efficiency* for a radiation detector must be determined for each geometry in which it will be used. The *instrument efficiency* is measured by exposing the detector to a wide-area or a planchet calibration source with a NIST-traceable surface emission rate[7] to a detector in a geometry that matches that of measurements for which the detector will be used.

This *instrument efficiency*, ε_i, for the radiation type (alpha or beta radiation) is calculated according to:

$$\varepsilon_i = \frac{n/t - n_B/t_B}{q_{2\pi}} \tag{2}$$

where:

- ε_i = instrument efficiency for radiation type (alpha or beta radiation);
- n = measured total count from the reference source;
- n_B = background count;
- t = total count time of the reference source [s];
- t_B = background count time [s]; and
- $q_{2\pi}$ = surface emission rate of the calibration source for radiation type (alpha or beta radiation) incident on the detector face [s^{-1}].

The surface emission rate incident on the detector face will depend on the area of the source subtended by the detector probe, and so will vary with source-detector distance. This effect is accommodated by determining the instrument efficiency in the same geometry used for field or sample measurements.

2.2 THE DETERMINATION OF SOURCE EFFICIENCY

As stated above, the overall efficiency is expressed as the product of the instrument efficiency and the source efficiency, $\varepsilon_i\,\varepsilon_s$. The determination of the instrument efficiency was addressed in

[7] It is important to distinguish sources calibrated for surface emission rate from those calibrated in terms of total source activity. Total source activity is generally expressed in units of absolute radioactivity, such as Bq, dpm, or Ci per source, and is usually determined by the manufacturer of the source by correcting the measured surface emission rate of the source to reflect the presumed backscatter and self-absorption properties of the source.

the previous section. The source efficiency is defined as the ratio of the number of particles or photons of a given type emerging from the front face of a source and the number of particles of the same type created or released within the source per unit time. Thus, the source efficiency is the ratio between the emission rate of the source (or surface) and the activity contained in the source. The source efficiency takes into account the increased particle emission due to backscatter effects, as well as the decreased particle emission due to surface roughness and self-absorption losses. These factors are usually unimportant for gamma radiations on a swipe sample, so the source efficiency can be estimated to be 0.5. Also, for an ideal source (i.e., no backscatter or self-absorption), the value of the source efficiency is 0.5. Many real sources will exhibit values less than 0.5, although values greater than 0.5 are possible, depending on the relative importance of the absorption and backscatter processes. The source efficiency for swipe samples of alpha and beta radiation will not vary as much as the source efficiency for surface materials encountered in the field. Values for ε_s can be determined for a specific swiping protocol in advance, thus reducing the uncertainty in quantifying swipes measurements. Otherwise, the values given in Table 1 in the next section could be used as defaults. For installed instruments with 4-π counting geometry (i.e., liquid scintillation counters), the source efficiency is essentially one.

2.3 INDIRECT MEASUREMENTS OF SURFACE CONTAMINATION ON SWIPE SAMPLES

For instruments with a 2-π counting geometry (i.e., gas-flow proportional counters, scintillation counters, portable survey meters, etc.), the activity per unit area, A_R, of the removable contamination of the swiped surface, expressed in Bq cm^{-2}, is given by the equation:

$$A_R = \frac{n/t - n_B/t_B}{\varepsilon_i \cdot F \cdot S \cdot \varepsilon_s} \tag{3}$$

where:

A_R = activity of the swipe sample per unit area [Bq cm^{-2}];
n = measured total count from the swipe sample;
n_B = background count;
t = total count time of the swipe sample [s];
t_B = background count time [s];
S = surface area [cm^2];
F = removal factor;
ε_i = instrument efficiency for radiation type (alpha or beta radiation); and
ε_s = source efficiency.

In some cases, it is possible to determine empirically the overall detection efficiency for a swipe geometry by measuring the response of the detector to a swipe spiked with a known (i.e., NIST traceable) activity of the radionuclide of concern. Thus, the measured swipe count rate can be converted directly to swipe activity without separate determinations of instrument and source efficiency. When this method is possible, it is important that the conditions of the calibration be the same as those used for the measurement of the swipe sample. These conditions include, among other things, the source-detector geometry, the distribution for activity on the surface, the depth of penetration of the activity, and the type of material and surface roughness of the swipe material.

2.4 DIRECT MEASUREMENTS OF SURFACE CONTAMINATION

The determination of an overall efficiency, as described above for swipes, has largely been abandoned for direct measurements of contamination due to the difficulty of obtaining representative NIST-traceable standards that will match the distribution for activity, the depth of penetration of the activity, and the type of material and surface roughness of surfaces encountered under field conditions.

The total surface activity per unit area A_{Total} of fixed-plus-removable contamination on the surface being checked, expressed in s^{-1} cm^{-2}, in relation to the measured count rate n/t, is given by the equation:

$$A_{Total} = \frac{n/t - n_B/t_B}{\varepsilon_i \cdot W \cdot \varepsilon_s} \tag{4}$$

where:

W = detector total window area (including screens) [cm^2] (the other factors are as defined in Equation 3).

Determining the source efficiency used to estimate the level of fixed-plus-removable surface contamination in Bq cm^{-2} from direct measurements is a difficult task, considering sources of uncertainty entering into this determination. An ideal assumption would be that under ideal conditions, 50% of the emitted decay particles are incident on the detector because radioactive material emits particles into 4-π radians and only half of these particles can be incident on the detector face. Source-detector geometry (e.g., distance, relative area) can cause variations from this.

Source efficiencies should be determined experimentally whenever possible. Documents such as ISO-7503-1 (ISO 1988) and NUREG-1507 (NRC 1995) provide suggested default surface efficiency values for beta- and alpha-emitters (see Table 1, for example). These values do not have a strong technical basis and may not always be conservative. They do provide, however, a sense of the relative impact of different surfaces on detector response. For gamma-emitters and medium-to-high-energy beta-emitters ($E_{\beta max} \geq 0.4$ MeV) on smooth clean surfaces, ε_s is estimated as 0.5. ASTM E1893-08 also includes data and references for determining source efficiency factors.

Radiation from low-energy beta-emitters (0.15 MeV < $E_{\beta max}$ < 0.4 MeV) and alpha-emitters can be blocked by very thin materials such as grease, moisture, dust, and paint. Measurements of beta activities for energies <0.15 MeV, using gas-proportional or G-M tube counting techniques, will not provide very reliable data due to self-absorption and low detector efficiency.

It is very difficult to make a direct estimate of the surface contamination under these circumstances, and any such estimate will have a high degree of uncertainty associated with it. Consequently, indirect methods may provide the only practical means for obtaining adequate data for low-energy alpha- and beta-emitters. In these cases, sampling by continuous swipe tests or even physical abrasion of the surface may be the only reasonable sampling approach. This

would be followed by indirect measurements of these samples by liquid scintillation counting (LSC), which may provide a much better means of analysis for low-energy beta-emitters (see subsequent discussion).

Table 1 – Surface Efficiencies by Type of Particle and Energy Range

Type of particle and energy range (MeV)	ϵ
Gamma	0.5
Beta ($E_{\beta max} > 0.4$)	0.5
Beta ($0.15 < E_{\beta max} < 0.4$)	0.25
Beta ($E_{\beta max} < 0.15$)	See note
Alpha	0.25

NOTE: For low-energy emissions, the absolute efficiency may be so low, and the associated uncertainties so high, that measurements of these are of very limited utility.

2.5 COMPARING DIRECT AND INDIRECT MEASUREMENTS OF SURFACE CONTAMINATION

A direct measurement of surface contamination is a combined estimate of fixed-plus-removable contamination, without distinguishing between the two. An indirect measurement of surface contamination is an estimate of removable contamination.

In terms of uncertainty, one can observe that the input factors for calculating both of these quantities involve many of the same factors. Typically, for direct measurements, the source efficiency, ε_s, will be a major source of uncertainty. At low activity levels, the uncertainty associated with background may be the predominant source of uncertainty. For low-energy beta and alpha radiation, the source efficiency may become vanishingly small. The same is true for low-energy gamma-emitters and X-ray-only-emitters. In this case, both indirect and "grab" sampling methods will be necessary. Also, indirect measurements may be the only way to estimate the removable contamination level. For indirect measurements, the uncertainty of the source efficiency will generally be smaller. Since the swipe material is always the same, it may be possible to estimate ε_s experimentally for a given type of radiation. To do the same for direct measurements, a sample from every surface followed by radiochemical analysis would be needed. Indirect swipe-sample measurements of removable activity have a key source of uncertainty that does not appear for direct measurements of combined removable-plus-fixed activity: the removal factor, F.

The removal factor is the ratio of the activity of the radionuclides removed from the surface by one swipe sample to the total removable activity. The removal factor can easily vary as much as the source efficiency, although for different reasons. The removal factor is discussed in more detail in Section 3.1.

2.6 SAMPLING SURFACE CONTAMINATION WITH SWIPES

There appears to be no consensus on what actually constitutes a swipe. There are many materials and procedures for taking swipe samples. The guidance is often very general, e.g., a swipe sample is taken by rubbing, with slight pressure, a piece of soft filter paper over a representative

type of surface area. Different facilities following the same guidance may have very different standard operating procedures for carrying out the actual sampling; thus, results tend not to be comparable. Yet the results are often compared to the same set of limiting values. While the general description of a swipe procedure is similar in many cases, the particulars may vary considerably. The pressure used will vary considerably among those individuals doing the sampling. The area sampled is often specified to be 100 cm^2. However, this is usually done freehand, so the area sampled can vary substantially. The pattern of wiping can also vary (e.g., circular, serpentine, etc.). Appendix C gives examples from EPA, ISO, and 10 CFR 835 on how to take swipe samples. Materials commonly used are Whatman #41 filter papers or glass-fiber filters. However, these can be wet or dry, and the efficiency of the solvent used on wet swipes depends on how well it dissolves the chemical form of the contamination being removed.

Project- and surface-specific calibrations together with careful estimates of uncertainty are currently the best ways to address and to minimize these issues. An uncertainty budget analysis can pinpoint those input parameters most needing additional study.

3. SOURCES OF UNCERTAINTY IN SWIPE PROCEDURES

Understanding the potential uncertainties in a sampling and measurement process is essential to a performance-based MARLAP process. DQOs and MQOs cannot be established without this understanding. Some of the more important sources of uncertainty specific to swipe sampling and analysis are considered below.

3.1 REMOVAL FACTOR

One fact that becomes immediately apparent is that the removal factor is an important parameter in interpreting swipe results. It seems to be universally accepted, although not commonly acknowledged in practice, that only a fraction of the removable contamination is sampled with the first swipe. Some of the parameters that affect the removal factor are the chemical form of the contaminant, and how it interacts or is absorbed on the surface under consideration. This can affect the fixed component, but the chemical form of the contamination will also affect the removal factor depending on whether dry or wet swipes are used.

There are large differences even for different dry swipe media. Hogue (2002) states:

> Regulatory requirements for smear [swipe] materials are vague. The data demonstrate that the difference in sensitivity of smear [swipe] materials could lead to a large difference in reported results that are subsequently used for meeting shipping regulations or evaluating workplace contamination levels…Available data on the sensitivity of smear [swipe] material are scarce.

The removal factor will depend on whether the contaminant has a greater affinity for the surface being sampled or the swipe material. Campbell et al. (1993) investigated the difference in tritium swipe efficiencies using dry swipes and wet swipes with either polar or non-polar solvents and found that the removal factors were directly related to the solubility of the tritium compounds in the swipe solution.

Sansone (1987) reviewed measurements of "transferrable" surface contamination and concluded

that among the many variables affecting the determination of such contamination were:

> ...[T]he specific chemical compound involved, its chemical state, the manner in which it is applied, the particle size of the material and the degree to which the material adheres to the surface.

The surface itself, its composition, and its roughness are also factors. The results of his extensive review are contained in Appendix B.

Royster and Fish (1967) looked at the removal factor for thorium dioxide dust particles using adhesive paper, swipes with Whatman #50 paper, and a device called a "smair," which dislodges material by an air flow and captures it on a filter on surfaces as smooth as glass and as rough as unsealed concrete. The percent removed varied from 1.32% to 78%. The highest removal tended to be for adhesive paper on smooth surfaces. The smair sample removal was much smaller. The typical swipe sample had removal factors of about 25% to 75%.

Jung et al. (2001) found it took up to 10 consecutive swipes to obtain a good estimate of the total removable activity, even on relatively smooth surfaces, with the initial swipe having a removal factor of 10% to 20%. The variability in swipe results, even from portions of surfaces that would be expected to give consistent results, was greater by an order of magnitude or more than the counting statistical errors. ISO 11929-7 (2005) contains an example calculation for the uncertainty and limit of detection for swipe samples. It models the removal factor with a rectangular distribution[8] from 0.06 to 0.62 with a mean of 0.34, based on the results of previous experiments.

Yu et al. (2003) reviewed the literature and concluded by modeling the removable fraction as a triangular distribution[9] from 0 to 1 with a mode (most likely value) at 10%. The removal factor can be determined experimentally using the ISO 7503 method of "exhaustive removal by repetitive [s]wipe tests." The step-by-step addition of the removable activities leads to a good approximation of the total removable activity (A_T) to which the activity removed by the initial swipe test (A_R) can then be related to yield the removal factor.

Warren (2007)[10] examined removal factors using ^{32}P as orthophosphate in dilute hydrochloric acid on various surfaces swiped with Whatman GF/A 60-mm smear paper folded twice in half to form a four-leaved triangle. The swipe was obtained by holding the middle two leaves of the folded paper with tongs. Figure 2 shows Warren's results with demineralized water wet swipes on various materials. The surfaces included linoleum, aluminum, stainless steel, ceramic tile, and Perspex.[11] Stainless steel and aluminum show a high level of fixed contamination even after 11 swipes. As a rule of thumb, 10 swipes are probably enough to be considered exhaustive, but fewer may be adequate as long as the surface activity has leveled off sufficiently to determine a removal factor. The other surfaces showed both lower fixed contamination and higher removal factors for the first swipe. Figure 3 shows the removal factors he obtained using the "Exhaustive

[8] A random variable with a rectangular distribution is equally likely to take on any value between its endpoints, so the distribution is flat like a rectangle.
[9] A triangular distribution rises linearly from its lower bound to its most likely value, then decreases linearly to the upper bound, so the distribution is peaked like a triangle.
[10] EPA wishes to acknowledge the kind permission of Lawrence Warren to reproduce his data in Figures 1, 2, and 3 and Tables 2, 5, 6, and 7.
[11] Perspex is a hard, transparent plastic, an acrylic resin similar to Plexiglas.

Swipe Sampling" method for different materials and for dry and wet swipes with different wetting agents, 10% DECON 90,[12] demineralized water, and methanol. The bar chart makes it easy to see that the variation with dry and wet swipes with different solvents seems to have as much of an effect as the type of surface. The data are shown numerically in Table 2.

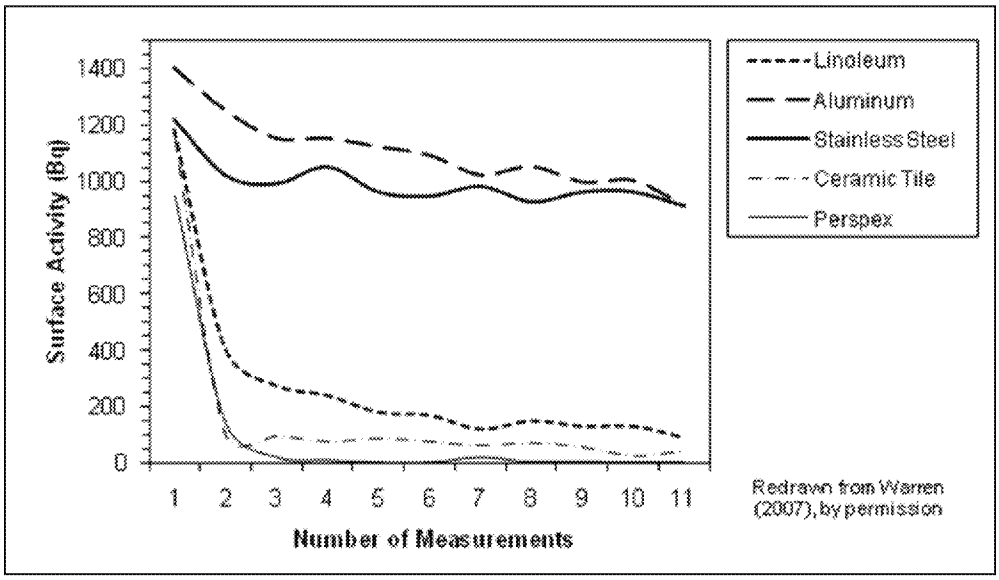

Figure 2 –Surface Activities After Swiping with Demineralized Water

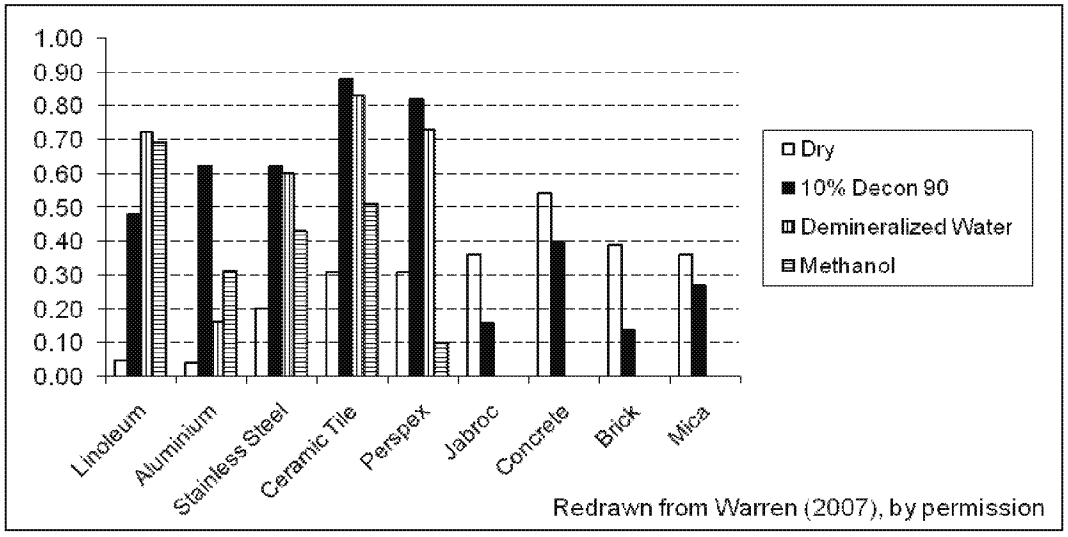

Figure 3 – Removal Factors Using "Exhaustive Swipe Sampling" Method

[12] Jabroc® is a non-impregnated, dense wood laminate. DECON 90 is a surface active cleaning agent, and/or radioactive decontaminant, for laboratory, medical and specialized industrial applications.

Table 2 – Removal Factors Using "Exhaustive Swipe Sampling" Method

Surface	Dry	10% DECON 90	Demineralized Water	Methanol
Linoleum	0.05	0.48	0.72	0.69
Aluminum	0.04	0.62	0.16	0.31
Stainless Steel	0.2	0.62	0.60	0.43
Ceramic Tile	0.31	0.88	0.83	0.51
Perspex	0.31	0.82	0.73	0.1
Jabroc	0.36	0.16		
Concrete	0.54	0.4		
Brick	0.39	0.14		
Mica	0.36	0.27		

Because the removal factor can vary so substantially, the sampling procedure following an RDD or IND should include multiple swipes from at least one location for each combination of surface type and swipe material. This should be repeated periodically as part of the overall quality assurance (QA) program.

3.2 SWIPE SURFACES AND MATERIALS

Swipe surfaces fall into four categories: rough non-porous, rough porous, smooth porous, and smooth non-porous. Swipes may be used on a variety of porous and non-porous surfaces, and may be used wet or dry. Many different materials are used for swipes. Table 3 lists some of the materials that fall into each of the four categories with suggested swiping materials designated by the diamond symbol.

Table 3 – Swipable Surfaces and Swiping Techniques

	Surfaces			
	Rough Non-porous	Rough Porous	Smooth Porous	Smooth Non-porous
Surface Examples / Swipe Technique	Unpainted or unpolished metals	Roof tile Concrete Unfinished wood Stucco Ceiling tile Fabric, wallpaper Limestone, slate Ventilation filters	Asphalt Finished limestone Finished wood Plaster Unglazed ceramic tile	Vehicle exteriors Linoleum Formica Painted wood/ wallboard Painted/plated metal Glass, hard plastics Polished metal Glazed ceramic tiles Finished furniture Vinyl siding
Strippable coating	♦		♦	♦
Wetted swipe				♦
Wetted swipe, with blotting	♦	♦	♦	♦
Dry swipe				♦

Urban surface contamination can be influenced by many factors, including the presence of dirt and dust, migration into pores and cracks, pH, humidity, chemical interactions of the contamination with the surface, and weathering. The depth of contamination will vary with the radionuclide, its chemical form, type of surface, and the time since deposition. Penetration of contamination into the surface does not necessarily imply that it is not removable.

Table 4 shows different types of surfaces and the suggested swipe material to use on each. Many of the swipe materials in Table 4 may be used wet or dry. If the swipe is wet, the solvent can vary. Various solvents may or may not be a good match for the chemical form of the radionuclide, and thus, may not always increase transfer efficiency. However, following an RDD, the chemical form may be known or ascertained quickly, providing an opportunity for a good match to the wetting solution.

Typically, loose surface dirt is removed much better with a wet swipe. If the surface is coated with a fine layer of dust and the contamination falls on top of the dust, removing the dust with a wet swipe would be very effective.

Table 4 – Suggested Swipe Material to Use on a Surface

Swipe or Removal Medium	Wood (finished)	Concrete	Wood (unfinished)	Tile or Linoleum (non-porous)	Asphalt	Stainless or Painted Metal	Unpainted Metal
Cotton	R	W	N	R	W	R	N
Glass Fiber	D	N	N	D	D	D	N
Paper	D	N	N	R	R	R	N
Masslin	W	N	N	W	W	R	W
Strippable Coatings	D	D	N	D	N	D	D
Strippable Gels	Shows promise for all surfaces						

W = wet with solvent, D = dry, R = either wet or dry, N = not useful

Strippable coatings have not been commonly used as "swipe" materials. However, they are often used for decontamination. Their use for swipes will require some experimental studies on the measurement of activity in this medium, especially for beta and alpha. Strippable gels have been developed that appear to work well on all surfaces and with high removal factors. Drying times depend on the thickness of the gel application and environmental conditions, and vary from about an hour to over 24 hours. These gels may be counted without further preparation for gamma radiation. Some gels are able to be rehydrated, and thus also amenable to rapid preparation and liquid scintillation counting.

Archibald and Demmer (1999) conducted tests with strippable coating using simulated contamination (SIMCON) of Cs and Zr salts dried (SIMCON I) or dried and then baked at 700 °C for 24 hours (SIMCON II) on 1-inch stainless steel disks. SIMCON I was used to simulate removable contamination, and SIMCON II was used to simulate fixed contamination. Three types of stripcoats were tested on the SIMCON coupons. TLC Stripcoat applied and peeled very easily. ALARA 1146 was difficult to remove if not sprayed on to a thickness of at least 1 mil (0.0254 mm). PENTEK 604 self-stripping coating was better at decontaminating SIMCON I, simulating removable contamination, than the other strippable coatings. For SIMCON II, simulating fixed contamination, the performance of all three was similar. The results are shown in Table 5.

Table 5 – Strippable Coating on Stainless Steel Disks

Stripcoat Material	SIMCON I Cs (% Removal)	SIMCON I Zr (% Removal)	SIMCON II Cs (% Removal)	SIMCON II Zr (% Removal)
TLC Stripcoat	87	66	42	73
ALARA 1146	83	76	45	76
PENTEK 604	96	90	57	75

For decontamination of lead bricks, the strippable coating was applied three times by Archibald and Demmer (1999), allowing one day for drying between applications. The first two coats were applied with a small brush. The third and final coat was applied by being poured onto the surface of the brick. This third coating was not uniform and took 12 hours longer to dry. The strippable coating stuck to areas with deep pores or cracks, but was removed with a small hand scraper. The initial contamination on the lead brick was reduced by a factor of 10, as shown in the last two columns of Table 6. Lead may subsequently oxidize, converting some fixed activity to removable. However, lead is not expected to be a commonly encountered surface following an RDD or IND. Thus, this data should be used only as an indication of performance on a surface other than stainless steel. Generally, any surface can degrade over time.

Table 6 – PENTEK 604 Strippable Coating on Contaminated Lead Bricks

Applications	Before Fixed Beta-gamma (cpm)	After Fixed Beta-gamma (cpm)	Before Swipable Beta-gamma/ Alpha (cpm)	After Swipable Beta-gamma/ Alpha (cpm)
First	*	*	4715/26	376/0
Second	*	15,000	376/0	150/0
Third	15,000	6000	150/0	**

* = unknown, ** = well below free release criteria (<200 dpm Beta-gamma, <10 dpm alpha)

Five stainless steel criticality barriers[13] were tested by Archibald and Demmer (1999) using PENTEK 604. The coating was applied to both sides of the barrier using a paintbrush and then left to dry overnight. PENTEK 604 was able to remove the swipable contamination from the lids. Some fixed contamination remained. The results are shown in Table 7. Again, this is an illustration only of potential removal factors that may be achieved using strippable coatings as swipe material. Actual surfaces likely to be encountered may be quite different.

Table 7 – PENTEK 604 Strippable Coating on Stainless Steel Criticality Barriers

Item	Swipable Before Beta/Gamma (dpm/100 cm²)	Swipable Before Alpha (dpm/100 cm²)	Swipable After Beta/Gamma (dpm/100 cm²)	Swipable After Alpha (dpm/100 cm²)
Criticality Barrier Lid #1	Front 43944 Back 132681	Front 348 Back 755	Front <1000 Back 1331	Front <20 Back 22
Criticality Barrier Lid #2	Front 13594 Back 20931	Front 237 Back 200	Front <1000 Back <1000	Front <20 Back <20
Criticality Barrier Lid	Front 51856	Front 452	Front <1000	Front <20

[13] Criticality barriers are stainless steel plates used in fuel pools to separate spent fuel during storage.

Item	Swipable Before Beta/Gamma (dpm/100 cm²)	Swipable Before Alpha (dpm/100 cm²)	Swipable After Beta/Gamma (dpm/100 cm²)	Swipable After Alpha (dpm/100 cm²)
#3	Back 12362	Back 104	Back <1000	Back <20
Criticality Barrier Lid #4	Front 22513 Back 10013	Front 192 Back 104	Front <1000 Back <1000	Front <20 Back <20
Criticality Barrier Lid #5	Front 16294 Back 67075	Front 126 Back 489	Front <1000 Back <1000	Front <20 Back <20

As seen in Tables 5–7, PENTEK 604 appears to be quite effective at removing swipable contamination, although procedures for using strippable coatings as swipe materials have not been fully developed.

Strippable gels such as Decon Gel 1101, which are relatively new materials, have a high removal factor (up to 90–100%), even on porous surfaces such as concrete (Holt 2007, Sutton et al. 2008, and VanHorne-Sealy 2008). The narrower range in removal factors should reduce the uncertainty associated with this factor. However, repeated sampling should be performed to verify this as both a quality control (QC) and validation measure. The removal factor for the strippable gel does not seem to depend on the chemical form of the contaminant. This could minimize the uncertainty due to the combination of material and solvent chosen for traditional swipes.

Strippable gels can be applied over an area larger than the desired sample area. The exact area needed can be cut from the stripped gel, provided it can be removed as a single large piece. This eliminates uncertainties in the area due to freehand swiping. Pressure applied would not appear to enter as a factor.

The gel can be counted directly if it has been previously calibrated for the radionuclide of concern. Variations in thickness may contribute to the uncertainty due to self-absorption. These gels may be rehydrated and the encapsulated radionuclides separated for analysis, for example, by liquid scintillation counting.

Further research is needed to determine the effectiveness of using strippable gels as swipe material, especially for recovery of the encapsulated contaminants. This is a relatively new technology, but preliminary results are encouraging. Ideally, this new material has the potential for making swipe measurements a more realistically quantitative determination of removable surface activity with detection limits that may be lower than current practice can achieve.

3.3 SAMPLING METHOD

A standard method or technique for taking swipe samples does not exist. As indicated in the ISO guidance and in other references for swipes taken freehand with moderate pressure, no quantitative measure of pressure is identified. The uncertainty of the area swiped can be minimized by using a template with a defined area and sampling within a template. Variability among sampling personnel might be reduced by inserting the swipe material in a standard mount so that the entire swipe is in contact with the surface. Swiping pressure might be regulated, either by using weights, or incorporating a pressure sensor in the block. The effect of swiping pressure on linoleum was examined by Warren (2007). Figure 4 shows that the effect of pressure seems to

impact wet swipes more than dry.

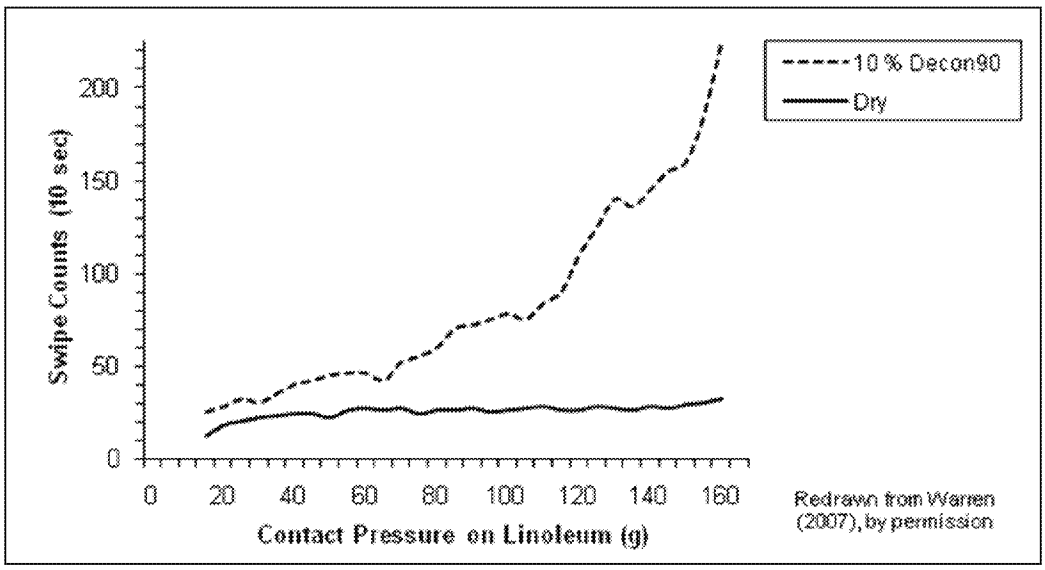

Figure 4 – Swipe Activity (10-Second Counts) Versus the Contact Pressure as Measured by Placing the Linoleum on a Scale While Being Swiped

There is uncertainty in the determination of the swiped area, due to both the procedure used and how the procedure is applied. This has led to the development of automated swipe samplers (e.g., U.S. Patent Number 4,848,165, "Smear [swipe] sampling apparatus," Batilson et al., 1987). Seo et al. (2004) show a revealing example of a manual swipe that clearly shows that the contamination on the sample was confined to three fingerprint areas, where obviously the pressure was applied when taking the sample. Using an automated device or at least a solid backing block for the swipe would result in a more uniform pattern of activity on the swipe. Alternatively, the swipe material could be affixed to the back of an object such as a glass beaker, disposable plastic cup or Petri dish, provided that the fixative used does not interfere with subsequent analyses. Use of a template is recommended as this would also better define the swiped area. Current practice is "freehand."

Variations in hand/arm pressure also will contribute to the uncertainty in the amount of material removed from surfaces swiped. Moderate pressure is suggested for swipe sampling, but this concept is not well defined. Depending on surface roughness and the wiping material, the sample may be physically damaged even if the pressure is "moderate" (e.g., glass fiber on unsealed concrete).

4. RADIONUCLIDES AND CHEMICAL FORM

The chemical form of the contaminant determines how it interacts or is fixed on the surface under consideration. This will affect the ratio of fixed-to-removable contamination, but the chemical form of the contamination will also affect the removal factor, depending on whether dry or wet swipes are used. Radionuclides that might be present in an RDD, with their most likely starting chemical forms (pre-detonation, before weathering), are listed in Table 8. The chemical form of the contamination is likely to change following detonation and subsequent

weathering.

Table 8 – Common Chemical Forms of Some Radionuclides that May Be in an RDD

Alpha-Emitters				Beta/Gamma-Emitters			
Radio-nuclide	Chemical Form	Radio-nuclide	Chemical Form	Radio-nuclide	Chemical Form	Radio-nuclide	Chemical Form
^{241}Am	Am_2O_3, Am metal [4] Am_2O_3/Be	^{226}Ra	$RaSO_4$ [4] Ra/Be	^{141}Ce	$CeCl_4$	^{99}Mo	MoO_4^{2-}
^{242}Cm [3]	Cm, oxide, silicate or aluminate	^{228}Th [2]	ThO_2	^{144}Ce [3]		^{32}P	Organo-phosphorus compounds, PO_4^{3-}
^{243}Cm [3]		^{230}Th [3]		^{57}Co	Cyano-cobalamin (Vitamin B12)	^{103}Pd [1]	Pd metal
^{244}Cm		^{232}Th [2]		^{60}Co [1]	CoO, Co metal	^{241}Pu [3]	Pu oxide (mixed oxidation states), [4] PuOxide/Be
^{237}Np	NpO_3	^{234}U	U_3O_8	^{134}Cs [3]	Cs^+	^{228}Ra [2]	$RaCO_3$, $RaSO_4$, $RaCl_2$
^{210}Po	PoO_4, Po Metal	^{235}U		^{137}Cs	CsCl	^{103}Ru [3]	RuO_2
^{238}Pu	Pu oxide (mixed oxidation states) [4] PuOxide/Be	^{238}U		^{154}Eu [3]	Eu_2O_3	^{106}Ru [3]	RuO_2
^{239}Pu		U-Nat	Yellowcake, U_3O_8, $UO_2(NO_3)_2$, U metal	^{3}H	H-O-^{3}H, Organo-tritium compounds	^{75}Se	Organo-selenium compounds
^{240}Pu				^{125}I	AgI (within a titanium capsule), This salt would be carrier free.	^{89}Sr	$SrCl_2$
^{252}Cf	Cf_2O_3 in a Pd metal matrix, $Cf_2O_2SO_4$ in an Al powder matrix			^{129}I [3]	iodide, iodate or iodine (based on level of oxygen)	^{90}Sr	$SrTiO_3$, SrF_2
^{227}Ac [2]	[4] Ac/Be			^{131}I	NaI, KI, Sodium Iodohippurate	^{99}Tc ^{99m}Tc	TcO_4^-, Organo-technetium compounds
				^{192}Ir [1]	Ir metal		

[1] This group of radionuclides is used frequently in the metallic form in short, needle-like shapes.
[2] These radionuclides are naturally occurring and have little or no commercial use.
[3] These radionuclides result from fission reactions (either activation of transuranics or fission products) that do not have any routine commercial use. Their chemical forms after an event would be the result of environmental weathering.
[4] The specific combination of these alpha-emitters with beryllium oxide is referred to as a "neutron source."

5. COUNTING METHODS

A variety of analytical methods are available for measuring the activity on a swipe sample. Some of the available methods are discussed in this section. Each method has advantages and disadvantages that depend on the specificity and sensitivity of the technique. The selection of a particular method will depend on the radionuclides involved and the MQOs, especially the required method uncertainty. The establishment of MQOs is discussed in detail in Section 6.

For clarity, the various types of swipe analysis methods can be organized into two groups: non-destructive techniques, and techniques that may require destruction of the swipe material prior to analysis.

- Non-destructive measurement techniques, including field screening techniques and laboratory techniques, measure the activity on the swipe by directly exposing the swipe to the radiation detector. In some cases, direct measurements allow for rapid delivery of analytical data, and swipe sample integrity to be maintained so that other analytical methods may be performed, if necessary. The direct measurement of swipes requires that the instruments used be calibrated in an appropriate counting geometry that is equivalent to the swipes being measured.

- Destructive measurement techniques are generally performed in the laboratory and include those analytical techniques that require the destruction of the swipe sample in order to perform the analysis. Some techniques require dissolution of the sample material and chemical separation of the radionuclides of interest to minimize interference or to achieve the required MQOs.

In some cases, swipes simply may not conform to a standard counting geometry and may need to be leached or digested in order to facilitate what would otherwise be a direct analysis.

Whether the measurement technique is non-destructive or destructive, consideration also should be given to whether the technique is a "gross" measurement, or a "radionuclide-specific" measurement.

- Gross measurements, including field screening measurements, provide an estimate of the general type of radiation being measured, such as total alpha activity or gross gamma activity. When used as an estimate of activity from a specific radionuclide, these techniques may be subject to bias from interfering constituents. In addition, the instrument calibration may not account for the potentially vast array of radionuclides that might be encountered, and their various calibration factors. For that reason, gross measurements may be regarded as having relatively high levels of uncertainty.

- Radionuclide-specific measurements provide measurements of particular radionuclides and, in most cases, are not subject to significant interference or elevated uncertainty. The results are generally considered to be more accurate and reliable, but the preparation and analysis processes may be more lengthy and labor-intensive in some cases.

A simplified organization of analytical techniques into non-destructive or destructive, and gross vs. radionuclide-specific is presented in Table 9, with additional discussion following.[14]

[14] A more detailed comparison of the various field and laboratory instrumentation can be found in the companion document, *Uses of Field and Laboratory Measurements During a Radiological or Nuclear Incident* (in preparation). More information on these and other gross and radionuclide-specific techniques may be found in the *Inventory of Radiological Methodologies for Sites Contaminated with Radioactive Materials* (EPA 2006c).

Table 9 – Organization of Analytical Techniques into Non-Destructive or Destructive and Gross or Radionuclide-Specific

	Destructive	Non-Destructive
Gross	• G-M Probe • Gas Proportional Counting • Liquid Scintillation Counting	• G-M Probe • Alpha scintillation • Gas Proportional Counting • Beta scintillation • Beta spectrometry
Radionuclide-specific	• Gamma Spectrometry • Alpha Spectrometry • Gas Proportional Counting • Liquid Scintillation Counting • ICP-MS and others	• Gamma Spectrometry

Geiger-Muller (G-M) probes may be useful, particularly for hand-held field measurements, when only an estimate of the gross sample activity is needed. G-M probes are designed for the measurement of gamma and beta radiation, but under certain conditions may also respond to higher levels of alpha radiation.

Gamma spectrometry, including thallium-activated sodium iodide [NaI(Tl)] and high-purity germanium (HPGe) detection systems, may be used to count the sample directly or after chemical digestion and preparation. Gamma spectrometry is used to identify specific radionuclides and can quantify the radionuclide activity with high precision under the appropriate conditions.

Gamma analyses by a G-M, a NaI(Tl), or an HPGe detector can be performed with little preparation aside from ensuring that the samples are properly contained to avoid detector contamination. A 47-mm diameter round swipe, for example, is commonly used. These swipes may be left in their glassine sleeve or wax envelope, which may then be placed inside a protective sealable plastic bag. The bag can then be placed directly on the detector. A variety of sizes and shapes of swipe material can be analyzed directly for gamma activity, with appropriate consideration for the counting geometry.

Large swipes, such as shop towels or absorbent pads, may require a geometry that accommodates the physical constraints of the detector system and shield assembly. For example, the laboratory may choose to create a counting geometry that consists of a large swipe that is either folded or packed into a container that is typically used for solid materials. In any case, the instrument calibration sources should conform as closely as possible to the actual samples. Swipes that require gamma analyses may need to be leached or digested and the digestate solution analyzed in a geometry intended for liquid samples. This approach preserves the digestate for further testing, if necessary.

Alpha scintillation detectors, which may be found in hand-held field measurement detectors as well as laboratory screening detectors, may be useful for the estimation of elevated levels of gross alpha activity. These devices may be useful when it is necessary to discriminate between gross alpha activity and gross beta/gamma activity at higher activity levels.

Gas proportional counting (GPC) is used to measure both alpha and beta activity. These measurements may be done simultaneously, with good alpha/beta discrimination. Some GPC detectors operate with very low background count rates and relatively high counting efficiencies, allowing for the detection of low levels of alpha and beta activity.

Properly sized swipes may be analyzed directly for alpha and/or beta activity by counting on an alpha scintillation detector, GPC, or other appropriate survey instrument. This requires the direct exposure of the instrument to the sample, and care should be taken to minimize the risk of detector contamination and to monitor frequently for such contamination. In some cases, friable residue or other loose material that presents an increased risk of detector contamination may be fixed to the swipe surface prior to analysis with commercial hair spray or some other fixative agent. The laboratory should determine whether this practice will have an effect on the analysis, for example by increasing attenuation, and make appropriate corrections during calibration. For example, using fixatives may not be appropriate for swipe samples of low (<200keV) beta-emitters. Pure beta-emitters, such as ^{90}Sr, might be analyzed by beta spectrometry or using beta scintillation counters. The use of combined alpha-beta scintillation detectors with appropriate cross-talk corrections may also be considered.

Liquid scintillation counting is primarily used for the measurement of lower energy beta emissions that may not be detected easily with a GPC detector, and the measurement of volatile radionuclides, such as ^{3}H and ^{14}C, that may not be amenable to analysis by other techniques, though LSC counting may also be useful for the analysis of routine alpha and beta activity as well. A consideration in LSC counting is that the sample must be immersed in scintillation cocktail during analysis, which may interfere with future analyses.

Care must be taken in the direct analysis of swipes by LSC to ensure that analytical interference from particulates, chemicals, or other "quenching agents" is properly addressed. The loading of dirt or other interferents in field swipes can be notoriously inconsistent, and the laboratory may need to create calibration "quench curves" to address these issues.

Alpha spectrometry may be a valuable technique when the isotopic speciation and/or low-level quantification of specific alpha-emitting radionuclides are necessary. Alpha spectrometry generally requires rigorous chemical separation techniques and may employ long sample count times, which should be considered when the rapid delivery of analytical data is requested.

Inductively coupled plasma mass spectrometry (ICP-MS) may be a useful technique for the analysis of very long-lived radionuclides (e.g., ^{235}U, ^{238}U, ^{237}Np, ^{232}Th, ^{99}Tc, etc.), after sample dissolution. In some cases, the instrument can achieve very low detection limits very quickly, which can be useful when large numbers of samples must be analyzed.

Kinetic phosphorescence analysis (KPA) may be used as a fast and relatively inexpensive approach for the analysis of uranium, and X-ray fluorescence (XRF) may still be employed under certain circumstances for the rapid measurement of high concentrations of certain analytes under proper conditions. The list of analytical methods shown above is not intended to be exhaustive, but is meant to highlight the most common techniques.

In some cases, the swipe material may require wet- or dry-ashing or even chemical fusion prior to dissolution. In all cases, care should be taken to ensure that the additional processing of the sample does not compromise the analytical methods that are used. For example, the dry-ashing of a sample would invalidate any subsequent analyses for volatile radionuclides.

While there seem to be few analytical methods specifically developed for swipes, swipe samples are amenable to most radionuclide-specific analyses, and analytical methods that require the dissolution of a solid sample.

6. PLANNING MEASUREMENTS OF SURFACE ACTIVITY CONCENTRATION BY MEANS OF SWIPE SAMPLES

Acceptable uncertainty depends on the anticipated use of the data. Screening measurements may have different requirements than radionuclide-specific measurements. The action level and tolerable decision-error rate should be established and considered in selecting measurement methods. Example scenarios should be developed in advance, as there will be little time for this in an emergency.

Given the complexity of interpreting swipe measurements in general, these examples should focus on particular applications for assessing removable radioactivity following a radiological or nuclear event. Specific sources of uncertainty in the interpretation of swipe results should be considered. Specific cases can then be considered for developing an uncertainty budget.

6.1 MEASUREMENT QUALITY OBJECTIVES AND THE DATA QUALITY OBJECTIVES PROCESS

MQOs are statements of performance objectives or requirements for a particular analytical method performance characteristic. Examples include:

- Method uncertainty,
- Detection capability,
- Quantification capability,
- Ruggedness,
- Specificity, and
- Range.

The most important MQO is the required method uncertainty at a specified concentration (the analytical action level), u_{MR}. The calculation of u_{MR} is discussed in Table 10C, Step 6.3.

MQOs need to be developed separately for each radionuclide and each phase of the incident to ensure that the data quality will be sufficient for the decisions to be made. Generally, the value of the required method uncertainty[15] (u_{MR}) should decrease from the earlier to later phases,

[15] Method uncertainty, u_M, refers to the predicted uncertainty of the result that would be measured if the method were applied to a hypothetical laboratory *sample* with a specified *analyte* concentration. Although individual measurement uncertainties will vary from one measured result to another, the *required method uncertainty,* u_{MR}, is a target value for the individual measurement uncertainties, and is an estimate of *uncertainty (of measurement)* before the sample is actually measured.

reflecting the fact that the action level will be decreasing. Even in the early phases of an incident, MQOs may be very different for highly affected areas near ground zero as opposed to less affected boundary areas because the analytical action levels (AALs) may differ. In addition, the input quantities that enter the model equation for the measurement result may differ. An uncertainty budget is a tool that can be used to understand sources of uncertainty and the influences of changes in the measurement process on the overall measurement uncertainty. Thus, an uncertainty budget can be used to understand the measurement process and identify the factors that may most influence the ability of the measurement process to meet the MQOs. The development and use of an uncertainty budget are discussed further in a later section of this report.

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

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

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

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

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

Table 10B – Possible Decision Errors

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

Data that are inconsistent with the null hypothesis will cause it to be rejected. The probability of this happening in error (a Type I error) is more easily controlled during the statistical design. In order to choose an appropriate null hypothesis (or baseline condition), consider which decision error would have the greater consequences. Then choose the null hypothesis so that the Type I error (false rejection) corresponds to the decision error with the greater consequence, i.e., would cause the greatest harm.

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

STEP	OUTPUT
Step 6. Specify limits on decision errors	

Step 6.1 Determine analytical action level (AAL) on the gray region boundary and set baseline condition (null hypothesis, H_0)	Which is considered worse: decision error (a) deciding that the parameter of interest is less than the AAL when it actually is greater, or (b) deciding that the parameter of interest is greater than the AAL when it actually is less? Case (a) is usually considered to be a conservative choice by regulatory authorities, but this may not be appropriate in every case.
	
	If (a), the AAL defines the upper boundary of the gray region (UBGR). The null hypothesis is that the sample activity is above the AAL. (All samples will be assumed to be above the AAL unless the data are convincingly lower.) A desired limit will be set on the probability (α) of incorrectly deciding the sample is below the AAL when the sample activity is actually equal to the AAL (Figure 5).
	
	If (b), the AAL defines the lower boundary of the gray region (LBGR). The null hypothesis is that the sample activity is below the AAL. (All samples will be assumed to be below the AAL unless the data are convincingly higher.) A desired limit will be set on the probability (α) of incorrectly deciding the sample is above the AAL when the sample activity is actually equal to the AAL (Figure 6).

6.2 Define the discrimination limit (DL)	If (a), the discrimination limit defines the lower boundary of the gray region.[1] It will be activity below the AAL where the desired limit will be set on the probability (β) of incorrectly deciding the sample is above the AAL. (see Figure 5)
	
	If (b), the discrimination limit defines the upper boundary of the gray region.[2] It will be activity above the AAL where the desired limit will be set on the probability (β) of incorrectly deciding the sample is below the AAL.

STEP	OUTPUT
6.3 Define the required method uncertainty at the AAL	According to MARLAP Appendix C, under either case (a) or case (b) above, the recommended required method uncertainty is: $u_{MR} \leq \frac{UBGR - LBGR}{z_{1-\alpha} + z_{1-\beta}} = \frac{\Delta}{z_{1-\alpha} + z_{1-\beta}}$ where $z_{1-\alpha}$ and $z_{1-\beta}$ are the $1-\alpha$ and $1-\beta$ quantiles of the standard normal distribution function.[3]
Step 7. Optimize the design for obtaining data	Iterate Steps 1–6 to define optimal values for each of the parameters and the measurement method required.

NOTES:

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

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

[3] Values of $z_{1-\alpha}$ (or $z_{1-\beta}$) for some commonly used values of α (or β), taken from tables of the cumulative normal distribution (EPA 2009), are:

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

Failing to detect a sample that exceeds the AAL could have consequences to public health, and analyzing additional samples will slow the overall process and therefore, may also impact public health. The probability that such decision errors occur is defined as the parameters α and β in Steps 6.1 and 6.2 in Table 10C. Values of alpha and beta should be set based on the consequences of making an incorrect decision. How these are balanced will depend on the AAL, sample loads, and other factors as specified by Table 9C.

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

In this document, the analytical decision level (ADL) is the concentration or activity corresponding to the *critical value* (see MARLAP Attachment 3B.2). The critical value is the minimum measured value of the instrument signal required to give confidence that a positive (nonzero) amount of *analyte* is present in the material analyzed. Thus, a measurement less than the critical value would result in a *decision* that the analyte is not present. The critical value is sometimes called the *critical level*.

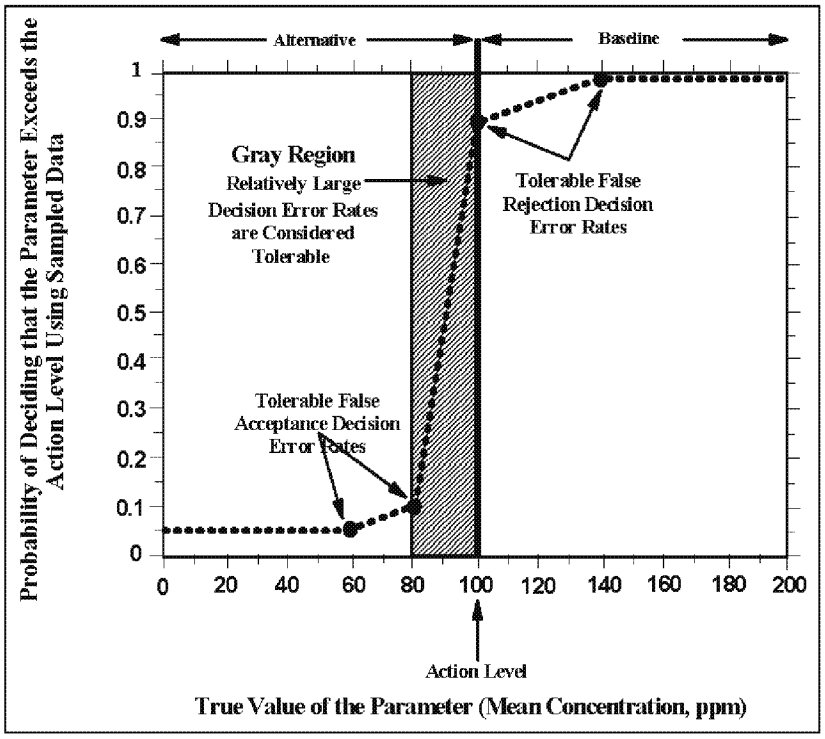

Figure 5 – Example Illustrating Case (a) (see Table 9C, Step 6.1). Baseline Condition (null hypothesis): Parameter Exceeds the AAL.

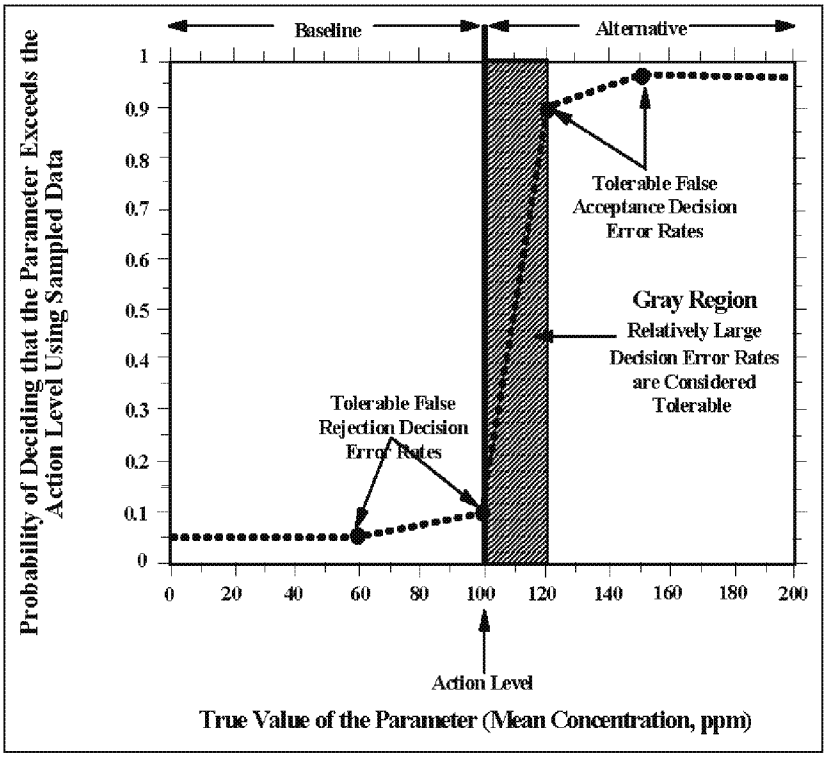

Figure 6 – Example Illustrating Case (b) (see Table 9C, Step 6.1). Baseline Condition (n Figures 5 and 6 taken from EPA QA/G-4 (2006) **d the AAL.**

Figure 5 shows that in case (a), the ADL will be

$$\text{UBGR} - z_{1-\alpha}\, u_{\text{M}} \tag{6}$$

where u_{M} is its combined standard uncertainty of the measurement result, x, and UBGR is the upper boundary of the gray region. Only measurement results less than the ADL value will result in rejecting the null hypothesis that the true activity is greater than the AAL.

Figure 6 shows that for case (b), the ADL will be

$$\text{LBGR} + z_{1-\alpha}\, u_{\text{M}}, \tag{7}$$

where u_{M} is its combined standard uncertainty of the measurement result, x, and LBGR is the lower boundary of the gray region. Only measurement results greater than the ADL will result in rejecting the null hypothesis that the true activity is less than the AAL.

Decisions related to specific samples will be made by comparing the results of measurements to ADLs. Whenever the measured analyte activity equals or exceeds the applicable ADL activity, it will be concluded that the AAL (from a protective action guide or from an agreed upon cleanup level) has been exceeded.

The equations for the ADL given above are consistent with the acceptable decision error rates established during the DQO/MQO process. In this process, the MQO of greatest significance is the required method uncertainty, u_{MR}.

For example, an ADL can be calculated for a hypothetical AAL of 180 dpm/100 cm^2 and DL of 90 dpm/100 cm^2 for ^{90}Sr based on previously determined tolerable Type I and Type II error rates of 5% and an assumed required method uncertainty, u_{MR}, of 27 dpm/100 cm^2:

$$\text{ADL} = \text{UBGR} - z_{1-\alpha}\, u_{\text{M}} = \text{AAL} - z_{1-0.05}\, u_{\text{M}} = 180 - 1.645\times 27 = 136 \text{ dpm/100 cm}^2 \tag{8}$$

Measurement Type	AAL (dpm/100 cm^2)	ADL (dpm/100 cm^2)	u_{MR} (dpm/100 cm^2)
Radionuclide-specific	180	136	27

Only measurement results less than the ADL value will result in rejecting the null hypothesis that the true activity is greater than the AAL.[16] For example, a result of 100 dpm/100 cm^2 would result in the decision that the sample does not exceed the AAL, while a result of 160 dpm/100 cm^2 would result in the decision that the sample does exceed the AAL. The fact that the measurement result itself does not exceed the AAL is not relevant. It is the ADL that is used as the decision criterion specifically to avoid making the wrong decision by calling a sample below the AAL when it may actually be above it. The result may be below the AAL only by chance—random variations in the observed concentration.

[16] Note that these values are being used only for demonstration purposes, and have no regulatory basis. Specific AALs will be provided by the Incident Commander (or designee) and likely will be different.

Many types of measurements will be made during an incident, and the specified AAL may change as the response moves from early to recovery phases. Because different DQOs and MQOs are applicable to different types of measurements, different u_{MR} and corresponding ADL values will be required for each measurement. It is anticipated that in the case of an incident, specific DQOs and MQOs may be developed by Agency personnel to reflect the specific nature and concerns of the incident.

Developing the required method uncertainty, u_{MR}, will be crucial in selecting measurement methods for both direct and indirect measurements. Certain uncertainty factors may dominate for direct measurements that are different from those for indirect measurements. For example, the uncertainty in the source efficiency is likely to be larger for direct measurements than for indirect measurements. The removal factor for swipes, in contrast, has an uncertainty that affects only swipe samples. Establishing the appropriate uncertainties for the source efficiency for direct measurements requires laboratory analysis of physical samples of the various surfaces. An evaluation of the uncertainty in removal factors may be obtained by exhaustive swipe sampling. Some sources of uncertainty that should be considered in developing the required method uncertainty, u_{MR}, and in reporting the uncertainty of individual activity measurements include:

- Instrument efficiency,
- Self-absorption in the surface being measured,
- Distance between surface and detector,
- Count/count rate,
- Time of measurement,
- Area of measurement,
- Effective area of detector,
- Ambient background radiation (especially for gamma),
- Variability of background with surface type, and
- Inherent detector background.

The ISO *Guide to the Expression of Uncertainty in Measurement* (GUM, ISO 1995) should be used to determine measurement uncertainties. MARLAP Chapter 19 provides additional examples. It is not sufficient to consider counting uncertainty alone.

It may be useful to use a tool such as Table 11 to assist in developing DQOs and MQOs. The three distinct phases of emergency response are the early, intermediate, and recovery phases. The radionuclides considered in this example are ^{137}Cs, ^{90}Sr, and ^{238}Pu.

Table 11 – Example Table for Establishing DQOs and MQOs

Incident Phase	Nuclide	Type of Analysis, α β or γ	Null Hypothesis H_0 Choose > AAL or < AAL i.e., case (a) or case (b)	Analytical AL	Discrimination Level (DL) DL < AAL in case (a) and DL > AAL in case (b)	Δ = UBGR-LBGR (often equal to AAL - DL)	Type I error rate α	Type II error rate β	u_{MR}	φ_{MR} [1]	MDA	Analytical Decision Level (ADL) or Critical Level	Source of AAL
Early	^{137}Cs	γ											
Early	^{90}Sr	β											
Early	^{238}Pu	α											
Intermediate	^{137}Cs	γ											
Intermediate	^{90}Sr	β											
Intermediate	^{238}Pu	α											
Recovery	^{137}Cs	γ											
Recovery	^{90}Sr	β											
Recovery	^{238}Pu	α											

[1] φ_{MR} is the required relative method uncertainty at the AAL. $\varphi_{MR} = u_{MR}$ / AAL.

6.2 EXAMPLE SCENARIO

An explosion covering about 36 square blocks occurred in the middle of the downtown area of a large city with a population over one million. It was determined by first responders that this was very likely an RDD event, and there was potential for alpha-emitting radionuclides to be present. It was confirmed by radiochemical analysis that the alpha-emitter used was ^{241}Am from an AmBe neutron source. No other radionuclides were detected except for naturally occurring radioactive materials from the concrete rubble created following the detonation.

The decontamination of the affected areas is now underway under the recovery phase. The agreed upon AAL for removable surface contamination activity of ^{241}Am is 20 dpm/100 cm^2. The discrimination level has been established as zero, although a different value may be appropriate depending on the alpha background activity present. The Type I (α) and Type II (β) error rates for field measurements of swipes have been set at 0.20 for both. These error rates apply at the boundary of the gray region and fall sharply as one moves to lower or higher concentration values. These error rates were chosen to balance the risk of missing a relatively low AAL against the longer counting times that would be needed to achieve smaller error rates. The shorter counting times allow more swipes to be taken and analyzed in the field.

The desired required method uncertainty is:

$$u_{MR} \le \frac{AAL - DL}{z_{1-\alpha} + z_{1-\beta}} = \frac{\Delta}{z_{1-\alpha} + z_{1-\beta}} = \frac{20}{0.842 + 0.842} \sim 11.9 \text{ dpm/100 cm}^2,$$

or about 12 dpm/100 cm^2 at and below the AAL. The required relative method uncertainty is about 60% above the AAL. Swipe samples taken over a 100 cm^2 area whose activity exceeds the AAL when counted using field instrumentation are to be sent immediately to a radioanalytical laboratory for confirmatory analysis using alpha spectrometry. The decision is based on whether the measurement exceeds the ADL of AAL – $z_{1-\alpha}\, u_M$ = 20 – (0.842)(11.9) = 10 dpm/100 cm^2. Confirmation that ^{241}Am exceeds 20 dpm/100 cm^2 will require that the surface be re-cleaned and re-tested.

Below is a row from Table 11 that has been filled in for this example. The actual values are for illustrative purposes only.

Incident Phase	Nuclide	Type of Analysis, α β or γ	Null Hypothesis H_0 Choose > AAL or < AAL i.e., case (a) or case (b)	Analytical AL (dpm/100 cm^2)	Discrimination Level (DL) DL < AAL in case (a) and DL > AAL in case (b)	Δ = UBGR-LBGR (often equal to AAL - DL)	Type I error rate α	Type II error rate β	Required method uncertainty, u_{MR}	Required relative method uncertainty, φ_{MR}	MDA	Analytical Decision Level (ADL) or Critical Level (dpm/100 cm^2)	Source of AAL
Recovery	^{241}Am	α	a	20	0	20	.20	.20	12	.60		10	Incident Commander

The 100 cm^2 area swipe samples were taken from interior building surfaces using a 47-mm diameter cellulose-acetate filter paper. A representative sample of swipes from each batch was weighed initially, and each swipe was re-weighed in the field after sampling but prior to counting. The difference in the weight of the swipe before and after sampling provides an indication of the particle loading that can be used to estimate the amount of self-absorption of emitted radiation in the swipe material.

6.3 UNCERTAINTY BUDGET FOR EXAMPLE SCENARIO: FIELD TOTAL ALPHA

The field measurements were made using a ZnS(Ag) scintillator in a 50-mm drawer with a scaler for recording alpha counts. Recall from Section 2.3 on indirect measurements of removable surface activity using swipe samples:

For instruments with a 2π counting geometry (i.e., gas-flow proportional counters, scintillation counters, portable field survey meters, etc.), the activity per unit area A_R of the removable contamination of the swiped surface, expressed in dpm/100cm^2, is given by the equation:

$$A_R = \frac{60 \cdot (n/t - n_B/t_B)}{F \cdot (S/100) \cdot \varepsilon_i \cdot \varepsilon_s} = \frac{60 \cdot (n/t - n_B/t_B)}{F \cdot (S/100) \cdot (\varepsilon_i \cdot e^{-\frac{(w_a - w_b)}{100\rho R}})} \tag{9}$$

where:

A_R = removable activity per unit area of the swiped surface [dpm/100cm^2]
n = measured total count from the swipe sample
n_B = background count
t = total count time of the swipe sample (s)
t_B = background count time (s)
S = swiped surface area (cm^2)
F = removal factor
ε_i = instrument efficiency for radiation type (alpha or beta radiation)
ε_s = source efficiency

Based on empirical data for this particular detector, the product of these efficiencies can be expressed as

$$Overall\ efficiency = \varepsilon_i \varepsilon_s = \varepsilon_i \cdot e^{-\frac{(w_a - w_b)}{100\rho R}} \tag{10}$$

where:

R = mean linear range for alpha particles or beta particles in the swiped matter, (e.g., 30 μm)
ρ = density of the swiped matter (g/cm^3)
w_a = weight of filter with swiped matter (mg)
w_b = weight of clean filter (mg)
100 = represents the 100 cm^2 surface area for deposition.

The specific values given for measured input quantities are purely for illustrative purposes and are not to be construed as typical of current or possible future practice.

The uncertainty analysis for this sample is shown in Table 12. Note that there is an entry for each input variable in the right hand side of the equation for A_R. The name of the input quantity and its symbol are given in the first two columns. The value is the best estimate of the input for this sample. The standard uncertainty is determined using the GUM methodology. The distribution assumed for the input quantity is also given. The component of uncertainty due to a given input is its standard uncertainty multiplied by its sensitivity coefficient. The sensitivity coefficient is obtained by evaluating the partial derivative of the equation for A_R with respect to the input variable, evaluated using the data for the particular sample. This is done to weight the uncertainty contribution of each input according to the effect changes in that input have on the output. The combined standard uncertainty of the output, A_R, is the square root of the sum of the squares of the components of uncertainty. The percent of the combined variance is the ratio of the square of each input component of uncertainty to the sum of the squares of all the uncertainty components. This is an indicator of how much each input contributes to the overall uncertainty.

From this uncertainty budget, it is clear that most of the uncertainty is due to the removal factor (56%) and the efficiency factor (21%). The relative combined standard uncertainty in the

estimated activity per unit area is about 52%. Clearly, this would be improved by experimentally determining the removal factor by the method of exhaustive swiping. If the uncertainty in the removal factor were halved, its contribution to the overall variance would be reduced from 56% to about 24%, and the overall relative uncertainty in the result would be reduced from 52% to 42%. Further improvement may be possible by reducing the uncertainty in the value 0.37 of the efficiency factor. By using available software, it is possible, with little additional effort, to determine the effect that reducing the uncertainty in particular input parameters would have on the result.

If one were concerned only with the activity on the swipe, the factors $S/100$ and F would not be used. In this case, the activity on the swipe would be 10.7 dpm with a combined standard uncertainty of 3.6 dpm or 34%. The major contributors to the uncertainty budget are the efficiency factor (55%) followed by the sample counts (34%) and the background counts (11%).

Nonetheless, the value found in Table 12, 53 dpm/100 cm^2, clearly exceeds the threshold for sending the sample to the laboratory for alpha spectrometric analysis, but the required relative method uncertainty was met.

Table 12 – Uncertainty Budget for Gross Alpha Count[1]

Input Data Quantity	Symbol	Value	Standard Uncertainty	Distribution	Component of uncertainty	Percent of combined variance
Sample counts	n	56	7.5	Poisson	10.5	13.1
Time sample counted	t	600 s	0.2887	Rectangular	0.0379	0.000
Background counts	n_B	18	4.2	Poisson	5.97	4.2
Time background counted	t_B	600 s	0.2887	Rectangular	0.0122	0.000
Area swiped	S	100 cm^2	12.247	Triangular	6.54	5.1
Efficiency factor	ε	0.37	0.0925	Normal	13.4	21.1
Removal factor	F	0.2	0.08165	Triangular	21.8	56.4
Weight of filter before swiping	w_B	800 mg	10	Normal	0.848	0.085
Weight of filter after swiping	w_A	825 mg	1	Normal	0.0848	0.001
Range of alpha particles in swiped matter	R		0	Constant		
Density of swiped matter	ρ	2.1 g/cm^3	0	Constant		
Results						
Removable activity	A_R	53 dpm/100cm^2				
Standard uncertainty in the removable activity	u(A_R)	29 dpm/100cm^2				

[1] Calculations were performed using the software GUMCalc available at www.mccroan.com/gumcalc.htm.

6.4 UNCERTAINTY BUDGET FOR EXAMPLE SCENARIO: LABORATORY ALPHA SPECTROMETRY

The swipe sample was analyzed in the laboratory for ^{241}Am by alpha-particle spectrometry. The swipe was spiked with the radioactive tracer ^{243}Am and muffled at 600 °C, and the ash residue was acid-digested. The acid digestate was gravimetrically split, with 50% directed to the ^{241}Am analysis and 50% reserved for re-analysis, if necessary. Americium was separated from the analysis fraction by solid-phase ion-chromatography extraction, and the final sample test source was prepared by microprecipitation onto a membrane filter. The sample test source was counted for 600 minutes using an ion-implanted silicon detector, enabling spectrometric measurement of the individual americium isotopes. Chemical yield of the separation process was determined by the measured recovery of ^{243}Am in the sample and that yield determination was applied to the ^{241}Am activity calculation.

The full mathematical model for this measurement might be given by

$$A_R = \frac{N_{as}/t_s - N_{ab}/t_b}{N_{ts}/t_s - N_{tb}/t_b} \times \frac{2.22 \times c_t \times V_t \times D_t \times P_t}{(V/V_d) \times D_a \times P_a \times F \times (S/100)} \tag{11}$$

where:

A_R = removable ^{241}Am activity per unit area of the swiped surface [dpm/100cm^2]
N_{as} = sample count in the ^{241}Am region of interest (ROI)
N_{ab} = blank count in the ^{241}Am ROI
N_{ts} = sample count in the ^{243}Am ROI
N_{tb} = blank count in the ^{243}Am ROI
t_s = sample count time [s]
t_b = blank count time [s]
c_t = ^{243}Am activity concentration of the tracer solution [pCi/L]
V_t = volume of tracer solution added to the sample aliquant [L]
D_t = correction factor for decay of ^{243}Am from the tracer reference date through counting
P_t = alpha emission probability for the ^{243}Am ROI
V = volume of the sample aliquant analyzed [L]
V_d = total volume of solution after the filter is dissolved [L]
D_a = correction factor for decay of ^{241}Am from sample collection through counting
P_a = alpha emission probability for the ^{241}Am ROI
S = swiped surface area [cm^2]
F = removal factor

For simplicity in this example, the decay factors will be neglected since they are very close to 1. The alpha emission probabilities are assumed to be exactly 1 (with no spillover outside each region of interest (ROI). The resulting model equation is:

$$A_R = \frac{N_{as}/t_s - N_{ab}/t_b}{N_{ts}/t_s - N_{tb}/t_b} \times \frac{2.22 \times c_t \times V_t}{(V/V_d) \times F \times (S/100)} \tag{12}$$

Because the count times t_s and t_b have negligible uncertainty, only the uncertainty components due to N_{as}, N_{ab}, N_{ts}, N_{tb}, c_t, V_t, V_d V, S, and F will be considered.

The uncertainty analysis for this sample is shown in Table 13. The analysis assumes:

- None of the input estimates are correlated with each other;
- Dead time is negligible;
- Peaks in the alpha spectrum are cleanly separated, and there is no spillover from either ROI.
- Subsampling uncertainty is negligible for this sample;
- Historical QC data indicate no significant amount of ^{241}Am contamination in method blank samples; and
- The decay-correction factors are negligible.

Table 13 – Uncertainty Budget for Alpha Spectrometry Count[1]

Input Data Quantity	Symbol	Value	Standard Uncertainty	Distribution	Component of Uncertainty	Percent of Combined Variance
Sample count in the ^{241}Am region of interest (ROI)	N_{as}	810	28.478	Poisson, $u(N_{as}) = \sqrt{N_{as}}$	1.66	0.673
Blank count in the ^{241}Am ROI	N_{ab}	1	1.414	Poisson (low level) [2], $u(N_{ab}) = \sqrt{N_{ab}+1}$	0.0824	0.002
Sample count in the ^{243}Am ROI	N_{ts}	1282	35.819	Poisson, $u(N_{ts}) = \sqrt{N_{ts}}$	1.32	.425
Blank count in the ^{243}Am ROI	N_{tb}	2	1.732	Poisson (low level), $u(N_{tb}) = \sqrt{N_{tb}+1}$	0.0638	0.001
Sample count time (s)	t_s	60 000 s		Negligible uncertainty		
Blank count time (s)	t_b	60 000 s		Negligible uncertainty		
^{243}Am activity concentration of the tracer solution	c_t	3360 pCi/L	50 pCi/L	U = 100 pCi/L (k = 2)	0.702	0.12
Volume of tracer solution added to the sample aliquant [L]	V_t	1 mL, or 0.001 L	0.000006 L	$u(V_t)$ = 0.006 mL, or 6 × 10^{-6} L	0.283	0.02
Volume of the sample aliquant analyzed	V	0.1500 L	0.0013 L	$u(V)$ = 0.0013 L	0.409	0.041
Total volume of solution after the filter is dissolved	V_d	0.3000L	0.0030L	$u(Vd)$ = 0.0030 L	0.471	0.054
Area swiped	S	100	12.247	Triangular	5.77	8.147
Removal factor	F	0.2	0.08165	Triangular	19.2	90.5
Results						
Removable activity	A_R	47 dpm/100cm^2				
Standard uncertainty in the removable activity	$u(A_R)$	20 dpm/100cm^2				

[1] Calculations were performed using the software GUMCalc available at www.mccroan.com/gumcalc.htm.
[2] As recommended in MARLAP, when counts are low, N is replaced by N+1.

The output estimate (the activity concentration of ^{241}Am) is calculated below.

$$\begin{aligned} A_{\mathrm{R}} &= \frac{N_{\mathrm{as}}/t_{\mathrm{s}} - N_{\mathrm{ab}}/t_{\mathrm{b}}}{N_{\mathrm{ts}}/t_{\mathrm{s}} - N_{\mathrm{tb}}/t_{\mathrm{b}}} \times \frac{2.22 \times c_{\mathrm{t}} \times V_{\mathrm{t}}}{(V/V_d) \times (S/100) \times F} \\ &= \frac{810/(60000\ \mathrm{s}) - 1/(60000\ \mathrm{s})}{1282/(60000\ \mathrm{s}) - 2/(60000\ \mathrm{s})} \times \frac{(2.22)(3360\ \mathrm{pCi/L}) \times (0.001\ \mathrm{L})}{(0.150\ \mathrm{L}/0.300\ \mathrm{L}) \times (100/100) \times (0.2)} \\ &= 46.72\ \mathrm{dpm/100cm^2} \end{aligned} \tag{13}$$

From Table 13, it can now be seen that the analytical uncertainty is dwarfed by the uncertainty in the removal factor, which accounts for 90% of the variance. Including the uncertainty of the swiped area (8%), these factors account for virtually all of the uncertainty in inferring surface removable activity from swipe samples. If the uncertainty in the removal factor were halved, the relative combined standard uncertainty would fall from 43% to 23%. The dominant contributors to the field measurement uncertainty were the removal factor, the instrument efficiency, and the number of sample counts. Clearly, there would be much to be gained from a better understanding of removal factors for the initial swipe. It may be of benefit to examine two or three successive swipe samples at each of several locations, with at least one exhaustive swipe series for each different surface type.

Again, if one were concerned only with the activity on the swipe, the factors $S/100$ and F would not be used. In this case, the ^{241}Am activity on the swipe would be 9.43 dpm with a combined standard uncertainty of 0.48 dpm or 5%. The major contributors to the uncertainty budget are the sample counts (50%) followed by the tracer counts (32%) and the background counts (11%), and followed by the tracer activity (9%). The volume determinations each contribute a few percent. Thus, the laboratory analysis of the activity on the swipe has a much smaller relative uncertainty than the gross alpha count in the field. In addition, it is a radionuclide-specific measurement so that one does not need to be concerned about any alpha-emitting background radionuclides that may be present.

7. CONCLUSIONS

From the data and examples considered in this document, it would appear that determining the activity on the swipe is not especially difficult, particularly if the swipe is dissolved and radionuclide-specific measurements are made in a laboratory. The major issues concern inferring from the activity on the swipe what the amount of removable contamination is on the surface. The major sources of uncertainty in making this inference are primarily in the removal factor (F), and in the area swiped (S). Direct counting of the swipe has the added uncertainty of estimating the source efficiency. Direct counting of the surface itself will increase this contribution to the uncertainty, and it is not a measure of removable activity alone, but of fixed-plus-removable contamination.

Current practice for determining the removal factors often involves simply assuming that it is 1 (the swipe defines removability) or using 0.1 (a value that may be considered conservative). Often, the value used is not reported. The actual value in a specific instance most likely lies between these extremes. In the absence of any data, the use of a conservative value with a large

uncertainty is probably necessary in practice. As suggested in this document, the data from some multiple swipes or occasional exhaustive swipes can reduce this uncertainty.

Much of the uncertainty in determining the removable activity from the activity on a swipe can be reduced by simply improving the specified protocol for obtaining the swipe sample, and making it more uniform. Current practices involving freehand swiping using hand pressure introduce uncertainties that can be reduced by using templates for the area sampled and some type of mounting jig for the swipe material. Specifying improved protocols to be used during the recovery phase of an RDD or IND event is one possibility.

The uncertainty in both S and F could be reduced dramatically by the use of strippable gels as a swipe material. In early studies, these have shown high removal efficiencies (over 90%) and the desired area can be cut from the sample with much less uncertainty than freehand swiping. Research would be needed to determine how well these materials perform as a surrogate swipe. The application method drying time, ease of stripping an intact sample, the source efficiency for direct counting, and the method of dissolution for radiochemical analysis all need further investigation. However, this preliminary examination of early results indicates that this would be well worthwhile.

When contamination consists of alpha or low-energy beta activity, grab sampling of the surface followed by radiochemical analysis may be the only alternative to swipe sampling. The area sampled would need to be carefully controlled. More importantly, how the sample is taken will strongly affect what the result represents. If the surface is lightly abraded, it may be a representative of removable activity. A deeper sample may more closely represent fixed-plus-removable contamination.

If swipes are to be used as a quantitative measure of whether remediation meets required limits, rather than simply as a method-based, prescriptive sample indicating the presence of removable activity, it is clear that improvements in sampling, analysis, reporting, and interpretation are necessary.

8. RECOMMENDATIONS

First and foremost, it is necessary that the uncertainty of swipe results should be reported along with the results. In reporting the results, it should be clearly specified what the results represent (e.g., activity on initial swipe, estimate of total removable contamination, etc.).

Each phase of the event will need a basic swipe investigation to determine the best combination of swipe material and solvent to use for the radionuclides of interest, their chemical forms, and the surfaces involved. The data needed will depend on the action levels and data quality objectives for the swipe samples. Fortunately, the amount of information available from laboratory analyses of the RDD material will increase for each successive event phase, as action levels also decrease. Such additional information should help reduce the uncertainties in the measurements due to the assumptions that may be necessary without this information. This will help the laboratory meet more stringent MQOs (e.g., required method uncertainty, minimum

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detectable activity, etc.) as the event unfolds. For example, optimizing the swipe material and solvent should increase the removal factor and reduce its uncertainty.

A more specific protocol for obtaining swipes would reduce the overall uncertainty in the removable activity. Existing swipe procedures (see Appendix C for examples) could be improved by specific improvements in defining the area sampled. It is becoming more common to use a template to define a reproducible area. Care would be needed to prevent cross-contamination, and may require disposal after each use. A pad of paper templates may be a practical solution. Strippable coatings can be applied, and then a coupon of the size desired can be cut from the dried coating.

Table 2 (page 16) suggests that dry swipes may have higher removal factors on rough surfaces and wet swipes may have higher removal factors on smoother surfaces. This should receive further investigation.

Mounting the swipe material on a block would prevent the large inhomogeneities in activity across the material caused by finger pressure. A weight or spring might be used to control the pressure applied to the surface and reduce the uncertainty due to this variable. Strippable coatings may reduce these effects, but reproducibility would need to be verified.

Removal factors should be determined periodically by means of exhaustive swiping. At a minimum, each type of surface should be evaluated. This would include multiple applications of strippable coatings if they are used.

If there are large differences between direct and indirect measurements, the implication may be that there is a large amount of fixed activity, or the source efficiency for the direct measurements is incorrectly specified, or both. Periodic physical sampling and laboratory analysis of the surface material for certain matrices should be performed to assess the accuracy of direct measurements. This is analogous to repeated swipes being used to evaluate removal factors.

For analyses of swipe samples, the weight of the swipe material before and after use could be used to estimate source efficiency for the swipe.

9. REFERENCES

References used in this document are listed in Section 9.1. Other sources, including discussions with subject matter experts and additional Internet searches, are listed in Section 9.2.

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APPENDIX A: REVIEW OF REGULATORY APPROACH AND APPLICATIONS FOR SWIPES IN RADIATION PROTECTION ACTIVITIES

A.1 INTRODUCTION AND DEFINITION OF CONCEPTS

If a radiological dispersal device (RDD or IND) were detonated in the United States, a large number of samples would need to be analyzed to assess and control the spread of fine particulate matter contaminated with radionuclides. A review of Department of Energy (DOE), Nuclear Regulatory Commission (NRC), and Department of Transportation (DOT) regulations and regulatory guidance documents was conducted to identify various uses of swipes that might be applicable to incident response activities, especially in the intermediate and recovery phases. Other agencies, including the U.S. Environmental Protection Agency (EPA), Department of Homeland Security (DHS), Centers for Disease Control and Prevention (CDC), Department of Defense (DOD), and Food and Drug Administration (FDA), clearly have interests within the area of radiation protection. To minimize redundancy, it is noteworthy and reassuring that different agencies appear to approach this topic in a similar manner. This need not be surprising since although DOE and NRC are now autonomous agencies, they used to be a single entity, and the licensing and use of radioactive materials for all other entities in the United States are regulated by the NRC. Thus, the following discussion focuses primarily on the approach presented in the NRC documents reviewed.

Minimizing the dose of ionizing radiation to the public is a key goal of radiation protection activities. In order to effectively protect members of the public, one must be able to measure the sources of radiation and radioactive materials that lead to radiation exposures. Radiation protection regulations differentiate between the doses caused by exposure to external and internal sources of ionizing radiation. External exposures result from high levels of gamma- or X-ray radiation (i.e., penetrating radiations) located outside the body. The absorbed dose that a person receives from exposure to external or ambient sources of radiation is dependent upon the energy, rate of exposure, and length of time that the individual spends in proximity to the radiation. Exposure rates high enough to be of concern to health and safety generally will cause a response in an appropriate radiation detector placed in very close proximity to the radioactive source and are thus relatively easy to measure in surveys for ambient radiation. Internal exposures result when radionuclides (especially alpha- and beta-emitters) are taken into the body (via inhalation, ingestion, injection, or absorption). Once within the body, relatively small amounts of radioactivity will cause much more damage than comparable sources of radioactivity outside the body (especially alpha and beta particles). Additionally, since some radionuclides inside the body are only slowly excreted from the body, they will lead to larger exposures since the exposure can continue possibly for the rest of an individual's life.

Health physicists and regulatory bodies tasked with radiation protection recognize that there is a substantial difference in risk between internal and external radiation doses and have developed approaches to measure and control sources of radiation and radioactive materials that could lead to radiation dose. The approaches taken by the NRC and DOE, while not strictly identical, share substantial common direction in almost all respects. This paper discusses examples of how

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regulatory entities approach the measurement and controls related to internal dose.

It is also important to distinguish between the concepts of radiation and radioactive contamination. Radiation refers to gamma-rays, X-rays, and alpha and beta particles that are emitted following the radioactive decay of radionuclide. On the one hand, gamma- and X-rays are electromagnetic radiations that are emitted as radioactive atoms decay (e.g., ^{137}Ce). Gamma- and X-ray radiation is very penetrating and thus is a hazard to health and safety, even when its source is outside or "external" to the body. However, this radiation has no substance or mass and does not persist once the source of radiation is removed from the area. In contrast, radioactive contamination refers to the physical presence of a substance (in this case, radioactive materials or radionuclides) in a place where it constitutes a hazard to human health and safety. An example of contamination would be the presence of radioisotopes of strontium (e.g., ^{90}Sr) or cesium (^{137}Cs) on the floor in an entryway to a building. The contaminants are the atoms of radioactive strontium or cesium.

In the discussion of swipes, the terms "removable contamination" and "fixed contamination" also need to be defined. Removable contamination refers to the portion of radioactive contamination that is transferred from a contaminated surface to the swipe. Swipe samples of removable contamination (also referred to as "swipes," "wipes," or "smears") are used to determine the presence of radioactive contamination, and to estimate the amount of contamination that could be removable into the body and thus lead to an internal dose. Fixed contamination refers to the portion of contamination that remains attached to a surface after reasonable attempts to clean or decontaminate that surface. Since the contamination is fixed to the surface, it will not be transferred to the body and is of concern only as a source of external exposure. As mentioned in the above discussion, it is the contamination that is removable that poses the greatest hazard and thus, is of greatest regulatory concern. The levels of removable contamination that are of concern are much lower than those for fixed contamination because the intensity and effective duration of the exposure to radiation caused by internally-deposited radionuclides are much greater than sources of radiation outside the body.

A.2 PERFORMANCE OF SURVEYS – PROCEDURES, TYPICAL SENSITIVITY, AND APPROPRIATE INSTRUMENTATION

NRC (1999) provides consolidated guidance on radioactive materials licenses and may be one of the best sources of information on operations involving swipes. Section 8.10.7 of NUREG-1556 (NRC 1999) defines a survey as "an evaluation of the radiological conditions and potential hazards incident to the production, use, transfer, release, disposal, or presence of radioactive material or other sources of radiation." Among the types of surveys that this document addresses are ambient "radiation surveys" and "contamination surveys." Contamination surveys measure and evaluate the (unwanted) presence of radioactive materials to determine whether the levels of radioactive contamination constitute a hazard to the health and safety of workers or the general public. Fixed contamination is addressed separately from removable contamination. Since by definition, swipes cannot measure fixed contamination, the subsequent discussion will restrict itself to removable contamination surveys.

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NRC takes a performance-based approach to a number of topics. Thus, as NUREG-1556 (NRC 1999) points out, 10 CFR Part 20 does not specify action limits for removable contamination, nor does it prescribe a specific method for performing swipe surveys. Instead, the licensee must propose an approach for approval by the NRC. Appendix S of NUREG1556 (NRC 1999), however, does present examples of action limits, frequencies, and survey procedures that are "acceptable to the NRC." Similarly, the footnotes to Table S.5 of Appendix S provide an example of a method for performing swipes that would be "acceptable to the NRC":

> A standardized method for smear [swipe] testing of a relatively uniform area should be used to aid in comparing contamination at different times and places. A smear taken from an area of about 100 cm^2 is acceptable to indicate levels of removable contamination.
>
> The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the [s]wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be [s]wiped.

Table A-1 – Table 1 from NRC RG 1.86 – Acceptable Surface Contamination Levels

NUCLIDE [1]	AVERAGE [2, 3]	MAXIMUM [2, 4]	REMOVABLE [2, 5]
U-nat, U-235, U-238, and associated decay products	5,000 dpm α/100 cm^2	15,000 dpm α/100 cm^2	1,000 dpm α/100 cm^2
Transuranics, Ra-226m Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125. I-129	100 dpm/100 cm^2	300 dpm/100 cm^2	20 dpm/100 cm^2
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1,000 dpm/100 cm^2	3,000 dpm/100 cm^2	200 dpm/100 cm^2
Beta-gamma-emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above.	5,000 dpm β-γ/100 cm^2	15,000 dpm β-γ/100 cm^2	1,000 dpm β-γ/100 cm^2

[1] Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

[2] As used in this table, dpm means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[3] Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each object.

[4] The maximum contamination level applies to an area of not more than 100 cm^2.

[5] The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with a dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the [s]wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be [s]wiped.

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Table S.5 in Appendix S of NUREG-1556 (NRC 1999) lists "acceptable surface contamination levels" for removable and fixed contamination surveys for unrestricted areas.[17] Table S.5 is derived from Table 1 in NRC Regulatory Guide 1.86 (NRC 1974).[18] It lists action limits for removable contamination down to 20 dpm/100 cm^2 for a number of alpha-, beta-, and photon-emitting radionuclides, including several that are of incident response concern (e.g., radium-226, all isotopes of plutonium, americium, curium, neptunium, iodine-125, iodine-131, and strontium-90). It is not envisioned that these are the exact levels that would be applied during an incident response. Rather, these values are provided as a starting point to consider detection levels that might be applicable to measurements of removable contamination during an incident response during the recovery phase. As pointed out in Footnote 17 on this page, the as-low-as-reasonably-achievable (ALARA) principle would possibly drive detection sensitivity needs to levels lower than those shown in Table 1.

Appendix S indicates that "appropriate instrumentation" should be used to perform measurements of swipes and specifically lists low-background liquid scintillation counting, sodium iodide or germanium gamma counting, or gas-proportional alpha/beta counting. Appendix S also specifies that "to ensure achieving the required sensitivity of measurements, survey samples will be analyzed in a low-background area" while Table S.5 footnotes continue, saying that the instrument must be calibrated for "background, efficiency [implying a radionuclide-specific calibration] and geometric factors associated with the instrumentation."

While the action limits shown in Table A-1 above will vary case-by-case, they are helpful in considering the sensitivity needed for instruments appropriate for use when measuring swipes. Given these action levels, and considering ALARA, any instrument used to measure removable contamination would have to dependably obtain minimum detectable activities below 20 dpm/100 cm^2 levels for the nuclide(s) in question. Such measurements are generally not problematic at fixed laboratories, where environmental conditions such as ambient background and environmental conditions are well-known and carefully managed, and strong quality assurance and quality controls are in place to demonstrate such.

If one wishes to count swipes outside of a fixed laboratory, however, it is critically important that one look beyond theoretical capabilities of an instrument. It is vital to empirically assure that all environmental conditions, but especially ambient background, are stable and well-known, and that there are effective controls in place to identify and document any excursions from these conditions. Otherwise, dependable measurements at very low activity levels will be of questionable quality and may lead to false detection and false non-detection of analyte in these samples.

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[17] Any reference to "acceptable levels" for unrestricted release should be understood in the context of "ALARA" (as-low-as-reasonably-achievable). Under ALARA, radioactively contaminated areas are decontaminated, where possible, until there is no contamination present. When decontamination to zero levels is technically impossible or economically unfeasible, "acceptable" levels of residual contamination are established. In all likelihood, these levels will be lower than Table 1 values (shown in Table A-1 above).

[18] Table S-5, NUREG-1556, Volume 11. According to NUREG-1757, volume 1, revision 2, the values and the swipe procedure presented in this table were originally derived from Table I in NRC RG 1.86 (shown in Table A-1 above).

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A.3 APPLICATIONS TO WHICH REMOVABLE CONTAMINATION SURVEYS APPLY

NUREG-1556 (1999) addresses applications for which swipes are applicable and required of radioactive materials license holders. The common theme for all of these is control of removable contamination that could cause a risk to the health and safety of workers or members of the general public. Surveys for removable contamination are conducted using swipes for:

- Routine contamination surveys, monitoring, and control in and adjacent to areas where radioactive materials are used or stored.
- Verification and control of the integrity of radioactive sources to detect and thus minimize contamination that would result from source leakage.
- Control of contamination during shipping and receiving of radioactive materials packages.
- Contamination surveys of equipment, facility, and infrastructure, and areas adjacent to the above that could be subject to contamination during release of equipment from licensed facilities or facility decommissioning of entire facilities prior to release for unrestricted (or possibly restricted) use.[19]

NUREG-1556 (NRC 1999) also mentions the use of surveys complementary to those for removable contamination. Surveys for ambient radiation are routinely required to control external exposures. These surveys, primarily for gamma- and X-ray radiation, may also serve as a first indicator of the presence of high levels of radioactive contamination in an area that should trigger special radiation protection measures and controls to minimize personal exposures and potential contamination of equipment.

Similarly, total contamination survey measurements are in-situ measurements of alpha, beta, and photon emissions that reflect the total or combined radioactive contaminant activity (fixed and removable). Depending on the contaminant, the stability of detector efficiency, ambient background activity levels, and the quality and sensitivity of in-situ measurements may not be adequate to measure the presence of removable contamination at low levels. Rather, a measurement of total activity may provide an early indication of the possible presence of high levels of removable contamination and allow use of measures to prevent personal exposures or the contamination of sensitive low-background instrumentation that will be used to analyze the swipes.

In 10 CFR Parts 30, 40, 70, and 72, the NRC addresses the termination of operating licenses (i.e., decommissioning) for a number of different types of facilities. This situation perhaps most closely resembles survey activities that might be encountered during the recovery phase of an incident response. Paragraph 36, Section (j)(2)(i) of each of the above-mentioned parts stipulates that the licensee must perform surveys and report the results documenting levels of fixed *and* removable contamination:

[19] None of the guidance documents consulted consider the question of transfer efficiency coefficients (the amount of non-fixed activity actually transferred to a swipe relative to the total non-fixed contamination present) and the advantage of modifying approaches to taking swipes to improve or at least account for transfer efficiency.

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> [L]evels of gamma radiation in units of millisieverts (microroentgen) per hour at one meter from surfaces, and report levels of radioactivity, including alpha and beta, in units of megabecquerels (disintegrations per minute or microcuries) per 100 square centimeters—removable and fixed—for surfaces…

Several additional NRC-related applications requiring the use of swipes in radiation protection are noted in CFRs. These are less *apropos* in terms of their applicability to incident response and environmental protection. For example:

- 10 CFR Parts 20, 31, 32, 34, 35, 39, and 70 require the use of swipes to test various types of sources and equipment containing sealed sources for leakage that could lead to contamination.
- In 10 CFR Parts 20 and 71, the NRC requires the use of swipes to determine removable contamination when shipping and receiving Type A quantities of radioactive materials. Note that the specifications are similar to those specified by DOT in 49 CFR 173.433. Specifically, the shipper must perform dose rate and swipe surveys to determine whether removable contamination may be present above acceptable levels of <0.5 mrem/h and <0.005 μCi/100 cm^2, respectively.[20]

A.4 CONCLUSIONS

- Swipes will be applicable to incident response activities given the likelihood for spread of fine particulate matter contaminated with radioactive materials following the detonation of a radiological dispersal device.
- In the documents consulted, the approach to measuring removable contamination (i.e., radioactive contamination) was relatively consistent from agency to agency. The approach used by the NRC in regulating licensees addressed all swipe-related applications encountered from other agencies and was deemed as the best example to use for considering issues related to use and measurement of swipes in the assessment of contamination.
- The NRC makes extensive use of swipe surveys, as well as other measurements, to identify, estimate, and control the amount of removable radioactive contamination in a number of different applications, including:
  - Routine operational contamination survey and monitoring in and adjacent to areas where radioactive materials are used,
  - Leak-testing sources,
  - Shipping and receiving of radioactive materials,
  - Determining unrestricted release of (potentially) surface-contaminated objects, and
  - Determining unrestricted release of facilities as part of decommissioning and radioactive material license termination.
- NRC regulations consistently differentiate between, and thus require separate surveys for "ambient radiation," "fixed contamination," and "removable contamination." Unique controls and action limits apply to each of these.
- NRC does not specify limits for "acceptable" levels of removable (or fixed) contamination in 10 CFR regulations, or in its regulatory guidance documents.

[20] DOE requirements in 10 CFR Parts 830 and 835 read very similarly to the corresponding NRC regulations. Similarly, Department of Transportation requirements in 49 CFR Part 173 specify use of swipe and gamma dose rate surveys when shipping radioactive materials.

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- DOE, however, has established limits in Appendix D to 10 CFR 835.[21] The corresponding table, given in Appendix C of this document, provides a reasonable initial target when considering the sensitivity that would be required for measurements of swipes. Detection requirements below these established limit values may be influenced by the ability of the detection system to distinguish "real" values above background but below these established limits. ALARA considerations might then drive the detection requirements to values lower than those listed in these tables.
- The non-mandatory acceptable activity levels of removable contamination for alpha- and beta-emitters for unrestricted release shown in NUREG-1556 (NRC 1999), Table S-5, and Regulatory Guide 1.86 (NRC 1974) Table 1 are low enough (especially for alpha and very low energy beta-gamma activity) such that environmental conditions (e.g., variability of ambient background in the field) will in many cases prevent reliably detecting these levels using field instrumentation.
- The procedure for performing dry swipes as listed in NUREG-1556 (NRC 1999) Table S-5, consistent with personal experience, is the most commonly applied approach to performing removable contamination surveys.
- The NRC guidance consulted did not address several issues that may be of concern in using swipes, including:
  - The second most common technique in common use in the industry, based on personal experience, of using a swipe wetted with a solvent to enhance transfer efficiency;
  - Use of other procedures for performing swipes such as large area swipes with masslin cloth, beyond noting that NRC requires licensees to propose their own procedures; and
  - Applicability, use, and determination of material transfer efficiency.

[21] These limits appear to be based on NRC's Regulatory Guide 1.86 (NRC 1974) Table 1 (reproduced as Table A-1 in this document).

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APPENDIX B: MEASUREMENTS OF TRANSFERRABLE SURFACE CONTAMINATION REPORTED IN THE LITERATURE

The table is derived from data contained in Sansone (1987), adapted with the kind permission of Springer Business Media. Data on swipes for microorganisms have been omitted, as they are probably not relevant for radionuclides. Note that the author uses the term "wipe" rather than "swipe." The original terminology has been retained.

Contaminant	Surface	Surface contamination measurement	Removal efficiency (%)	Remarks
^{204}TlCl	Resin tile	Wiped with 2.5-cm dia quantitative filter paper #5 using a mean pressure of 1 kg	4.0 ± 1.3	1 mL of an aqueous solution (pH = 5.4) was used; data are the mean and standard deviation for five samples
	Waxed resin tile		6.6 ± 1.5	
	Painted resin tile		9.9 ± 0.5	
	PVC		53.0 ± 9.9	
	Vinyl sheet		45.4 ± 4.9	
	Glass		42.1 ± 7.7	
Various radioisotopes	Waxed resin tile		1.7–37.3	^{137}Cs, ^{90}Sr-^{90}Y, ^{32}P, ^{60}Co, and U applied in HNO_3 solutions
	Vinyl sheet		45.8-66.5	
U	Smooth concrete or embossed metal plates	Wipe with Whatman #1 paper over 100 cm^2	2–3	
Pu	Plywood, Perspex, PVC, stainless steel, aluminum, linoleum, waxed protective paper	Wipe 100–1000 cm^2 using 10-cm square Whatman D.H.C. filter paper	11-20	Wipe pressure about 30 g/cm^2
α-Emitters	Granolithic concrete	Rate meter	8–53 mean = 37	Surfaces sampled before and after water wash
	Cotton	Wiped with dry filter paper per over 100 cm^2	2–17	
ThO_2	Stainless steel	Wipe [1]	96, 86, 49	Data for 1.5-, 5-, and 10-µm settled particles respectively; the 10-µm particles were agglomerates; constant area sampled
		Adhesive paper [2]	96, 100, 68	
		Smair [3]	58, 75, 10	
PuO_2	PVC	Wipe, no details	14	PuO_2 applied in aqueous suspension and dried
	Waxed linoleum		58	
	Unwaxed linoleum		20	
$Pu(NO_3)_4$	Paper		0.1, 0.2	$Pu(NO_3)_4$ applied in HNO_3 solution and dried
	PVC		21, 29, 31	
	Waxed linoleum		6	
α –Emitters	Granolithic concrete	Dry filter paper wipes (6) over 900 cm^2	1-3	Water wash removed 25%; subsequent detergent wash 43%
Ra	Not specified	Wipe	50-85	Calculated from reported data

Contaminant	Surface	Surface contamination measurement	Removal efficiency (%)		Remarks
[^{3}H] Sodium acetate		Wipe (wet or dry) with Whatman #1 papers	Dry	Wet	
	Shellstone		5-10	7-19	Range for three replicates
	Fiberglass		20-30	26-32	
[^{3}H] Paraffin	Shellstone		18-23	12-17	
	Fiberglass		15-30	5-6	
ThO_2	Various	Wipe [1]	24-75		Constant area sampled; particle size ~1 µm
		Adhesive paper [2]	44-86		
		Smair [3]	1-33		
Be	Wood	Wipe (back and forth) 1 ft^2 with 5" x 8" Whatman #41	3 of total, 20 of loose for each of three wipes over same area		Large portion of total remained in wood after washing with detergent
U	Preaflex	Smair [4]	0.06-2.6		U as $UO_2(N0_3)_2 \cdot 6\ H_2O$ in HNO_3, UO_2 in C_2H_5OH, and UO_2 powder; standard deviation usually ≤ 15% of mean
		Wipe-constant pressure (8 g/cm^2) over 100 cm^2	20-67		
		Wipe over 100 cm^2 using 5.5-cm dia filter paper	42-70		
Various α- and β-emitters	Stainless steel	Wipe, no details	21		
^{3}H	Brass	Wiped with Whatman #3 filter paper soaked with glycerol	26.1 ± 4.4		Successive wipes removed 9.4 ± 1.1 and 7.2 ± 1.7%; ethylene glycol-soaked paper gave similar results, dry paper removed about half as much, and aluminum foil about a quarter
[^{3}H] Thymidine	PVC	Wiped with 2.5 cm dia filter paper 15 times across a 5-cm square	28.2 ± 4.8		Ten replicates; three different papers used for wipes showed no marked differences
	Stainless steel		86.1 ± 4.6		
	Glass		70.4 ± 5.4		
	Wood		4.2 ± 1.0		
Various radioisotopes	23-mm dia unwoven fabric on adhesive tape	Remove tape from surface and count with appropriate detector	No data		Correlation coefficient = 0.82 for tape-smear comparison
Pb	Wood, painted or varnished	Wiped "briskly" with a paper towel over 1 ft^2	80–100		Efficiencies calculated for surfaces sampled before and after scrubbing with water and a brush
	Formica		>95		
Pb	Not specified	Wiped with a paper towel impregnated with 20% denatured alcohol and 1:750 benzalkonium chloride over 1 ft^2	77 ± 2		Second wipe removed the remaining contamination
^{210}Po and ^{241}Am			Po	Am	
	PVC	Wiped using 25-mm dia, 30-mg/cm^2 Toppan paper over 100 cm^2 using 0.2 kg/cm^2 pressure	48.1 ± 1.4	42.3 ± 1.2	1 ml of nitrate dissolved in 0.1 *N* HNO_3 was spread over 100 cm^2 of the surface and dried; mean and standard deviation for six samples
	Aluminum		19.3 ± 0.5	20.4 ± 1.1	
	Glass		68.1 ± 2.0	69.8 ± 1.5	

Contaminant	Surface	Surface contamination measurement	Removal efficiency (%)	Remarks
^{125}I	Not specified	Wipe 100 cm^2 using swab soaked in 70% isopropyl alcohol	Assumed 10% of total removed	
Inorganic salts	Zinc	1.27-cm square Whatman 542 ashless, hardened paper moistened with distilled water placed on surface and removed after drying	100	Three successive samples removed all chloride, nitrate, sulfate, and sodium, ammonium, potassium, magnesium, and calcium cations from "normally contaminated" surfaces; from surfaces "heavily contaminated" with smoke, three samples removed all nitrate and ammonium and Mg cations; pH variation from 4.0-5.8 had no effect
PbO	Formica	Wiped with moist Whatman #42 paper, 10 × 10 cm, over 100 cm^2	86-91	Removal generally increased with increasing surface concentration from 64 to 730 μg/100 cm^2
		Wiped with moist paper towel, 10 × 10 cm, over 100 cm^2	74-84	

NOTES:
[1] Whatman #50 paper on #5 rubber stopper; rubbed over 5.8-cm diameter sample location.
[2] 3.8-cm square paper pressed with #10 stopper against sample location.
[3] 5-cm^2 head held for six s on sample location (air flow = 30 m/s).
[4] 113-cm^2 head held for five min on sample location (air flow = 30 m^3/ h).

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APPENDIX C: EXAMPLES OF RECOMMENDED SWIPE PROCEDURES

EPA

Note that EPA (2006b) has published *Sample Collection Procedures for Radiochemical Analytes in Environmental Matrices.* This is excerpted from *Module II: Sampling Procedures – Site Characterization and Remediation Phases:*

7.0 Collection of Surface Area Samples Using Swipes

NOTE: Appropriate swipe materials and sizes to be used for the collection of surface area samples, along with the number of swipes that should be taken, are selected based on requirements included in the Sample Collection Plan (SCP).

7.1. Dry Swipes

7.1.1. Measure or determine by observation the total surface area to be sampled, and record the area on the Field Sample Logbook.

7.1.2. Using a large area swipe [e.g., at most 300 cm^2 (48 $inches^2$)], [s]wipe the surface area in parallel strokes. Place the swipe into a glassine envelope or bag, and place a sample label on the envelope or bag.

7.1.3. Using a small area swipe [e.g., 25 cm^2 (4 $inches^2$) disc or square], [s]wipe the surface in one continuous stroke of approximately 40 cm in length (16 inches), or a 10 x 10 cm (4x 4 inches) square area, so that an area of approximately 100 cm^2 is sampled. An "S" pattern, or moving from one edge to the other without overlap, is the preferred method. Place the swipe into a glassine envelope or bag, and place a sample label on the envelope or bag.

7.1.4. Proceed with 7.4 (Swipe Handling).

7.2. Wet Swipes

7.2.1. Measure or determine by observation the total surface area to be sampled, and record the area on the Field Sample Logbook.

7.2.2. Dampen either a large area or small area swipe with the solvent fluid prescribed by the SCP. DO NOT soak the swipe. If necessary, allow the swipe to dry slightly before use.

7.2.3. If a volatile solvent is used, proceed with speed to prevent evaporation of the solvent.

7.2.4. [S]Wipe the area per the procedures described in Section 7.1 (Dry Swipes) for either large area or small area swipes.

7.2.5. Proceed with 7.4 (Swipe Handling).

7.3. Tape Swipes

NOTE: Tape swipes are typically collected for field screening and are not intended for transport to and analysis in the laboratory. When analyzed for radioactivity, the glue side of the tape must face the detector, because the paper backing of the tape will attenuate any alpha particles.

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7.3.1. Measure or determine by observation the total surface area to be sampled, and record the area on the Field Sample Logbook.

7.3.2. Create a tape swipe by laying successive strips of 5 cm (2 inches) duct tape sufficient to collect an area of 100 cm^2 (16 $inches^2$) or less. The edges of the tape should be folded over or covered with tape to prevent them from sticking to the surface of the object. This will create a "picture frame" around the actual sample.

7.3.3. Lay the tape swipe onto the surface to be sampled and press down over the sample area.

7.3.4. Carefully remove the tape and cover the exposed area with a piece of plain paper.

7.3.5. Place the swipe in a plastic bag or envelope. A sample label is to be placed on the bag or envelope.

7.3.6. Proceed with Section 7.4 (Swipe Handling).

7.4. Swipe Handling

7.4.1. Exit the sampling area using proper techniques to minimize the spread of contamination.

7.4.2. Record the required information on the Field Sample Logbook, Field Sample Tracking Form, and the sample label(s). The following information is to be included at a minimum:

- SIC (Sample Identification Code)
- Time and date sample collected
- Sample location
- Sample area collected
- Percent of total area (calculated from surface area recorded in the Field Sample Logbook)
- Sampler's initials

7.4.3. Place a sample label on the container.

7.4.4. Once outside of the area and back at an appropriate location, process the sample for direct reading by Radiation Protection Personnel or, if required in the SCP, for transport per the requirements of Module I, Section 7.0 (Sample Packaging and Transport).

ISO

ISO 7503 contains the following guidelines on swipe sampling:

Detection and evaluation of surface contamination can be carried out using one or more dry or wet smear [swipe] samples. When taking smear [swipe] samples from large areas, the following points shall be taken into consideration to determine the distribution of contamination:

a) If possible, the area to be smeared [swiped] shall measure 100 cm^2;
b) Where regulations permit the averaging of the surface contamination over larger areas, such areas may be used for sampling and shall be included in the calculation of the result;
c) The smear [swipe] material should be chosen to suit the surface to be checked (for example, filter paper for smooth surfaces, cotton textile for rough surfaces);
d) If a wetting agent is used for moistening the smear [swipe] material, this wetting agent should not exude from the material; WARNING: since the contamination may be absorbed into the structure of the smear [swipe] material or may be covered by residual moisture, the use of a wetting agent may lead to a significant underestimation of the contamination in the case of alpha-emitters;
e) The smear [swipe] should be pressed moderately against the surface to be checked, using fingertips or, preferably, by means of a holder which is designed to ensure uniform and constant pressure;
f) The entire area of 100 cm^2 shall be smeared [swiped];
g) If possible, circular filter papers should be used as the smear [swipe] material;
h) The contaminated area of the smear [swipe] sample shall be smaller than or equal to the sensitive area of the probe;
i) After sampling, the smear [swipe] material shall be carefully dried in such a way that loss of activity is prevented.

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CFR

10 CFR 835 Appendix D—Surface Contamination Values—contains the following:

The data presented in Appendix D are to be used in identifying and posting contamination and high-contamination areas[22] in accordance with § 835.603(e) and (f) and identifying the need for surface contamination monitoring and control in accordance with § 835.1101 and 1102.

Surface Contamination Values[1]

Radionuclide	Removable (dpm/100 cm^2) [2, 4]	Total (Fixed + Removable) (dpm/100 cm^2) [2, 3]
U-nat, U-235, U-238, and associated decay products	1,000 [7]	5,000 [7]
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	20	500
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	200	1,000
Beta-gamma-emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above [5]	1,000	5,000
Tritium and STCs [6]	10,000	[6]

[1] The values in this appendix, with the exception noted in [note] 6 below, apply to radioactive contamination deposited on, but not incorporated into the interior or matrix of, the contaminated item. Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides apply independently.

[2] As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[3] The levels may be averaged over one square meter provided the maximum surface activity in any area of 100 cm^2 is less than three times the value specified. For purposes of averaging, any square meter of surface shall be considered to be above the surface contamination value if: (1) from measurements of a representative number of sections it is determined that the average contamination level exceeds the applicable value; or (2) it is determined that the sum of the activity of all isolated spots or particles in any 100 cm^2 area exceeds three times the applicable value.

[4] The amount of removable radioactive material per 100 cm^2 of surface area should be determined by swiping the area with dry filter or soft absorbent paper, applying moderate pressure, and then assessing the amount of radioactive material on the swipe with an appropriate instrument of known efficiency. (Note - The use of dry material may not be appropriate for tritium.) When removable contamination on objects of surface area less than 100 cm^2 is determined, the activity per unit area shall be based on the actual area and the entire surface shall be [s]wiped. It is not necessary to use swiping techniques to measure removable contamination levels if direct scan surveys indicate that the total residual surface contamination levels are within the limits for removable contamination.

[5] This category of radionuclides includes mixed fission products, including the Sr-90 which is present in them. It does not apply to Sr-90 that has been separated from the other fission products or mixtures where the Sr-90 has been enriched.

[6] Tritium contamination may diffuse into the volume or matrix of materials. Evaluation of surface contamination shall consider the extent to which such contamination may migrate to the surface in order to ensure the surface contamination value provided in this appendix is not exceeded. Once this contamination migrates to the surface, it may be removable, not fixed; therefore, a "Total" value does not apply. In certain cases, a "Total" value of 10,000 dpm/100 cm^2 may be applicable either to metals of the types from which insoluble special tritium compounds are formed, that have been exposed to tritium, or to bulk materials to which insoluble special tritium compound particles are fixed to a surface.

[7] These limits apply only to the alpha-emitters within the respective decay series.

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[22] *Contamination area* means any area, accessible to individuals, where removable surface contamination levels exceed or are likely to exceed the removable surface contamination values specified in Appendix D of this part, but do not exceed 100 times those values. *High contamination area* means any area, accessible to individuals, where removable surface contamination levels exceed or are likely to exceed 100 times the removable surface contamination values specified in Appendix D of this part. (10 CFR 835.2)

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