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DOE-HDBK-1216-2015

DOE HANDBOOK

Environmental Radiological Effluent Monitoring and Environmental Surveillance

U.S. Department of Energy **AREA ENVR**

Washington, D.C. 20585

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FOREWORD

Effluent monitoring and environmental surveillance of radioactive materials are a continuing major part of the radiological protection programs at Department of Energy (DOE) sites. The purpose of this Handbook is to identify procedures, systems, methods, instruments and practices that may be used to plan and implement radiological effluent monitoring and environmental surveillance that meet the requirements in DOE Order (O) 458.1, *Radiation Protection of the Public and the Environment*. Effluent monitoring and environmental surveillance activities, like other DOE activities, present risks and hazards that need to be considered in planning the work. The focus of this document is on the sampling, monitoring and analysis activities and although not addressed in detail in this Handbook, appropriate job hazard analyses are necessary to ensure worker safety.

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1 INTRODUCTION

The Department of Energy's (DOE) environmental and public radiation protection framework is principally contained in DOE Order (O) 458.1, *Radiation Protection of the Public and the Environment.* This Handbook describes elements that may be used to implement the radiological effluent monitoring and environmental surveillance requirements in DOE O 458.1. The Handbook can be used by all DOE elements, including the National Nuclear Security Administration (NNSA), and their contractors to support implementation of DOE O 458.1. The information in this Handbook may also be useful in developing plans and programs for other DOE activities that require monitoring to comply with requirements. Many of the principles described herein may also be of use in designing the non-radiological portions of an integrated environmental monitoring or environmental surveillance program.

This Handbook is not a "requirements" document and may not be considered as requirements in any audit or assessment of compliance with associated Policy, Order, Notice, or Manual. This Handbook updates information contained in *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (DOE/EH-0173T, 1991).

1.1 Objectives

The objectives of this Handbook are to:

- Assist DOE elements in establishing and maintaining effective environmental monitoring activities: to measure radionuclide releases for DOE activities; characterize the radiological condition of the environs on and around DOE activities; and support assessment of potential public exposure through available pathways (e.g., air, water, soil, and biota);
- Provide information on appropriate methods for sampling and analyzing effluent and environmental media for radionuclides of interest; and
- Present information on appropriate methods for performing data assessments and statistical analyses.

1.2 Environmental Monitoring

Environmental monitoring is the collection and analysis of samples or direct measurements of environmental media. For the purposes of DOE O 458.1, "Environmental Monitoring" includes, but is not limited to effluent monitoring, environmental surveillance, meteorological monitoring, and pre-operational monitoring.

Environmental monitoring is a necessary part of characterizing routine and non-routine releases of radioactive materials from DOE operations, evaluating the distribution of the releases to the environs, and determining the potential pathways of exposure to members of the public to demonstrate compliance with the public dose limit cited in DOE O 458.1.

Effluent and environmental monitoring should start prior to the commencement of site or facility operations and continues for the entire operational phase. Sampling and analyses of effluent releases and environmental pathways are performed on a periodic basis (e.g., weekly, monthly, quarterly, annually) or when additional information is necessary to verify compliance. Therefore, temporal and spatial variations in the concentrations of the analyte(s) of interest are important to evaluate potential effects on environmental pathways, and the eventual dose to members to the public.

Environmental monitoring should be commensurate with the radiological activities at the site and adapted to unique physical, geological, hydrological, and meteorological characteristics. Environmental monitoring should include: sampling points located on prioritized areas of the site that are particularly susceptible to contamination and represent the contaminant pathway into the environment; sample collection that reflects specific facility needs (type and frequency of sampling); sample analysis protocols that are approved by appropriate regulatory agencies; monitoring data recordkeeping; and data assessment and quality assurance mechanisms to demonstrate the validity of the data.

The overall objective of environmental monitoring is to demonstrate that discharges are at safe planned levels, identify trends and anomalies, and provide early detection of unplanned releases to the environment. In the event of an unplanned release, environmental monitoring is designed to trigger a response according to the site contingency plan and to provide sufficient data to characterize the release.

1.3 Key Requirements and Supporting Documents

DOE O 458.1, *Radiation Protection of the Public and the Environment*, contains requirements for protecting the public and the environment by establishment of the Public Dose Limit. One way DOE sites can demonstrate compliance with the Public Dose Limit is through environmental monitoring. DOE O 458.1 requires that environmental monitoring be conducted to: (1) characterize routine and non-routine releases of radioactive material from radiological activities; (2) estimate the dispersal pattern in the environs; (3) characterize the pathway(s) of exposure to members of the public; and (4) estimate the doses to individuals and populations in

the vicinity of the site or operation commensurate with the nature of the DOE radiological activities and the risk to the public and the environment. Site-specific environmental monitoring criteria need to be established to ensure that representative measurements of quantities and concentrations of radiological contaminants are conducted and that the effects from DOE radiological activities on members of the public and the environment are monitored sufficiently to demonstrate compliance. DOE O 458.1 also requires that DOE sites perform dose evaluations to demonstrate compliance with the public dose limit and to assess collective dose.

DOE O 231.1B, *Environment, Safety and Health Reporting*, requires that annual site environmental reports include information on: (1) effluent releases; (2) environmental monitoring; (3) types and quantities of radioactive materials emitted or discharged; (4) total effective dose and collective dose; (5) where it is of concern, radon and its decay products; and (6) property clearance activities.

DOE O 232.2, *Occurrence Reporting and Processing of Operations Information*, includes reporting criteria pertinent to DOE O 458.1 for the following: releases of radionuclides from a DOE facility; spread of radioactive contamination; and radiation exposure.

DOE-STD-1196-2011, *Derived Concentration Technical Standard*, supports the implementation of DOE O 458.1 and supersedes the Derived Concentration Guides for Air and Water contained in DOE Order 5400.5. DOE-STD-1196-2011 establishes Derived Concentration Standards (DCS) values that reflect the current state of knowledge and practice in radiation protection.

DOE-STD-1153-2002, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*, provides practical screening and analysis methods that can be used to demonstrate compliance with the DOE O 458.1 requirements for protection of biota.

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2 DESIGNING, REVIEWING, AND DOCUMENTING RADIOLOGICAL ENVIRONMENTAL MONITORING PROGRAMS

The impact on the surrounding environment (i.e., on-site and off-site) is measured, documented, evaluated and responded to in environmental monitoring programs. Appendix B of this Handbook identifies lines of inquiry. A lines of inquiry approach is provided to: conduct self-assessments; verify that the program is effective and in compliance with appropriate requirements; and ensure the existence of continuous improvement of the program.

2.1 Designing an Environmental Monitoring Program

According to DOE O 458.1, DOE or DOE contractors conducting radiological activities must develop and implement a documented Environmental Radiological Protection Program (ERPP). The ERPP is a composite of plans, procedures, protocols, and other documents describing the methods used to achieve compliance with DOE O 458.1. The environmental monitoring program should be flexible and use a graded approach for monitoring activities. A graded approach allows the degree of planning, the scope of programs, and the level of detail in documentation to be tailored to the particular radiological activities at a site and to be commensurate with the risk to the public and the environment associated with DOE operations. The graded approach allows the environmental monitoring program to be modified as necessary to include newly identified potential pathways of exposure. Additionally, the graded approach may provide flexibility for excluding pathways of exposures not present or considered to be an insignificant contributor at a site.

A comprehensive environmental monitoring program includes mechanisms to assess the impact to the site and the environs. The comparison reference for assessing environmental impact is obtained during the pre-operational phase.

In general, the environmental monitoring program should: (1) demonstrate compliance with applicable requirements; (2) confirm adherence to DOE environmental and radiation protection policies and directives, and (3) support of environmental management decisions. Other specific objectives of the environmental monitoring program include, but are not limited to:

- Collecting data for characterizing the pre-operational radiological condition of the site;
- Determining background levels and site contributions of radionuclides in the environment;

- Supporting the assessment of radiological doses to the public and biota from DOE operations;
- Providing data to support preparation of an annual site environmental report (ASER);
- Identifying and reporting alarm levels and potential doses exceeding DOE reporting limits;
- Determining long-term accumulation of site-related radionuclides in the environment and predicting trends;
- Determining the effectiveness of treatment and controls in reducing effluents and emissions;
- Determining the validity and effectiveness of models used to predict the concentration of radionuclides and their movement in the environment;
- Detecting and quantifying unplanned releases;
- Evaluating the effectiveness of remedial actions;
- Evaluating and quantifying radionuclide transport into the environment; and
- Identifying and quantifying existing or new environmental quality concerns.

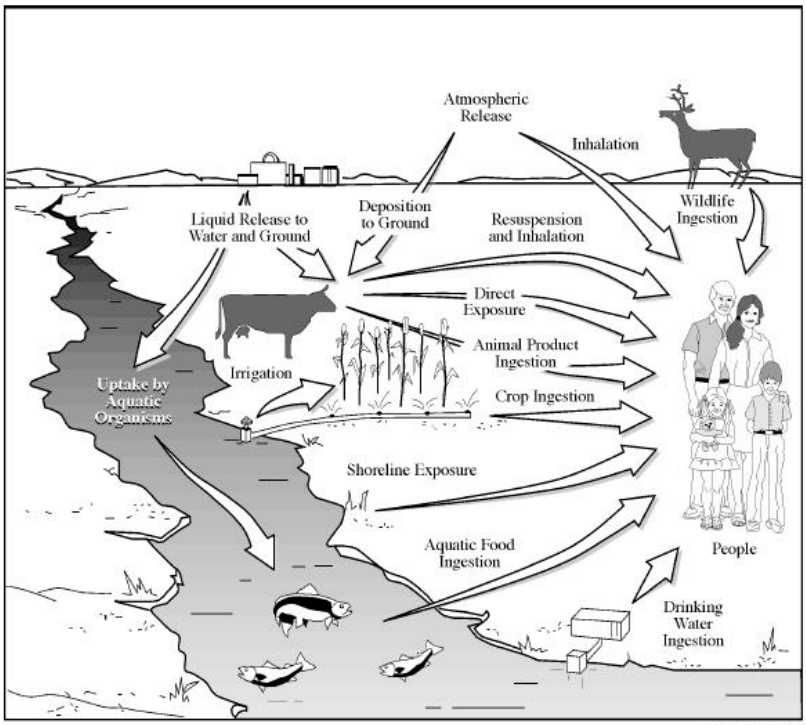

FIGURE 2-1. Potential Radiation Exposure Pathways to Man

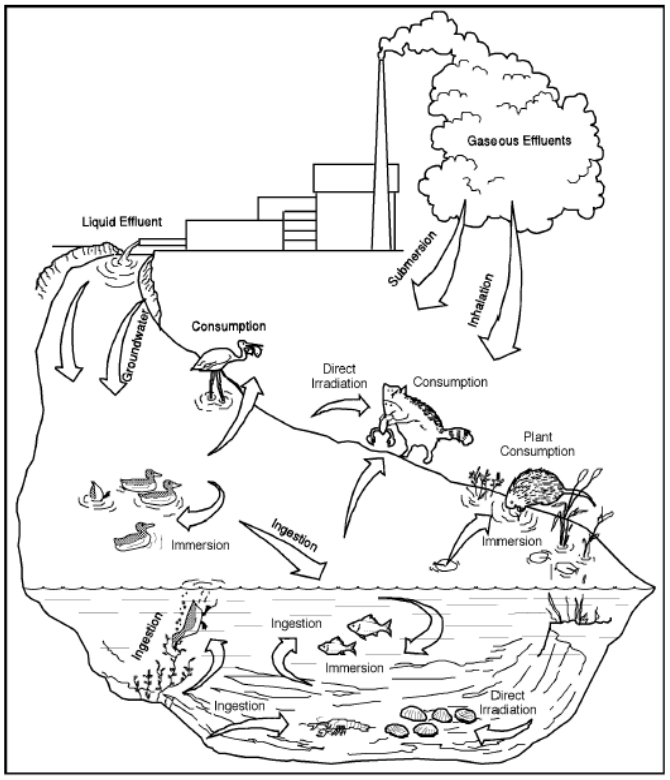

FIGURE 2-2. Potential Radiation Exposure Pathways to Biota

The gaseous and liquid effluent monitoring activities for all media may be included in a site's environmental monitoring plan or in other appropriate documentation. Some sites develop independent facility effluent monitoring plans. The determination to develop independent effluent monitoring plans is based on an initial evaluation of potential radioactive material sources within a facility. If a significant quantity of releasable radioactive material is present in a specific location, then a plan may be prepared for that facility. The effluent monitoring plan should include radiological material inventories; discussions on source-term identification and characterization for each effluent stream; identification and characterization of fugitive sources (if applicable); release pathways; and effluent points of discharge.

Facility-specific effluent monitoring plans are focused on the "major" sources of effluents located on the site which are sources that, if uncontrolled, may release radionuclides sufficient to cause a dose of 1 percent of the 10 mrem in a year air pathway dose limit (40 CFR Part 61). Therefore, effluent monitoring plans should be prepared for any facility having the potential to release quantities of airborne radioactive materials that could cause a total effective dose in excess of 0.1 millirem (mrem) per year to the maximally exposed individual (MEI).

The environmental monitoring program should be designed to allow the identification of major releases or migration of radionuclides, pathways of exposure, sampling locations, and data trends over time. Samples should be collected and analyzed from areas near the operational activities and effluent release points; areas within the site boundary where radioactive material may accumulate due to air or water dispersion; and areas beyond the site boundary where members of the public may be exposed to radioactive materials. Environmental monitoring includes monitoring ground water, water impoundments, runoff water, soil, sediment, food, and biota sources that potentially may be affected by site operations. The sampling frequency for environmental media and the mechanisms used to determine compliance with the public dose limits should be described in the environmental monitoring program. Statistical analyses may be performed to identify abnormalities or changes over time. These analyses may lead to the collection of additional samples or remediation activities.

2.2 Reviewing the Environmental Monitoring Program

As part of the environmental monitoring program maintenance, a radiological pathway analysis and exposure assessment should be performed at a periodic frequency determined by the level of significance of the potential effluents and how often there are changes in the program or mission(s) of the site. The pathway analysis should be based on source term data and on the comprehensive pathway and dose assessment methodology used for estimating radiation doses to the public and the environment from site operations. The results of the pathway analysis and exposure assessment should serve as a basis for future years' environmental monitoring program design. Environmental and food-chain pathways are monitored near facilities releasing effluents and at potential offsite receptor locations. Figure 2-1 and Figure 2-2 illustrate the identification of potential pathways of radiation exposure to humans and biota, respectively.

The design of the environmental monitoring program should be reviewed periodically along with planned waste management and environmental restoration activities, including decontamination and decommissioning (D&D) activities. The need for changes in the effluent monitoring program or surveillance monitoring should be evaluated continuously in response to changes in operations, environmental conditions and/or land use. Input from local residents, including Native American tribes and other stakeholders, needs to be considered in the final monitoring program design. The final sampling design and schedule should be documented and updated periodically as necessary.

2.3 Updating the Environmental Monitoring Program

As the needs and requirements of the environmental monitoring program change, the design of the program has to change. Site-specific information on radiation source dispersion patterns, location and demography of members of the public in the vicinity of DOE radiological activities, land use, food supplies, and exposure pathway information should be updated, as necessary, to document significant changes that could affect dose evaluations.

Site organization representatives should discuss proposed updates of the environmental monitoring program. Updates should consider the input of personnel from environmental monitoring, radiation protection, operations, planning and scheduling, budget, site strategy, security, laboratory analyses, and any other organization that could contribute information on proposed site activities during the next 1 to 5 years. The environmental monitoring program updates should also consider the potential impact on the overall site budget. The shifting and sharing of resources (e.g., equipment and personnel) may be part of the planning and necessary to maintain the adequacy of the environmental monitoring program.

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3 LIQUID RADIOLOGICAL EFFLUENT MONITORING AND SAMPLING

Liquid radiological effluent monitoring and sampling is performed as part of the overall environmental monitoring for a site. This can be accomplished using either monitoring or sampling systems or a combination of both. In the context of this chapter of the Handbook, "monitoring" is active, essentially real-time monitoring using a detection system to characterize the liquid effluent. "Sampling" is the collection of samples from the effluent for analysis by a laboratory; additionally, screening can be performed in the field with less sensitive instrumentation.

All liquid effluents from DOE facilities should be evaluated and their potential for release of radionuclides assessed. Liquid effluents from DOE facilities that have the potential for radioactive discharges should be monitored in accordance with DOE O 458.1. Monitoring results should be documented (e.g., in the ASER, monitoring reports, etc.). The liquid radiological effluent monitoring program should be integrated with monitoring for non-radiological effluents and environmental surveillance when possible.

As necessary, the following elements should be documented for all liquid effluent monitoring programs:

- Sampling locations used for providing quantitative effluent release data for each outfall;
- Procedures and equipment used to perform the extraction and measurement;
- Frequency and analyses required for each extraction (continuous monitoring and/or sampling location);
- Minimal detectable activity (MDA) and uncertainty for equipment used for measurements;
- Quality Assurance (QA) components; and
- Effluent outfall alarm settings and technical bases.

Appendix B of this Handbook identifies lines of inquiry. A lines of inquiry approach is provided to conduct self-assessments; to verify that the program is effective and in compliance with appropriate requirements; and to ensure the existence of continuous improvement of the program.

3.1 Key Requirements

DOE O 458.1*, Radiation Protection of the Public and the Environment*, establishes requirements for control and management of radionuclides from DOE activities in liquid discharges (see DOE O 458.1, paragraphs 4.g (1) - (11)). Operators of DOE facilities discharging or releasing liquids are required to characterize planned and unplanned releases of liquids containing radionuclides from DOE activities, consistent with the potential for on- and off-site impacts, and provide an assessment of radiological consequences as necessary to demonstrate compliance with the requirements of the Order.

3.2 Summary of General Criteria and Monitoring Program Needs for Liquid Effluents

Operators of DOE facilities should provide monitoring of liquid effluents to: (1) demonstrate compliance with the applicable requirements of DOE O 458.1; (2) quantify radionuclides released from each discharge point; and (3) alert affected personnel of accidents/malfunctions/ disruptions in processes and emission controls. Criteria in Table 3-1 can be used to guide development of the liquid radiological effluent monitoring program at the site.

> Tritium in liquid effluents is a potential issue for some DOE sites. DOE recognizes there is no practical treatment method for removal of low concentrations of tritium, and that it is difficult to detect at low concentrations with a continuous monitoring system. It is necessary, however, that process alternatives be reviewed to ensure that tritium releases are ALARA. Tritium in liquid effluent streams represents an important exemption to the DOE BAT selection process.

Continuous radionuclide monitoring should be provided within the effluent stream to estimate radionuclide discharges at release points that could contain radionuclides in concentrations that are a significant fraction of, or exceed, the Derived Concentration Standard (DCS) (averaged over one year) (See Table 3-1). The recommendations in Table 3-1 are generally applicable to process streams but may not be appropriate for intermittent or low-flow streams where potential for exposure is low; in such cases, alternatives such as periodic grab sampling may be appropriate irrespective of the concentration. For non-routine releases, continuous monitoring should be considered when unplanned or unanticipated releases to the environment could cause the effluent stream annual average concentration to exceed the DCS and could produce

potential doses to a likely receptor from the uncontrolled releases that exceed 100 mrem or a significant fraction thereof.

TABLE 3-1. Recommended Criteria for Liquid Radiological Effluent Monitoring

Derived Concentration Standards (DCS) Sum-of-fractions	*And*	*Potential Annual Dose from Exposure to a Likely Receptor (mrem)*	*Minimum Criteria for Liquid Radiological Effluent Monitoring*
≥ 1		--	1. Apply BAT to reduce effluent releases (except ^{3}H) 2. Use continuous monitoring/sampling, but where effluent streams are low flow and potential public dose is very low, (<<1 mrem in a year) alternative sampling approaches may be appropriate.
≥ 0.01 to 1		>1	1. Continuously monitor or sample 2. Identify radionuclides contributing ≥ 10 percent of the dose 3. Determine accuracy of results (± percent accuracy and percent confidence level)
≥ 0.001 to 0.01		< 1	1. Monitor using a graded approach to select the appropriate method and duration 2. Identify radionuclides contributing ≥ 10 percent or more of the dose 3. Assess annually the facility inventory and potential for radiological effluent release
< 0.001		--	1. No monitoring required 2. Evaluate annually the potential for liquid radiological effluent release

Continuous sampling (with frequent analysis) may be used in lieu of continuous monitoring if radioactive materials in the effluents are not detectable by state-of-the-art continuous monitoring devices. The monitoring efforts for liquid effluents should be commensurate with the release potential of the sources during routine operations and with the impacts of potential accidents on the potential contribution to public dose or to the contamination of the environment. When continuous monitoring or continuous sampling is provided, the overall accuracy of the results should be determined (± % accuracy and the % confidence level) and documented.

The detection limits of the continuous monitoring system (e.g., lower limit of detection (LLD), minimum detectable activity (MDA) or minimum detectable concentration (MDC)) should be stated in the Environmental Monitoring Plan or equivalent environmental monitoring documentation. The LLD and the associated MDC or MDA should be sufficient to ensure that analyses necessary to comply with the reporting requirements of DOE O 458.1 can be completed.

Additionally, provisions for monitoring liquid effluents during an emergency should be considered when determining routine liquid effluent monitoring program needs. Emergency liquid effluent monitoring systems and procedures should be specified in the site/facility Emergency Response Plan.

3.3 Performance Standards for Liquid Effluent Monitoring Systems

The selection or modification of a liquid effluent monitoring and sampling systems should be based on a careful characterization of: (1) the sources, (2) contaminants (characteristics and quantities); (3) sample-collection systems (if applicable); (4) treatment systems; and (5) final release points of the effluents.

Pre-operational assessments should be conducted and documented for all new or modified facilities where liquid effluent and monitoring or sampling system characteristics could be affected. These assessments should document the types and quantities of liquid effluents expected from the facility and establish the associated effluent monitoring needs of the facility.

The actual or potential presence of radionuclides and chemical and physical properties that could affect performance of the sampling or monitoring equipment should be identified.

The performance of the effluent monitoring systems should be sufficient to determine whether effluent releases of radioactive material are within the values contained in DOE-STD-1196-2011, and to calculate doses that will demonstrate compliance with DOE O 458.1 limits and constraints. LLDs of the analysis and associated MDCs or MDAs for the monitoring systems should be sufficient to demonstrate compliance with all applicable requirements consistent with the characteristics of the radionuclides that are present or expected to be present in the liquid effluent.

3.3.1 Continuous Monitoring/Sampling

For those effluent streams requiring continuous monitoring/sampling, all data received from the continuous monitoring system should be used when performing statistical analyses. In the case of discharge points releasing radionuclides emitting alpha or weak beta radiation, with no documentable ratios to beta and/or gamma emitters that could be used as indicator radionuclides (i.e., where it is not technologically feasible to monitor continuously), continuous proportional sampling and analysis can be used as an alternative to continuous monitoring. However, the consideration of new technologies to continuously monitor such effluent streams is encouraged.

3.3.2 Sampling Systems

Sampling systems should be sufficient to: (1) collect representative samples that provide for an adequate record or timeline of facility releases; (2) predict trends; and (3) quantify releases.

3.3.3 System Calibration

Continuous monitoring and sampling systems should be calibrated before use and recalibrated any time they are subject to maintenance, modification, or system changes that could affect equipment calibration. Monitoring and sampling systems should be recalibrated at least annually and routinely checked with known sources to determine that they are consistently functioning properly. Proper functioning of the monitoring or sampling system should be verified before a facility is placed in operation.

A redundant monitoring system may be used if necessary to provide adequate sampling capabilities and prevent delays in process operation. Alternatively, one of the following options could be used to permit continued monitoring during replacement or servicing of the system: (1) a substitute sampling method that provides the capabilities, or (2) an alternate method for estimating releases when the system is not capable of operating.

3.3.4 Environmental Conditions

Environmental conditions (e.g., temperature, humidity, radiation level, dusts, and vapors) should be considered when locating liquid effluent monitoring and sampling systems to avoid conditions that could influence the operation of the system, including unusual operational impacts. At sample collection points, the ambient dose rate originating in the effluent line and the sampling apparatus should be evaluated for compliance with shielding and contamination control

requirements necessary to reduce worker exposure. Components of the sampling system should be replaced if they become contaminated (to the point where the sensitivity or reliability of the system is affected) with radioactive materials or if they become ineffective in meeting the design basis within the established accuracy/confidence levels.

3.4 Sampling System Design Criteria

Reliable quantification of radionuclides in liquid effluent streams requires representative sampling, which in turn requires: (1) consideration of stream flow rate and variability; (2) sample port and collector design; (3) delivery system reliability; (4) effluent stream chemical and biological characteristics; and (5) the need for sample preservation.

3.4.1 Selection Criteria for Liquid Effluent Monitoring and Sampling Systems

Detection of radionuclides in liquid effluents can be performed using either: (1) continuous monitoring systems, or (2) sampling systems. Selecting and designing an appropriate monitoring or sampling system for a facility should include consideration of the purpose, types and levels of expected radionuclides in the effluent, potential background dose rates, expected duration of releases, and environmental effects of the expected radionuclides.

One of the main reasons to use a continuous monitoring system is its ability to provide a prompt signal if a significant release occurs.

Continuous monitoring systems can either be in-line, where a radiation detector is placed in the effluent stream, or off-line, where a portion of the effluent is extracted and run by the detector. Continuous monitoring systems generally are limited to direct detection of gamma-emitting radionuclides with sufficient gamma energy to penetrate the effluent stream and reach the detector. Gross beta measurement may be possible using thin, plastic scintillator detectors. The ambient external dose rate from the effluent stream should be considered.

Moderate dose rates may require system shielding, while high dose rates may prevent use of an in-line system and require use of a remote, shielded off-line monitor. NCRP (2010) identifies currently available types of in-line monitoring equipment.

If the primary purpose of the monitoring system is to alert operating personnel to significant unplanned increases in gamma-emitting radionuclides in the liquid effluent, then in-line monitoring may be preferred. A combination of in-line and off-line monitoring may be needed to accommodate both routine and emergency monitoring. An off-line continuous monitoring

system requires consideration of some of the same criteria used for sampling systems because of the extraction (sampling) of a portion of the effluent stream for monitoring.

If there are well-known and documented ratios of strong gamma-emitters to weak beta-gamma or alpha-emitting radionuclides then continuous monitoring systems can be used to indirectly detect these radionuclides. Follow-up sampling and associated radioanalysis should be conducted to verify and document the radionuclide release.

Sampling systems can be used to quantify beta and alpha-emitting radionuclides as well as strong and weak gamma-emitters. Sampling and analysis takes longer than monitoring but provides LLDs and more definitive and quantitative information.

There are four basic types of liquid effluent sampling systems:

- *Continuous sampling* – samples are collected continuously at a known, uniform rate; appropriate for taking samples at a constant rate from effluents that have near constant flow (i.e., flow that does not vary by more than 50 percent).
- *Flow proportional sampling* – a known fraction of the effluent is collected at defined volume intervals for laboratory analysis; appropriate for obtaining representative samples from streams with fluctuating flow rates or radionuclide concentrations.
- *Time proportional sampling* – used when a stream flow rate is relatively constant so that effluent streams are sampled by taking timed aliquots, which are analyzed in the laboratory; suitable for quantifying uniformly low concentrations of radionuclides being released via effluent lines to the environs.
- *Periodic (grab) sampling* – samples of effluent streams are taken periodically, composited if desired, and submitted for laboratory analysis; suitable for ensuring that previously determined release rates have not changed significantly or that radionuclides are not being introduced into the previously non-radioactive liquid effluent being sampled.

3.4.2 General Design Criteria for Sampling Systems

The following should be considered when operating a liquid effluent sampling system:

- Location of sampling and monitoring systems;
- Use of a pump in areas where necessary to provide a uniform continuous flow in the main sample line;

- Location of sample ports in liquid effluent lines sufficiently far downstream from the last feeder line to allow complete mixing (as complete as possible) of liquid and design of the sample port to allow intake of a proportional part of the liquid effluent stream;
- Capability to determine the effluent stream and sample-line flows within an accuracy of at least ±10 percent; and
- Design of the system to minimize deformation and sedimentation and to prevent freezing of effluent sample lines.

3.4.3 Stream Flow Characteristics

Variability in the flow rate of liquid effluents may be the most significant factor in sample calculations. Therefore, continuous measurement and recording of effluent flow rate should be performed. If continuous monitoring or determination of the effluent flow rate is directed by the criteria in Table 3-1 but is not feasible for a specific effluent stream, the extenuating circumstances and justification for not doing it should be documented. Liquid effluent flow rates should be measured with an uncertainty of no more than 10 percent and recorded. A variety of measuring devices are available for measuring flow rates, such as V-notch weirs or ultrasonic or turbine flow meters.

Very little accuracy is gained from using flow proportional sampling systems where effluent streams having near constant continuous flow. Continuous constant rate sampling (sampling continuously over regular time intervals) is more reliable and simpler. Thus, time proportional (rather than flow proportional) sampling is recommended for near constant, continuous flow effluent streams (i.e., flow that does not vary by more than 50 percent). Constant rate sampling may also be used for intermittent effluent streams when during the time the streams flow the discharge rate is constant and known.

3.4.4 Sampling Locations

The sampling ports should be located in accessible sections of the liquid effluent lines sufficiently far enough downstream from the last feeder line to allow liquid mixing to be as complete as possible. When appropriate, design sample ports to allow proportional effluent sampling. If proportionality cannot be automated, both the effluent and sample flow rates should be measured, with the capability to determine the effluent stream and sample-line flows within an uncertainty of no more than ± 10 percent.

3.4.5 Delivery Lines

For buried pipe or pressurized lines, maintain the integrity of the junction of the liquid effluent sample line with the sampling port by considering expansion and contraction of the liquid effluent lines due to thermal loading variation. Design for such a junction should consider either line scrubbers or special fabrications to handle the added mechanical stress.

3.4.6 Liquid Movers

A constant volume sampling pump should be used to maintain a uniform continuous flow in the main sample line, unless sufficiently high and constant hydraulic pressure exists within the effluent system. Removal of the sample from the liquid effluent line where a sampling pump is required should be accomplished using a constant-volume pump that will maintain a constant flow, regardless of line pressure changes.

3.4.7 Sample Collectors

The collector portion of the sampling system should be designed to allow for the collection of a sample that is consistent with the method of analysis. For example, if the effluent stream has a small flow, a small container might be used to obtain a grab sample that is counted directly in the laboratory. If concentration of the sample is necessary, a large volume sample is required. If the collection system requires measured aliquots taken sequentially every few minutes, then both the frequency and required sensitivity of analysis have an impact on the size of the container to be used. The return sample line (after the sample collection) should be routed back to either the effluent line or a waste treatment system. Location of the sample collection system can be based in part on the sample return line.

3.4.8 Special Considerations for Liquid Effluent Monitoring and Sampling Systems

The following special conditions should be considered when designing and operating a liquid effluent monitoring or sampling system for a DOE facility:

- Effluent lines are frequently buried in soil, which creates accessibility problems for monitoring and sampling unless special provisions are considered in the discharge system design;
- Effluent monitoring and sampling system lines and components should be designed to be compatible with the chemical and biological nature of the liquid effluent;

- Biological growths can cause sample line flow restrictions. Biological growth around or within a sampling/monitoring system can plug or distort sampling orifices and equipment. If biocides are used, they should be selected and applied so as not to interfere with the sampling and analytical processes;
- Effluent lines often move or are stressed mechanically;
- The system should be designed to minimize deformation and sedimentation and to prevent freezing of the sample lines. For example:
  - Sampling heads can be placed above the streambed where sedimentation issues are less problematic, and
  - Sampling heads with strainers may further reduce problems;
- Large fluctuations in effluent flow rates are common, especially during a rain storm incident or flood which in turn affect the accuracy of the measurement results;
- Sample collection may require extra precautions (e.g., pre-coating sample containers);
- Effluent velocity and corrosion can significantly affect in-line sampling or monitoring probes;
- Effluent monitoring systems and procedures should be designed to identify and quantify the full range of potential accidental releases as well as those from normal operating conditions;
- Small volume wastes are easier to collect in batch tanks, lending themselves to grab sampling and analysis before release. When batch tanks are used for collecting liquid effluents before release to the environment, these factors should be considered:
  - Adequate mixing of the sampled volume to ensure that liquids in the tank are homogeneous for sample withdrawal;
  - Recirculation of tank liquid through the sample lines so that he sample is representative; and
  - Frequent checks for residual liquid or sludge accumulation as needed; and
- Components of the monitoring system should be readily accessible for maintenance.

3.4.9 Environmental Considerations

The external environment surrounding the sampling system and effluent lines needs to be considered. The sampling system should be protected from adverse environmental factors including unusual operational impacts. At sample collection points, the ambient dose rate originating in the effluent line(s) and the sampling apparatus should be evaluated for compliance

with shielding and contamination control requirements necessary for reducing worker exposure. Components of the sampling system should be readily accessible for maintenance.

3.5 Monitoring System Design Considerations

Design considerations for liquid effluent monitoring systems should include the purpose of the monitoring, the types and levels of expected radionuclides, potential background dose rates, expected duration of releases, and environmental effects. One of the primary purposes of using a monitoring system is to utilize its ability to provide a prompt signal if a significant release occurs. Therefore, responsible personnel should continuously monitor the output signal from monitoring systems. In addition, written response procedures should be provided to describe the actions that responsible personnel need to take if an abnormal signal is detected. The output signal instrumentation, monitoring system recorders, and alarms should be in a location that is continuously monitored or occupied by operations or security personnel.

3.5.1 Monitoring Purposes

An unshielded in-line monitoring system should be sufficient to quantify the gamma-emitting radionuclides in the liquid effluent line, if low ambient dose-rate conditions exist. For moderate ambient dose rates, in-line monitoring may be sufficient, but shielding should be employed. For high ambient dose conditions (i.e., those above which shielding is no longer a practical solution to controlling the ambient background influence), off-line monitoring should be used.

If the primary purpose of the monitoring system is to alert operating staff to significant unplanned increases in gamma-emitting radionuclides within the liquid effluent line, in-line monitoring may be preferred. A combination of in-line and off-line monitoring may be necessary to accommodate both routine and emergency monitoring.

3.5.2 General Design Criteria

The following general design criteria should be considered in the design and operation of routine liquid effluent monitoring systems:

1) If off-line monitoring is used:
    a. Use adequate shielding for detector operation and to maintain personnel exposure as low as reasonably achievable (ALARA);
    b. Locate alarm annunciators in normally occupied locations and use stable electric power sources to provide uniform voltage to the monitor and alarm systems; and

c. Use a predefined alarm level that is above normal variations in release levels. The alarm should provide timely warning of the potential to exceed administrative levels designed to keep releases ALARA and of the potential to exceed established concentration guides or limits.

2) If in-line monitoring is used:
   a. Use the criteria for off-line monitoring, and
   b. Computer software programs should provide rapid readout of radionuclide release rates. Alternatively, develop conversion factors or interpretive curves (primarily for ion chamber and Geiger-Muller (GM) tube monitors) that allow quick conversion of dose rates or count rates to radionuclide release rates (e.g., microcuries per minute (μCi/min)), such that both concentrations of and curies released by the pertinent radionuclides can be estimated. Maintain these methods as a back-up method in case of computer failure.

3.5.3 Batch Release

Release duration is a factor in selecting a monitoring or sampling system. If the release is not continuous, the effluent is considered a “batch” release. Before a batch is released, a representative grab sample should be drawn from the batch and analyzed to determine if release criteria are met.

3.5.4 Types of Radiation

In liquid effluent streams, direct measurement is only possible with gamma-emitters or by making gross beta-gamma measurements. In situ alpha measurement is not feasible (at this time) with existing technology. Exceptions may exist when coincident gamma radiation is involved with alpha emissions. Gross beta measurement is possible using thin, plastic scintillators. It should be demonstrated that the chosen detector has the necessary sensitivity. Sampling and analysis should be used to quantify release of alpha emitters and some beta emitters (i.e., those that cannot be adequately measured using detectors).

3.5.5 High Background

Even though some shielding is provided by the liquid contents themselves, direct or indirect measurements in areas with high ambient radiation levels require shielding or off-line analysis. Even with shielding, the low-energy gamma spectrum may be biased when using in situ monitoring in locations of relatively high background dose rates, depending on the

radionuclide(s) being measured and the composition of the background. A high background can interfere with the measurement of low dose rates from the radionuclides. Consequently, when designing installations for locations that are expected to have relatively high radiation dose rates, off-line monitoring should be used.

3.6 Environmental Effects

Environmental conditions can play a key role in the efficient design of a monitoring or sampling system. Air conditioning for hot locations and heating for cold locations should be considered to provide reliable system operation, particularly for systems using electronic components. The system should be designed and located so that the ambient dose rates will permit access for system calibration and servicing, and reduce worker exposure consistent with the ALARA process. Shielding may be required to control worker exposure during calibration and servicing.

3.7 Alarm Levels

To signal the need for corrective actions that may be necessary to prevent public or environmental exposures from exceeding the requirements of DOE O 458.1, when continuous monitoring systems are required, they should have alarms set to provide timely warnings. To prevent the cumulative impacts of small releases from producing a significant impact, routine grab, continuous or proportional samples should be collected often enough to detect radionuclides of interest including those with relatively short half-lives.

3.8 Operational Considerations for All Monitoring and Sampling Systems

Procedures to address the full range of potential accidental release conditions as well as normal routine operations should be developed and implemented. The proper operation of continuous monitoring equipment should be verified at a frequency justified by the site to ensure required accuracy and precision. Operational checks should include positive air- or liquid-flow indication, non-zero response to background activity, and internal check sources or 60-Hertz electronic checks when available (DOE-STD-1098-2008).

All data received from continuous monitoring or continuous sampling systems when performing statistical analyses should be used. The liquid effluent flow rates and the concentrations of radionuclides measured in the sample provide the information needed to compute the total amount of radioactive material released to the environment via the sampled liquid effluent stream.

Calibrate monitoring and sampling system components before use and recalibrate at any time maintenance, modification, or system changes occur that could affect equipment calibration. Systems should be recalibrated at least annually and detectors routinely checked with known sources to demonstrate that they are functioning properly. Calibration(s) should be performed in a manner consistent with manufacturers' instructions and specifications.

Replace off-line liquid transport lines that become radioactively contaminated (to the point where the sensitivity of the system is affected) or become ineffective in meeting the design basis within the established accuracy/confidence levels.

3.9 Quality Assurance

As they apply to the monitoring of liquid effluents, the general quality assurance (QA) program provisions described in Chapter 11 of this Handbook should be followed.

4 AIRBORNE RADIOLOGICAL EFFLUENT MONITORING AND SAMPLING

Airborne effluent streams with the potential to release radionuclides to ambient air (i.e., emission points) should be identified and assessed for direct effluent sampling and continuous air monitoring. Diffuse sources of emissions require identification and release assessment, as well. Quality assurance is essential to the airborne radiological program. Environmental surveillance of radioactive air emissions, which may supplement the effluent sampling and monitoring program, is addressed in Chapter 6.

A point source is a single well-defined point (origin) of an airborne release, such as a stack or vent or other functionally equivalent structure. Point sources are actively ventilated or exhausted.

A diffuse (fugitive) source is an area source from which radioactive air emissions are continuously distributed over a given area or emanate from a number of points randomly distributed over the area (generally, all sources other than point sources). Diffuse sources are not actively ventilated or exhausted. Diffuse sources include: emissions from large areas of contaminated soil, resuspension of dust deposited on open fields, ponds and uncontrolled releases from openings in a structure.

Direct effluent radioactive air sampling is typically conducted at the exhaust point (i.e., point source) and considers particulates and gases in use. Depending on the types and quantities of emissions to the environment, monitoring (e.g., a continuous air monitor [CAM]) may be required. A CAM provides timeliness in assessing releases and alarm capabilities. Radiological effluent results are used in determining doses to members of the public from airborne releases.

Objectives of the airborne radiological effluent sampling and monitoring program include:

- Evaluation of compliance with applicable Federal, State, and local environmental radiation protection requirements;
- Evaluation of the performance of radioactive waste-confinement systems;
- Determination of concentration trends of radiological airborne effluents in the environment at, and adjacent to, DOE facilities, waste disposal sites, and remedial action activities;
- Monitoring all inactive, existing, and new low-level waste-disposal sites to assess radiological hazards (also see Chapter 6);

- Determining the effectiveness of treatments and controls used to reduce radiological airborne effluents;
- Detecting and quantifying unplanned radiological airborne releases;
- Sampling and/or monitoring point sources that have a potential to exceed 1 percent of the site-wide 10 mrem/yr NESHAPs standard (per 40 CFR Part 61, Subpart H (61.93(b)(4));
- Monitoring fugitive emissions;
- Monitoring surplus facilities before decontaminating or decommissioning;
- Sampling and/or monitoring new and existing sites, processes, and facilities to determine potential environmental impacts and releases of radiological airborne contaminants; and
- Monitoring and assessing radiological airborne effluents and potential exposure to the public and the environment.

Documentation of the site's airborne radiological effluent monitoring program should show:

- Rationale for the design and selection of airborne radiological effluent sampling and/or monitoring (sampling or in situ measurement) extraction locations used for providing quantitative emission data;
- Procedures and equipment needed to perform the extraction and measurement;
- Frequency and analyses required for each location;
- Required minimum detectable concentration (or limit) and uncertainty;
- QA components; and
- Investigation and alarm levels.

A lines of inquiry approach is provided to conduct self-assessments; to verify that the program is effective and in compliance with appropriate requirements; and to ensure the consideration of continuous improvement of the program. Lines of inquiry are identified in Appendix B of this Handbook.

4.1 Key Requirements

DOE O 458.1, *Radiation Protection of the Public and the Environment*, establishes requirements for airborne radioactive effluents. Airborne radioactive effluents need to comply with EPA regulatory standards. Further requirements specify waste and operations emissions of radon-220 and radon-222 emissions which apply to certain DOE facilities. The ALARA process is also required.

40 CFR Part 61, *National Emission Standards for Hazardous Air Pollutants (NESHAP)*, Subpart H, establishes the limits for the release of radionuclide emissions other than radon to the air from DOE facilities, and specifies corresponding requirements for monitoring, annual reporting and recordkeeping. According to 40 CFR §61.92, the emissions of radionuclides to the ambient air from DOE facilities shall not exceed those amounts that would cause any member of the public to receive in any year an effective dose equivalent of 10 mrem/yr. Compliance is demonstrated by calculating doses to the public at offsite locations[1] (40 CFR §61.94) using standardized methods (40 CFR §61.93). [Additional EPA requirements that cover specific DOE operations are found in 40 CFR Part 192, regulating emissions from uranium and thorium mill tailings operations.]

Note: Section 61.91 of 40 CFR Part 61, Subpart H, defines a "Facility" to mean all buildings, structures and operations on one contiguous site (e.g., Hanford Site, Oak Ridge Reservation, Savannah River Site, Idaho National Laboratory).

40 CFR Part 61, Appendix B, Method 114, *Test Methods for Measuring Radionuclide Emissions from Stationary Sources*, establishes the requirements for: (1) stack monitoring and sample collection methods appropriate for radionuclides; (2) radiochemical methods which are used in determining the amounts of radionuclides collected by the stack sampling; and (3) quality assurance methods which are conducted in conjunction with these measurements.

40 CFR Part 61, Appendix D, *Methods for Estimating Radionuclide Emissions*, establishes the adjustment factors for the physical form of the radioactive material as well as emission factors for effluent controls.

ANSI/HPS N13.1-1999 (re-affirmed 2011), *Sampling and Monitoring Releases of Airborne Radioactive Substances From the Stacks and Ducts of Nuclear Facilities*, establishes the guidelines and performance criteria for sampling the emissions of airborne radioactive substances in the air discharge ducts and stacks of nuclear facilities. Emphasis is on the extractive sampling from a location where the contaminant is well mixed. ANSI/HPS N13.1-

[1] Under certain circumstances (e.g., where DOE permits members of the public to work on a DOE site without DOE access controls) dose estimates for onsite locations may be required for demonstration of compliance.

1999 provides performance-based criteria whereas the 1969 version of the standard was prescriptive with an emphasis on the isokinetic sampling of airborne radioactive material from exhaust points (some DOE systems may be grandfathered to use the 1969 version as promulgated by EPA). A grandfathered sampling system may become subject to ANSI/HPS N13.1-1999 standards if dose estimates substantially increase as a result of facility changes, modifications, or new construction.

DOE O 414.1D, *Quality Assurance*, contains requirements for the development and implementation of a QA program using a graded approach by DOE elements.

DOE O 436.1, *Departmental Sustainability*, establishes requirements for: (1) the systematic planning, integrated execution, and evaluation of programs for protecting public health and the environment; (2) pollution prevention; and (3) assuring site compliance with applicable environmental protection requirements.

Memorandum of Understanding Between the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy Concerning The Clean Air Act Emission Standards for Radionuclides 40 CFR Part 61 Including Subparts H, I, Q & T, established an agreement between the two agencies on implementation of the NESHAPs requirements related to radioactive air emissions from DOE sites.

Note: Although 40 CFR Part 61, Subpart H provides procedures for evaluating only emissions from point sources, under a 1995 Memorandum of Understanding (DOE 1995) DOE and EPA agreed to the collection, analysis and review of emissions data from diffuse sources. Therefore, the dose standards in the regulation are applicable to emissions from diffuse sources as well as point sources.

4.2 Summary of General Objectives

The air sampling and monitoring activities at each facility and each emission point at a facility should be commensurate with potential radiological emissions and their estimated contributions to public dose during both routine operation and in unplanned release scenarios. While EPA has established standards for public dose from a facility's emissions, criteria for each emission point need to be considered and incorporated into the whole of the facility program.

4.2.1 Performance Standards for Air Sampling Systems

The emission point criteria for airborne radiological effluent sampling and monitoring listed in Table 4-1 should be used to establish the airborne emission monitoring program for DOE sites. Application of these criteria to an emission point requires that an adequate study of the expected releases, potential exposure pathways, and resulting dose be conducted. Quality assurance applies to radiological air sampling systems. A graded approach should be used and incorporated into a quality assurance plan and applied during implementation.

Pre-operational assessments should be conducted for all new emission points or emission points that have been modified such that the effluent release quantity or quality, or the sensitivity of the monitoring or surveillance systems is affected. These assessments should document the types and quantities of airborne emissions to be expected from the emission point, and establish the associated airborne emission monitoring needs of the emission point. According to 40 CFR Part 61, new emission points that require sampling or modified emission points resulting in an effective dose equivalent greater than 1 percent of the 40 CFR Part 61 Subpart H standard must use ANSI/HPS N13.1-1999. For existing grandfathered sources with emissions resulting in an effective dose equivalent greater than 1 percent of the standard, the air sampling system design needs to use either ANSI N13.1-1969 or ANSI/HSP N13.1-1999. However, applicable maintenance, calibration, and field check requirements specified in ANSI/HPS N13.1-1999 need to be followed for all emission points.

The performance of the airborne emissions monitoring systems should be sufficient for determining whether the releases of radioactive materials are also within the limits or requirements specified in DOE O 458.1. Sampling and monitoring systems should be calibrated before use and recalibrated any time they are subject to maintenance or modification that may affect equipment calibration status. These systems should be recalibrated at least annually and routinely checked with known sources to determine that they are consistently functioning properly. Provisions for monitoring airborne emissions during non-routine situations should be considered when determining routine airborne emission monitoring needs.

4.2.2 Gases vs. Particulates

Radionuclides in gaseous airborne effluents can be in the form of non-condensable gases and particulate materials. Inertial forces play a role in the distribution of gases and particulates in the exhaust air stream. For gases/vapors (considered to have similar flow behaviors) sample design criteria can be less rigorous since the effects of inertial forces are less prominent. For

new emission points, sampling at a well-mixed location is required as identified in ANSI/HPS N13.1-1999.

TABLE 4-1. Emission Point Criteria for Airborne Radiological Effluent Sampling and/or Monitoring

*H_E (mrem/yr) **	*Minimum airborne radiological effluent criteria*
$H_E \geq 5$	Continuous sampling for a record of emissions with retrospective, off-line periodic analysis. Continuous in-line, real-time monitoring with alarm capability; consideration of separate accident monitoring system.** Additional considerations: 1) Identify radionuclides that contribute > 10 percent of the dose 2) Determine accuracy of results (± percent accuracy and percent confidence level) 3) Establish alarm set-points for continuous monitoring 4) Conduct a confirmatory environmental survey annually <u>or</u> Monitor at a representative receptor location with prior EPA approval***: 1) Continuously sample air at a representative receptor location 2) Collect and measure any radionuclide contributing ≥ 1 mrem above background 3) Establish sampler density sufficient to estimate dose to critical receptor given typical variability of meteorological conditions 4) Recommended completion of a data quality objectives document for program implementation 5) See Chapter 6, Environmental Surveillance guidance
$0.1 < H_E < 5$	Continuous sampling for record of emissions, with retrospective, off-line periodic analysis.** Additional considerations: 1) Identify radionuclides that contribute > 10 percent of the dose 2) Determine accuracy of results (± percent accuracy and percent confidence level) 3) Conduct a confirmatory environmental survey at a frequency consistent with a graded approach but at least once every 3 years
$H_E \leq 0.1$	Using a graded approach, conduct periodic confirmatory sampling and off-line analysis, or complete an annual administrative review including engineering calculations of emission point uses to estimate emissions and/or confirm the absence of radioactive materials in forms and quantities not conforming to prescribed specifications and limits. Additional considerations: 1) Test to determine need to sample by calculating dose (H_E) for normal operations, assuming that the effluent controls are inoperative 2) Conduct a confirmatory environmental survey at least every five years

** H_E = calculated maximum dose (mrem/yr) from airborne radiological effluent to members of the public with no abatement controls in place*
*** 40 CFR Part 61 Subpart H requires effluent streams that have the potential to result in doses to a receptor >0.1 mrem/year to be directly monitored continuously with an in-line detector or have representative samples withdrawn continuously*
****40 CFR Part 61 Subpart H requires EPA approval to use environmental monitoring as an alternative compliance measurement to effluent monitoring*

4.2.3 Design Criteria for System Components

Airborne emission sampling and monitoring systems should demonstrate that quantification of airborne emissions is timely, representative, and adequately sensitive. The design of airborne radiological effluent sampling and monitoring systems begins with a characterization and documentation of the effluent sources. Cross-sectional homogeneity of the radionuclide distribution in the effluent stream at the sampling point is addressed in ANSI/HPS N13.1-1999. The level of detail should be sufficient to prove that the system is qualified for the task (i.e., a graded approach). A number of factors are critical to this characterization, but their importance can vary in a specific situation.

The following are among those factors that should be considered:

- Identification of the actual or potential radionuclides present (e.g., type, concentration);
- Identification of fallout and naturally occurring (i.e., background) radionuclides;
- Presence of materials (e.g., chemical, biological) that could adversely affect the sampling and monitoring system or detection of radionuclides;
- Internal and external conditions that could have a deleterious effect on the quantification of emissions;
- Process descriptions and variability; and
- Particle-size distribution of the particulate materials (nominally set at 10 microns).

4.2.4 Alarm Levels

Continuous air monitoring systems require alarms that provide timely warnings to signal the need for investigation or corrective actions. Alarm levels should be set to provide timely warnings and yet avoid spurious alarms. Background fluctuations should be considered when setting the alarm levels. Requirements to protect the public and environment in DOE O 458.1 should be considered when establishing alarms.

4.3 Point Source Emissions

For point sources that require effluent sampling and/or monitoring, the important characteristics of the exhaust handling system, other pertinent structural information, the pertinent characteristics of the process and process-emission control systems, and the sampling and measurement systems should be documented as part of an Environmental Management System. Reports or data from studies conducted to evaluate systems that may have real or

suspected deficiencies of the systems should be retained at a single, readily accessible location.

4.3.1 Direct Effluent Sampling

Direct effluent sampling systems include probes, transport lines, air handling systems, flow measurement devices, and sample collection devices which are discussed below.

4.3.1.1 Sample Extraction Sites

Samples should be extracted from the effluent stream at a location and in a manner that provides a representative sample taking into account the velocity profile, gas and aerosol particle concentration profiles, and cyclonic flow. Sample extraction sites should be from an accessible location in the stack downstream from any obstruction, preferably near the outlet, so that concentrations of the material of concern are uniform and so that the physical state is similar to what will enter the atmosphere. Details are provided in ANSI/HPS N13.1-1999, and test methods for velocity traverses and cyclonic flow are in 40 CFR Part 60, Appendix A (Smith 1984).

4.3.1.2 Sampling System Components

Sampling components include extraction (sample) probes, transport lines, air flow measurements and controls, and sample collectors.

4.3.1.2.1 Extraction Probes

ANSI/HPS N13.1-1999 states that, in place of multiple point sampling, single-point representative sampling should be used with the requirement that both fluid momentum and contaminant mass are well mixed at the sample extraction location; the ANSI/HPS N13.1-1999 standard promotes the use of shrouded nozzles/probes. While now discouraged, if multiple inlet probes are used, the volume flow through each inlet should be proportional to the volume fraction of the airborne radiological effluent flow in the annular area sampled. Transmission of sample constituents through the probe needs to meet specific performance criteria (e.g., the transmission ratio of 80 percent to 130 percent).

If the material of concern exists as a gas or vapor that does not interact with particulate material in the gaseous airborne effluent, simply extracting a known fraction of the airborne radiological effluent flow is adequate, provided the criteria for uniform flow and concentration are met.

Position probes for sampling iso-axially in the stack or exhaust duct, and size them for the appropriate exhaust velocity. The presence of the probe should not obstruct the contaminant stream in the duct. For new or modified facilities that use ANSI/HPS N13.1-1999, the recommendation for isokinetic sampling is no longer required by EPA in 40 CFR Part 61, Subpart H, effective on October 9, 2002.

Probe nozzles for the sampling of aerosols should be made of seamless stainless-steel tubing (or, for corrosive atmospheres, other rigid, seamless tubing that will not degrade under sampling conditions) with sharp, tapered edges. Probes should be designed so that they can be removed easily for cleaning, repair, replacement, or deposition evaluation.

4.3.1.2.2 Transport Lines

Sample transport lines should be kept as short as possible and designed to minimize sample loss. Systems that directly expose the collector or monitor to the airborne radiological effluent stream are preferred. Line diameter and materials of construction should be selected to minimize wall losses under anticipated sampling conditions (ANSI/HPS N13.1-1999). Aerosol transport lines should be rigid and should be electrically grounded to the point where the particles are collected or accumulated. Transport lines should be made of materials resistant to corrosion under anticipated sampling conditions and should be insulated and/or trace-heated to prevent condensation of materials under anticipated sampling conditions.

Aerosol transport lines should not have sharp bends. Changes in direction should be minimized and be made with radii of curvatures of at least three tube diameters and no greater than 10 (NCRP 2010). There should be no inward facing steps at tubing connections in excess of a 1 percent reduction in tube diameter. Flattening of a bend cannot exceed 15 percent. Bends, steps, and flattening, cause sample losses that need to be accounted for in the sample transport line. In general, sample penetration can be demonstrated empirically or by using models where the penetration of a 10 micron particle through the sample line should not be less than 50 percent (ANSI/HPS N13.1-1999).

If the material(s) of concern is (are) in the form of gas(es) or vapor(s), ensure that the lines have no significant leakage or loss of material (e.g., chemical reactions and condensation). For consistency with 40 CFR Part 60, Appendix A, Method 5, “significant leakage” is any leakage rate in excess of either 4 percent of the average sampling rate or 0.02 cubic feet per minute (cfm), whichever is less (Smith 1984).

4.3.1.2.3 Air Flow Measurement and Control

Air-moving systems for gaseous airborne radiological effluent sampling should be constant displacement systems (e.g., rotary vane, gear) or other systems that will maintain constant air flow in anticipated sampling conditions. Pumps and other mechanical components should be designed to operate continuously under anticipated operating conditions, with scheduled preventive maintenance and repair. Equipment used for intermittent or grab sampling should be designed to operate continuously for the duration of the sampling period(s).

Sampler gas flows should be measured continuously and recorded over the duration of the sampling period. Periodic gas-flow gauge readings during collection should be conducted and recorded. If it can be demonstrated that the sample flow rate is essentially constant from the start to the end of each sampling period, then periodic gas-flow readings may not be essential.

Unless extenuating circumstances dictate otherwise, the flow measurements should be accurate to ± 10 percent by calibration with standards traceable to the National Institute of Standards and Technology (NIST) (DOE 1983). Regardless of the type of device used, calibrate it under conditions of anticipated use with NIST-traceable or equally acceptable standards (in the case where an NIST standard does not exist). Flow-measuring devices used for compliance determinations should be located downstream from the extraction probe.

ANSI/HPS N13.1-1999 established performance standards and design criteria for the measurement and control of the bulk airborne radiological effluent flows. The characteristics and conditions of gas flow can vary widely, therefore, the need for airflow feedback systems should be considered and take into account the potential for large fluctuations in flow. The frequency of the measurements needed to accurately meet flow-rate determination will be based on the stability of flow and the significance of the radiological impact to the environment. Gas-stream measurement methods include 40 CFR Part 60, Appendix A, Method 1 (used to determine location and quantity of velocity measurements), Method 2 (used to measure and determine stack gas velocity, static pressure, and volumetric flow rate), and Method 4 (used to determine moisture content in stack gases) (Smith 1984); ASTM D3154-00 (2006); ASTM D3195M-10 (2010); ASTM D3464-96 (2007); and ASTM D3796-90 (2004). Measurements may be impacted by various characteristics such as the velocity, static pressure, temperature, and moisture content.

4.3.1.2.4 Sample Collectors

The design and capabilities of the sample collector will depend on the physical and chemical form of the radionuclides to be collected, the sampling conditions, and the analytical techniques to be used. The radionuclides in airborne effluents can be found in three forms — gases, vapors and particulate materials. Different techniques are needed to collect and separate the physical forms or individual chemical compounds within the forms. Collector housing and hardware should be designed to minimize sample loss and leakage. Sample preservation methods should be consistent with the analytical procedures used.

Table 4-2 illustrates a variety of sample elements and their associated sampling methods. Additional guidance can be found in ANSI N13.1-1969 or ANSI/HPS N13.1-1999 (for new or modified facilities) as well as NCRP 169 (NCRP 2010); ISO 2889 (ISO 2010); 40 CFR Part 61, Appendix B, Method 114; and Maiello and Hoover (2010). These resources provide detailed information on the sampling methods, media, processes, efficiencies, and analytical approaches.

TABLE 4-2. Collection Methods for Specific Radioactive Effluent

Radioactive Effluent	*Collection Method*
Particulates	Filter media including acrylic copolymers, glass fiber, cellulose, and quartz.
High Temperature Particulates	Sintered metals or mineral particles.
Tritium Oxide	Ethylene glycol bubbler, silica gel, molecular sieves, and condensers.
Elemental Tritium	Palladium or other catalyst to transform to the oxide for collection as the Tritium Oxide collection method.
Tritium in Organic Compounds	Platinum or aluminum oxide catalyst in combustion chamber for collection as the Tritium Oxide collection method.
Noble Gases (excluding Radon)	Silver zeolite, flow-through or evacuated chambers, activated carbon, cryogenic condensing, and compressed gas.
Radon	Activated carbon, alpha track, and continuous radon monitors.
Elemental Iodine	Plain or cadmium iodide treated activated carbon.
Organic Radioiodine	Potassium iodide or triethylene-diamine treated activated carbon.
Other Gases (e.g., oxygen, carbon, nitrogen, and sulfur compounds)	Bubble through sodium hydroxide solutions, solid-phase sorbents, and activated carbon.

4.3.2 Direct Effluent Monitoring

Direct continuous effluent monitoring, as shown in Table 4-1, is system specific and includes specifications for continuous monitoring systems, in-line and off-line approaches, and radionuclide monitoring systems for specific radionuclides.

4.3.2.1 Continuous Monitoring Systems

Where the offsite radiological impacts to the applicable receptor location are well below the standard, radionuclide sampling and collection with periodic measurement (e.g., laboratory analysis) are sufficient to quantify the radionuclides. However, where a significant potential (greater than once per year) exists for approaching or exceeding a large fraction of the emission standard (e.g., 20 percent), continuous monitoring should be required. Continuous monitoring system specifications require a careful balancing of sensitivity, energy response, response time, and accuracy for the radionuclide of interest (ANSI N42.18-2004). Compensation or adjustment in the system should accommodate pressure, temperature, humidity, and external background. To interpret the measurements correctly, the composition of any noble gases present needs to be known. If significant amounts of tritium are present, tritium removal may be necessary before other measurements are taken. Gross alpha and gross beta monitoring may be accomplished using gas flow proportional counters. When monitoring for gamma-emitting radionuclides, use monitors that have a stainless-steel vessel with a known volume of gas and a lithium-drifted germanium detector [Ge(Li)] or an intrinsic germanium detector or equivalent (DOE 1983).

The requirements of sampling at a well-mixed location apply equally to continuous monitoring systems. However, additional maintenance, repair, and calibration are necessary. The continuous monitoring system is particularly useful in either normal or upset conditions where appropriate alarm levels have been set.

4.3.2.2 In-Line/Off-Line System Specifications

Air monitoring can be performed by either in-line or off-line systems. In-line systems are those in which the detector assembly is immersed in the airborne radiological effluent stream, usually in a well or other protective enclosure, while off-line systems pull an aliquot from the airborne radiological effluent stream for collection or conveyance to a detector assembly. In-line systems are less complex than off-line systems but may not provide specific radionuclide measurements directly (DOE 1983). These approaches provide for near real-time analysis and feedback.

For in-line monitoring, special housing may be necessary to meet the specifications identified below.

- Place only the detectors and small electronic assemblies in, or adjacent to, the airborne radiological effluent stream (IEC 60761, 2002). A detector should not be particularly sensitive to environmental conditions or need frequent attention or adjustment.
- Use appropriate calibrations for radionuclides to be measured, including ratios to other non-measurable radionuclides, if present.
- Meet performance requirements within the anticipated environmental conditions (e.g., temperature, humidity, and radiation levels). Systems to control the environment for the proper functioning of the monitors should be provided.
- Have adequate access for maintenance, repair, and calibration.
- Have a stable source of electrical power.

The available signal range should include the full range of operating conditions. The signal range of routine airborne radiological effluent monitoring systems that also are identified for use during non-routine emissions should be sufficient to monitor releases projected from applicable design basis accidents.

If a measuring cell or gas chamber is used to provide a known volume of gas for measurement with an immersed or adjacent detector, consider the following design features:

- A flow-through type vessel or chamber with or without absorbing medium or pressurization;
- Specifications for cell volume and pressure;
- Separation of the detector from the sample by a protective screen, if practicable; and
- A readily removable detector mounted so that it will be returned to, and maintained in, its original position and provision for an alternate position or other means of varying response by a factor of at least 10 to accommodate non-routine situations (includes accidents). An alternative method would be to use two detectors, the second one with a higher range.

4.3.3 Specific Radionuclide Monitors

The following sections summarize monitoring methods for a variety of specific emission types. Other methods not discussed here may be more applicable in certain situations. As state-of-

the-art technology improves and new detector methods become available, additional or alternate methods may become standard practice.

4.3.3.1 Tritium

Ionization chambers are widely used for measuring gaseous tritium (DOE 1983). Tritium measurements of about 10^{-5} µCi/mL are possible in low-background environments, which produce ions at a rate equivalent to 1 mrem/hr. Shielding may be necessary for specific applications. If shielding is not practical, a second chamber exposed to the same gamma field without tritium is recommended. Ionization chambers are more sensitive to radioactive (noble) gases that produce larger energies per disintegration and may cause major interferences.

Proportional counters also are used to measure airborne tritium (DOE 1983). They are relatively insensitive to background radiation and have energy discrimination capabilities. Systems using proportional counters are more complicated than those using ionization chambers. Proportional counters require a counting gas, and many gases are flammable or combustible.

Radioactive material present in natural products (e.g., commercial natural gas) may provide interference for tritium measurements and should be accounted for if used.

Additional concerns that should be considered in instrument design for tritium monitors based on the IEC standard (IEC 60761, 2002) are as follows:

- Temperature control during sample transport to prevent condensation (much of the tritium may be in the form of airborne water vapor), and
- Trapping or retention of water by a filter or sorbent (since much tritium is commonly in the form of tritiated water (HTO)).

4.3.3.2 Iodine

Activated charcoal, charcoal, and silver zeolite cartridges used to collect radioiodine may be monitored at the collection point with a shielded gamma spectrometer/detector. Usually the cartridge is placed downstream of the particulate filter which removes other airborne radioactive contaminants that might otherwise be collected on the cartridge and therefore interfere with the iodine analysis. Considerations for determining the frequency of sampling or replacing the cartridge include cartridge loading, breakthrough potential, the number of cartridges in series, cost, and radioiodine species half-life.

In-line measurements of low concentrations of radioiodine in air usually will not be feasible because of the presence of other radionuclides or radiation fields. Additionally, the monitoring of airborne radioiodines may be complicated by the occurrence of several species, including particulate iodine (bound to inert particles), elemental iodine vapor, and gaseous (usually organic) compounds. Monitoring system design should consider the iodine forms in the effluent. While it may not be necessary to differentiate routinely between the various species, care should be taken so that no significant error results by neglecting one or more of them (DOE 1981). Several designs (e.g., Keller et al. 1970) have been used to distinguish the several chemical forms of radioiodine that may be present in the atmosphere (as related to environmental surveillance).

Cartridges for the collection of radioiodine in air are subject to channeling, as with any packing of loose materials. Baffled-flow cartridge design, packing to a minimum required weight, and pre-testing of randomly selected cartridges for pressure drop before operation in the field should minimize the problem (DOE 1981).

Specifications to be considered for iodine monitors are as follows:

- Protection of the detector head from particulate contamination by an interchangeable thin screen, easy removal of supplemental devices such as temperature sensors and heaters in the inlet for decontamination, and use of construction materials that are easily decontaminated or are contamination resistant;
- Design of radioiodine monitors will be such that the replacement of sorbent and filter should not disturb the geometry between the collector and detectors;
- Design of collection assembly and detector to minimize the holdup of gases;
- Establish minimum levels of detectability for various iodine isotopes; and
- Determination of the characteristics (e.g., collection efficiency, retention capacity, delay-time constants) for all media in the collection train (solid sorbent, absolute particulate filter) for various radioactive gases of significance in the gaseous effluents, including radon.

4.3.3.3 Noble Gases (Excluding Radon)

The radioactive noble gases include forms of argon, krypton, and xenon.[2] Flow-through ionization chambers or proportional counters may be used. Usable signals from noble gas monitors may depend on the adequate removal of other radionuclides from the sample stream.

Activated charcoal cartridges monitored by a gamma spectrometer may also be used for noble gases. Cartridges would be placed downstream of the particulate filter. This method requires knowing the adsorption coefficient for the noble gas which is affected by temperature, pressure, concentration, and carrier gas on the activated charcoal/carbon (Underhill 1996).

Additional concerns whether using ionization chambers, proportional counters, or activated charcoal cartridges include establishing minimum levels of detectability.

4.3.3.4 Radon

Radon effluent monitoring may be accomplished using a scintillation cell or ionization chamber (continuous radon monitors), passivated ion-implanted planar silicon detection which includes the collection of radon progeny with spectral analysis output, or activated charcoal cartridges monitored by a gamma spectrometer. Because radon tends to a lower pressure it migrates easily making monitoring difficult. As with other gases, minimum levels of detectability need to be established.

4.3.3.5 Other Gases (Oxygen, Carbon, Nitrogen, and Sulfur)

Radionuclides of elements such as oxygen, carbon, nitrogen, and sulfur may be in gaseous form but also in particulate form. Particulate measurements are addressed in the section below. For gases, flow through ionization chambers, proportional counters/beta detectors, and gamma spectrometry may be used.

As with the noble gases, minimum levels of detectability need to be established. Additional concerns include the low emission energies of these elements and interference from

[2] Note: radon releases are subject to separate requirements and specific sampling guidance is provided in Section 4.3.3.4.

background and other radioactive materials; therefore, results from these methods are often difficult to quantify.

4.3.3.6 Particulates

Particulates are generally extracted from the effluent stream and passed through a filter media to remove the particles. Gross alpha and gross beta/gamma counting can be accomplished using a gas-flow proportional counter. Other alpha and gamma spectrometry and beta counters may be used, as appropriate, for specific applications. In addition to ANSI/HPS N13.1-1999, IEC 60761 (2002) and ANSI N42.18-2004 address aerosol airborne radiological (gross alpha and gross beta) effluent monitoring. Chapter 6 provides additional filter media details.

DOE (1983) and IEC 607461 (2002) provide additional information on specific types of aerosol monitors — alpha-emitting transuranics; uranium; and other particulates.

- Transuranics (e.g., plutonium): ANSI N317-1980 addresses CAMs that also are used as gaseous airborne radiological effluent monitors; these instruments can be used for monitoring transuranic (TRU) effluent.
- Uranium: The continuous strip filter counters with combined alpha and beta counting ratios can be considered if uranium is the only particulate radionuclide present. Gamma spectroscopy is suggested for consideration at high concentrations.
- Other Particulates Including Fission and Activation Products: Other radionuclides in the form of particulate materials commonly are monitored by collection on filters and counted for gross beta activity if the identities and ratios of radionuclides are known (DOE 1983). Shielded beta detectors are considerably more practical than gamma detectors, and most gamma emitters also emit beta radiation. If measurements of specific, gamma-emitting radionuclides are necessary, sodium iodide (thallium activator) (NaI(Tl)) or intrinsic germanium detectors should be used.

Additional characteristics that should be considered include:

- The best estimate of the surface emission rate determined from a primary or secondary standard or by reference to an instrument that has been calibrated against a primary or secondary standard;
- A check source, supplied with the monitor, designed to be used in place of the filter in the retention device;
- A protective cover over the detector that can be easily exchanged from the front of the detector or designed to facilitate decontamination of the detector head;

- Filter properties (e.g., Maiello and Hoover, 2011; ANSI/HPS N13.1-1999; and Barnett et al., 2009), see also Chapter 6;
- Filter holder design (e.g., leakage minimization, ease of use);
- Assessment of minimum detectable activities for instruments used;
- Avoidance of gross non-uniform particle deposition on the collection surface;
- The total equivalent window thickness in units of milligrams per square centimeter (mg/cm^2) that an ionizing particle normally emitted from the surface of the collected aerosol will cross to reach the sensitive area of the detector (i.e., distance covered in air plus the window thickness and that of any thin, protective screen);
- A useful detector area approximately equal to that of the particle collecting surface;
- Assess the collection efficiency of the retention device over the range of 0.01 to 10.0 μm aerodynamic equivalent diameter under normal conditions of proposed use;
- Assess detector characteristics (e.g., maximum total equivalent window thickness, protective coating, and variation in detector efficiency as a function of energy); and
- Methods of discrimination against natural background radiation (i.e., delayed measurements after suitable decay, energy spectrum analysis; physical properties; and electronic compensation to subtract the contributions from radon and its progeny).

4.4 Diffuse Sources and Fugitive Emissions

Diffuse sources should be identified and assessed for their potential to contribute to public dose and should be considered in designing site emissions monitoring programs. With regard to annual compliance assessment, DOE (1995) was signed by EPA and DOE to address the supplemental evaluation of diffuse releases, which are not specifically included in the 40 CFR Part 61, Subpart H, requirements. DOE O 458.1 addresses the ALARA process and compliance with radon emissions. The category of diffuse sources covers many situations, most of which are difficult to characterize. Examples are shown in Table 4-3 (based in part on Savannah River Nuclear Solutions (2012), and NCRP (2010)).

Attempts to precisely define the airborne emissions under such an array of conditions, as well as other complex and ill-defined factors that affect the transport of the emissions (generally meteorological and topographical factors), could necessitate complex and costly sampling techniques and configurations. Therefore, alternative methods for diffuse emissions release estimates are used in many cases.

TABLE 4-3. Examples of Diffuse and Fugitive Sources at DOE Sites

Structures without ventilation or with ventilation that does not result in a well-defined release point
Passively vented stacks or vents
Breathing buildings or tanks
Decontamination or demolition activities
Surface soils from future or active remediation sites
Windblown dust from storage piles
Evaporative losses from ponds
Losses from open tanks or tank connections
Unplanned intrusions/disruptions (animals, flooding, digging)
Airborne emissions from past liquid releases to soil
Plant transpiration of groundwater plumes
Abandoned sealed sources

All diffuse sources should be identified, assessed, documented, and verified annually. Identification and assessment includes determination of release rates, airborne dispersion modeling, and public dose determinations.

4.4.1 Diffuse Sources

Diffuse sources, by definition have no well-confined emission release location. Determination of the radioactive material release rates can be done by calculational methods, sometimes in conjunction with environmental surveillance. Additional considerations for diffuse source evaluations include knowledge of local point source emissions and background, and may also include non-routine emissions from on-site events and emissions from off-site events.

4.4.2 Diffuse Source Release Rates

Environmental surveillance is used to determine release rates for some diffuse sources (see Chapter 6). For large sites, close-in environmental monitoring can be used to more precisely estimate releases. Environmental surveillance can also be done and assumed to occur over the entire year to approximate annual emissions. The validity of all release estimates relies on the professional judgment and knowledge of the individuals involved and usually is difficult to verify. As a general rule, reliance will be placed on the site environmental surveillance program to confirm predictions. Diffuse emissions rates are typically overestimated. Expenditures to fine-tune the overestimate depend on how close the overestimate is to a limit of concern.

Calculational methods for determining release rates depend on the radioactive source and the characteristics of the potential environmental release. The radioactive emissions from diffuse sources can be calculated using 40 CFR Part 61, Appendix D methodology or a previously approved method. Documenting the operating parameters or source specific activity data is important, and all assumptions should be stated.

Meteorological conditions are responsible for dispersing the emissions once they are airborne. Other factors that have a significant influence on the air suspension of radionuclides from diffuse source situations depend on the force applied (which results in suspension of the radionuclide in air) and the factors that resist suspension (e.g., subdivision of liquid surface by shear stress (sprays) from ambient winds, over-pressure phenomena within a structure that result in the atmospheric release of radionuclides, the exchange of indoor and outdoor atmospheres at portals, and aerodynamic entrainment of contaminated soil.) A potential diffuse source should be described adequately enough to show the radionuclides present, the form of the materials, and the factors contributing to suspension. The rationale to substantiate the approach used to assess and characterize the source should be documented. The radionuclide amounts in fugitive emissions can be, but are not necessarily, lower than point source discharges. This is notably the case at legacy sites with much newer laboratory facilities. It may not be feasible to directly measure and quantify fugitive emissions. Because of low concentrations, unpredictable release patterns, and different release points, values of fugitive releases from a given facility generally can only be estimated (NCRP 2010).

Fugitive radionuclide emissions can be estimated by screening models or calculation methods using operating parameters or site-specific radioactivity data. A report prepared for EPA entitled *Methods for Estimating Fugitive Air Emissions of Radionuclides from Diffuse Sources at DOE Facilities* (Eastern Research Group 2004) contains extensive information on: (1) various release mechanisms that affect fugitive emissions; (2) methods for estimating the fugitive emissions from various operations; (3) step-by-step procedural guidance for estimating fugitive radionuclide emissions from diffuse emission sources; (4) selected models for calculating the fugitive emissions of radionuclides; and (5) case studies illustrating various activities performed at DOE sites to quantify fugitive emissions. For situations where these methods or models are not appropriate, alternative methods may be proposed for consideration provided that they are technically justified and fully documented. Regardless of the method or model utilized, data on diffuse and fugitive emissions at DOE facilities need to be reported in the ASER and, per DOE (1995), in annual radioactive air emissions compliance reporting.

4.4.3 Diffuse Source Assessment

A diffuse source assessment is recommended for all diffuse sources potentially emitting radionuclides that contribute to the receptor dose. In most situations the receptor location will be at an offsite location; however, in some situations (e.g., where DOE permits members of the public to conduct non-DOE work on a DOE site) the receptor location may be onsite. The following procedures should be applied to assessments:

- The assessment should be accomplished by using appropriate computational models and/or a downwind array of samplers arranged and operated over a sufficient period to characterize the concentrations of radionuclides in any resulting plumes.
- Empirical data and sound assumptions should be used with the computational models to define the source term for a diffuse source.

Computer codes such as CAP88 (Beres 1990; EPA 1992; EPA 2000b; and Rosnick 2007) and AIRDOS-PC can provide supporting documentation for the diffuse source assessment. Additional insight into the parameters necessary for estimating dose from fugitive effluents is provided by Whelan et al. (1987), Gilbert et al. (1989), and EPA (1987). If prior approval is granted from the regulator, compliance for emissions can be demonstrated using environmental surveillance results (or equivalent) and 40 CFR Part 61, Appendix E, Table 2.

4.5 Quality Assurance

Follow the general QA program provisions in Chapter 11, as applicable to the monitoring of airborne effluent. The emission monitoring requirements in 40 CFR Part 61, Subpart H, Section 61.93(b) includes the implementation of a QA program where appropriate that meets the requirements described in 40 CFR Part 61, Appendix B, Method 114.

Additionally, compliance aspects of a radioactive airborne effluent program include assessment and conformance to not only the regulations but also permit authorization requirements. In addition, government bodies (e.g., DOE 2002b) carry out occasional performance reviews. Two applicable standards for continual improvement and quality are: (1) *Environmental Management Systems* (ISO 14001, 2004), and (2) *Quality Management Systems* (ISO 9001, 2008). ANSI/HPS N13.1-1999 also outlines a basic QA program plan.

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5 METEOROLOGICAL MONITORING

Meteorological monitoring programs acquire information on atmospheric conditions that can be used to characterize atmospheric dispersion of normal operational or unplanned releases of radiological material.

The scope of the meteorological monitoring program should be based on an evaluation of the applicable requirements in regulations and DOE directives, and on a determination of the meteorological data sufficient to support: (1) environmental monitoring and surveillance programs; (2) emergency response field survey team deployment; (3) in situ radiological data acquisition; (4) facility operations; (5) environmental impact assessments; (6) safety analyses; (7) environmental restoration activities; and (8) the consequence assessment element of emergency preparedness and response programs. Additional guidance documents or consensus standards appropriate for use in the design and operation of meteorological monitoring programs include EPA (2000a), NRC (2007b), and ANS/ANSI (2010).

A meteorological monitoring program should consider the following factors:

- Level of radiological activities at the site, including the type and magnitude of potential sources of radioactive and hazardous materials;
- Topographic characteristics of the site that affect atmospheric transport that generate complex flows;
- Distances from release points to each critical receptor (i.e., worker, co-located worker, MEI);
- Planned future uses of the site;
- Possible pathways of these materials to the atmosphere;
- Frequency of extreme weather conditions (e.g., lightning, tornadoes, hurricanes, extreme straight-line winds, extreme precipitation events); and
- Proximity of the site to other DOE facilities as well as to non-DOE facilities that handle radioactive and/or hazardous materials and nearby stationary and mobile offsite sources (for example, proximity to river barges and trains that transport hazardous materials).

A lines of inquiry approach is provided to conduct self-assessments; to verify that the program is effective and in compliance with appropriate requirements; and to ensure the existence of continuous improvement of the program. Appendix B of this Handbook identifies lines of inquiry.

The site's meteorological monitoring program should be documented in the site's ERPP or other appropriate document and in the ASER (per DOE O 458.1 and DOE O 231.1B).

5.1 Key Requirements

The following DOE directives apply to meteorological monitoring:

- DOE O 458.1, *Radiation Protection of the Public and the Environment*, requires environmental monitoring, including meteorological monitoring, as part of demonstrating compliance with the Public Dose Limit. According to DOE O 458.1, meteorological monitoring must be commensurate with the level of site radiological activities, the site topographical characteristics, and the distance to critical receptors, and the scope of the monitoring must be sufficient to characterize atmospheric dispersion and model the dose to members of the public. The meteorological monitoring program can be integrated into the Environmental Radiological Protection Program.
- DOE O 151.1C, *Comprehensive Emergency Management System,* requires that DOE facility/site meteorological data be available to support timely (real-time) assessments of the onsite and offsite consequences of an unplanned radiological release. Additionally, these data should be made available to the National Atmospheric Release Advisory Center (NARAC) in a timely manner to facilitate near real-time computations.

5.2 Meteorological Monitoring Program Design

Meteorological monitoring program design requires the proper siting of meteorological towers and equipment, the collection of valid meaningful data, the appropriate analysis and application of the data, and the archiving of the data. Meteorological data are essential to characterize transport, diffusion, deposition, and re-suspension of radiological material released to the atmosphere at DOE facilities and sites, and to represent other meteorological conditions (e.g., precipitation, temperature, and atmospheric moisture) that are important to environmental surveillance activities, such as air quality and radiological monitoring.

Such characterization is necessary to assess the following:

- Potential consequences of radiological releases from projected new or modified facilities;
- Consequences of actual routine radiological releases from existing facilities to demonstrate compliance with applicable regulations and standards; and
- Consequences to the worker and public from actual accidental radiological releases.

Meteorological information also is important to consider in the design of environmental monitoring networks.

In general, DOE sites should have onsite measurements of meteorological data. These include, but are not limited to wind direction (transport), wind speed (transport and dilution), turbulence (diffusion). Turbulence may be determined explicitly using sonic anemometers that are used to measure fluctuations in the three components of wind (u, v, and w) and temperature or inferred from a measurement of atmospheric stability (e.g., solar radiation plus temperature lapse rate over a vertical distance of at least 50 meters).

Large DOE sites with multiple facilities and the potential for complex terrain flow characteristics should establish meteorological measurements at more than one location since spatial variations in meteorological conditions need to be considered in evaluating atmospheric dispersion among facilities and to points of public access. At some sites additional monitoring may be needed to provide supplemental information, to support safety aspects of operational programs (e.g., lightning protection, protection from cold and hot weather). It may not be necessary to establish a meteorological monitoring program for each individual facility.

Some smaller sites with limited potential for the atmospheric release of radiological materials may choose to establish a meteorological program that makes use of meteorological measurements obtained from offsite sources such as a first-order National Weather Service station or cooperative stations.

For data from an offsite source to be an acceptable substitute for onsite data, the offsite data should be spatially representative of conditions at the DOE facility where material may be released and subsequently transported and provide statistically valid data consistent with onsite monitoring requirements. A documented determination of offsite data source(s) that is (are) acceptable and spatially representative should be established and ensure the analysis will achieve data quality objectives. Additional guidance can be found in ANSI/ANS-3.11-2005 (R2010) and EPA (2000a).

5.3 Meteorological Monitoring Program Models and Data

Atmospheric models, used to determine consequences of airborne dispersion of material, simulate winds for bulk transport and turbulence for diffusion. Sometimes these two functions, transport and diffusion, are handled by separate models, and sometimes they are incorporated in the same model. The complexity of the models needed depends upon the application and

the complexity of the atmospheric conditions, as well as the complexity of the mechanisms resulting in the release of material to the atmosphere.

Transport models may vary from being as simple as using a constant single wind speed and direction, to complex time-dependent three-dimensional models which explicitly treat divergence, vorticity, deformation, rotation and strain.

The transport model may generate wind fields that:

- Represent the wind fields in one, two or three dimensions;
- Are time dependent or time independent (i.e., constant);
- Employ diagnostic wind fields, which may be generated by interpolation/extrapolation routines, mass conservation, or varying degrees of dynamic complexity and parameterization;
- Include radiation (i.e., non-ionizing long wave and visible), hydrostatic or non-hydrostatic effects, etc.; and
- Employ diagnostic and prognostic wind fields.

Diffusion models may also be very simple, with an assumed statistical distribution, or utilize varying degrees of complexity. The diffusion models may:

- Employ simple or complex turbulent closure methods;
- Employ Eulerian, Lagrangian, or hybrid Eulerian-Lagrangian methods;
- Include wet and/or dry deposition, with or without re-suspension;
- Include airborne plume chemistry; and
- Include health effects.

These models may also include or utilize a source characterization model.

Meteorological data required to drive the atmospheric transport and dispersion calculations range from wind speed, wind direction, and a direct or inferential measure of atmospheric turbulence at one location and one measurement height for spatially-invariant Gaussian models to extensive network of monitoring locations with in situ or remote measurements (i.e., SOund Detection and Ranging (SODAR) or Light Detection and Ranging (LIDAR)) taken at multiple levels for some of the computer-intensive Lagrangian complex terrain flow modeling techniques. Use of simple screening compliance assessment techniques (NCRP 1993; NCRP 1996), which are based on conservative assumptions and use selected meteorological conditions (i.e., wind

speed and a Pasquill stability class), could be sufficient for some DOE sites, especially those with limited radiological hazards.

DOE sites that have completed their essential missions and that are presently in decontamination and decommissioning programs will have reduced hazards. For this situation, these sites may consider the use of simpler modeling techniques, commensurate with the remaining emergency management consequence assessment element requirements.

For sites where onsite meteorological measurements are not required, programs should include a description of the climatology in the vicinity of the site. Data from offsite sources, such as the National Weather Service, the Federal Aviation Administration (FAA), or military installations may be used in these situations if the meteorological instruments are well maintained and the data are readily available and representative of conditions at the site. It should be noted that some airport data (specifically ASOS/AWOS) may not meet criteria for dispersion modeling due to high wind speed thresholds for calm conditions and/or variable wind parameterizations.

Data from other offsite sources also need to be examined for their quality and applicability prior to application. As an example, the use of the CAP88-PC or an EPA-approved alternative per 40 CFR 61.93 is required to demonstrate compliance with 40 CFR Part 61 Subpart H. The meteorological input to the CAP88-PC model includes the joint-frequency distribution of wind speed, wind direction and a Pasquill stability class. This model also requires an average mixing-layer depth, an average absolute humidity, and an average temperature.

As the maximum magnitude of potential releases from a facility increases, the use of more realistic, and therefore complex, models may be necessary to either assess the consequences of the releases or to demonstrate compliance with applicable laws, regulations, and DOE Orders. Complex terrain environments may require a comprehensive onsite meteorological monitoring program to provide sufficient meteorological data to allow complex terrain models to be employed. Computational techniques based on straight-line Gaussian models (e.g., CAP88-PC) are appropriate for facilities that are located in simple topographic settings. Straight-line Gaussian models are described in detail in many reports (e.g., Slade 1968 and Randerson 1984).

At a minimum, these models require specification of wind direction, wind speed, and an indicator of atmospheric turbulence such as a Pasquill stability class. Some models may require the specification of mixing-layer height to account for plume reflection from the capping layer. Remote sensing instrumentation (e.g., Radio Acoustic Sounding System [RASS],

SODAR, LIDAR) is now available to assist in mixing height determinations as indicated in ANSI/ANS-3.11-2005(R2010). If the models estimate wet deposition (i.e., precipitation scavenging), they could require information on precipitation rates, and if the models compute mechanical and buoyant plume rise for stack releases, the ambient air temperature could be required to compare to the temperature of the effluent. For the evaluation of chemical accidents, especially with respect to pressurized liquid and gas releases, or releases of deliquescent chemicals, both the temperature and the relative humidity could be required to accurately assess the time-varying source term.

Estimation of plume rise requires air temperature and wind speed at release height, direct or inferential measure of turbulence, and, in some cases, an estimate of the mixing-layer thickness. Mixing layer thickness is only required to determine if the plume rise will be capped by the inversion, or if the plume is emitted above the inversion, in which case it will be lofted and prevented from reaching the ground level. When it is necessary to evaluate the consequences of a release on receptors near the release point, the basic models should be modified to account for deviations from this assumption.

For new DOE sites with complex terrain or buildings with low stacks where wake effects[3] may be significant, onsite measurements (e.g., field tracer gas studies, wind tunnel experiments) could be used to help model atmospheric transport and dispersion and could also aid in model selection.

For emergency response applications, which require real-time meteorological measurements for diagnostic consequence assessment evaluations, and weather forecasting information for prognostic consequence assessment determinations, straight-line Gaussian transport and dispersion models are not appropriate for facilities that are located in valleys, near coastlines or mountains, and on large sites with varying terrain. In these settings, strictly applied straight-line Gaussian models could not only underestimate the consequences of a release, but also can incorrectly identify locations where higher concentrations can occur, sometimes by more than

[3] Building wake effects can cause a plume from a stack source located within a few times the height of a nearby building to be forced down to the ground much sooner than it would if a building were not present, thereby increasing the concentration nearer the source than might otherwise be expected.

one order of magnitude. This can lead to the selection of inappropriate measurement locations or have undesirable effects on subsequent protective actions.

Complex terrain trajectory models provide more realistic assessments in these settings, as they more accurately account for temporal and spatial variations in atmospheric conditions and release rates.

Complex terrain airflow trajectory models (NRC 1979; NRC 1983; NRC 1986) treat atmospheric transport and dispersion as separate processes. This additional complexity is necessary to consider spatial and temporal variations of the atmosphere. These models generally require the same types of meteorological data as the straight-line models. However, to make full use of their capabilities to characterize three-dimensional spatial variations, use of meteorological data from more than one location and at more than one height above the surface is necessary. In addition, input to complex terrain trajectory models is a series of meteorological observations at different levels in the atmosphere that include wind direction and speed, a direct or inferential measure of turbulence indicator of stability class, temperature, and other important variables, rather than sets of frequency distributions.

5.4 Meteorological Data Requirements for Other Applications

Meteorological data and site-specific forecast services may also be needed to support daily operations and responses to actual hazardous conditions. These include weather conditions that may:

- Produce a threat or challenge to personnel safety and health;
- Damage or destroy property and facilities;
- Lead to a variety of accidents that could result in injury or loss of life; and,
- Facilitate optimum plant operations.

5.5 Meteorological Data Requirements for Quantifying Turbulent Diffusion

Atmospheric dispersion models require data characterizing turbulence in the atmospheric boundary layer to determine the diffusion of a contaminant as it is transported downwind. Many of the contemporary advanced models use or calculate horizontal and vertical velocity variances (or turbulence kinetic energy) directly and apply the resulting statistics in a Lagrangian particle or Gaussian diffusion model (e.g., EPA's AERMOD). Sonic anemometers can be used to determine these velocity variances and other required boundary layer scaling parameters such as friction velocity (u*), convective velocity scale (w*), and Obukov length (L), as described by

Monin-Obukov similarity theory. The use of these direct turbulence measurements in atmospheric dispersion modeling is preferred, whenever possible.

For sites that do not use sonic anemometers, or where traditional instruments are used as a backup data source, average values of wind speed and temperature from two levels on a tower can be used to calculate the Bulk Richardson number (Rb). The value of Rb can be used to determine L, which in turn can be used with wind speed and surface roughness length, z_o to calculate the appropriate scaling parameters.

Gaussian straight-line and complex terrain trajectory transport and dispersion models make use of dispersion coefficients (e.g., the terms σ_y and σ_z in the Gaussian plume equation) to describe the lateral and vertical spread of the contaminant, respectively. Values for these coefficients are determined using well-established empirical expressions, which couple turbulent diffusion with the distance the material has traveled since released. Most of the commonly applied Gaussian models, such as CAP-88, utilize expressions for σ_y and σ_z that are dependent on discrete categories of atmospheric turbulence such as Pasquill stability class. Gifford (1976) discusses various sets of stability dependent expression for σ_y and σ_z including those derived by Briggs (1984) and Pasquill-Gifford (Gifford, 1976).

Acceptable methods for determining Pasquill stability class from typical onsite meteorological measurements are:

Method 1. Solar radiation coupled with the temperature difference between two levels in the vertical (ΔT).

Method 2. The standard deviation in fluctuations in the elevation angle of the wind (σ_φ) coupled with wind speed and time of day.

Method 3. The standard deviation in fluctuations of wind direction azimuth (σ_θ) coupled with wind speed and time of day.

EPA (2000a) provides appropriate criteria for determining Pasquill stability using each of these methods. Methods 2 and 3 have the appeal of utilizing direct measurement of turbulence, whereas method 1 is similar conceptually to Pasquill's original method. Use of ΔT data alone for stability classification, as outlined in Nuclear Regulatory Commission Regulatory Guide 1.23, Rev. 1 (2007b) is not recommended for use in stability classification since there is only a weak relationship between turbulence intensity and lapse rate in unstable conditions.

For sites utilizing meteorological data from the National Weather Service or other private and public sector organizations, the use of Pasquill's original scheme, as modified by Turner (1970) (summarized in Table 5-1) is appropriate. Classification criteria for Turner's method is summarized in Table 5-1 and described in EPA (2000a).

TABLE 5-1. Key to Pasquill Stability Categories

A: Extremely Unstable Conditions B: Moderately Unstable Conditions C: Slightly Unstable Conditions			D: Neutral Conditions E: Slightly Stable Conditions F: Moderately Stable Conditions		
	Daytime Insolation			Nighttime Conditions	
Surface Wind Speed (m/s)	Strong	Moderate	Slight	Thin overcast or ≥ 4/8 low cloud	≤ 3/8
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Note: Neutral category D should be used regardless of wind speed, for overcast conditions during day or night

For some models, the dispersion coefficients consist of continuous functions of atmospheric turbulence intensity and downwind distance (Hanna et al. 1977; Irwin 1983; Pasquill 1979; Ramsdell et al. 1982). Pasquill strongly advocated the explicit use of turbulence data to evaluate dispersion coefficients, and models with continuous functions for σ_y and σ_z should be used when possible. One advantage is that lateral and vertical diffusion can be calculated independently rather than depend on one single characterization of turbulence.

5.6 Criteria for Meteorological Measurements

The meteorological monitoring system design should be based on the needs and objectives of the facility and the guiding principles for making accurate and valid meteorological measurements. Meteorological measurements should be made in locations that, to the extent feasible, provide data representative of the atmospheric conditions into which material will be released and subsequently transported.

A qualified professional meteorologist or atmospheric scientist with experience in atmospheric dispersion and with meteorological instrumentation should be consulted in selecting measurement locations and in the design and installation of the meteorological monitoring system.

Factors to be considered in selecting the appropriate measurement locations and for the determination of the installation of the instruments should include the prevailing wind direction, the topography, and the location of man-made and natural obstructions. Any special meteorological monitoring requirements imposed by other agencies (i.e., outside of DOE) should be taken into consideration when designing meteorological measurement systems and establishing measurement locations (e.g., a DOE-owned facility that is licensed by the NRC).

The instruments used in a meteorological monitoring program should be capable of continuous operation within the expected range of atmospheric conditions at the DOE facility. An uninterruptible power supply should be included in the system, and an alternate source of power should be available for longer duration outages.

5.6.1 Criteria for Siting and Locating Meteorological Measurements

Wind speed and wind direction measurements should be able to adequately characterize the wind and turbulence (if being directly measured) at potential release heights. If a vertical temperature difference (i.e., $\Delta T/\Delta z$) is used along with solar radiation to determine atmospheric stability, the temperature difference should be determined over an interval of sufficient thickness to avoid undue influence of the ground (typically at least 50 meters). The temperature monitoring levels should be selected and spaced such that the profile is representative and characterizes the magnitude of atmospheric turbulence at the potential release height(s).

EPA (2000a) and ANSI/ANS-3.11-2005 (R2010) provide information on siting and exposure of meteorological towers and sensors for the in situ measurement of the primary meteorological variables. EPA (2000a) includes information on siting in simple terrain, complex terrain, coastal locations and urban locations.

Other necessary meteorological measurements should be made using appropriate instrumentation in accordance with accepted procedures. Standard meteorological measurement techniques for the basic meteorological measurements (i.e., wind speed, wind direction, temperature, and precipitation) and site-specific supplemental meteorological measurements (i.e., atmospheric moisture, solar and net radiation, barometric pressure, mixing height, soil temperature, soil moisture) are outlined in ANSI/ANS-3.11-2005(R2010) and EPA (2000a).

Meteorological measurement techniques applicable to complex terrain features, coastal locations, and urban locations are outlined in EPA (2000a).

Additional information on meteorological monitoring to characterize turbulence can be found in ANSI/ANS-3.11-2005 (R2010), and EPA (2000a). Other necessary meteorological measurements should be made using standard instrumentation in accordance with accepted procedures and manufacturers' recommendations.

5.6.2 Instrument Mounting Criteria

Monitoring site locations need to be selected to reduce aerodynamic influences of obstructions and external influences that may adversely affect the measurements. Wind measurements should be made at locations and heights where airflow modification by obstructions such as large structures, trees, or nearby terrain with heights exceeding one-half of the height of the wind measuring device is minimized. Air temperature and relative humidity measurements should be made in a way to avoid modification by heat and moisture sources (e.g., heating ventilation and air conditioning sources, cooling towers, nearby water bodies, large paved parking lots). The meteorological tower should be sited in an accessible location and the accessibility should be maintained. The meteorological monitoring tower should not be located on or near man-made surfaces such as concrete or asphalt.

Mounted wind instruments may be placed on top of the towers or on booms extending to the side of the towers to avoid confounding effects of tower-generated turbulence. Instruments mounted above a tower should be mounted on a mast extending at least one tower diameter above the tower. Instruments mounted on booms extending to the side of a tower should be at least two tower diameters from the tower. Furthermore, the booms should be oriented in directions that minimize the potential aerodynamic effects of the tower on the wind measurements. The orientation of booms for wind instruments should be determined after considering the frequencies of all wind directions. Orientation of the booms on the basis of only the prevailing direction might not minimize tower effects. In some locations, placement of wind instruments on opposite sides of the tower could be necessary to obtain reliable wind data for all wind directions. For locations with two distinct prevailing wind directions, the sensors should be mounted in a direction perpendicular to the primary two directions.

Temperature sensors should be mounted and placed in fan-aspirated radiation shields, and the shields should be oriented to minimize effects of direct and reflected solar radiation. The shield should provide ventilation of the sensor at appropriate flow velocities recommended by the vendor. The shield inlet should be at a distance at least 1.5 times the tower horizontal width away from the nearest point on the tower.

5.6.3 Measurement Recording Systems Criteria

The onsite meteorological monitoring system should use an electronic digital data acquisition system housed in a climatically controlled environment as a primary data recording system. A backup recording system for the meteorological monitoring system is recommended, particularly for DOE sites that require a high assurance and availability of valid data. The current generation of data loggers is so well temperature compensated that environmental control is only required in very extreme conditions. The output of the instruments should be displayed in a location where instrument performance can be monitored on a regular basis.

Digitally recorded data used to determine averages for storage into the archive database should consist of, except for $\sigma_{\Theta,}$ σ_{φ} and precipitation, at least 30 samples taken at intervals not to exceed 60 seconds. The time period represented by the averages should generally be 15 minutes. A minimum of 180 equally spaced wind direction samples is required for estimation of σ_{Θ} and σ_{φ}. For turbulence measurements with sonic anemometers, a 10 Hz sampling rate should be used. Fifteen-minute averages should be stored in a permanent archive. Additional information on sampling frequency and statistical considerations, such as determining 15-minute and hourly averages, as well as on the standard deviation of wind direction for turbulence characterization is detailed in ANSI/ANS-3.11-2005 (R2010) and EPA (2000a).

5.7 Measurement System Accuracy Criteria

The accuracies of the monitoring measurements should be consistent with the specifications set forth in either ANSI/ANS-3.11-2005 (R2010), or EPA (2000a). The specifications in the EPA guidance are usually similar to or more stringent to those found in ANSI/ANS-3.11-2005(R2010). The minimum system accuracy and resolution requirements for digitally recorded data and instrument specifications identified in ANSI/ANS-3.11-2005 (R2010), and EPA (2000a) are presented in Table 5-2. System accuracy should be estimated by calculation of the root-mean-square of the accuracy of the individual components of the system.

TABLE 5-2. Standards of Accuracy of Meteorological Criteria

Criterion	Standard of accuracy
Horizontal and vertical wind direction	±5º in azimuth with a starting threshold of 0.45 m/sec (1 mph). If a wind vane is to be used to determine σ_ϕ, the damping ratio needs to be between 0.4 and 0.6, and the delay distance should not exceed 2 m
Wind speed	±0.22 m/sec (0.5 mph) for speeds less than 2.2 m/sec (5 mph); within 5% for speeds of 2.2 m/sec (5 mph) or greater, starting speed of less than 0.45 m/sec (1 mph)
Air temperature	±0.5ºC
Vertical air temperature difference	±0.1ºC/50m*
Dew point temperature	±1.5ºC
Relative humidity	±4%
Solar/Terrestrial radiation	±5 watts/m^2 for <100 watts/ m^2
Barometric pressure	±3 mb (0.3kPa)
Soil temperature	±1ºC
Soil moisture	±10% of actual
Precipitation	±10% of volume
Time	±5 min

* The vertical air temperature difference accuracy requirement is more precise since this parameter is generally used in turbulence typing where very small differences may result in different stability class determinations.

5.8 Inspection, Maintenance, Protection, and Calibration Criteria

The meteorological monitoring program should include routine inspection of the measured data for validity. Scheduled maintenance and calibration of the meteorological instrumentation and data-acquisition system should be performed semi-annually at a minimum, or at another appropriate interval based on the calibration recommendations of the manufacturers. Inspections, maintenance, and calibrations should be conducted in accordance with written controlled procedures. Logs of the inspections, maintenance, and calibrations should be kept and maintained as permanent records within the site's records management system. ANSI/ANS-3.11-2005 (R2010) provides guidance on recommended calibration practices and on field calibration checks for meteorological instrumentation.

The meteorological monitoring system should be capable of providing data recovery of at least 90 percent which is quality assured on an annual basis for the combination of wind direction, wind speed, and those data necessary to classify atmospheric stability.

All elements of the monitoring and data recording systems should be protected from lightning-induced electrical surges and severe environmental conditions. Functional checks of instrumentation, including recalibration, should be performed after exposure to damaging meteorological conditions or other events with the potential to compromise system integrity.

5.9 Criteria Associated with Supplementary Meteorological Instrumentation

Supplementary meteorological data may be needed to support site-specific programs, including, but not limited to, flows in complex terrain over large distances. The topographic setting around a DOE facility, especially with regard to the types of air flow encouraged by the local topography, and the distances from the facility to points of public access should be considered when evaluating the need for any supplementary meteorological instrumentation. Supplementary measurements should be made if meteorological measurements at a single location cannot adequately represent atmospheric conditions for transport and diffusion computations (that is, spatial representativeness).

Additional meteorological data may be necessary for making estimates of atmospheric transport and dispersion for large distances. Data from spatially representative meteorological stations (e.g., military, National Weather Service, cooperative stations) can be useful for these applications. The determination of the number of additional data sources and their location(s) is dependent on the heterogeneity of the terrain, the possibility of the presence of three-dimensional atmospheric flow phenomena, and the complexity of the application for which the data will be applied. These judgments require an extensive knowledge of atmospheric transport and dispersion principles. Accordingly, qualified meteorologists should be consulted with respect to these judgments.

In some instances, in situ measurements may be augmented by measurements from remote sensing technologies. These include various widely deployed (i.e., commonly used) systems, and less widely deployed systems.

5.10 Meteorological Data Processing Criteria

Designing environmental surveillance programs, establishing compliance with applicable regulations and DOE directives, and analyzing the consequences of potential or actual releases

require information on a common set of meteorological elements. Typically, these elements are wind direction, wind speed, a direct or inferential measure of turbulence, air temperature, and mixing layer thickness. Data should be averaged over a period not to exceed 15 minutes for archival in the permanent database. Although the individual applications could require data for a common set of meteorological elements, the format in which the data are required will vary by application and assessment procedure. Many of these applications will need an averaging interval of one-hour for construction of a time series of data over a defined period of record, or to develop a data set consisting of the joint frequency of occurrence of wind direction sectors and wind speed categories by Pasquill stability.

5.11 Data Summarization and Archiving Criteria

It is important that every facility have a valid and accurate meteorological database, which can be utilized to evaluate environmental impacts and consequence assessments. For licensing and other regulatory purposes, five years of meteorological data are recommended. For future facilities, there should be at least a one-year period of pre-construction data and one- to two-years operational data that meet the aforementioned 90 percent quality assured data recovery requirements. These data should be examined and entered into the permanent archive at least monthly. Meteorological data, raw and quality-assured, should be retained for the life of the facility.

5.12 QA and Documentation Criteria

As they apply to meteorological monitoring, the general QA program provisions described in Chapter 11 should be followed. Guidance in quality assurance related to meteorological measurements and meteorological data processing may also be found in Finkelstein et al. (1983) and ANSI/ANS-3.2-1994.

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6 ENVIRONMENTAL SURVEILLANCE

The purpose of the environmental surveillance program is to characterize the radiological conditions of the DOE facility environs and, if appropriate, estimate public doses related to these conditions, and confirm predictions of public doses based on effluent monitoring data. Environmental surveillance data also may be useful in evaluating doses to the biota consistent with DOE O 458.1 and DOE-STD-1153-2002. The environmental surveillance program should be conducted in accordance with the requirements of DOE O 458.1 and other applicable regulations and DOE directives. Media routinely monitored in environmental surveillance include air, water, terrestrial foodstuffs, aquatic foodstuffs, soil and sediment.

The responsible DOE field organization needs to determine the scope of the environmental surveillance program by considering the following factors:

- Applicable regulations;
- Hazard potential of the effluents;
- Expected quantities and concentrations of effluents;
- Nature of potential or actual impacts on air, land, biota, and water;
- Extent to which facility operations are routine and unchanging;
- Need for supplementing and complementing effluent monitoring;
- Size and distribution of the exposed population;
- Cost effectiveness of modifications to environmental surveillance; and
- Availability of measurement techniques that provide sufficiently sensitive comparisons with the applicable standard and “ambient” measurements.

A lines of inquiry approach is provided to conduct self-assessments; to verify that the program is effective and in compliance with appropriate requirements; and to ensure the existence of continuous improvement of the program. Lines of inquiry are identified in Appendix B of this Handbook.

6.1 Key Requirements

DOE O 458.1, *Radiation Protection of the Public and the Environment*, requires that environmental monitoring conducted as part of demonstrating compliance with the Public Dose Limit include environmental surveillance.

6.2 Summary of General Criteria

The criteria listed in Table 6-1 can be used to establish environmental surveillance program elements for DOE sites. Any additional site-specific criteria should be documented in the site Environmental Monitoring Plan (EMP) or other supporting documentation.

An evaluation (e.g., critical pathway analysis) should be conducted and used as the basis for establishing environmental surveillance for DOE sites. The results of this evaluation should be documented in appropriate records to show the following:

- Environmental measurement and sampling locations used for determining ambient environmental levels resulting from facility operations;
- Procedures and equipment needed to perform the measurement and sampling;
- Frequency and analyses required for each measurement and sampling location;
- Minimum detection level and accuracy;
- QA components; and
- Investigation and alarm levels.

TABLE 6-1: Minimum Criteria for Determining Need for Environmental Surveillance

Topic	***Criteria***
Routine Surveillance of All Pathways (Ingestion, Inhalation, and Immersion and Submersion Doses)	When feasible, all environmental media that, as determined by site-specific radiation exposure pathway analysis, might lead to a measurable annual dose of site origin at the location of the MEI (or a representative location) should be routinely sampled and analyzed for the radionuclides important to dose estimation, and routine measurements of penetrating radiation should be performed at those sites that, as determined by site-specific exposure pathway analysis, might result in an annual dose of site origin at the site boundary, if the total exceeds: a) 5 mrem effective dose, or b) 100 person-rem collective effective dose to the affected population (e.g., within a radius of 80 kilometers (km) of a central point in the site).
Periodic Confirmation	Environmental surveillance measurements may be performed occasionally when potential dose is low, but should be performed at least every five years even when the projected annual effective dose to the public is less than 0.1 mrem. The frequency and magnitude of environmental surveillance should be proportional to the potential annual dose. Where potential annual dose represents a significant fraction of the reference dose for routine surveillance, environmental sampling should be more frequent. At 20 percent of the reference dose (e.g., 1 mrem effective dose from emissions during a year), annual surveillance for confirmation should be considered. Similarly, more frequent measurements may be warranted if the biota screening levels are challenged.
Pathway Measurements	Actual measurements on two media for each critical radionuclide/pathway combination, one of which might be the effluent stream, should be performed as part of the site routine environmental monitoring and surveillance program.
Characterization of Background	Use of data should be based on statistically significant differences between the point of measurement and background data.
Unplanned Releases	Provisions should be made, as appropriate, for the detection and quantification of unplanned releases of radionuclides to the environment.

6.2.1 Evaluation of Need for Sampling

The need for environmental sampling and analysis should be evaluated, by exposure pathway analysis, for each site radionuclide effluent or emission (liquid or airborne). This analysis with appropriate data, references, and site-specific assumptions, along with site-specific criteria for selection of samples, measurements, instrumentation, equipment, and sampling or measurement locations, should be adequately and appropriately documented as part of the ERPP. If actual releases are significantly greater than expected, or if unplanned or accidental releases occur, re-evaluate the environmental surveillance needs based on the actual releases. A critical pathway analysis (radionuclide/media) should be performed, documented, and referenced in appropriate documentation (e.g., ERPP-related documents, ASER). If the projected dose equivalent from inhalation of particulates exceeds the criteria of Table 6-1, a particle-size analysis of the sample should be conducted at least annually. In addition, the lung solubility class that is assumed for the particulates in question should be justified and re-substantiated on an annual basis if it is likely to vary with changing facility operations. If environmental surveillance data are to be used with (or in place of) effluent monitoring and modeling to support the assessment and demonstration of compliance with such regulations as 40 CFR Part 61, consider the special requirements of those regulations in the planning and implementation of the environmental surveillance system.

The radionuclides of interest are site specific and should be identified based on process knowledge, previous sampling results, and other pertinent information. Radionuclides of interest discussed in this document are provided as a general guide only. While it is tempting to include every suggestion, excessively long lists of radionuclides may lead to:

- Extra expense;
- Spectral interference; and
- False positives.

Expense: depending on the procedure, the analytical laboratory may charge more for extra analytes.

Spectral interference: occurs when the alpha-particle or photon energies for different radionuclides are too close. Peaks may overlap, or one peak can affect the estimated background of another, or unwanted data from one radionuclide may be within the region of interest of another. This is a frequent problem, and becomes more frequent with a long list of analytes.

False positives: typically, a few percent of the peaks reported by a computer program are false positives, and the more peaks the computer is asked to look for, the more false positives it will find. The problem of false positives is aggravated by the common practice of reporting the number of counts in a “region of interest” regardless of whether there is a well-defined peak in the right place and with the right shape. The human eye is good at pattern recognition; if a peak does not look real to a human eye, it probably is not real. If there are serious ramifications with a false positive, health-physics staff should examine the shapes and locations of the peaks, and consider whether all the expected peaks are credible, and have areas consistent with expectations.

Health physics staff should help to develop a list of radionuclides with a credible chance of being observed. Legacy materials are likely to predominate at most DOE sites. In this case, materials with short half-lives are unlikely unless there is a long-lived parent.

When determining radionuclides of interest, staff should consider each category: transuranics, uranium, fission products, and activation products.

Transuranics: the most common transuranics are: Pu-238, Pu-239, and Am-241. Transuranics should be measured by alpha spectrometry or elemental analysis techniques. Detection of transuranics by gamma spectrometry is unreliable because of the spectral interference between the low-energy gammas emitted by transuranics and the K-shell and L-shell x-rays emitted by many radioactive materials.

Uranium: may be categorized as natural uranium, uranium tailings, refined uranium, enriched uranium, and depleted uranium. Uranium should be measured by alpha spectrometry or elemental analysis techniques. The first two categories include Pb-214 and Bi-214, the other three do not. Refined uranium does not include measurable amounts of Pb-214 and Bi-214, because Th-230 and Ra-226 were removed during the refinement process and they take thousands of years to grow in. Therefore, at facilities that use only refined uranium, the presence of Pb-214 and Bi-214 indicate natural uranium. On the other hand, facilities that processed uranium ore will have Th-230, Ra-226, Pb-214, and Bi-214 in the tailings. The isotopic ratios of U-234:U-235:U-238 are useful, though staff should be aware that water is usually enriched in U-234 because the decay process causes the U-234 to become dislodged, and so makes it more soluble.

Fission products: normally occur together in a mixture known as “mixed fission products.” At reactor facilities or re-processing facilities, the list of fission products will be long. In legacy

material, only two fission products are normally measurable: Sr-90 and Cs-137. However, Cs-134 is easy to detect by gamma spectrometry when sampling shortly after fission product accident events (e.g., Fukushima-Daiichi). Iodine isotopes are potentially important, though most have short half-lives; iodine-129 is naturally occurring and is very difficult to detect.

Activation products: Co-60 is easy to detect by gamma spectrometry. Na-22 is also easily detected by gamma spectrometry and may be measurable in more recently activated materials. Tritium is widespread and requires specialized detection techniques. At accelerators, the list of activation products will be long.

Radionuclides in sealed sources are unlikely to be found in the environment. Also, small quantities of radionuclides used in a well-managed modern facility are unlikely to be found in the environment unless there is a leak or spill. Discharges from a permitted outfall are monitored and the data should guide the environmental staff.

Measurement of background/ambient and near-site naturally-occurring radionuclides (e.g., Be-7, K-40, Tl-208, Pb-212, Pb-214, Bi-214, and Ac-228) may be useful as a reality check and to confirm that systems are behaving as expected.

The mobility of radionuclides and the likelihood of uptake into biota should also be considered. Tritium is the most mobile and is readily taken up by biota. Iodine is mobile, readily taken up by mammals, and concentrates in the thyroid, so it should be monitored if recent fission products are credible; several iodine isotopes are readily detected by gamma spectrometry when sampled shortly after fission product accident events (e.g., Fukushima-Daiichi). Strontium behaves like calcium and it is moderately mobile. Uptake of strontium into biota depends on the availability of calcium in the environment, though some plants do not easily discriminate between strontium and calcium. Cesium cations attach strongly to the soil matrix and are less mobile than strontium. Most biota can discriminate between cesium and potassium, so uptake of cesium is dependent on the availability of potassium. For example, cesium uptake is common near Savannah River where the soil is deficient in potassium, and less common where potassium is abundant. Transuranics are generally less mobile and not easily taken up by biota.

6.2.2 Emergency Monitoring Provisions

Emergency monitoring is beyond the scope of this document. However, provisions for monitoring during an emergency situation should be considered when planning for environmental monitoring and determining routine program needs. Further provisions should be

made, as appropriate, for the detection and quantification of unplanned releases to the environment of radioactive materials, including radionuclides that may be transported by storm water runoff, flooding, or re-suspension of ground-deposited material. It is important to establish an environmental surveillance program that will provide adequate data to compare to measurements taken to support a response should an emergency occur.

6.3 Performance Requirements for Environmental Surveillance Programs

For all new or modified DOE facilities, a pre-operational assessment should be made and documented to determine the types and quantities of effluents to be expected from the facility and to establish associated environmental surveillance programs. Calibration of dosimeters and exposure-rate instruments should be based on NIST traceable standards. Where significant variations in effluent releases are observed or expected, obtain environmental samples or perform measurements either continuously or at an interval less than one-half the expected peak-to-peak interval. Gross radioactivity analyses should be used only as trend indicators, unless documented supporting analyses provide a reliable relationship to specific radionuclide concentrations or doses. The overall precision (± percent uncertainty) of all measurements should be estimated, and the LLD at specified confidence levels for appropriate radionuclides should be determined and documented. Sample preservation methods used to assure integrity should be consistent with the analytical procedures used. All environmental surveillance programs and procedures should be designed to ensure representative samples or measurements of the radiation exposure pathway media are obtained.

6.3.1 Specific Performance Requirements

Sampling or measurement frequencies for each significant radionuclide - environmental medium combination (e.g., those contributing greater than 0.1 mrem effective dose or greater than or equal to 10 percent of the annual offsite dose from all emissions) should take into account the half-life of the radionuclides to be measured and should be documented in the site environmental surveillance description. When considering short-half-life radionuclides, ensure that the sampling and measurement intervals do not exceed twice the half-life of the radionuclide. “Background” or “control” location measurements should be made for every significant radionuclide and pathway combination for which environmental measurements are used in the dose calculations. An annual review of the radionuclide composition of effluents or emissions should be conducted and compared with those used to establish the site environmental surveillance monitoring program plan or other document that describes the

environmental surveillance. Deviations from established environmental surveillance requirements, including sampling or measurement station placement, should be documented.

6.3.2 Air Sampling System

Air sampling equipment calibrations should be performed by either a primary measurement device or a calibrated secondary measurement device at the field location. Recalibration should be performed on a pre-determined schedule. The air sampling rate should not vary by more than ± 20 percent, and total air flow or total running time should be indicated or recorded; air sampling systems should be leak-tested, flow-calibrated, tested, and inspected on a routine basis. At a minimum, the manufacturer's recommended calibration frequency should be followed.

6.3.3 Consultation with Game Officials

If protected species are selected through the critical pathway analysis to sample, analogous species should be selected and sampled in their place whenever possible. State and local game officials should be consulted when selecting appropriate protected species to sample.

6.3.4 Consultation with Local, State and Regional EPA Representatives

DOE field elements and contractor staff should ensure that ground water monitoring plans are consistent with applicable State and regional EPA ground water monitoring requirements. DOE Federal and contractor staff should consult as needed, with local, and State representatives and regional EPA offices, to ensure that applicable requirements are incorporated into environmental surveillance program documentation.

6.4 Design Criteria

It is important that overall objectives for environmental monitoring programs be established and documented. It is also important that the environmental surveillance program be reviewed periodically and modified as program needs change. The general design criteria for establishing an environmental surveillance program for radioactive materials released in the effluents or emissions from DOE-controlled facilities are discussed in the following sections.

6.4.1 Environmental Surveillance Program Objectives

Environmental surveillance programs conducted at all DOE sites should enable the following to be determined:

- Compliance with all applicable environmental quality standards and public exposure limits; and the requirements of DOE O 458.1;
- Background levels and site contributions of radioactive materials in the environment;
- Effectiveness of effluent treatment and controls in reducing effluents and emissions;
- Validity and effectiveness of models to predict the concentration of contaminants in the environment;
- Quantification of contaminant transport into the environment;
- Long-term buildup and prediction of environmental trends from site-released radioactive material; and
- Detection and quantification of unplanned releases.

In addition to determining the need for an environmental surveillance program based on the objectives noted above, certain subsidiary objectives should also be considered. For example, site history and current public interests might indicate the need for an environmental surveillance program that examines specific aspects of a site's environmental impact, even when no other need is indicated.

The following is a partial list of subsidiary objectives (as provided in ICRP 1985) that should be considered when establishing environmental surveillance program objectives:

- The environmental surveillance should provide information that is available to the public;
- The environmental surveillance program should provide data that enable distinguishing site radiation contributions from other local sources (natural or manufactured);
- The environmental surveillance program should be capable of obtaining data that may be needed to assess the consequences of an accident; and
- Elements of the environmental surveillance program should be capable of determining site-specific values for transfer parameters where appropriate. Information on transfer parameters is provided in IAEA (2010a), ICRP (2009), and Staven et al. (2003).

6.4.2 Program Planning and Design

Factors that affect the relative level of environmental surveillance and to some extent the points at which measurements are to be made, include:

1) The potential hazard of the materials released, considering both expected quantities (including unplanned releases) and relative radiotoxicities;
2) The extent to which facility operations are routine and unchanging;
3) The need for supplementing and complementing effluent monitoring;
4) The size and distribution of the exposed population;
5) The cost effectiveness of modifications to the environmental surveillance program; and
6) The availability of measurement techniques that provide sufficiently sensitive comparisons with the applicable standard and “background” measurements.

The environmental surveillance media sampled or radiation measurements made should represent, as much as possible, the actual exposure vectors to people. Selection of locations, frequency, media and radionuclides to be measured, and measurement techniques are the basis of an environmental surveillance program. This program also should include any special monitoring required, such as trend indicators and additional samples/measurements required for quality assurance. The effort devoted to the environmental surveillance program should reflect the significance of the projected radiation doses.

Once the critical pathways and nuclides are identified (i.e., a critical pathway analysis is carried out), an annual review comparing reported effluent releases with those considered in the original analysis should be conducted and changes in the environmental surveillance program noted in a revised version of the appropriate program document and discussed in the ASER.

The effluents and the environment into which they are dispersed are dynamic, exhibiting both spatial and temporal variations of nearly all constituents. The importance of each individual radionuclide depends on its physical and chemical form, which determines its movement in the environment and eventual uptake, deposition, and retention by humans, and on the differential metabolism of the radionuclide by humans.

Providing site-specific tables of the environmental sampling/measurement locations per site as a function of calculated annual total effective dose (TED) to the representative person or to the MEI or collective dose is recommended. Any changes in site-specific factors (e.g., location of samples, type of samples, average temperatures, wind direction or velocities) and the basis for

the change(s) should be indicated in environmental surveillance program documentation. Information previously used should be preserved in historical records.

6.5 External Exposure Monitoring

A primary objective of external exposure monitoring is to assess and limit the actual or potential radiation dose to persons in the site environs. External exposure monitoring considerations include: (1) external exposure in air; (2) external exposure in water; (3) external radiation measurement locations and frequency; (4) factors in selection of indicator locations; (5) locations of background measurement stations; (6) onsite and offsite locations needed to characterize discharges or confirm effluent monitoring and modeling projections; (7) shoreline locations; and (8) height and frequency of measurements.

For most DOE facilities, the whole-body exposure is limited, and penetrating radiation measurements are satisfactory. Exceptions could include the atmospheric release of beta emitters such as uranium decay products or krypton from fuel manufacturing or reprocessing facilities, respectively. For DOE sites, the gamma (and, where applicable, neutron) exposure (or exposure rate) should be measured or calculated; any significant skin dose from airborne beta emitters should be calculated from effluent data. If external beta doses from deposition are considered to be significant, they should be estimated from effluent data, from beta-sensitive dosimeters, or by soil or vegetation sampling and laboratory analysis.

6.5.1 External Exposure in Air

One of the “critical pathways” of exposure for population groups living within the vicinity of DOE facilities is exposure to external radiation from those sites (Denham 1979). Exposure of population groups to external radiation from DOE operations includes: (1) cloud passage of airborne effluents; (2) previously released and deposited radionuclides on soil, vegetation, or sediments; (3) radiation-generating facilities, especially high-energy accelerators or industrial x-ray equipment, and large isotopic radiation sources; and (4) the storage, disposal, or movement of large sources of radioactive waste.

6.5.2 External Exposure in Water

External exposures from radionuclides in water generally are insignificant. However, unique situations could arise where recreational, commercial, or industrial use of a receiving body of water might cause exposure to certain individuals. Appropriate environmental measurements should be included in the routine program to better define an unusual “source” if the site-specific

pathway analysis shows this to be a significant (greater than 10 percent of the total offsite dose) source of exposure.

6.5.3 External Radiation Measurement Locations and Frequency

Considerable judgment needs to be used in locating environmental radiation measurement stations. Before final placement of any environmental radiation measurement station (background or control and indicator locations), an initial on-the-spot survey should be performed and documented to determine the absence of possible naturally occurring anomalies that could affect interpretation of later measurements. The recommended technique for making these pre-surveys is to use a low-level radiation survey instrument (e.g., micro-R meter) followed up with a pressurized ion chamber (PIC) measurement at those geographic locations selected on the basis of the preliminary screening by portable instrument survey. If desired, an in situ gamma- ray spectrometer (e.g., NaI, IGe (Intrinsic Germanium detector), or Ge(Li)) can be used to determine which terrestrial nuclides are contributing to the observed exposure rate.

Examples of dosimeter placement locations to be avoided, if at all possible, include the following:

- Locations of unique or different geology (i.e., reflecting changes in the terrestrial background);
- Locations where the altitude differs significantly (e.g., altitudinal differences between “background” or control locations and those indicator locations to be used around a given DOE site should not exceed 150 m (reflecting changes in the cosmic-ray background));
- Locations where the proximity of structures could alter the measurement results (reflecting changes from shielding or high background radiation levels due to naturally occurring radionuclides in building materials (e.g., thorium, uranium, radium)); and
- Valleys or hollows (where puddles of precipitation or runoff could accumulate, or where local topography could shield the dosimeters from the possible passage of airborne effluents).

6.5.4 Factors in Selection of Indicator Locations

Selection of the indicator locations[4] for external exposure monitoring should be based on expected sources of external radiation – noble gas plumes, soil-deposited atmospheric particulates released from the site, onsite radiation-generating facilities or large radiation sources, or potential routes of waste transport from the site – and the local population distribution and prevailing wind directions. The technique described by Waite (1973a, 1973b) for placement of air samplers, based on average meteorological conditions and existing population distributions should be considered for determining external radiation measurement locations.

6.5.5 Location of Background Measurement Stations

Background or control measurement stations should be located a minimum distance of 15 to 20 kilometers (km) from the larger sites and 10 to 15 km from the smaller sites in the least prevalent wind direction. Control stations should also be placed in areas typical of local geology, away from buildings (which can shield the detectors), and at similar elevations to those for indicator stations. The emphasis here is on the placement of dosimeter stations such that the difference between background/control or pre-operational data and the data from those stations expected to be affected by site effluents/activities can be assessed accurately.

6.5.6 Offsite Locations

Offsite radiation measurement locations should be monitored for each DOE site where predicted external radiation doses exceed the 0.1 mrem effective dose criterion in Table 6-1. These offsite measurement locations include a background or control location, site perimeter or boundary locations, and locations in nearby communities (within a pre-determined distance from the site to include communities in the predominant transport regions). The site perimeter or boundary locations should include locations directly upwind from the maximum predicted

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[4] Indicator locations are monitoring locations intended for measuring radioactive material or radiation that has or may be present as a result of a DOE activity or operation. Background or ambient background locations are those monitored or sampled to establish to establish radiation or radioactive material levels that are not associated with DOE activities. Indicator locations also are used to verify or validate modeling projections and in such cases may indicate nothing above background.

ground-level concentration from atmospheric releases averaged over a period of 1 year. Offsite measurement locations should coincide with locations where maximum predicted levels occur and where any member of the public resides or abides.

For those sites larger than a few kilometers in radius, the maximum predicted concentrations may actually be onsite. In this case, radiation measurements may be made at the onsite location of predicted maximum air concentration(s), as well as other locations that may be helpful in the interpretation of offsite results.

6.5.7 Shoreline Locations

If exposure measurements are to be made at shoreline locations, dosimeters should also be placed to correspond to key water sampling locations (including the site boundary), as well as locations important for recreational, commercial, or industrial use. However, changes in water elevation caused by tides or fluctuating releases from dams may make this impractical, in which case intermittent exposure-rate measurements need to be used during the seasons in which recreational use of the shoreline (for hunting, fishing, sun-bathing) actually occurs.

6.5.8 Height and Frequency of Measurements

The recommended height for external radiation measurement is 1 m above the surface. If another height is used, the relationship to the 1 m height should be established and documented for the site. The frequency should be based on predicted exposure rates from site operations at the measurement locations. Integrating devices (e.g., dosimeters) should be exposed long enough (typically 1 calendar quarter) to produce a readily detectable dose (e.g., 10 × the minimum sensitivity of the dosimeter). If intermittent external radiation measurements are made, their frequency should be timed to coincide with batch atmospheric releases or the intermittent use of large sources or the operation of radiation-generating facilities.

6.6 Direct Radiation Measurement (Pressurized Ion Chamber-Type Instrumentation)

Factors for direct radiation measurement that need to be considered include: (1) continuous exposure monitoring; (2) neutron monitoring; and (3) instruments and methods to use.

6.6.1 Continuous Exposure Monitoring

Continuous environmental gamma-ray monitoring is available (Jackson et al. 1985; Urabe and Katsurayama 1984) and highly desirable, yet it cannot always be justified on the basis of initial

system cost or long-term maintenance. However, in situ gamma spectrometry should be used as a method of documenting environmental mixtures of radionuclides resulting from natural and manufactured sources (e.g., for dosimeter placement). Historical monitoring information also should be considered. The deployment of at least one continuously recording exposure-rate instrument is recommended, preferably near the site boundary in the expected direction of a potential plume. An array of continuously recording exposure-rate instruments should be considered if there is a potential for release of large inventories of gamma emitters.

6.6.2 Neutron Monitoring

For some sites, especially in the vicinity of high-energy facilities, neutron monitoring also may be necessary. Application of detection techniques to measure environmental levels of neutrons is limited. Commonly used materials for detection of slow or thermal neutrons include using a Bonner multisphere, etched track detectors, silicon diodes, and ionization detectors such as boron trifluoride proportional counters. Monitoring for fast neutrons will require use of Columbia Resin #39 (CR-39) detector material.

When neutron monitoring is necessary, the method of measurement should be based on the anticipated flux and energy spectrum. A fixed monitor (moderated boron trifluoride (BF_3) counter or rem counter) is recommended, yet site-specific conditions may warrant the use of intermittent portable instrument surveys only during the infrequent periods of machine operation. As with all external radiation measurements, neutron monitoring (or surveys) should be performed at the site boundary or location of nearest occupancy in the direction of maximum expected exposure rates, especially from beam dumps or accelerator targets.

6.6.3 Instruments and Methods

Instruments or dosimeters that have application to DOE environmental surveillance programs include Geiger-Muller (GM) and gamma scintillation systems, Pressurized Ion Chambers (PICs), Thermoluminescent Dosimeters (TLDs), Optically Stimulated Luminescence (OSL) Dosimeters and moderated BF_3 counters or rem counters. The method of measurement should depend on the anticipated type of radiation (beta, gamma, or neutron).

At high-energy particle accelerators, muon fields are monitored with scintillation counters located in the beam line. The muon fluence may fluctuate with the mode of operation of the accelerator. A typical application of in situ muon monitoring is to mount detectors on a vehicle

with the associated electronics and data acquisition system, and collect data while traversing the beam line.

Where integrating dosimeters are used, two or more dosimeters should be provided at each location (in the same package, if possible). Integrating dosimeters should be read without undue delay. It is critical that readings are made at a consistent time following collection.

DOE sites are encouraged to participate in international inter-comparison studies, such as the ones reported by dePlanque et al. (1976) and Gesell et al. (1982).

Only if adequate precautions are taken to avoid recording a significant exposure in transit can integrating dosimeters be sent to a distant location for processing.

6.7 Air Measurements and Sampling

The categories of airborne radionuclides that should be considered for measurement in air sampling systems include: (1) particulates; (2) gases (principally the noble gases); (3) halogens (principally radioiodines); and (4) tritium. These constituents are important because they account for virtually all of the radioactive materials released from DOE sites.

6.7.1 Basis for Air Sampling

Since air is a primary exposure pathway to humans from radionuclides released to the atmosphere, air sampling should be conducted to evaluate potential doses to populations from inhaled or ingested radionuclides or from exposure to radiation sources external to the body. The inhalation of airborne radionuclides, coming either directly from the source (facility) or from re-suspension following deposition, may result in their absorption from the lung or gastrointestinal (GI) tract. Absorption through the skin because of immersion in a “cloud” of gas and/or particulates may contribute to human exposure.

Radioactive materials in particulate form can result in radiation exposures to individuals both by direct inhalation and by deposition onto other environmental media. Therefore, wet/dry deposition monitoring should be included.

Although particle sizes range across a broad spectrum, with diameters ranging from about 0.01 to 10 micrometers (μm), the optimum size for deposition in the upper respiratory tract (and subsequently the deep lung) tends to be in the range of 0.01 to 3 μm, with 1 μm often used for dose assessment. However, particulate filters used for sampling will function over the entire size spectrum, collecting particulates in the “respirable” range, as well as those that are not.

The collection efficiency of filters used to collect particulate materials should be considered when calculating the concentration of radionuclides in the air that was sampled. If releases of particulate materials could contribute significantly to environmental doses, measurements of particle size should be made. When inhalation of particulates may be significant, lung solubility class assumptions should be substantiated.

The filter type should be appropriate for the particles being emitted. EPA (2002a) identified some choices:

- Cellulose B – a general-purpose filter, but not suited to alpha-emitting nuclides;
- Glass fiber – high collection efficiency, without high airflow resistance, good for high temperature applications;
- Membrane – good for alpha-emitting nuclides, but is fragile and has high airflow resistance; and
- Synthetic fiber – special fibers tailored to specific needs and situations.

NCRP (2010) provides further discussion of the characteristics, advantages and limitations of selected filter media.

It is often more feasible to determine the impact of short-lived gamma-emitting gases (e.g., nitrogen-13 (N-13) and argon-41 (Ar-41)) by measuring the direct exposure (i.e., external radiation) resulting from them rather than by sampling and analysis. Gamma spectroscopy of grab samples (e.g., filling a previously evacuated Marinelli sampler) can be used to quantify the concentrations of short-lived gases, which can then be correlated with the observed increase in exposure rates. For longer-lived noble gases (e.g., krypton-85 (Kr-85) and xenon-133 (Xe-133)), one technique used is the collection of an air sample by compression or cryogenic techniques, separation and purification of krypton and xenon by adsorption on chromatographic columns, and analysis by liquid scintillation counting (Grossman and Holloway 1985; Trevathan and Price 1985). For noble gases, sampling using an activated charcoal is another method. For other halogens, noble gases, and water vapor, activated charcoal is an efficient absorber. Because the adsorption process is not radionuclide-specific, the analyses of other radioactive halogens and noble gases with charcoal will require analytical discrimination to measure the concentrations (NUREG-1400).

Rainwater surveillance could be included in the evaluation of the airborne pathway. Locations for rainwater sampling should be co-located with air, vegetation, and soil surveillance locations. Sampling for deposition should be collected over a predetermined area, such as a 2-foot by 2-

foot stainless steel pan located on top of the monitoring stations. Dry deposition on the pan prior to rainfall is washed through the system with the rainfall. Therefore, the sample represents both wet and dry deposition. The rainwater is collected beneath the station in a collection bottle and is then analyzed in the laboratory for the required analyses. Separation of tritium from non-tritium isotopes could occur during the field collection using an ion exchange resin column or at the laboratory.

6.7.2 Sampling Locations

Offsite air samplers should be employed at each DOE site having potential airborne releases that could result in an annual effective dose greater than 1 mrem to the MEI. The exact number of samplers will be determined by meteorology, demography, and the magnitude of projected doses to the surrounding population.

Sample locations should include the following: (1) a background or control location; (2) representative locations of maximum predicted ground-level concentration from stack (or vent) releases, averaged over a period of 1 year where members of the public reside or abide; (3) locations in the nearest community within a 15-km radius of the site's sources; and (4) locations necessary to confirm modeling or to characterize impacts of off-normal discharges.

For those sites larger than a few kilometers in radius, the maximum predicted concentrations may actually be onsite. In this case, onsite sampling may include the locations of predicted maximum concentration(s) and any other locations needed to help interpret the offsite sample results. However, if there are no receptors onsite, depending on the sampling network, it may be cost effective not to have an additional sample at the maximum predicted location.

Selection of background sampling and measurement locations for air should be made with special care. For measurements to be compared with the effects of airborne releases, a minimum distance of 15 to 20 km from the larger sites and 10 to 15 km from the smaller sites in the least prevalent wind direction (that is, upwind) is suggested for background sampling. If the MEI could receive a TED of more than 5 mrem, additional air samples should be collected in those communities within a 15-km radius of the site boundary for which the projected dose equivalents exceed the criteria in Table 6-1, and at a background location (10 to 20 km from the site in the upwind direction).

Unless documented site-specific evidence exists to justify otherwise, the sample(s) at each air sampling station should be collected at a height of 1-2 m above ground level (approximately the

height of inhalation for adults), in a location free from unusual localized effects or other conditions (e.g., in proximity to a large building, vehicular traffic, or trees) that could result in artificially high or low concentrations. If possible, locations should be selected to avoid areas where large-particle (non-respirable) fugitive dusts can dominate the sample (Ludwig 1976).

A method similar to that developed (Waite 1973b) and evaluated by Waite (1973a) should be used to determine the number of air sampling stations and their placement. Waite's method entails examining demographic and meteorological data for the site to determine the distance to local population centers, their population, and the wind frequency distribution and weighting factors that are scaled to equal the desired number of sampling locations. The application of this method to sites in coastal or agricultural areas requires only minor modification of the procedure illustrated (i.e., sites in coastal zones would adjust the number of radial divisions to the number required to cover the surrounding inhabited land mass).

6.7.3 Sampling Frequency

Many factors should be considered to determine sample frequency. In general, the frequency of collection for air samples is adjusted to take into account the limitations of the sample collectors (collection efficiency), the capabilities of the air movers (e.g., vacuum pumps), and the physical problem of retrieving samples from each location on a fixed frequency, typically 1 to 2 weeks. However, the operational status of relevant facilities should also be considered. Unless otherwise justified, the maximum air particulate filter exchange frequency should be biweekly.

A common practice, especially for the longer-lived radionuclides, has been to composite filters for subsequent analysis from several locations and/or successive time periods, taking advantage of the larger volume of air sampled to achieve the desired sensitivity. Use of compositing techniques assumes that the concentration of a given radionuclide at the locations or for the time composited is sufficiently constant for the end use of the data. NCRP (2010) identified the following disadvantages of compositing: (1) poor resolution in time or location for an elevated concentration; (2) masking a single spike of high concentration by large numbers of filters with normal low activity; and (3) difficult modifications to analytical procedures when large numbers of filters are combined. Since the applicable standards are annual standards, comparison of annual averages to the standards is appropriate. For dose calculation purposes, the annual average concentration for a location or for a group of locations can still be compared against an annual average for a background location as an indication of potential facility impact during the year in question. Also, averages for successive years can be compared for detection

of general trends. Requirements for sample collection and analysis, including the use of compositing, are shown in Table 6-2 as a function of effective dose to the MEI or representative person.

For air sampling of non-particulate material, the available tradeoff between sensitivity and frequency of sample removal is governed primarily by the fact that “breakthrough” can occur with the charcoal cartridges, molecular sieves and silica gel. These breakthrough phenomena can be based on flow rate, total volume, activity, or a combination of these. The sample exchange frequency for non-particulate sampling should be determined on a site-specific basis and should be documented.

For facilities with a significant release of iodine, measurements can be made at site-perimeter and control stations to characterize local site environs. It is also recommended that the relationship between iodine-129 (I-129) and natural iodine (I-127) be determined. However, it may be assumed that because of the extremely long half-life of I-129, its accumulation (if any) in the environment may be better observed in milk or soils than in air.

6.7.4 Sampling Methods and Criteria

Filtration is by far the most popular air-sampling method (Lee 1974) and the method generally required for air-particulate collection at DOE sites. Correct use of the International Commission on Radiological Protection (ICRP) lung model, as described in ICRP Publication 66 (ICRP 1994), requires knowledge of the chemical state and the particle size distribution. The need for particle size measurements is especially important at those sites where re-suspension of previously deposited material is or can be a significant factor in environmental air concentrations. Such particle size measurements will also be useful in distinguishing re-suspended material from that of current emissions. Several methods, including impactors (e.g., multistage cascade impactor) and electrostatic precipitators, can be used to classify particle size (ISO 2010). Particulate filters can be made of any fibrous material, and a variety of filter media (e.g., cellulose, glass fiber, membrane, polystyrene) are commercially available. No single filter type is best for all purposes, but the specific filter to be used should be selected to meet site-specific requirements, such as high collection efficiency, particle size selectivity, retention of alpha emitters on the filter surface, or ease of radiochemical analysis. According to ANSI/HPS N13.1-1999 filter media used to sample airborne radioactive particles should have a minimum efficiency of 95 percent. (See also Table 4-2).

Airborne radioiodines can be collected with charcoal or silver zeolite cartridges in series behind the particulate filter, and analyzed by gamma spectrometry, the method suggested by the American Public Health Association (1988). For greater sensitivity, I-129 extraction from the charcoal media for concentrated gamma spectrometry or liquid scintillation counting can be performed. (HASL 300, I-01 (modified), EPA (1980a), Method 901.1 [modified] (EPA 1980b)). Compound filter canisters of several designs (e.g., Keller et al. 1970) have been used to distinguish the several chemical forms of radioiodine that may be present in the atmosphere. Generally these canisters will contain a particulate filter and silver wire or mesh plus charcoal, each of which is analyzed separately. This type of collection device should be used if the levels of radioiodine or the cause of the release warrant.

Routine environmental surveillance for short-lived noble gases (e.g., Ar-41) should be performed by external radiation measurements. Laboratory analysis of periodic grab samples of ambient air (Denham et al. 1974) should be performed for the longer-lived radionuclides, principally $^{-}$Kr-85 when the critical pathway analysis indicates the potential dose exceeds the criteria given in Table 6-2. Suggested methods for radioactive gas (Kr-85) sampling, either grab or continuous, can be found in the *Proceedings of the Noble Gases Symposium* (Stanley and Moghissi 1974) and in reports by Grossman and Holloway (1985) and Trevathan and Price (1985). Atmospheric stability and wind speed and direction during the period in which the samples were collected should be recorded to aid in interpreting and using the data for dose calculations.

Several methods are available for collection of atmospheric tritium, such as bubblers, molecular sieves, and silica gel (Denham et al. 1974; Guthrie et al. 2001; Patton et al. 1997; Rosson et al. 1998; Rosson et al. 2000). The American Public Health Association (1988) method recommends the use of silica gel as a desiccant to remove moisture (water (H_2O), HTO) from air, followed by re-evolution, collection as a liquid, and liquid scintillation counting (Griffin et al. 1972; Ostlund 1970; and Osborne 1974). Measurement of the specific activity of tritium in atmospheric moisture, using a passive device such as a container of silica gel suspended in air to collect tritiated water vapor, is considered satisfactory as a qualitative device only. Measurements using an active air sampling system that includes flow through a silica gel column at measured flow rates and volumes are acceptable as a quantitative measure if: (1) the silica gel is pre-dried before field use, and (2) is evaluated for internal intrinsic moisture exchange with tritium oxide in the atmosphere.

TABLE 6-2: Minimum Air Sample Collections and Analyses to Be Performed as a Function of Estimated Total Effective Dose (TED) to the Maximally Exposed Individual (MEI) or Representative Person, as Determined from Gaseous Effluent Releases

Sample Analysis Type	*Sample Collection/Analysis Criteria*		
	TED < 1 mrem[a]	*1 mrem < TED < 5 mrem*[a]	*TED > 5 mrem*
Air particulate:			
- Total beta	Yes, as indicators	Yes,[b] as indicators	Yes,[b] as indicators
- Total alpha	Yes, as indicators	Yes,[b] as indicators	Yes,[b] as indicators
- Gamma spectroscopy	Yes, annual composite	Yes, quarterly composite	Yes, monthly composite
- Other[c]	No	Yes, quarterly or annual composite	Yes, quarterly composite
- Alpha spectroscopy[d]	No	No	Yes
- Particle size determinations	No	Yes	Yes, one sample per quarter
Noble gases:			
- Direct radiation measurement	No[e]	No[e]	Yes
- Sample collection	No	No	Yes, one sample per quarter
Halogens (radioiodine):			
- Charcoal (KI impregnated) or silver zeolite	No	Yes	Yes
- Species differentiation (I_2 + CH_3I + HOI)	No	No	Yes, one sample per quarter
Tritium	No	Yes	Yes

a. Implemented when this TED is estimated to have been received during preceding 12 months

b. Assess relationships to specific radionuclide concentrations or use radiochemical analysis.

c. Some examples include Sr-90, Pu-239, U-natural or other radionuclides that need to be chemically separated prior to counting; the nuclides chosen need to be based on site-specific effluent data and contribution to dose.

d. Only if actinides other than Pu-239 contribute significantly to the dose as shown.

e. Routine environmental monitoring for incremental exposures of < 1 mrem/yr of direct radiation is not realistically achievable and levels < 5 mrem/yr are questionable.

6.7.5 Radioiodine

Thyroid and whole body exposure to atmospheric release of radioiodine can occur through several pathways including: (1) ingestion of foodstuffs such as milk; (2) inhalation; and (3) air submersion. The inhalation pathway is normally assessed by air sampling, while the external radiation component is assessed along with other external radiation sources by dosimeters. In certain instances, a special sampler and/or a multiple cartridge sampling train might be necessary to identify iodine species (elemental, organic, and hypoiodous acid (H0I)).

Species identification allows differentiation of those forms of iodine that are prone to deposition on vegetation and soil (elemental) from those that are not (organic forms and H0I). All chemical forms can be readily inhaled and contribute to thyroid exposure; however, it is primarily the elemental form that enters the food chain. The manner in which radioiodine concentrations are distributed among the various chemical forms is key input information for accurate environmental dose estimates.

6.7.6 Tritium

Environmental tritium is predominantly found in two forms: tritiated molecular hydrogen gas and tritiated water vapor (or tritiated oxide vapor). In terms of exposure potential, tritiated water vapor yields a dose equivalent approximately 25,000 times that of tritium gas for the same concentration (ISO 2010).

When tritiated water vapor is released to the environment, several exposure pathways including inhalation, ingestion, and absorption are possible. According to a model developed by Anspaugh et al. (1973), approximately 35 percent of the dose to individuals results from inhalation; the remaining 65 percent is due to ingestion (vegetable (36 percent), milk (13 percent), and meat (16 percent)). These percentages are modeled estimates. Actual values will vary from one site to another because of such factors as climate and land use.

For facilities that release tritium to the atmosphere, air sampling is an important medium, but clearly not the only one. Therefore, air-sampling techniques should employ methods that collect moisture from the air. Rosson et al. (2000) determined that a correction is needed to calculate the activity concentration of airborne tritium oxide when dried silica gel is used as the collector.

6.7.6.1 Precautions

A number of precautions should be taken when using the referenced methods and equipment for air sampling in the environment. Some of these relate to general air sampling and some relate specifically to the sampling of particulates, radioiodines, noble gases, or tritium:

1) Sufficient material needs to be obtained for analysis of samples in a time frame set to meet reporting and data-retrieval requirements. The requirements of sufficient volume of air and number of samples should be evaluated and the need for compositing samples considered (DOE 1981).
2) Excessive material (sample or dust) collected on filters can invalidate the sample in several ways; the flow rate through the filter may be unknown, the pump may fail, the particulate material may penetrate the filter, the analysis for alpha emitters may be affected, or material on the surface may be lost when the flow is interrupted (DOE 1981).
3) Excessive sampling velocity can invalidate the sample if too much sample is collected during a specific time period.
4) Collection efficiency of an air filter is affected by flow rate; too low an air sampling velocity can produce reduced collection efficiency for specific filters (Keller et al. 1970).
5) Ambient levels of radon and the decay products can affect the analysis of a number of filter samples. These naturally occurring radon decay products are found on air particulate filters because they adhere to particulate matter and are thus efficiently trapped by the air sampling filter.
    - Therefore, it is necessary that any gas measurement system for other alpha and/or beta emitters (e.g., Sr-90 and plutonium-239 (Pu-239)) be able to discriminate against the typically much larger “background.”
    - Rather than resorting to spectroscopic or chemical separation techniques, a common method of discrimination is to retain the filter from 1 to 7 days after collection and before counting, to allow for decay of the short-lived radon decay products.
    - A method for the determination of the minimum detectable activity of a sample for a two count method for stripping short-lived activity out of an air sample has also been developed for use (Allen 1997).
    - Application of patented techniques in portable instrumentation which apply auto-adaptive, real-time spectrometric compensation to evaluate and reduce radon isotope interferences on fresh filters.

6) Too high a sampling rate reduces both the collection efficiency and retention time of charcoal filters, especially for the non-elemental forms of iodine (Bellamy 1974; Keller et al. 1970).
7) The monitoring of airborne radioiodines is complicated by the occurrence of several species, including particulate iodine (bound to inert particles), elemental iodine vapor, and gaseous (usually organic) compounds. Monitoring should take into account the probable occurrence of the different iodine forms, because their subsequent history in the environment will differ. While it may not be necessary to differentiate routinely between the various species, care should be taken so that no significant error results by neglecting one or more of them (DOE 1981).
8) Charcoal cartridges (canisters) for the collection of radioiodine in air are subject to channeling, as with any packing of loose materials.
    - Baffled-flow cartridge design, packing to a minimum required weight, and pre-testing of randomly selected cartridges for pressure drop before operation in the field should minimize the problem.
    - An alternative is to mount several cartridges in series to prevent loss of iodine; each cartridge needs to be counted in this case (DOE 1981).
9) For the short-lived radioiodines (mass numbers 132, 133, 135), environmental sampling is complicated by the need to obtain a sufficient volume for analysis while at the same time retrieving the sample soon enough to minimize decay (with half-lives ranging from 2 to 31 hours). Short-period grab sampling with charcoal cartridges is possible, with direct counting of the charcoal as soon as possible for gamma emissions, but radon isotopes including radon-220 will affect detection levels (DOE 1981).
10) Because of the extremely long half-life and normally low environmental concentrations I-129 determinations can be performed by neutron activation analysis after chemical isolation of the iodine or by mass spectrometry, liquid scintillation counter (LSC), or enhanced gamma spectrometry.

The following operational criteria relate to environmental sampling instrumentation and methods:

- The linear flow rate across particulate filters and charcoal cartridges should be maintained between 20 and 50 m/minute (DOE 1981).
- To the extent possible, the air sampling system should be protected from factors such as weather, tampering, and theft.

- Air sampling devices, such as “quick-disconnect” filter holders, should be designed so that the potential for loss of sample during the collection process is minimized.
- If impregnated, activated carbon is used as the adsorbent for radioiodine, the adsorber system should be designed for an average atmospheric residence time of 0.05 seconds per centimeter (0.25 second per 2 inch) of adsorbent bed (NRC 2012).
- NRC (1992a) contains guidance relative to determining errors associated with the total volume of air sampled.

6.8 Sampling of Terrestrial Foodstuffs

Sampling of terrestrial foodstuffs can provide information on the presence and movement of radionuclides released to the environment. Considerations for the sampling of terrestrial foodstuffs need to include the possibility of long-term buildup of radionuclides in the terrestrial environment, and the potential presence of radionuclides in agricultural products, milk, vegetation, meat, eggs, and game animals.

If the preliminary analysis of public dose indicates that the annual TED from ingestion of terrestrial foods is 5 mrem or greater, then sufficient sampling and analysis should be conducted so that the foods and radionuclides contributing at least 90 percent of this ingestion dose have been evaluated.

If the annual TED is between 1 and 5 mrem then sufficient sampling and analysis should be carried out to provide reasonable assurance that the doses are within this range.

If the annual TED is between 1 and 0.1 mrem then sufficient environmental surveillance should be conducted to show that the radionuclides are behaving in the environment as expected from historical measurements.

The principal pathways by which foods become contaminated are deposition from airborne materials and crop irrigation from surface or ground waters. The relative contribution of various pathways, foods, and radionuclides to the total dose depends on several factors, including:

- Agricultural uses of the land;
- Farming and gardening practices;
- Soil type;
- Climate (e.g., temperature, rainfall, growing season);
- Dietary habits; and

- Quantities of specific radionuclides released to air and water and their chemical and physical forms.

6.8.1 Possibility of Long-Term Buildup

Even in those instances where the annual TED from ingestion of terrestrial foods is less than 1 mrem, periodic sampling and analysis of indicator materials, such as soil or vegetation should be performed to determine if there is measurable long-term buildup of radionuclides in the terrestrial environment. Such long-term buildup could affect the relative contributions of certain radionuclides and foods to the total radiation dose of site origin. However, the availability of these radionuclides to plants grown in such soil may decrease with time as a result of several natural processes. These processes include changes in chemical or physical form of the radionuclides caused by weathering or the action of soil bacteria, fixation onto soil materials or the litter layer, migration below the root zone of the plant with irrigation water or rainfall, and removal of contaminated soil by wind or water erosion or by cultivation.

Unless terrestrial foods or indicator organisms are being analyzed routinely, the pathway evaluation should be repeated annually to reaffirm the original evaluation. Foods to be considered in the pathway analysis, listed in approximate descending order of importance, are: milk, vegetables, meat, eggs, grain, and fruit. If wild game, such as deer, game birds, or fish, is available locally then these should also be considered in the pathway analysis.

6.8.2 Agricultural Products

Representative samples of the pathway-significant agricultural products grown at locations surrounding the site should be collected and analyzed for radionuclides potentially present from site operations. These samples should be collected in at least two locations: the place of expected maximum radionuclide concentrations and a “background” location unlikely to be affected by radionuclide effluents and emissions released from the site.

Fresh produce, meat, poultry, and eggs can be purchased from local farmers or from commercial outlets if the local origin can be identified. Where warranted, and based on site-specific considerations, it may be necessary for individual DOE sites or facilities to conduct sampling at extended distances from the site or facility.

6.8.2.1 Milk

Cow milk, and in certain localities goat milk, is widely consumed by all age groups. Therefore, milk is frequently one of the most important foods contributing to the radiation dose to people if dairy animals are pastured near a DOE site. The source of where the dairy gets its feed for the cows should be documented. If dairy herds or "family" cows (or goats) are present in the vicinity of the site (within a distance normally downwind that would be impacted by releases of radioactive materials), representative milk samples should be taken and analyzed for radionuclides potentially present from site operations. The frequency of sampling will depend on the magnitude of the radiation doses potentially received via this source. Radionuclides of potential significance in milk include: strontium-89 (Sr-89), strontium-90 (Sr-90), iodine-131 (I-131), cesium-137 (Cs-137), and possibly H-3 and I-129.

The number of locations to be sampled depends on the number and distribution of the dairy herds or family cows in the potentially impacted vicinity of the site (i.e., one sample at highest annually averaged air concentration and in each area where estimated doses exceed the criteria in Table 6-1) but a minimum of one background and one potentially affected location should be sampled at least annually. For I-131 analyses, sampling should be at least biweekly during the local grazing season. The frequency should be increased if the I-131 release rate is highly variable. For longer-lived radionuclides such as Sr-90, I-129, and Cs-137, quarterly composite samples are usually adequate.

Milk samples should be as representative of the location of interest as possible. Commercially-available processed milk, while representative of consumption by the general public, may include milk produced in areas remote from the site. Information about the dates and distribution patterns of local milk production is essential if the analytical results are to be meaningful. Raw milk should be sampled for evaluation of potential radiation doses to individuals consuming milk produced by a family cow.

No particular sampling preservation techniques are necessary, other than to guard against cross-contamination and souring or curdling of the milk. However, specific requests should be made to the milk producer so that techniques are in accordance with the protocol accepted by the appropriate State agriculture department. A 4-liter sample of cow's milk is necessary to achieve the required detection level for the contamination expected at most DOE sites. However, for goat's milk, a 1-liter sample may be all that can be obtained, especially from a single goat. Milk samples should be refrigerated or frozen, or otherwise preserved (e.g., packed

in ice) prior to analysis; however, the analytical procedure to be used should be considered when choosing a sample preservation method. Radioanalysis of milk usually involves ion-exchange techniques (for concentration) followed by beta or gamma counting.

When fresh milk is not available, analytical results of leafy vegetable (or fresh forage) samples can be used to estimate concentrations in milk using transfer coefficients or concentration ratios for dose calculations.

6.8.2.2 Vegetation

Vegetation includes three categories: vegetables, grains, and fruit. If vegetation (i.e., vegetables, grains, and fruit) is not one of the contributing pathways involved in determining the dose to humans from the site, native (non-cultivated) vegetation can be used as indicator species. Collection and analysis of vegetation samples can serve three useful purposes: (1) evaluating the potential radiation doses received by people consuming such vegetation; (2) predicting the possible concentrations in meat, eggs, and milk from animals consuming contaminated forage (and resultant radiation doses to consumers of the animal products); and (3) monitoring trends in environmental contamination and possible long-term accumulation of radionuclides.

Radionuclides of interest in vegetation include those listed previously for milk (H-3, Sr-89, Sr-90, I-129, I-131, and Cs-137, and possibly ruthenium-106 (Ru-106)). Several kilograms of vegetation may be needed to provide a sufficient sample for analysis, depending on the analytical sensitivities for the radionuclides of interest. The particular samples collected will depend on species availability, seasonal growth patterns, farming practices, and the reasons for sample collection. Where actual measurement of radioactivity cannot be made (e.g., radioactivity levels are below minimum detectable concentrations), estimates of ingestion dose should be obtained using atmospheric dispersion and dose modeling computer programs such as EPA's CAP88 code.

The vegetable category includes common garden crops (e.g., corn, beans, potatoes, tomatoes, etc.). If the samples of garden vegetables are being collected for evaluation of radiation doses, then the edible portions of the vegetables should be analyzed for the radionuclides of interest. Analysis may include direct gamma measurement, or alpha or beta counting after drying, washing, and/or chemical separation of the desired radionuclide. The results should be expressed in terms of the radionuclide concentrations in the vegetables (consumed state) used in the dose calculation (e.g., fresh weight, peeled weight, etc.).

Samples of vegetables should be collected at local farms or from family gardens when the effective dose to individuals is being evaluated. When collective doses are being evaluated, fresh produce from commercial sources should be included in the samples. Care should be taken to collect vegetation from open, unshaded areas where radionuclide ground deposition would be expected. It is important that the origin of the materials sampled be within a 10- to 15-km radius of the site and be identified. Analyses of commercial food items of known origin can also provide data on concentrations of naturally occurring or fallout radionuclides.

The grain category includes sweet corn, field corn, wheat, and other cereal grains. It is not likely that field corn would need to be sampled, since it is used for animal feeds, and animal products would be more logical items to sample for evaluation of intake of radionuclides by humans. Strontium and cesium are usually the only radionuclides of interest in cereal grains. With the exception of fresh sweet corn from local farms, most grains, by the time they are consumed, would not be likely to contain any radionuclides with half-lives shorter than a few weeks. In addition, most pathway models use concentration ratios (picocuries per kilogram (pCi/kg) plant per pCi/kg soil) that reflect the average concentration of radionuclides in the whole plant.

Radionuclides of potential interest in fresh sweet corn include: zinc-65 (Zn-65), Sr-90, and I-131. Local sweet corn should be sampled annually at harvest time from a “background” farm and a farm where there is a potential for contamination with radionuclides released from the site. A 1- to 2-kg sample of corn should be sufficient for analysis unless the pathway analysis indicates an unusually high potential for contamination, other grains will probably not need to be sampled.

The category of “fruit” includes: tree fruits, berries, melons, and grapes. Unless the pathway analysis indicates that some unusual circumstances are present, it is normally not necessary to sample such fruit.

Samples collected for evaluation of intake of radionuclides by farm animals should be representative of the vegetation consumed by the animals. This includes silage and hay as well as fresh forage when available. Samples collected for monitoring of long-term trends in environmental contamination should be capable of accumulating the radionuclides of interest to permit detection at the desired level. Such samples should be collected from the locations of interest, including, but not necessarily limited to, a background location and a maximum location.

6.8.2.3 Meat

Due to the time delay for transfer of radionuclides from the point of release through vegetation to beef, pork, and poultry, samples of these meats are not good indicator materials. Therefore, frequent sampling of meat is normally required only when it is necessary to evaluate the radiation doses received via this foodstuff.

With a few exceptions, radiation doses from ingestion of radionuclides in meat are of secondary importance. (One such exception occurs when carbon-14 (C-14) from the facility's effluent is the predominant radionuclide present in the environment. In that instance, the doses from inhalation and external exposure would be small compared to those from ingestion of foods, and also the contribution from milk and vegetables would be less than that from meat.) The preliminary pathway analysis will determine whether frequent meat sampling is required.

Because of the time delay mentioned above, shorter-lived radionuclides (those with half-lives of less than 1 month) are not likely to be present in measurable concentrations in meat samples. The additional time lag (about 2 weeks for cattle and a few days for poultry) imposed between slaughter and delivery of the meat to retail outlets can be avoided by sampling directly at local farms or slaughterhouses. However, this time delay should be accounted for when the analytical results are used to calculate radiation doses from consumption of commercially available meat.

A 1- to 2-kg sample of meat is usually sufficient for analysis. Meat may be purchased from local farms, retail stores, or slaughterhouses with confirmation of local origin. All samples should be placed in plastic bags, sealed, and properly labeled before delivery to the analytical laboratory. Meat samples collected at farms or slaughterhouses should be reduced to edible portions in a manner similar to commercial and home preparation before analysis.

It should be noted that concentrations for several of the radionuclides of interest are generally lower in pork than in beef, despite the fact that many of the radionuclide concentration ratios (pCi/kg meat per pCi/kg feed) are somewhat higher for pork than for beef. The concentrations reflect the fact that the consumption rate of feed by swine is about 20 to 30 percent that of beef cattle. Similarly, the radionuclide concentrations in chickens are generally lower than those in pork because chickens have a much lower feed-consumption rate than swine.

6.8.2.4 Eggs

Under certain circumstances, eggs may make a contribution to radiation doses received from terrestrial foods. The preliminary pathway analysis will determine whether frequent sampling and analysis of eggs are required or whether annual sampling is sufficient. Eggs collected from small local farms where the chickens are free to range over open soil are more likely to contain detectable amounts of effluent radionuclides than eggs from large poultry farms where the hens are confined. As with other foods, it may be difficult to determine the origin of commercially purchased eggs. Do not purchase eggs for analysis unless their local origin is confirmed.

One dozen large eggs, which have a combined weight of about 600 to 700 grams (without the shells), is normally a large enough sample for analysis. Analysis should be done on the whole egg (without the shell). It is not necessary to analyze the yolk and white separately. Analytical results from local farm eggs, when available, should be used for estimating potential individual dose for the farming locations, while those from commercial eggs should be used for estimating collective dose to the affected population.

Several elements have relatively high concentration ratios in eggs (pCi/ kg egg per pCi/day intake) including isotopes of phosphorus, rubidium, iodine, calcium, cesium, barium, tellurium, copper, iron, cobalt, and nickel. Many radionuclides of these elements have such short radioactive half-lives that they would not be detectable in eggs. In addition, some of the radionuclides would not likely be present in the effluents from most DOE sites. Cesium, iodine, and barium could be present in both liquid and gaseous effluents from many different types of facilities. Phosphorus-32 and phosphorus-33, and iron, cobalt, and nickel could be released as activation products with liquid effluents from operating nuclear reactors.

6.8.3 Game Animals

At some sites, game animals are components of the diets of some individuals. Hunting of indigenous game (e.g., deer, small mammals, game birds) is permitted at or around several DOE sites. The practice of allowing hunting and harvesting of deer and other game is part of an ecosystem approach to local wildlife management and conservation efforts to restore and sustain the health, productivity, and biological diversity of a well-balanced ecosystem. Reptile species (e.g., turtles and alligators) that are categorized as game should also be considered if a pathway exists.

A review of the hunting habits in the local area should be included in the preliminary pathway analysis to determine if such game is an important part of the diet of the local population or of hunters from outside of the region. If the results of the preliminary survey indicate that local game could make an important dose contribution, then a more detailed survey of the amounts of each type of game harvested and the disposition of the meat should be made and documented.

It is also important to determine whether the meat is eaten, and if so, whether it is eaten fresh or frozen or given to others. If the results of the preliminary survey indicate that this pathway contributes a TED of less than 1 mrem/yr, then annual sampling and analysis of two or three representative species should be sufficient to determine whether or not this pathway is still insignificant. Radionuclides of interest in wild game are similar to those of interest in dairy cattle. Again, 1- or 2-kg samples should be sufficient for analysis.

Wild game samples can be obtained from wildlife that is trapped, acquired by hunters, or, for larger animals, such as deer, collected after accidental road-kills, or samples can be obtained from an appropriate State agency. Wildlife that is relatively rare locally should not be taken as environmental samples. When sampling deer and other game animals, it is important not to contaminate the meat sample with radionuclides that may be present on the animal's fur or in its gut. Wildlife samples should be kept on ice until transported to the laboratory for analyses.

Where this pathway exists it needs to be considered when demonstrating compliance with the DOE public dose limits and ALARA process requirements of DOE O 458.1. Information pertaining to radiological control and release of game for human consumption is contained in Appendix C of this Handbook.

The following should be considered for DOE sites where this pathway exists:

- The selected approach and level of effort should be commensurate with the importance of the pathway and needs to take into account the degree of uncertainties in dose estimates associated with each approach. Sites and facilities are responsible for documenting and implementing the approach used. The direct measurement approach provides a high level of confidence that the hunting pathway doses comply with DOE requirements.
- The selected approach should provide reasonable assurance that the dose attributable to the consumption of game will not exceed the DOE dose constraint of 25 mrem/yr from a single pathway and will be well below the public dose limit for all pathways of 100 mrem/yr.

- Approaches may entail:
  - Process or site-wide knowledge approach;
  - Selective or statistical sampling approach; or,
  - Direct measurement approach.
- Dose estimates and measurements compared to screening guidelines should be based on edible portions of the animal (e.g., muscle tissue).
- Although gamma measurements alone may be used to estimate alpha and beta contributions when radionuclide concentration ratios are generally uniform, if a consistent ratio (e.g., Cs:Sr) cannot be demonstrated from available data, then specific analyses may be necessary to measure concentrations of the alpha and beta emitting radionuclides.
- If potential doses associated with beta and alpha emitters are low (i.e., a small fraction of the gamma emitters) or a small fraction of the dose constraint (whether or not there is variability in the ratios), they need not be measured regularly.
- Tritium may be analyzed in a separated blood specimen and its content in meat estimated by assuming the same specific activity (pCi H-3 per gram of stable hydrogen).

Because strontium concentrates in the bone, strontium may be measured in non-edible tissue for screening purposes. If the concentrations are very low or non-detectable, no muscle tissue need be analyzed. Because it is difficult to estimate muscle concentrations and dose from consumption of the meat from analysis of non-edible tissue, analysis of strontium in edible tissue samples may be necessary only when analysis of the non-edible portions (e.g., bone) indicates the significant presence of the radionuclide.

6.9 Basis for Sampling Soil

Soil provides an integrating medium that can account for contaminants released to the atmosphere, either directly in gaseous effluents or indirectly from re-suspension of onsite contamination, or through liquid effluents released to a stream that is subsequently used for irrigation. Hence, soil sampling and analysis should be used to evaluate the long-term accumulation trends and to estimate environmental radionuclide inventories. In addition to radionuclides that are specific to a particular operation or facility, naturally occurring (e.g., the uranium and thorium decay chains and beryllium-7 (Be-7)) and fall-out radionuclides can be expected in soil samples. The relative importance of these contributors is dependent on site operations and site conditions including site geography, geology, and meteorology.

Radionuclides that are often detected include ^{3}H, cobalt-60 (Co-60), Sr-90, zirconium-niobium-65 (^{65}Zr-Nb), Ru-106, Cs-137, cerium-praseodymium-144 (^{144}Ce-Pr), plutonium-238 (Pu-238), Pu-239, and americium-241 (Am-241). The relative abundance of these materials varies with the source and half-life. Analytical and sample preparation procedures should be tailored to the radionuclides of interest.

As pointed out in Denham et al. (1974), perhaps the greatest diversity among sites occurs in the techniques used for sampling and analyzing soil. Part of this diversity arises from different purposes for soil sampling and analysis (e.g., trend evaluation, projection of future plant uptake, contaminant inventory, and comparison with applicable standards).

Plutonium is one of the most commonly analyzed contaminants in soil (ASTM C998-05(2010)e1). However, there are many limitations of sampling and analysis of plutonium in soil, as indicated in NRC (2007a). Although concentrations of plutonium and other radionuclides in soil are generally readily detectable, the determination of their significance in terms of exposure to humans is less readily quantifiable, except perhaps for the gamma emitters, such as Co-60 and Cs-137. Therefore, it is desirable to assess, document, and periodically reassess the distribution and fate of radionuclides in the environment, especially plutonium in soil samples.

6.9.1 Soil Sampling Location and Frequency

Background determinations should be based on soil sampling and analysis at points corresponding to background (or control) air sampling locations. Where possible, soil sampling locations should be selected to coincide with air sampling stations, since the comparability of data may be important in achieving the objectives of the overall environmental sampling program. Except where the purpose of the soil sampling dictates otherwise, every effort should be made to avoid tilled or disturbed areas, locations near buildings, or areas of unusual wind or precipitation influences when selecting soil sampling locations.

An annual sampling frequency is recommended for long-term accumulation trends. In some situations a lower sampling frequency may be justified but generally should be at least once every three years. The sampling frequency of soil collected for purposes other than long-term environmental accumulation should be based on site-specific source terms and radionuclide half-life, with the purpose(s) and details documented.

6.9.2 Soil Sampling Methods

Several reports are available that provide useful information on sampling, preparing, and analyzing soil for plutonium (L'Annunziata 2003, Ohtsuka et al. 2006, Montero et al. 2000, Lee et al. 2007, ASTM C1001), for radium (GJ/TMC-13 1985; Meyer and Purvis 1985; Myrick et al. 1983; L'Annunziata 2003; IAEA 2010b), and for other radionuclides (ASTM C998-05(2010)e1 and C999-05(2010)e1; Mohrand and Franks 1982). Additionally, Healy (1984) has proposed a standard for comparing observed-to-allowable concentrations of plutonium.

It is recommended that trends in local environmental radionuclide levels be determined through routine soil sampling. Surface soil sampling should be conducted according to methods of NRC 2007a, ASTM C998-05(2010)e1, or HASL-300. Profile depths need to be established. For example, HASL-300 recommends profile depths up to 30 cm to measure the total amount of a radionuclide deposited on the soil, during pre-operational assessment, after a disturbance of the soil, and periodically as needed. Useful information about soil contamination levels can also be obtained using in situ gamma-ray spectrometry. Prior to counting and analysis, soil samples should be homogenized (by grinding and blending, as appropriate in the procedures), and the radioanalytical results reported on the basis of activity per dry weight.

Estimates of individual radionuclide contributions in soil can be made from field spectra, such as those developed by HASL-195, HASL-258, ICRU 1994, Tyler 2007 and reported in NVO-213. The soil concentration estimates depend on distribution of radionuclides with depth, soil density, soil moisture, and chemical composition.

When evaluating the airborne pathway and bioaccumulation in the environment, soil and grassy vegetation samples should be co-located with air surveillance sampling locations.

6.10 Water Sampling

When liquid effluents are released to streams (with continuous or intermittent flow), rivers, or lakes, samples of these surface waters should be collected according to the methods, locations, and frequencies specified in this section or in applicable permits if the releases are projected to result in radiation doses exceeding the criteria given in Table 6-1. Information related to sampling at the liquid effluent release point is provided in Chapter 3. Water sampling frequency and volume of water samples should be chosen to provide adequate sensitivity for the analysis using the general criteria in Table 6-1.

The principal exposure pathways to individuals and/or groups of individuals in the environment from waterborne radionuclides are: (1) consumption of fish, other aquatic species and ducks; (2) consumption of irrigated crops; and (3) ingestion of drinking water. Of lesser significance is external radiation from surface water (swimming, water-skiing, and boating).

Deposits of radionuclides are even more likely from facilities that discharge or have previously discharged liquid effluents to the ground via cribs, pits, or trenches. Routine laboratory analyses of water samples should include those radionuclides that are determined by pathway analyses to represent a significant fraction (e.g., more than 10 percent) of the potential dose from the water pathway. Where documented operating experience and/or system design show that no release (or significant potential for a release) will be made to surface waters that could cause the dose criteria presented in Table 6-1 to be exceeded, this portion of the environmental surveillance program may be reduced accordingly.

Potential for unplanned releases, including those caused by runoff, leaching, flooding, or re-suspension should be considered in planning for monitoring.

6.10.1 Water Sampling Locations

The basic recommendations that follow should be applied at all DOE sites where radioactive liquid effluents are discharged to surface streams. Special studies, examining site-specific ground water and surface water flows, may be necessary to establish preferential sampling locations for ponds or lakes. Therefore, detailed hydrological and radiological studies should be conducted for each site on streams, ponds, and lakes to establish the best sampling locations and frequencies to determine radiological doses.

6.10.2 Surface Water

Surface waters can be divided into two basic types: (1) those that are constantly moving (e.g., rivers and streams), and (2) those that are stationary (or not constantly moving) (e.g., ponds and lakes). The type of surface water needs to be considered when specifying surface water sampling location requirements.

Samples should be collected at each location where water is withdrawn for public use. Representative background samples from surface water sources including rivers, streams, ponds, and lakes should be collected routinely at locations unaffected by site operations.

An investigation should be conducted and documented to show that the surface water source is independent of local influence from site operations.

6.10.2.1 Moving Waters

Background samples provide control data used to compare data from potentially affected sampling locations. Care should be taken to avoid sampling from eddy currents. At a minimum, other offsite sampling locations for surface water should be at the edge of the effluent mixing zone and at the nearest down-current point of withdrawal for domestic or other uses. Continuous or flow-proportional samples may be needed at certain locations.

Multiple sampling points, based on diffusion and transport studies of the mixing zone, may be necessary to obtain a reliable and representative estimate for that location. Sampling at the first downstream point of withdrawal for public use provides an upper-bound estimate of the amount of radioactive material in the water supply (for drinking or irrigation) of the potentially affected population group(s).

For characterization studies, as compared to routine sampling:

- Samples should be taken on a traverse, at more than one depth, and at a number of points equidistant across the stream flow such that a representative set of samples are taken based on the size of the stream and the nature of the discharge.
- Each sample should represent no more than 10 percent of the total stream flow.
- This sampling strategy may not be applicable for very small streams.
- Traverse studies should be repeated whenever a significant change occurs either in the types or quantities of radionuclides (actual or expected) released or in the flow regime of the stream (such as from the addition of hydroelectric or flood-control dams).

Ground water may contain detectable or more highly radioactive materials (particularly Tritium) from liquid effluent storage systems (leakage) or discharges to surface water.

Drinking water supplied from any source (surface or ground water) that receives effluents from nuclear facilities is a potential source of radiation exposure to humans.

6.10.2.2 Stationary Waters

Another possible solution is to sample from another nearby pond or lake with the same water source (i.e., fed by the same stream or located within a similar runoff regime). If the receiving pond or lake is onsite, an offsite counterpart pond or lake may be used to collect background samples.

Other offsite sampling locations for ponds or lakes should be at the edge of the effluent mixing zone (based on dye or other local transport studies) and at the nearest point of withdrawal for domestic or other uses. Sampling locations near the discharge outfall should be located beyond the turbulent area caused by the discharge. Multiple sampling points, based on diffusion and transport studies of the mixing zone, may be necessary to obtain a reliable representative estimate for that location.

Sampling a lake or pond at the nearest point of withdrawal (i.e., closest to discharge) for public use usually provides an upper bound estimate of the amount of radioactive material in the water supply (for drinking or irrigation) of the potentially affected population group(s). Samples on the traverse or axial sampling lines should be taken at more than one depth and at a minimum of three to five equally spaced points along each of four radials. Traverse or axial studies should be repeated whenever significant change occurs either in the types or quantities of discharges or in the water level of the pond or lake.

6.10.3 Storm Water Runoff

The potential impacts of storm-water runoff as a pathway of exposure to humans or biota should be evaluated. Where radioactive materials in storm water runoff could significantly increase the risk to humans or biota, the water and the receiving ecosystem should be monitored and the doses should be assessed.

Contaminated soil or sediment that could be moved by storm water should be considered for evaluation with RESRAD and RESRAD-Biota for potential impacts on the receiving ecosystem. Wildlife habitats, agricultural land, and intakes to drinking water systems are especially important. Table 6-1 should be used to assess the need for surveillance.

Storm water with significant, visually observable, settleable solids should be filtered, and concentrations in the sediment should be analyzed and reported separately from the filtrate. The concentrations of radionuclides in the sediment should be compared with those at the source of the storm water to determine the amounts from DOE activities. Where the storm water is a potential source for a public drinking-water system, the filtrate may be compared with the 15 pCi/L gross-alpha standard, and the concentrations should be kept ALARA.

Storm water can contain more than one hundred grams per liter of suspended sediment, in which case unfiltered samples are unsatisfactory for the following reasons:

- Many of the standard analytical methods are designed for drinking water with much less sediment than storm water.
- The amount of sediment that can be dissolved using standard methods may vary, leading to inconsistent results.
- Aliquots from a single sample will contain variable amounts of sediment, also leading to inconsistent results.

The 5-pCi/g and 50-pCi/g limits for settleable solids (DOE O 458.1) apply to “liquid discharge,” which as defined in Attachment 2 of DOE O 458.1, does not apply to storm water.

When comparing concentrations of radionuclides in the sediment with those at the source of the storm water, the background concentrations provide a “fingerprint” that may be matched with that in the storm-water sediment. For example, naturally-occurring soil may contain ~1 pCi/g of each of the decay products in the uranium and thorium decay chains.

Natural uranium may be distinguished from refined uranium by methods such as process knowledge, isotopic analysis, and by the presence of Pb-214 and Bi-214 in the natural uranium decay chain. Pb-214 and Bi-214 are removed during the refinement process and remain with the mill tailings, together with their parents, Th-230 and Ra-226. The Pb-214 and Bi-214 decay products grow in with a half-life of 75,000 years so they are undetectable in the refined uranium used at many DOE sites.

Global-fallout radionuclides are likely to have higher concentrations than average for the following reasons.

- Fallout was deposited on the surface and usually remains near the surface, so it is preferentially swept into storm water.
- Fallout is mostly brought to earth by rain and snow fall, which are often higher than average where storms occur.
- Fallout often washes off rocky or impermeable slopes and accumulates in low-lying areas and in the path of storm-water runoff.
- Concentrations in ash are especially high because most fallout materials are refractory.

Global fallout may be distinguished from local contamination by methods such as process knowledge, isotopic analysis, and by the ratios of radionuclides, especially Pu-239, Pu-240, Am-241, and Cs-137. Sr-90 tends to be more mobile than Cs-137 but may provide useful indications in some cases. Pu-239 may be distinguished from Pu-240 by mass spectrometry.

Typical ratios of global fallout radionuclides, decay corrected to 2012 are shown in Table 6-3 (derived from UNSCEAR 2000, Annex C, Table 9). Generally, these radionuclides were deposited together and they are bound tightly to the soil matrix so they move together when the soil is physically disturbed. Under some conditions, they can go into solution, in which case the ratios will be different.

TABLE 6-3: Global fallout activity relative to Pu-239, Pu-240

Nuclide	Ratio
Pu- 239, Pu-240	1.00
Am-241	0.42
Cs-137	28
Sr-90	18

In solution, the activity ratios are likely to be considerably different from those in the sediment because of different solubility. For example, U-234 concentrations are usually higher than U-238 concentrations because the decay process dislodges the U-234 from the lattice and makes it more soluble (Arndt and West 2004, Eisenbud and Gesell 1997, Kraig and Gladney 2001).

6.10.3.1 Biota

For compliance with the biota dose limits, it may be helpful to consider the data for filtered water separately from the sediment residue because the bioaccumulation factors for soluble and insoluble material are different. For example, the default bioaccumulation factor (B_{iv}) for radium in aquatic animals is 3200 L/kg (DOE 2002a and RESRAD-Biota) but this high value may not be appropriate for insoluble radium in sediment.

Both man-made and naturally-occurring radioactive material should be assessed. However, "high background levels of naturally occurring radionuclides … may be taken into account when determining compliance of DOE activities with biota dose limits" (DOE 2002a).

6.10.4 Drinking Water

Drinking water may be supplied from surface water sources or from ground water sources. Thus, the drinking water sampling location requirements are presented according to the type of drinking water source that is available.

The sampling location for drinking water derived from surface water sources should be of the treated water at the point of maximum probable effluent concentration in the surface water.

Samples of untreated water prior to treatment should also be taken to determine any removal by water treatment and to improve the reliability of dose estimates. If surface water sampling and analytical results indicate that the dose criteria given in Table 6-1 are not exceeded, further drinking water sampling is not necessary. Such conditions should be documented and periodically (at least annually) reviewed to determine that the potential doses are still below the criteria in Table 6-1.

The sampling location for drinking water derived from ground water sources should be at the nearest domestically used well down-gradient from the surface (crib, pond, lake, or stream) discharge point. Another well up-gradient from the discharge point should be used for the control or background sample. When comparisons with control wells are conducted, the sampling stations should be located in the same hydrologic unit. If a significant number of wells are used domestically in the vicinity of the site, it may be necessary to sample several wells to determine if drinking water sources are affected by discharges from the site.

6.10.5 Ground Water

Ground water monitoring should be conducted onsite and in the vicinity of DOE facilities. Ground water monitoring should be designed and operated to:

- Obtain data for the purpose of determining baseline conditions of ground water quality and quantity;
- Demonstrate compliance with, and implementation of, applicable regulations and DOE Orders;
- Provide data for the early detection of ground water contamination;
- Identify existing and potential ground water contamination sources and maintain surveillance of these sources; and
- Provide data upon which decisions can be made concerning land disposal practices and the management of ground water resources.

The siting and number of ground water monitoring stations should be governed by the nature of ground water use and the location of known and potential sources of contamination. When possible, existing wells and historical data should be used. In the event that additional wells are necessary, their number and placement should be directly related to contaminant pathways. Quality control in well construction is essential. Predicting contaminant pathways requires a three-dimensional geologic, hydrologic, and geochemical analysis. General guidance for implementation of ground water surveillance monitoring can be found in DOE (2004). Additional

guidance may be found in documents and technical procedures prepared by regional EPA offices and State agencies.

Mechanisms for subsurface contaminant dispersal are not fully understood. The rate and extent of contamination are influenced by:

- Characteristics of the source of contamination;
- Nature of the geologic formations in the saturated and unsaturated zones;
- Physical and chemical properties of the contaminants; and
- Phenomena that affect the fate of a contaminant which include capillary action, decay, adsorption, dispersion, and diffusion.

No comprehensive Federal statutes regulating ground water quality and monitoring currently exist. Ground water requirements are drawn from a number of distinct laws enacted to protect other resources or to regulate specific sources of contamination.

In addition to Federal statutes that authorize programs and activities for ground water protection, many States also are developing and implementing ground water policies, statutes, and strategies. Often States have the authority or “primacy” to administer several Federal environmental laws. Under this authority, States may, and often do, impose more stringent requirements than the Federal government. In many States, State agencies, regional authorities, and local governments share responsibilities for protecting ground water.

Contaminants covered by ground water quality standards vary from State to State. It is important that DOE Federal and contractor staff work closely with State and regional agencies when determining the specific monitoring requirements for each DOE facility.

6.10.6 Water Sampling Methods

Since most water measurements are made on samples taken in the environment and sent to laboratories for analysis, the two major concerns in water sampling are: (1) the collection of a representative sample, and (2) the maintenance of radionuclides in their original concentrations before analysis. Kahn (1972) discusses the general problem of the measurement of radioactive material in environmental water. Water sampling procedures are discussed in APHA (2012) and EPA (1983).

6.10.6.1 Water Sample Collection

Waste management practices often result in periodic or batch discharges of liquid wastes, rather than a continuous release.

The following factors should be considered when selecting water sampling equipment:

- Probability of significant fluctuations in concentration of the water sampled;
- Potential for significant human impact (dose);
- Potential for contaminating the environment; and
- Applicability to radionuclide(s) of interest.

The recommended practice for surface water samples is automated continuous sampling followed by analysis of the unfiltered sample. When the data are to be used for dose calculations, the method should use a fixed-time sampling frequency. If the data are to be used for radionuclide transport or inventory purposes, these samples should be taken with timing proportional to flow rate where practical.

When circumstances prohibit this type of automated continuous sampling (e.g., power restrictions, prohibitive pumping requirements, freezing temperatures, etc.), compositing should be performed by manual collection on a frequency based on effluent release and on information on the receiving body of water. An acceptable scheme is weekly grab samples of surface water composited for monthly analyses and daily grab samples of drinking water composited for weekly or monthly analyses.

Because the flow of most ground water systems is on the order of centimeters to meters per day (compared with tens or even hundreds of kilometers per day for surface stream flows), periodic grab sampling of ground water should be sufficient. Unless circumstances prohibit, ground water grab sampling should be done by pumping. Examples of pumps include pressure air lift, submersible pump and variable speed pump. In any case, the pump should be operated for a length of time sufficient to obtain a representative sample of water in the aquifer. In some cases, other innovative methods may be used, such as diffusion sampling and bailing. Diffusion sampling methodology is discussed in EPA (2009a).

To approximate conditions at the tap, finished drinking water conditions may require filtering of ground water samples to remove well-casing effects.

NOTE: For pre-analytical handling of water samples, it is common practice to well-mix all environmental water samples prior to splitting or transferring to holding containers (APHA 2012, Standard Methods for the Examination of Water and Wastewater, 22nd Edition, Section 1060, *Collection and Preservation of Samples*). Before some analytical procedures however, the sample is allowed to settle and then decanted to not include the settled fraction in the analysis. That fraction is not added to the water totals, but would be considered a "sediment" sample (APHA 2012, Section 2560, *Particle Counting and Size Distribution*). For some analyses (gamma spec and radiochemical isotopic) analytical steps incorporated into the methods eliminate interferences in nonhomogeneous samples. Therefore, the entire fraction of the mixed sample, including any sediment, can be considered as a "water sample," thus providing a conservative approach. (APHA 2012, Section 7010).

6.10.6.2 Sample Size

The size of water samples will be determined by the analytical procedures (see Chapter 7) to be used. A 3.5-liter (approximately 1 gallon) sample is usually adequate other than for tritium or gross activity measurements. The sample volume needs to be increased where splitting of samples for replicate analysis or individual radionuclide determinations is planned.

6.10.6.3 Representative Water Sampling

Natural waters are frequently two-phase systems (i.e., solid materials are suspended in, or floating on, the water). Therefore, all surface water samples should be carefully taken from beneath the water surface to avoid floating debris and any bottom sediments or growths. The soluble fraction provides an indication of possible stream transport, while the insoluble fraction can be used as an indication of potential sedimentary material. So that data are comparable, both fractions, if analyzed, should be added in reporting the total concentration.

Filtration of ground water samples is recommended because suspended material is usually an artifact of the sampling process (well-casing particles and dirt near water-soil interface) and is not representative of the ground water. Caution should be exercised to prevent water samples from different locations being cross-contaminated by reuse of sampling containers. When obtaining surface water grab samples, the sample container should be rinsed twice with the water being sampled before the actual sample is taken. When extracting aliquots from a larger

water sample, extra effort should be taken to provide that the aliquot is representative of the entire sample.

6.10.6.4 Water Sample Preservation

Continuing biological and chemical action in the sample during and after collection can cause changes in chemical form, deposition on container walls, and removal of radioactive material from solution by biological growths.

Known phenomena include the following:

- Cations, at very low concentrations, can be lost from solutions (e.g., cesium can exchange with potassium in the container (glass));
- Radionuclides can be absorbed by algae or slime growths in sample lines or on container walls, especially in sample containers that remain in the field for extended periods;
- Hydrolysis and sorption on container walls or on particles in the water can occur at low acidities (typical of many natural waters);
- Radio-colloidal phenomena may result in large flocculent particle formation or additional plate-out on container walls;
- Pretreatment may induce change in nuclide distribution (e.g., acidification can leach suspended particles in the original sample so that more radioactive material appears in solution);
- Acids used as biocides can oxidize iodide to iodine, resulting in its volatilization;
- Acids may quench standard liquid scintillation cocktails; and
- A change in counting geometry may occur for gamma-ray counting if finely divided particulate activity settles out or if soluble species become fixed on the container walls during counting.

EPA (1983), the Environmental Measurement Laboratory (EML) Procedures (HASL-300), the MARLAP Manual, and the Radiological and Environmental Sciences Laboratory procedures (DOE 1982) provide useful information on sample preservation, storage, and analysis methods. Radioiodine analyses should not be performed on an acidified sample because organic forms may be transformed to elemental forms that are more volatile.

6.10.7 Settleable Solids in Effluent Discharge

DOE O 458.1 requires that the radioactivity in the settleable solids in liquid discharge streams be limited to 5 pCi/g above background for alpha-emitting radionuclides, and to 50 pCi/g above background for beta-gamma emitting radionuclides.

The following method should be used to determine the radioactivity of settleable solids:

- Use the gravimetric test (APHA 2012, Section 2540 F, *Settleable Solids*[5]) to determine settleable solids in mg/L in the water sample. The gravimetric test method in Section 2540 F, 3.b, may be used to determine both the total suspended solids and non-settleable solids. The solid fractions of the total suspended solids and non-settleable solids samples should be retained for later radioactivity measurements.
- Determine the radioactivity of alpha-emitting radionuclides in pCi/g and the radioactivity of beta-emitting radionuclides in pCi/g in the recovered solid fraction of each of the total suspended solids and non-settleable solids samples.
- Determine the gross activity concentration of the settleable solids, using information obtained above and the equation:

$$A_{ss} = \frac{(M_{ss} \times A_{TSS}) - (M_{NSS} \times A_{NSS})}{M_{TSS} - M_{NSS}}$$

Where A_{SS} = *activity concentration of settleable solids, pCi/g*
M_{TSS} = *mass concentration of total suspended solids, mg/L*
A_{TSS} = *activity concentration of total suspended solids, pCi/g*
M_{NSS} = *mass concentration of non-settleable solids, mg/L*
A_{NSS} = *activity concentration of non-settleable solids, pCi/g*

- Since the sedimentation standard is presented as net settleable solid radioactivity, the activity of background settleable solids needs to be subtracted from the sample settleable solids activity.
- Determine the background radioactivity from an appropriately selected background water sample, using the same methods and equation.

[5] In some older editions of the APHA *Standard Methods*, discussion of *Settleable Solids* was identified as Section 209 E.

The settleable solids requirements in DOE O 458.1 are standards based. If using the method prescribed in the Order, settleable solids are not detected or the quantity of solids is so small that the radionuclides cannot be detected, the requirements are satisfied. Direct environmental monitoring of sediments, under the site environmental monitoring plan or other procedure in use, will further verify that radionuclides are not accumulating or increasing due to changing conditions.

6.11 Basis for Sampling for Aquatic Foodstuffs

Aquatic foods, including local fish, shellfish, and waterfowl, are eaten in relatively large quantities by residents of some regions of the country.

Aquatic plants are not normally a component of the human diet in the United States. However, there are exceptions; for example, along the California coast a particular species of seaweed is harvested and processed into a thickener for foods, such as milkshakes. Aquatic plants can be vectors in the water-plant-animal-human pathway.

If the preliminary analysis indicates that the potential annual TED from ingestion of aquatic foods is 5 mrem or greater, then sufficient sampling and analysis should be carried out to provide that the foods and radionuclides contributing at least 90 percent of this ingestion dose have been evaluated.

If the potential annual TED is between 1 and 5 mrem, then sufficient sampling and analysis should be carried out to provide reasonable assurance that the doses are in this range.

If the annual TED is potentially between 1 and 0.1 mrem, then sufficient surveillance should be done to show that the radionuclides are behaving in the environment as expected.

Only one generic concentration ratio for aquatic organisms (pCi/kg organism per pCi/L water) is less than 1; namely, 0.5 for uranium in marine plants. As a result, any radionuclide present in the water will be present in aquatic organisms, and most, but not all, radionuclides detectable in water will be present at detectable concentrations in the organism.

Aquatic animals, sediments, and other predictive environmental media should be sampled and analyzed at least annually to demonstrate compliance with the DOE O 458.1 requirements for

protection of biota. DOE (2002) provides practical screening and analysis methods for demonstrating compliance with the requirements for protection of biota. DOE (2002) and the RESRAD-BIOTA[6] code are the preferred tools for estimating and evaluating doses to biota, unless there are site-specific requirements that necessitate the use of an alternative method or model, or it is determined that such alternate approaches will provide better results.

The sampling program should be determined on a case-by-case basis considering such factors as the estimated dose as determined from measured concentrations in organisms or predictive environmental media in comparison with the limit and any variation behavior of the contaminants involved.

Special permits from State fish and wildlife agencies are usually required for fish, shellfish, and waterfowl sampling for monitoring purposes.

6.11.1 Freshwater Foods

Concentrations of many elements in fresh water are highly site-dependent. This variation can affect the observed concentration ratios of radionuclides of these or biologically similar elements in freshwater organisms. (Except in estuaries, the elemental composition of seawater is relatively constant, and the concentration ratios of radionuclides in marine organisms are not nearly as site-dependent as they are for freshwater organisms.)

If the aqueous effluents are discharged into a surface body of fresh water (pond, lake, stream), then the background sampling point should be far enough from the discharge point for radionuclide concentrations in the water and sediment to be unaffected by the effluents.

The indicator sampling location should be downstream of the discharge point(s) at a location in which the water is determined to be well mixed (e.g., based on water-sample traverses). In choosing the locations to be sampled, consideration should be given to the possible migration of fish between upstream and downstream locations.

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[6] The RESRAD-BIOTA code and its User's Guide serve as companion tools to DOE-STD-1153-2002 (DOE 2002a) for evaluating doses to biota.

6.11.1.1 Fish

The species of fish likely to contain the highest concentrations of radionuclides are those that feed at or near the bottom and do not migrate very far from the places having the highest water or sediment concentrations. These species are useful as indicator organisms for monitoring trends in aquatic contamination levels. However, they may not always be the ones that are consumed at the highest rate by the local population. Studies of fishing pressure and fish consumption, coupled with preliminary radiochemical analysis of the different types of available fish should be used to define the proper species to monitor for the purposes of dose calculation.

Fish can be collected by using nets, rod and reel, or other methods (e.g., slat traps, shocking), or they can be purchased from commercial sources if their origin can be determined. For use in dose calculations, the edible portions of the fish consumed by humans should be analyzed. In most instances that includes only the muscle. However, the whole fish should be analyzed if it is used for preparation of fishmeal or fish burgers. Fishbone should be analyzed when part of the local diet includes boiling the fish such as the preparation of catfish stew. It is also appropriate to analyze the whole fish when the data are used for trend indication. If fish are the critical pathway, then they should be analyzed by species. If the results are to be used as trend indicators, then the fish may be grouped by type for analysis (e.g., bottom feeders, insectivores, or predators).

The following factors should be considered when determining the frequency of sampling:

- Variability of the radionuclide release rates;
- Seasonal variations in the feeding habits of the fish and in the availability to consumers; and
- Where the freshwater habitat includes a flowing stream, the variability in the stream flow rate.

Radionuclides of potential interest in fish include H-3, phosphorus-32 (P-32), phosphorus-33 (P-33), Zn-65, cesium-134 (Cs-134), and Cs-137. Although the concentration ratio for ^{3}H is only 1, it is often present in high concentrations in aqueous effluents. Strontium-90 (Sr-90) might be of importance in samples of whole fish since it concentrates mostly in bones. Phosphorous (P-32 and P-33) concentrates in fish flesh as well as in bones.

The sample size required for analysis will vary from 1 kg to several kilograms, depending on the specific radionuclides being measured and their concentrations.

6.11.1.2 Shellfish

Shellfish include mollusks, which live in or on the sediment, and crustacea, such as freshwater crayfish, which live on or near the bottom. Decisions on sampling locations and frequencies involve the same types of considerations as discussed above for fish (i.e., variability of radionuclide concentrations in water and sediment and inclusion of upstream and downstream locations).

Freshwater shellfish are usually not a significant diet item. However, they may be eaten by some individuals in certain specific regions of the United States. A preliminary pathway analysis will determine if shellfish are a potentially important contributor to the TED that might be received by residents of the region.

Radionuclide concentration ratios are generally higher in invertebrates than in fish, and in some cases significantly higher. Radionuclides of potential interest in freshwater mollusks and crustacea include: P-32, P-33, cobalt-58 (Co-58), Co-60, Zn-65, Sr-90, Ru-106, and the rare earth radioelements.

A 1- or 2-kg sample is normally sufficient for analysis. Samples of shellfish may have to be purchased commercially to avoid the difficulties associated with field collection.

6.11.1.3 Waterfowl

Waterfowl, such as ducks and geese, may acquire radionuclides from their food sources. Some species are bottom feeders and tend to accumulate those radionuclides associated with sediments, such as Co-60, Zn-65, and Cs-137. Others feed predominantly on surface plants, insects or fish. Depending on the specific diet, these species may accumulate P-32, P-33, Zn-65, Sr-90, and Cs-137.

The migratory habits of waterfowl species vary widely. Some may be year-round residents of the local waterways (and effluent ponds). These are usually species that are less desirable to hunters. Others may migrate long distances, and the limited amount of time spent in the local area may not be enough to cause significant contamination of their flesh. Because of these variables, it is often difficult to predict which species is most important in terms of potential exposure to local hunters.

The preliminary pathway analysis should include consideration of the amount of waterfowl hunting, if any, in the local area and the number of birds shot. It should be remembered that

even though some individuals may harvest a relatively large number of waterfowl, the collective dose to the local population from waterfowl consumption may still be small. If the potential TED is significant, a minimum of two or three birds of each type (bottom feeders, plant eaters, and fish eaters) should be sampled during hunting season.

The most common method of collecting waterfowl is by hunting. Sampling of non-migratory, non-game species can occasionally provide useful information on contamination trends.

During preparation of the samples for analysis, care should be exercised not to contaminate the edible portions with radionuclides present on the external surfaces of waterfowl. Analysis should include the radionuclides listed above plus any others that prove to be of special concern at a specific site.

6.11.2 Marine Foods

Sites that are located on the seacoast, an estuary, or a river upstream of an estuary should include consideration of the potential consumption of contaminated marine foods, such as sports and commercial fish and shellfish, in their preliminary pathway analysis. Considerations discussed for sampling of freshwater aquatic foods also apply to marine foods. These considerations include sample size and radionuclides of potential interest.

Sports fish and shellfish will be of interest primarily for calculation of radiation doses to the MEI, while commercial seafood is of interest for estimating the collective dose. It is important to document the origin of the commercial samples. It may be necessary to track the path of an effluent plume or contaminated river for many miles along the seacoast to identify the important locations for shellfish sampling. Arrangements can usually be made to buy seafood harvested at known areas from local packing houses. Certain marine fish, such as salmon and tuna, which migrate over large areas of the ocean, will not normally be measurably contaminated from aqueous effluents discharged along the shore or reaching the coast line. If fish are found to be contaminated, it might be difficult to determine the exact source of radionuclides detected in them.

6.12 Basis for Sampling Sediment

The basis for sampling, location and frequency, and sediment sampling methods are considerations that need to be included when establishing the process to sample sediment. The sampling of sedimentary material from streams or ponds can provide an indication of the accumulation of undissolved radionuclides in the aquatic environment. The accumulation of

radioactive materials in sediment can lead to exposure of humans through ingestion of aquatic species, through sediment resuspension into drinking water supplies, or as an external radiation source irradiating people fishing, wading, or sunbathing. Hence, the sampling and analysis of sediment, or the measurement of the external radiation emanating from the sediment, provide indications of the potential for human exposure from these indirect pathways.

Because of the accumulation of contaminants, sediment sampling is a more sensitive indicator of waterborne radionuclides than water sampling or, for some aquatic species, aquatic biota sampling. This sensitivity is especially true for radionuclides that are not significantly accumulated by fish or shellfish. Sediment sampling is particularly appropriate for most of the transuranics (especially Pu-239); such activation products as Mn-54, Co-58, Co-60, and Zn-65; and several fission products such as zirconium-niobium-95 (Zr-Nb-95), Cs-134, and Cs-137. Radionuclide concentrations may vary for a given location based on many factors including the chemistry of the radionuclides and the characteristics of the sediment and water (NCRP 2010) and the potential uncertainties recognized when these data are used in dose assessments.

6.12.1 Location and Frequency of Sediment Sampling

The need for sediment sampling and the choice of locations and frequency should be based on site-specific evaluations. These evaluations should consider the potential for offsite exposure of humans as well as the potential dose to onsite or offsite aquatic organisms.

Sediment samples are normally taken to detect the buildup of radionuclides by sedimentation. Sediment sampling locations should be based on the type of surface water receiving site liquid effluents. For moving bodies of water, such as streams or rivers, sediment sampling locations should include an upstream site beyond any possible facility influence and two downstream locations. The two downstream locations should be located such that one is near the discharge site and the other is in an area that favors sedimentation, such as the inner bank of a bend in the stream or river (EPA 1972), the region of a freshwater-saltwater interface, or at a dam impoundment. If liquid effluents from a DOE facility are discharged to a lake, pond, or arroyo, a sediment sample should be taken near the outfall but beyond the turbulent area created by the effluents. Because sediments are usually not in a critical exposure pathway, an annual frequency for sediment sampling should be sufficient.

For rapidly moving streams (e.g., rivers), sediment sampling should be considered in conjunction with the spring freshet (i.e., just before or just after) if one occurs locally. For arroyos, the sampling should take place after cessation of water flow (i.e., upon first drying in

the spring). For ponds or lakes, the timing of sediment sampling should be considered on a site-specific basis, but normally at about the same time each year.

6.12.2 Sediment Sampling Methods

Samples of deposited sediments in water can be collected manually (by hand in shallow water or by diving in deeper water) or mechanically (by dredge or with a core sampler). The manual methods are recommended where conditions permit, because the location and depth of the sample can be well-defined. The dredge and coring methods use a sampling device dropped from a boat that is activated when the device contacts the sediment (benthos). Three types of dredges commonly are used: Petersen dredge, Ponar dredge and Eckman dredge (NCRP 2010).

Except for cases where inventory estimation is desired, representative surface (top 5 to 10 cm) sediment samples should be collected along with water depth and stream flow (or pond/lake elevation) data at the time of sampling. Characteristics of the sample, such as particle-size distribution, sediment type, stream type (i.e., intermittent, creek, pond, river, reservoir, etc.), ion-exchange capacity, and organic content, may be useful for proper interpretation of the analytical results.

Every few years, samples (e.g., dredge or core) should be taken in areas in which sediments have been most heavily deposited to determine the profile of the historical depositions and to determine trends and changes in control of effluents and their impacts.

All sediment samples should be oven-dried, homogenized (by grinding and blending, as appropriate in accordance with procedures used) and the radio-analytical results reported on the basis of activity per unit dry weight (g or kg). To prevent cross-contamination, thorough cleaning of equipment between samples is necessary. Portions of the detailed EML procedures (ASTM C999-05(2010)e1) for preparing soil samples for analysis are equally applicable to sediment samples.

Disturbance of the sediment due to sampling activities generally can be reduced by moving slowly and always approaching the sample location from downstream (moving waters) or downwind (stationary water) (NCRP 2010).

6.13 Quality Assurance

As they apply to environmental surveillance activities, the general QA provisions of Chapter 11 should be followed.

7 SAMPLE HANDLING, PREPARATION, AND ANALYSIS PROCEDURES

The establishment of good sample handling, preparation, and analysis procedures is vital to obtaining quality results from samples collected under the effluent monitoring and environmental surveillance program. Laboratory procedures should be documented in the site environmental monitoring plan or other documentation describing the environmental monitoring. A lines of inquiry approach is provided in Appendix B to conduct self-assessments and verify that the program is effective and in compliance with the appropriate requirements and to ensure continuous improvement of the program.

7.1 Key Requirements and Supporting Documents

DOE O 458.1, *Radiation Protection of the Public and the Environment*, requires demonstration of compliance with the public dose limit using a combination of documented surveys, measurements and calculations to evaluate potential doses.

The Multi-Agency Radioanalytical Laboratory Analytical Protocols (MARLAP) Manual, is a multi-agency consensus document developed to provide guidance for project planners, managers, and laboratory personnel to ensure that radioanalytical laboratory data will meet a project's or program's data requirements. The MARLAP Manual offers a framework for national consistency in the form of a performance-based and graded approach for meeting project- or program-specific requirements. The MARLAP Manual includes guidance for handling, preparing, and analyzing laboratory samples, as well as additional guidance for a number of the topics addressed in this chapter of the Handbook.

The *DoD/DOE Consolidated Quality Systems Manual (QSM) for Environmental Laboratories* (2013) is a manual incorporating quality systems of both DoD and DOE. It is based on Volume 1 of The NELAC Institute (TNI) Standards (September 2009) which incorporates ISO/IEC 17025:2005, General Requirements for the Competence of Testing and Calibration Laboratories. QSM Checklist 4, Data Quality for Radiochemistry Analyses, is a checklist used by DOD and DoD during audits of the laboratories. The checklist is an excellent reference for laboratories to use to ensure their quality system meets the needs for both DOE and DoD.

7.2 Summary of Laboratory Procedure Requirements

A DOE site does not need to maintain a full laboratory, but it does need to have the necessary laboratory capabilities available to it. At a minimum, the following capabilities should be available.

7.2.1 Documentation

To ensure that the analyses performed are consistent and of the highest quality, site-specific policies, programs (e.g., Environmental Monitoring Plan, Environmental Radiological Protection Program) and standard operating procedures should be developed to promote and provide consistency in the handling, preparation and analysis of laboratory samples. Specific methods for handling, preparing, and analyzing laboratory samples should be identified based on the sample matrix, sample activity, and radionuclide of interest. These methods should be documented and used to identify and quantify all radionuclides in the facility inventory or effluent that contribute 10 percent or more to the total effective dose to individual members of the public from DOE operations.

When available, standard analytical methods (DOE, EPA, ASTM, etc.) should be used for radioanalytical analyses. Any modifications of standard methods or deviations from the procedures should be documented appropriately, along with demonstration of capability data. Additionally, sample handling, sample preparation, analytical methods, data requirements, and other necessary documentation should be specified in analytical contracts.

7.2.2 Sample Identification System

Each monitoring and surveillance organization should have a sample identification system that provides positive identification of samples and aliquots of samples throughout handling, preparation, analytical and data reporting processes. The system should incorporate a method for tracking all pertinent information obtained in the sampling and analysis processes.

7.2.3 Chain-of-Custody

The possession and handling of samples need to be traceable at all times. A sample chain-of-custody should be used to document sample possession and to demonstrate that the sample was maintained in a controlled and unaltered state. Sample custody should be assigned to one individual at a time. A sample is considered in custody if it is:

- In the physical possession of the assigned individual;

- Remains in view of the assigned individual;
- Placed in a locked area or sealed to prevent tampering; or
- Is placed in a secure, controlled access area.

Chain-of-custody should be documented for all samples, data, and records used to demonstrate compliance. The chain-of-custody record may be a standardized form initiated by the individual collecting or overseeing the collection of samples and accompanies the samples throughout the handling, storage, transportation, analysis, and disposal processes. Any break in custody or evidence of tampering needs to be documented and investigated.

7.2.4 Screening of Samples

Environmental samples should be initially monitored (screened) to determine activity levels and to detect transferable contamination before transfer to an analytical laboratory to prevent contamination of materials and equipment with which they may come in contact. Samples with elevated screenings should be marked, along with the chain-of-custody.

7.2.5 Preventing Cross-Contamination

To prevent incorrect analysis results caused by the spread of contamination among samples, each laboratory should establish and adhere to written procedures to minimize the possibility of cross-contamination between samples. High-activity samples should be kept separate from low-activity samples to minimize the potential for cross contamination.

7.2.6 Sample Preservation

It is essential to maintain the sample integrity after collection to preserve the chemical and physical state of the sample, including the radiological constituents in the sample. The sample preservation practices should minimize degradation of the samples prior to analysis by using proper preservation and handling practices that are compatible with the sample matrix and analytical methods to be used. Examples of preservation practices include, but are not limited to:

- Biological samples should be kept frozen until they are processed.
- Water samples should have a small amount of acid (2-5% v/v HNO_3 is typical) added to inhibit biological growth and to prevent analyte hydrolysis, causing adherence to the sample container wall. However, acid should not be added if the radionuclide of interest is volatile in acidic solutions (e.g. tritium, C-14, and radioiodine).

- Water samples should be filtered if the analytical request is for dissolved solids. Water samples should not be filtered if the analytical request is for total analytes (dissolved plus not dissolved). Refrigeration should be used when necessary to prevent biological growth.
- Shielding from light may also be used to prevent chemical changes due to ultra-violet (UV) light exposures.
- Soil samples do not require special sample preservation. However, volatile radionuclides, such as H-3, C-14, and Tc-99, should not be dried prior to sample analysis.

7.2.7 Sample Packaging and Transportation

Samples that are sent offsite for analysis or for laboratory inter-comparison should be packaged, labeled, marked and transported in a manner that meets applicable transportation regulations and requirements. Samples that have been preserved with acids may be considered hazardous substances under RCRA and they should be packaged, labeled, marked and transported accordingly. Samples that show measurable surface contamination should be repackaged into uncontaminated containers before they are brought into the laboratory to prevent the spread of contamination or the loss of sample constituents.

7.2.8 Sample Handling

All samples for analysis should be handled in a manner that conforms to Section 7.2.5. of this chapter. All pertinent sample information and associated analysis should be recorded in a permanent laboratory record (e.g., logbook and/or computer system with backup). The sample identification number should enable tracking of the exact location of the record entry or computer file and indicate the chain-of-custody for the samples. Table 7-1 presents a summary of matrix-specific sample handling and preparation considerations as provided in the MARLAP Manual.

7.2.9 Sample Preparation

Sample preparation is a critical step for achieving quality analytical data and the type of sample preparation depends on the nature of the sample matrix and the radionuclide(s) of interest. Sample preparation is the physical manipulation of the sample to the point of chemical separation. Examples of sample preparation, depending on the sample matrix, include, but are not limited to: drying, screening, grinding, mixing, ashing, and acidifying. Whenever possible,

analytical methods that do not require complex sample preparations should be selected to avoid measurement uncertainties that can result from radionuclide losses during sample preparation. Carriers and/or tracers should be introduced as early as possible in the sample preparation procedures to facilitate adequate estimation of any loss of contaminants and the recovery efficacy (i.e., chemical yield) of the preparation procedure. Caution should be used when preparing soils, sediments, and biological materials (i.e., wet/dry washing, drying etc.) to prevent contaminant losses from volatilization, formation of dust or airborne particulates, or unexpected reactions such as combustion, foaming, and splattering.

Samples obtained for tritium and/or C-14 analysis should be sealed in airtight containers to prevent exchanges of H-3 and/or CO_2 vapor with atmospheric air. Biological samples selected for tritium and/or C-14 analysis may be preserved frozen (or refrigerated, at a minimum) to limit sample degradation if the sample is not analyzed immediately upon collection. Prior to analysis, tritium samples may require purification to eliminate contributions from environmental contaminants. For example, purification is necessary if: (1) color is visible, (2) organics are present, or (3) the sample or source history is unknown.

7.2.10 Instrumentation

All sites that release or could release radionuclides should have the capability—either internal to the organization or external—to analyze routine, special, and emergency samples to identify and quantify the radiological contaminants in a sample matrix of interest.

The instrumentation selected for assessing radiological contamination (screening and laboratory-based analyses) should be calibrated periodically in accordance with applicable procedures and national or international standards. Tables 16-19 of the QSM have the recommended calibration frequencies for laboratory instrumentation. At a minimum, the frequency recommended by the instrument manufacturer should be used as a starting point for periodic instrument calibrations. Additionally, instrument performance verifications (e.g., background counting, source checks) should be periodically performed on all instruments used to assess contamination or to identify and quantify radioactive materials to verify that the instrument(s) provide quality results meeting program- or project-specific requirements.

7.2.11 Laboratory Qualifiers

Laboratory personnel should recognize and respond to issues affecting the quality of sample results related to data validation (refer to Chapter 8). Examples include:

- Statistical uncertainty is too high to be accepted by the analyst;
- Radionuclide has no supporting photopeaks to make a judgment;
- Photopeak resolution is deemed unacceptable by the analyst;
- Result is below the decision critical level;
- Other radionuclides display gamma-ray interferences;
- A graphical display of analyzed photopeaks shows unacceptable fitting results;
- There is no parent activity, therefore the state of equilibrium is unknown and the radionuclide could not be quantified;
- Evidence of laboratory cross-contamination or quality control issues.

7.3 Uncertainty

The error of a measurement can be defined as the difference between the measured result and the actual value of the measurand (MARLAP). The measurement error is a result of systematic and random effects. The measurement error is a theoretical concept that implies knowledge of the actual value of the measurement (but in reality is unknown). Therefore, the International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) Guide 98-3:2008, *Guide to the expression of uncertainty in measurement (GUM)* (2008), and MARLAP suggest the term “uncertainty of measurement to denote a parameter associated with measurement results that characterizes the dispersion of the values that could be attributed to the measurand.” In other words, the uncertainty of a measurement is a value used to estimate the size of the measurement error; the smaller the uncertainty, the smaller the error.

7.3.1 Estimation of the Measurement Uncertainty

Uncertainty associated with any measurement result is unavoidable due to introduction of systematic and random errors. The uncertainty of a measurement is an important parameter to be reported together with the measurement result. For example, radioactive decay and the measurement method (the combination of the selected instrumentation and measurement technique) are potential sources of uncertainty of a measurement. The larger the uncertainty of a measured value, the lower the probability that the measured value is close to the true value it represents.

TABLE 7-1: Common Matrix-Specific Analytical Planning Issues

Sample Matrix	Recommended Issues	Key Issues
Solids (soil, sediment, structural material, biota, metal, etc.)	• Homogenization • Subsampling • Removal of unwanted material	• Sample identification • Container type • Container material • Sample preservation • Surveying samples for health and safety • Volatile compounds • Sample identification • Cross-contamination • Sample size • Compliance with radioactive materials license • Compliance with shipping regulations • Chemical and physical form of the substrate
Liquids (drinking water, ground water, precipitation, solvents, oils, etc.)	• Is filtering required? • Sample preservation • Should sample be filtered or preserved first?	• Sample identification • Volume of sample • Immiscible layers • Precipitation • Total dissolved solids • Reagent background • Compliance with radioactive materials license • Compliance with shipping regulations
Filters and Wipes	• Filter material • Pore size • Sample volume or area wiped	• Sample identification • Compliance with radioactive materials license • Compliance with shipping regulations • Subsampling • Background from filter material

(Information from Table 3.1 of the MARLAP Manual)

The laboratory should report each measured value with either its combined standard uncertainty or its expanded uncertainty (MARLAP). Estimating the combined standard uncertainty of a measurement can be accomplished by propagating the standard uncertainty of the individual components of the measurement. Based on information provided in NRC Regulatory Guide 4.16, *Monitoring and Reporting Radioactive Materials in Liquid and Gaseous Effluents from Nuclear Fuel Cycle Facilities* (NRC 2010), the overarching goal should be to obtain an overall estimate of the uncertainty of the measurement by evaluating the important contributors to the uncertainty. The combined standard uncertainty may vary depending on the measurement method and instrument capabilities.

Measurement uncertainties may be classified as systematic (i.e., biased) or random. Random uncertainties are associated with the variation of the result when the measurement is repeated (e.g., random nature of radioactive decay) from one measurement to the next. Systematic uncertainties, on the other hand, are related to activities that cause variations in the result by a constant or relative amount (e.g., calibration, sample-to-detector positioning, voltage drifts, and measurements of weight, volume, time, and distance). Systematic uncertainties, and other uncertainties associated with human performance, should be identified and corrected to limit their effect on the combined standard uncertainty of the measurement.

The combined standard uncertainty can be estimated mathematically using empirical calculations or via computational tools that simplify the process without compromising the calculation. Uncertainty propagation can be performed fairly easily for simple measurements. However, when multiple measurements are performed or when complex algebraic operations are necessary, computational software may be utilized to propagate the uncertainties from multiple parameters or operations and estimate the combined standard uncertainty of the measurement. Procedural steps for evaluating uncertainty can be found in MARLAP.

7.3.2 Significant Figures

All results should be reported as obtained and accompanied by their corresponding uncertainty. The number of significant figures included in the reporting of the results depends on the uncertainty associated with the result. Measurement results and their corresponding uncertainty should be reported to no more than two or three significant figures (MARLAP). It is important to stress that rounding should only be performed when reporting the final result. Any rounding during intermediate calculations may introduce round-off errors. Figure 7-1 illustrates the application of this convention. Further, to preserve power of statistical hypothesis tests that may

be necessary during the data quality assessment phase of the data life cycle, the appropriate number of significant figures for the sample results should be maintained. Several of the tests introduced in Chapter 8 are based on ranking the pooled data and by maintaining significant figures; ties between rankings may be minimized.

Measured Value (y)	Expanded Uncertainty $U = ku_c(y)$	Reported Result
0.8961	0.0234	0.896 ± 0.023
0.8961	0.2342	0.90 ± 0.23
0.8961	2.3419	0.9 ± 2.3
0.8961	23.4194	1 ± 23
0.8961	234.1944	0 ± 230

FIGURE 7-1: Example of reporting significant figures (MARLAP)

7.4 Analytical Procedures

The selection of appropriate analytical procedures and instrumentation depends on the sample matrix, the radionuclide(s) of interest, and associated radioactive emissions (i.e., alpha, beta, gamma). Some samples may require the addition of a "spike", that is, a known radionuclide(s) at a known concentration(s), to evaluate chemical/process recovery (yield) during sample preparation processes (e.g., chemical separation, filtration, evaporation, distillation) prior to analysis. Moreover, depending on the program- or project-specific goals, multiple analytical procedures may be needed to assess the radionuclide(s) of interest. Brief discussions of selected analytical procedures are included herein as examples. Additional analytical procedures, or a combination of multiple analytical procedures, may be needed to adequately assess the radiological components of the sample matrix of interest.

7.4.1 Alpha and Beta Measurements

7.4.1.1 Gross Alpha and Gross Beta Screening Measurements

Gross alpha and gross beta measurements are often used as a preliminary screening tool. Results above predetermined screening levels may lead to an increase in radiological controls. Gross alpha and gross beta measurements are typically performed after sample collection using hand-held instruments tailored to the emission of interest. Other instruments (e.g., gas proportional counters, liquid scintillation counters) may also be used for screening purposes in a laboratory setting.

7.4.1.2 Quantitative Alpha and Beta Measurements

Gross alpha and gross beta measurements are commonly reported in counts or as a count rate (i.e., counts per minute or cpm). When additional parameters are known (e.g., sampling area, mass, total efficiency), an activity or concentration can be calculated (e.g., disintegrations per minute per 100 cm^2, picocuries per liter, picocuries per gram). An approach such as that described in the International Organization for Standardization (ISO) Publication ISO/CD 7503-1, *Measurement of radioactivity – Measurement and evaluation of surface contamination – Part 1: General principles* (1988) can be used to quantify alpha and beta surface contamination.

A number of factors can impact the calibration of the instrumentation used for quantifying alpha and beta contamination; including, but not limited to, emission type, emission energies (particularly in the case of beta emitters), source-to-detector distances, detector type, and the calibration source geometry. For example, the instrument efficiency for Cs-137 (a high-energy beta emitter) and Co-60 (a low-energy beta emitter) will vary due to their distinct emission energies. If an instrument is calibrated for Cs-137 and Co-60 is measured, the resulting activity, and the calculated activity or concentration, would be erroneous without the application of appropriate energy response correction factors.

When a single radionuclide is present in the sample, the quantification of alpha and beta contamination is fairly straightforward. However, when multiple radionuclides are present (multiple alpha- or beta-emitters) a weighted instrument efficiency should be determined to account for the contributions to the measurement.

7.4.2 Gamma-Ray Spectroscopy

Gamma-ray spectroscopy is widely used in laboratory settings to identify and quantify gamma-emitting radionuclides. Gamma spectroscopy can be achieved by using scintillator detectors (i.e., sodium iodide thallium-activated crystals [NaI(Tl)]), or semiconductor detectors such as high purity germanium (HPGe). The gamma spectroscopy instrument of choice depends on the radionuclide(s) of interest, the potential activity, gamma-ray energy, and required resolution.

NaI(Tl) crystals have poorer energy resolutions and higher backgrounds than semiconductors. Because of these shortcomings, a limited number of radionuclides can be measured in complex radionuclide mixtures using NaI(Tl) crystals. NaI(Tl) detectors are best suited for counting known radionuclides with low activities and when the energy difference between the radionuclides in the sample matrix is large enough to allow identification of each energy

contribution (there is no overlapping between their distributions). HPGe detectors, on the other hand, are best suited for measuring unknown radionuclides independent of their activity.

Careful attention should be paid to the activity in the sample; the greater the radioactivity, the larger the dead time of the detector. Large dead times will affect the activity estimation in the sample matrix and could damage the detector. Proper sample screening should prevent large activity samples from being analyzed. When the level of radioactivity in the sample matrix is high, representative subsampling (lower sample mass or volume) may be used to reduce the sample activity to an acceptable counting range. When subsampling is not possible, the dead time can be reduced by increasing the detector-to-source distance. However, this will induce variations in the counting efficiency that may be corrected by performing an instrument calibration at the new distance of interest.

7.4.3 Alpha Spectroscopy

Alpha spectroscopy is used in a laboratory setting and is used when alpha emitting isotopes are the analyte(s) of interest. The separation chemistry leading to counting using alpha spectroscopy may be tedious and time consuming. However, detection limits for alpha spectroscopy are considerably lower than gamma spectroscopy.

After separation, the alpha emitting radionuclides are placed on a planchet. The sample should be made with as small thicknesses as possible. Increases in the sample thickness will increase self-absorption within the sample matrix. In turn, this will shield alpha particles emitted from the sample surface that are not facing the detector. Moreover, sample matrices for alpha spectroscopy should not be encapsulated. The encapsulation will shield the alpha particles and may prevent them from reaching the detector.

Examples of alpha spectroscopy detectors include Passivated Implanted Planar Silicon (PIPS), silicon surface barrier (SSB), or diffused junction type devices. Because of the nature of the sample matrix needed for counting, these detectors are operated under vacuum conditions to enhance detection. Prior to operation, the detector chamber should be vented from ambient air to reduce radon contributions or moisture that may introduce counting interferences.

7.4.4 Liquid Scintillation Counting

Liquid scintillation counters (LSC) are primarily used to measure beta-emitting radionuclides. Water and solid matrices may also be analyzed using LSC provided that adequate sample digestion and separation of the radionuclides is permissible. Alpha-emitting radionuclides may

also be measured using a combination of LSC and pulse shape discrimination to reduce the interferences produced by ambient gamma rays and beta emitters in the sample and scintillation cocktail.

7.4.4.1 Tritium Analysis

H-3 is a pure, low-energy beta emitter (E_{max} = 18.6 keV) with a half-life of 12.32 years. Tritium is typically analyzed via liquid scintillation counting methods due to its pure beta emissions and low-beta energies.

A representative sample, subsample, or purified subsample should be placed into a glass or transparent container (as required by facility-specific protocols and calibration requirements) and a pre-determined volume of scintillation liquid added to the sample container. For example, a liquid sample may be analyzed by obtaining a representative purified subsample of 1 milliliter (mL) of volume and mixing it with 10 mL of scintillation liquid. The LSC results are typically provided in counts or disintegrations, or counts or disintegrations per minute per mL, as programmed by the LSC user. Solid samples, biological materials, and semi-liquid samples can also be analyzed for tritium in a similar manner. However, the sample needs to be completely dissolved into the scintillation liquid prior to analysis.

The sample counting time will vary depending on the H-3 concentration in the sample. Environmental samples selected for tritium analysis are typically counted for 30 minutes or longer to enhance detection and to reduce measurement uncertainties due to the expected low environmental tritium concentrations. If the expected tritium concentrations are relatively high, the necessary count time can be reduced (e.g., 1 minute, 10 minute), based on minimum detectable concentration (MDC) considerations.

Blanks, reference, or background samples should also be prepared for each tritium sample matrix. These types of samples should be analyzed using the same count time of the sample, whenever possible, for direct comparison. When not possible, background counts should be subtracted manually during sample activity calculations. Check or calibration sources should also be periodically counted for quality control and quality assurance purposes and to document trends in the LSC response.

7.4.5 Elemental Analysis

Elemental analysis procedures can be used to identify and quantify radioactive, particularly hard-to-detect radionuclides, and non-radioactive contaminants present in a sample of interest.

Inductively coupled plasma mass spectrometry (ICP-MS) is an example of a commonly used elemental analysis technique. Another variation of ICP includes atomic emission spectroscopy (ICP-AES).

In ICP-MS procedures, the sample, or a portion of the sample, digested in chemical reagents is transported by a noble gas (e.g., argon) through a high-electron density plasma. The sample is subsequently vaporized in the plasma region to separate its individual constituents. The individual constituents are extracted by a differential vacuum pump and separated based on their respective mass-to-charge ratios. Because the sample, or a portion of the sample, is vaporized, interference corrections are necessary to compensate for potential ion contributions from the plasma gas, reagents, or sample matrix. Interference corrections can be achieved by using a series of "blanks" to establish a calibration curve, monitor for reagents in the sample or sample processing, and return the system to its initial state prior to evaluating the next sample.

Guidance for performing ICP-MS analyses is provided by EPA in SW-846 Methods 6020A, "*Inductively Coupled Plasma-Mass Spectroscopy*", and Method 200.8, "*Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma – Mass Spectroscopy*". The previously mentioned methods are typically used in conjunction with other sample preparation methods specific for the sample matrix of interest. Examples of sample preparation methods for ICP-MS analysis include, but are not limited to: (1) EPA Method 3050B, "*Acid Digestion of Sediment, Sludges, and Soils*", (2) Method 3005A, "*Acid Digestion of Waters for Total Recoverable or Dissolved Metals for Analysis by FLAA or ICP Spectroscopy*", and (3) Method 3010A, "*Acid Digestion of Aqueous Samples and Extracts for Total Metals for Analysis by FLAA or ICP Spectroscopy*".

Although Methods 6020A and 200.8 are the primary guidance documents for performing ICP-MS analyses, site-specific Standard Operating Procedures (SOPs) should be developed for analysis of the contaminants of interest and safe handling of the chemical solutions used in the sample preparation and measurement processes.

7.5 Quality Assurance

As applicable, the general Quality Assurance provisions of Chapter 11 of this Handbook should be followed. Additionally, the *DoD/DOE Consolidated Quality Systems Manual (QSM) for Environmental Laboratories* (2013) may also be a useful reference.

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8 DATA ANALYSIS AND STATISTICAL TREATMENT

Good data analyses and statistical treatment practices are essential for the production of quality results from the environmental monitoring program required by DOE O 458.1. The goals for analyzing effluent monitoring and environmental surveillance data should include:

- Estimate radionuclide concentrations along with an estimated uncertainty for each sample or measurement;
- Compare the estimated radionuclide concentrations at each sampling and/or measurement point to previous concentration estimates at that point to identify changes or inconsistencies in radionuclide levels;
- Compare the radionuclide concentrations at each sampling and/or measurement point to the established limit(s), or concentrations related to the applicable dose limit, for those radionuclides; and
- Compare radionuclide concentrations at single sampling and/or measurement points or groups of points to those at control/background/baseline or other relevant points and evaluate the reliability of those comparisons.

The characteristics of effluent and environmental data should be considered when selecting the statistical techniques used to support the concentration estimates, to determine their corresponding measures of reliability, and to compare radionuclide data between sampling and/or measurement points, periods, and regulatory concentrations. For example, the statistical techniques selected may require establishing the underlying data distribution characteristic as being either symmetric or asymmetric. As further discussed in this chapter, conclusions reached from the data quality assessment (DQA) phase—including statistical evaluations and summaries as well the results of hypothesis tests when applicable—depend on the quality of the data themselves, as described in Chapter 7.

This chapter examines the design and implementation of data analysis and statistical treatment for the data obtained from the implementation of environmental monitoring programs. A “lines of inquiry” approach is provided in Appendix B to verify compliance with the appropriate requirements, evaluate the effectiveness of the data analysis and statistical treatments, and promote continuous improvements based on the aforementioned goals.

8.1 Key Requirements and Supporting Documents

The following directives and guidance documents apply to data analysis and statistical treatment of radiological effluent monitoring or environmental surveillance data:

DOE O 458.1, *Radiation Protection of the Public and the Environment*, requires demonstration of compliance with the public dose limit using a combination of documented surveys, measurements, and calculations to evaluate potential doses.

MARLAP is a multi-agency consensus document developed to provide guidance for project planners, managers, and laboratory personnel to ensure that radioanalytical laboratory data meet a project's or program's data requirements. MARLAP offers a framework for national consistency in the form of a performance-based, graded approach. Many of the data analyses and statistical techniques described in MARLAP for laboratory analyses are also applicable to the evaluation of effluent monitoring and environmental data.

Several multi-agency and EPA unified guidance and quality assurance documents provide accepted/recommended DQA processes for data analyses. These documents include:

Intergovernmental Data Quality Task Force, *Uniform Federal Policy for Implementing Environmental Quality Systems - Evaluating, Assessing, and Documenting Environmental Data Collection/Use and Technology Programs,* provides recommendations and guidelines for documentation and implementation of acceptable Quality Systems for Federal agencies. (Publication Numbers: EPA-505-F-03-001, DTIC ADA 395303, DOE/EH-0667).

Guidance for Data Quality Assessment, Practical Methods for Data Analysis, EPA QA/G-9, was developed to assist in the determining whether the type, quantity and quality of data needed to support decisions have been achieved. (EPA/600/R-96/084)

Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance, provides a suggested framework, recommendations for the statistical analysis of groundwater monitoring data at RCRA facility units to determine whether groundwater has been impacted by a hazardous constituent release, and provides examples and background information that will aid in successfully conducting the required statistical analyses. (EPA 530/R-09-007)

8.2 Data Verification and Validation

There are three essential phases associated with the data life cycle; data verification, data validation, and data quality assessment. Once data packages are received from the field,

laboratory, or other source, an initial assessment should be performed to ensure that the data quality meets the project objectives and as well as the quality assurance project plan requirements. For example, these parameters might include:

- Data verification: Conducted so as to provide an independent assessment of QC checks, calibrations, transcription reviews, etc. to identify mistakes that would invalidate or limit use of the data.
- Data validation: Confirms the sample collection and handling were performed in accordance with procedures with any deviations documented. Field observations which could invalidate or qualify the results include: (1) insufficient sample volume; (2) torn filters; and (3) mechanical malfunctions of sampling equipment. Validation confirms that the required number of samples and types of data were collected in accordance with the sampling/monitoring plan; confirms the usability of the data for the intended end use via validation of analyses performed and data reduction and reporting; and ensures requirements were met such as detection limits, QC measurements, impacts of qualifiers, etc.
- Preliminary data assessment: Performed to evaluate the structure of the data; identify patterns, relationships, and/or the presence of anomalies; assess the basic statistical quantities including the population mean, standard deviation, median, and range; and the initial comparisons with an action level. Data may also be graphed or plotted.

The initial data quality assessment is to evaluate the field collection and laboratory information. The field documentation review is conducted to identify sample collection issues encountered that would invalidate or limit use of the data. Field observations which could invalidate the sample result include: (1) insufficient sample volume; (2) torn filters; and (3) mechanical malfunctions of sampling equipment, deviations to procedural requirements, cross contamination, etc. The laboratory report case narrative is reviewed. The case narrative should provide a summary of the following information: the sample condition upon receipt—ensuring containers were intact, date/time of receipt, acceptable temperature (when required), sample screening results, condition of custody seals, chain-of-custody documentation, etc.—a narrative of the sampling handling, preparation, and analyses and any issues encountered; and acceptability of the quality control/quality assurance processes for sample preparation and analyses.

The initial laboratory analytical report review ensures all requested analytical results were reported for each sample together with the measurement uncertainty. The review also verifies

that the reported detection limits satisfied project requirements. Additionally, the quality control/quality assurance results are reviewed. Quality control samples may include field blanks, laboratory blanks, duplicates, matrix spikes, or other quality assurance project plan requirements. The laboratory report should include a qualification flag for any identified data quality issues.

Data that pass initial screening are further evaluated prior to reporting. Databases may be used to record analytical data and maintain the data in a readily available and retrievable format. Backup systems or protocols should also be implemented to minimize potential losses of data. Comments on the quality of the samples and/or abnormal conditions should be recorded appropriately and should accompany the reported results. In addition to the data collected during the regular sampling program, logs of events that could have affected analytical analyses should be documented.

8.3 Preliminary Data Assessment

Once data validation and verification are completed, a preliminary data assessment is performed. The goal of the initial assessment is to determine the structure of the data—i.e., normal distribution, skewness, etc.—identify relationships/associations, trends or patterns between sample points/variables or sampling events; identify anomalies; and lastly selecting the appropriate statistical tests for decision making.

8.3.1 Basic Statistical Quantities

The data quality assessment will include development of summary statistics. Descriptive statistical parameters associated with the data sets will generally include the number of observations, data range, mean, median, variance, standard deviation, and coefficient of variation. Other parameters beyond the basic summary statistics might include a measure of the relative standing of the data to the sampled population and/or the confidence interval or upper confidence level of the mean when applicable. Each data point should be compared to previously obtained data to help identify unusual measurements that may require investigation or further statistical evaluations. The reported results should be assessed in terms of statistical significance with respect to sample locations, reported releases, laboratory analytical uncertainties, meteorological data, and other events (e.g., local and infrequent worldwide events) that could potentially affect the environment at the DOE.

8.3.2 Graphical Reviews

Graphing and/or plotting the data allows the data user to visually identify patterns or trends that may not be apparent when reviewing numerical values alone. A further advantage is that the graphical presentation in many cases may be used to summarize and present the data when incorporating into monitoring reports or presenting the information to stakeholders. Common methods and uses for graphing and plotting data are:

- Histograms for assessing data symmetry and variability, and may be applied to spatial or temporal measurements. Additional information on the use of histograms is provided in Section 8.4.3.
- Ranked Data or Quantile Plots also provide a graphical data representation useful for assessing data density, symmetry, and skewness; however, unlike histograms each data point is plotted. Quantile-Quantile plots pair two data sets, for instance monitoring event data as compared to normal probability plot or a plot of background data.
- Posting Plots are useful for assessing spatial relationships where the measurement/sample location is replaced by the respective data value.
- Other plots that may be used for various applications are Stem and Leaf Plots (a simple form of a histogram/frequency chart), Box and Whisker Plots which show a schematic of the basic statistics, and Scatter Plots for paired observations or two or more variables measured together.

8.3.3 Data Variability

The observed variability of an analytical value, for example within repeated measurements of a sample, will be a function of the bias and precision of the sample acquisition procedures/methods and the analytical methods. In other words, uncertainty in the estimated value of the parameter of interest is introduced by bias (systematic errors in the sampling or analytical preparation processes) and precision (random errors) that will ultimately determine the overall accuracy of a result, or deviation from known/actual value. Ultimately, increased uncertainty in the individual data points that may be used to describe a population will be propagated as increased uncertainty in the population descriptors. Careful design and execution of the monitoring program can substantially improve the quality of the radiological effluent monitoring and environmental surveillance results by minimizing the potential for systematic errors during sample collection, handling, and processing steps.

Potential sources of variability in effluent monitoring data, in addition to natural variability of any background parameters, are listed in Table 8-1. These sources can be divided into three categories: environmental, sampling, and recording. The analyses performed to determine and reduce the sources of variability should consider the relative importance of these sources with respect to the actual conditions at the sampling and/or measurement point.

Based on previous site monitoring and surveillance experience, an estimate of an acceptable relative percent for the data uncertainty should be used to develop data analysis and handling strategies for radiological effluent monitoring and environmental surveillance programs. These strategies should then be re-evaluated periodically (and after significant modification to site conditions) to determine whether they are adequate for the present site conditions.

TABLE 8-1: Variability in Effluent Monitoring Data (adapted from DOE 1981)

Category	Source	Examples
Environmental	Space	Distance from emission source, elevation, heterogeneous dispersion of material or differences in background radiation at various locations.
	Time	Variation in rates of emissions, variation in rates of dispersion or variation in cosmic background radiation throughout the year.
	Space × Time	Non-stationary differences between sampling stations over time
Sampling	Sample Collection	Non-representative sampling, inconsistent sampling techniques, sampling equipment failure
	Sample Handling	Chemical reactions, non-uniform storage conditions, container effects
	Sample Processing	Volume or weight measurement errors, insufficient sample mixing, non-representative sub-sampling
	Measurement	Calibration errors, instrument errors, readout errors
	Cross-Contamination	Residual contamination of containers and work areas, imperfect sealing of containers for transport, surface contamination from transport, separation of high- and low-activity samples, decontamination practices
Recording	Data Recording and Transfer	Errors in data entry, errors in transfer of data from laboratory records to electronic formats

8.4 Data Distribution Evaluation

The planning phase of the data life cycle may include an assumption of the expected data distribution based on historical knowledge, relative to the population. This historical knowledge or estimation of the distribution is needed when determining the required number of samples, determining sample locations, and planning for data assessments when the sample data will be used to make a decision regarding the population. Required decisions may include an estimate of the population mean, a determination as to whether a trend exists or data demonstrate random variability, a conclusion that an action level threshold has been exceeded, and/or to provide an answer to other principle study question(s). Once data are available, this evaluation will determine whether data are consistent with the initial underlying assumption, and therefore validate the use of the proposed statistical test(s). Otherwise, different statistical procedures may be necessary.

The distribution evaluations include determining if the distribution is symmetric or asymmetric. Outliers may exist in either case and information on symmetry can be obtained based on whether the outliers exist on both tails of the distribution or result in a left- or right-skewed distribution. For environmental data, normal distributions—where the data tend towards a central value and positive and negative deviations from this value are equally likely—are common with background populations. Lognormal distributions will have outliers that cause a right-skewed distribution if there are elevated concentrations of contaminants or there have been impulses of the analytes of interest during the monitoring period. The number of samples collected will also impact the ability to assume an underlying distribution. As sample size increases, under certain conditions, the probability of the results approximating a normal distribution increases based on the central limit theorem.

8.4.1 Measures of Central Tendency

A measure of central tendency is a single value calculated from the sample data that attempts to describe the central position of the population. The appropriate measure of central tendency depends on the characteristics of the probability distribution of the data collected and the underlying assumptions of the population. For normally distributed data with only a small number of extreme values, the arithmetic mean is the appropriate estimator of central tendency. The median is less sensitive to extreme values and should be used as a measure of the central tendency when a dataset contains large numbers of extreme values and/or skewed data. Because extreme values may routinely be present in environmental data due to anthropogenic

sources, site releases, or contamination, the median many times will be the distribution descriptor evaluated via hypothesis tests discussed in this chapter. The mode may also be used as a measure of central tendency. The mode is defined as the value of the dataset that occurs most often.

The use of a “trimmed” mean (the average of the dataset after a specified percentage of the upper and lower data values has been removed) may reduce the influence of extreme values when they occur on both tails of the distribution. However, application of a trimmed mean is discouraged without sufficient technical justification to exclude data from the set (an attempt to reduce bias). The necessity of using the trimmed mean occurs most often when the data either include less than values, which represent results below the detection limit, or to guard against unexplainable extreme outlier data in symmetric distributions (Gilbert 1987). The inclusion of less than values can be avoided by reporting actual values or other means such as those methods discussed in this chapter.

The geometric mean may be a better measure of central tendency when: (1) the data are presented on a multiplicative scale (e.g., logarithmic); (2) the values in the dataset differ by orders of magnitude; and/or (3) the distribution is lognormal.

8.4.2 Measures of Dispersion

Measures of dispersion describe the spread or variability of the data. Measures of dispersion include the range, quantiles, standard deviation, and variance. The range is the difference between the maximum and minimum data values. Quantiles, which are similar to percentiles, divide the data into fractions (e.g., the 25^{th}, 50^{th}, and 75^{th} quantiles). The variance of a sample is determined by sum of the squared differences of each data point from the arithmetic mean (in the numerator) divided by the number of data points minus one. The standard deviation is calculated as the square root of the variance.

For data with substantial numbers of extreme values, other measures should be used to estimate the dispersion around the central value. For example, the inter-quartile range (the range of data between the 25^{th} and 75^{th} percentiles) and the median absolute deviation (the median of the differences between each data point and the indicator of central tendency) are also acceptable measures.

8.4.3 Distribution Analyses

Dependent upon the planned statistical assessments or tests that will be used for decision making, data or transformed data may need to be tested for normality before any statistical approaches are evaluated and implemented. The testing requirement will generally be determined based on the use of parametric vs. non-parametric statistics, where non-parametric tests do not require the assumption of a normal distribution. Acceptable methods to assess normality include:

a) Histogram

In a histogram, the frequency of data is determined and the dataset is subsequently arranged in bins containing a specified range. A plot of the bins and the number of occurrences is created to form a probability of distribution. The preparation of a histogram should include considerations for optimizing the number of bins. Guidance on optimizing histogram bins is provided in NUREG-1505. Once created, a visual inspection of the histogram should reveal whether the dataset is normal (or not) and belongs to a single group with a symmetrical distribution around a mean value, i.e., a "bell-shaped curve". However, histograms should be used carefully as the determination of the degree of symmetry is interpreted in a subjective manner.

b) Chi-Square (χ^2) Test

The chi-square test can be performed when parameters of the distribution are either known or unknown. The chi-square test is a hypothesis verification test; that is, the assumed hypothesis is that the dataset is normally distributed.

When the mean, $\bar{x}$, and variance, σ^2, are known, the χ^2 can be defined as:

$$\chi^2 = \sum_{i=1}^{n} \frac{(observed\ count - expected\ count)^2}{expected\ count}$$

The χ^2 is then compared to a critical value based on the statistical confidence level for assigned Type I error (α) and the *n-1* degrees of freedom of the dataset. If the calculated χ^2 exceeds the critical value, the hypothesis is rejected and the data distribution is assumed to deviate from normality.

NUREG-1475, Revision 1, *Applying Statistics* (NRC 2011), provides a modified chi-square test when the mean and variance are unknown.

c) Shapiro-Wilk (W-) Test

The most widely used test of normality is the Shapiro-Wilk W-Test (Shapiro and Wilk 1965). The Shapiro-Wilk W-Test is the preferred test of normality because of its statistical power properties as compared to a wide range of alternative tests (Shapiro et al. 1968). If the W statistic is significant, for example when the p-value is less than a typical alpha level of 0.05 ($p < 0.05$,) then the hypothesis that the distribution is normal should be rejected.

Graphical depictions of the data should be a component of any evaluation of normality. Figure 8-3 depicts a graphical histogram along with the results of the Shapiro-Wilk W-Test. The data used for the illustration are comprised of five years of weekly gross beta measurements taken from 1997 to 2001 at the Arco air monitoring location near the perimeter of the Idaho National Laboratory. In the depicted example, the W statistic is highly significant ($p < 0.0001$), indicating that the data are not normally distributed. The histogram shows that the data are asymmetrical with right skewness. This suggests that the data may be lognormally distributed. The Shapiro-Wilk W-Test can be used to test this distribution by taking the natural logarithms of each measurement and calculating the W statistic. Figure 8-4 presents this test of lognormality. The W statistic is not significant ($p = 0.80235$), indicating that the data appear to be lognormal.

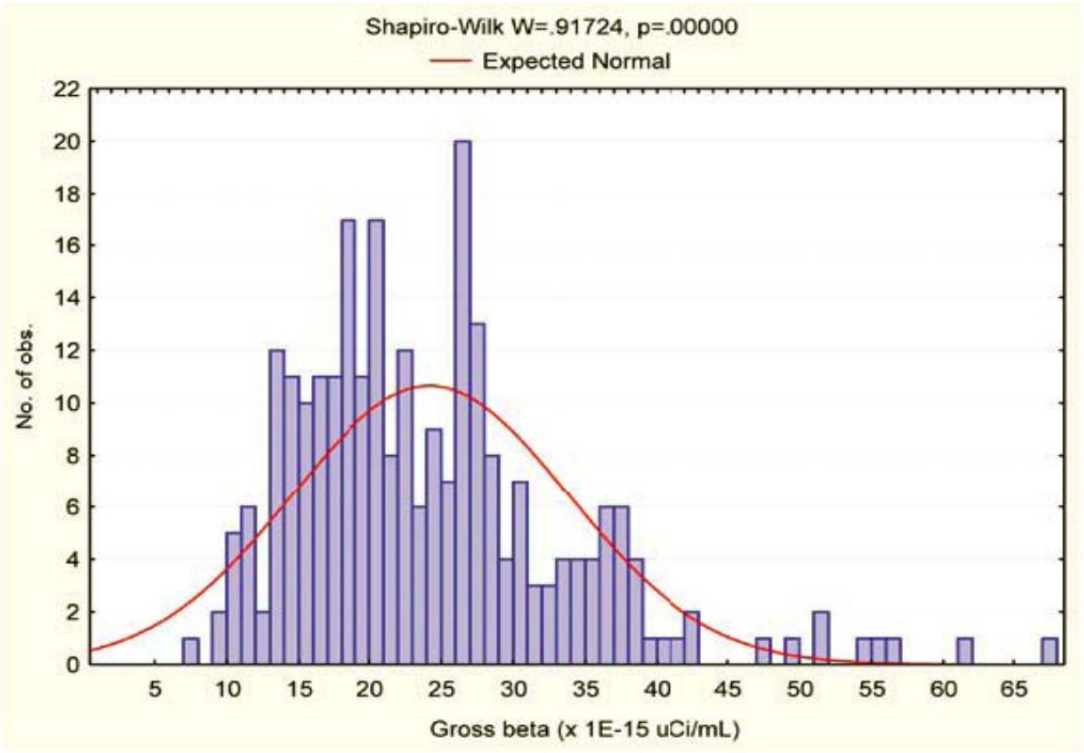

FIGURE 8-1: Example of Test of Normality for Arco Gross Beta Data (INL 2005)

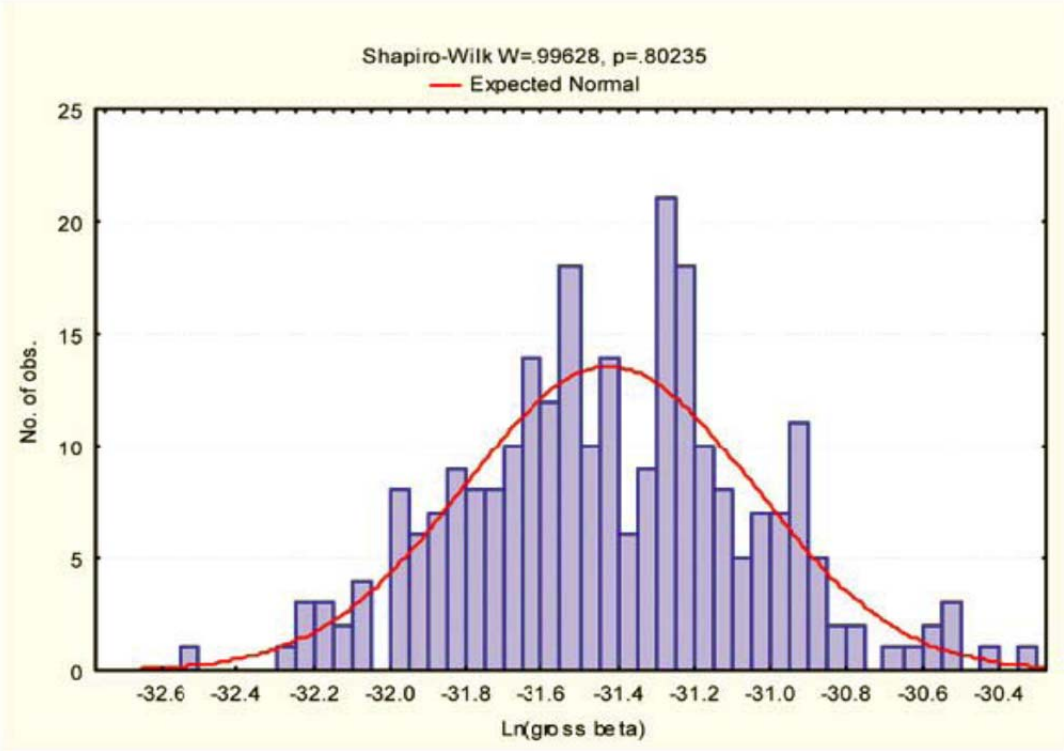

FIGURE 8-2: Example of Test of Lognormality for Arco Gross Beta (INL 2005)

Other normality tests, including the D'Agostino[7] and Ryan-Joiner[8], are available in the literature and the user should select the appropriate test based on specific features of the data set.

8.4.4 Testing for Outliers

Nonparametric statistical methods are usually less susceptible to the undue influence of outliers than parametric methods. If probable outliers are identified, nonparametric methods should be applied to the extent practicable.

Potential outliers can be identified using technical experience (e.g., values outside the range of measurement that are recognized as atypical) and visualization (e.g., boxplots, probability plots). Measures of dispersion can also be used to identify potential outliers. For example, a 2- or 3-standard-deviation probability ellipse can be constructed around a scatter-plot of all of the

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[7] Additional information can be found in NUREG-1475.

[8] Additional information can be found at:
http://www.minitab.com/uploadedFiles/SharedResources/Documents/Articles/normal_probability_plots.pdf

data, with points falling outside of that ellipse considered outliers. Although these tests are statistically valid, they only determine whether a point is extreme with respect to the mean or median of the entire dataset. Therefore, these tests are not adequate to serve as the sole justification for the inclusion or exclusion of data from the set.

A better approach to assess the exclusion of potential outliers is to perform a statistical test to evaluate if the extreme value is statistically different than the remaining data group. Tests such as the Dixon's test, Chauvenet's criteria (Turner et al. 2012), and Grubbs test are examples of statistical tests used to evaluate potential outliers. However, these tests are not without limitations. A significant underlying assumption in all three tests is that the dataset is normally distributed. Additionally, Dixon's test and Chauvenet's criteria can only test one outlier at a time. Grubb's test provides greater flexibility by allowing two potential outliers to be tested simultaneously.

When outliers that are not attributable to errors are contained in the dataset, estimators and statistical tests might be computed with and without the outliers to see if the results of the two calculations are significantly different. If the results differ substantially because of outliers in the data, then both results should be reported. A preferred option may be the application of nonparametric tests followed by evaluation of each potential outlier with a pre-determined action level, such as maximum allowable concentration. This method is commonly referred to as an elevated measurement comparison.

8.5 Statistical Analyses

The final step of the DQA process is the performance of the statistical analyses from which decisions are made regarding the population from which the sample data were collected. As stated previously, the statistical analyses selected for environmental monitoring typically depend on the underlying population distribution assumption—symmetric or asymmetric. For example, one of the main assumptions for the application of parametric statistics to a data set is the assumption that the population follows a normal distribution where the data are clustered around a central value, the likelihood of outliers is low, and there is zero skewness—the data are symmetrical around a mean value. This type of distribution is called a normal or Gaussian distribution. On the other hand, non-parametric statistics are often more appropriate when the underlying distribution is unknown or is otherwise a continuous distribution, other than a normal distribution. Thus, they can be applied to any dataset (e.g., symmetric/normal or asymmetric/skewed).

8.5.1 Statistical Tests for the Presence of Radioactivity

It should be the goal of the DOE program to minimize the probability of making an incorrect decision. There are two types of decision errors that can occur in hypothesis testing. A Type I error is made by rejecting the null hypothesis when it is true. A Type II error is made by failing to reject the null hypothesis when it is, in fact, false. From an environmental or public health standpoint, the null hypothesis should be established such that the assumed base condition is the most protective and therefore limiting. Therefore, the evidence needs to be overwhelming in order to reject the null hypothesis and accept the alternative hypothesis. An example would be for a monitoring program established to determine if a specific contaminant is present in the environment. The null hypothesis would be established such that the assumed base condition is that the contaminant is present. A Type I error would occur if the conclusion was reached that the contaminant was not present when it actually was. Alternatively, a Type II error for this example would occur if the decision was that the contaminant was present when it was not. In general terms, these errors combined with estimates of mean and the uncertainty will drive the sample size and consequently the power of the statistical tests. Insufficient sample sizes are likely to increase the probability of Type II error but should not impact the probability of Type I error.

The user is encouraged to compare and understand the implications of the Type I and Type II error discussions that are presented in this section and the discussion in Chapter 7. Regardless of the case, the Type I error occurs when the assumed based condition is incorrectly rejected in favor of the alternative condition. The difference between the two examples is the assumed base condition. The base condition for sample analysis is that the sample does not contain radioactivity (clean base condition) vs. the assumed environmental monitoring base condition where the contaminant is present until environmental monitoring data prove otherwise (dirty base condition).

8.5.2 Less-Than-Detectable Values

Monitoring programs often include measurements of extremely low concentrations of radionuclides that are below the detection limit of the counting instruments. Datasets with

less-than-detectable values[9] require special consideration in statistical analyses (Gilbert 1987). Although several of the statistical tests discussed in this chapter can still be used when as much as 40 percent of the data are reported as “less than” values, the overall robustness of the test will suffer and the probability of Type 2 error may increase above an acceptable, or planned for, level based on what will ultimately correspond to a reduction in sample size when the detection limit is substituted as the sample value. Non-parametric methods will work well even when the sample population contains non-detect data—the methods will work with up to 40% of non-detect data—because the methods are based on the ranking of data, where the results are ranked from lowest concentration to highest. When non-detects present each non-detect will receive the average rank. For example, if there are 10 results with the same non-detect concentration, and those data represent the lowest concentrations of the sample population, these data would take on the first 10 rankings (ranks 1 through 10). However, assuming the detection limit is the same for each sample, then they are considered tied data will each receive the rank of 5 (the average of ranks 1-10).

It is possible to calculate net results that are less than zero, although “negative” radioactivity is not possible. A common misconception is that negative or near zero results should not be reported. This practice is not recommended. The assignment of a zero, detection limit, or some in-between value to the less than detectable data point, or discarding those data points, will bias the resulting parameter estimates and should be avoided. The best practice is to report all results, whether positive, negative, or zero, as obtained along with the combined standard or expanded uncertainty and also the detection limit (Gilbert 1987).

For radiological counting instrumentation, there will normally be some number of counts greater than zero obtained during the analysis consisting of either background or background plus source. Net instrument responses, together with other factors, are used to calculate activity present. As background is a random distribution of its own, a truly net background distribution would be centered around a mean value of zero with equal probability of positive of negative values around the distribution’s center. The net counts may therefore always be converted to activity units, positive or negative, and reported as such.

[9] Sometimes referred to as “non-detects.”

Data from censored distributions (for which the number of less-than-detectable values is known) are more amenable to standard statistical analyses than are those from truncated distributions (for which the number of values below the detection limit are not known and which require special statistical techniques) (Gilbert and Kinnison 1981).

Regression on Order Statistics (ROS) is a way to estimate the geometric mean and geometric standard deviation of a normal or lognormal distribution for data with non-detects (Helsel 2005). The ROS method is based on the least squares regression model. The method may be used to verify that the data follow a normal or lognormal distribution and provides estimates for the parameters of the distribution when there are values in the dataset below the detection limit of the sample analysis device. As discussed above, when possible, the use of “less than” values can be avoided by requesting the laboratory provide the actual result, even when below the detection/quantification limit. For situations where available data do contain “less than results”, then the general guidelines for managing datasets with such results are provided in the following table (EPA 2000d).

TABLE 8-2: Guidelines for Managing Non-detects (adapted from EPA 2000d)

Percentage of Non-detects	Statistical Analysis Method
< 15%	Replace non-detects with DL/2, DL, or a very small number.
15% - 50%	Trimmed mean, Cohen's adjustment, Winsorized mean and standard deviation.
> 50% - 90%	Use tests for proportions

8.6 Draw Conclusions from the Data: Hypothesis Testing

Hypothesis testing is a statistical tool for making decisions under conditions of uncertainty. Statistical hypothesis tests are used in many types of applications. Examples of these applications include determining the distribution of a dataset, comparing a dataset with a fixed upper or lower limit, comparing two or more datasets, or deciding if trends are appearing in the data.

The first step in developing a hypothesis test is to translate the decision into statistical terminology by formulating a null hypothesis (H_0) and an alternative hypothesis (H_A). The formulation of the hypotheses statement are important factors to consider, and should be completed early during the planning stages of a sampling campaign. The assumed base

condition is usually formulated as H_0. The acquired environmental monitoring sample data then need to provide overwhelming evidence to reject the H_0 and accept the H_A. This example can be further expanded into two scenarios, dependent upon base conditions and action levels. NUREG-1505 defines the two scenarios as Scenarios A and B (NRC 1998). For this example assume that environmental monitoring samples are collected to determine if a site-related contaminant, that is also naturally occurring at varying concentrations, is present at either concentrations above some predetermined action level or alternatively at concentrations that are distinguishable from background. The action level example can be used to illustrate Scenario A. As incorrectly concluding that the contaminant is less than the action level is the most severe consequence of a decision error, the assumed based condition would be that the contaminant is equal to or exceeds the action level (H_0). The alternative decision that would be made based on the principle study question is that the data demonstrate that the contaminant distribution is less than the action level (H_A). The Scenario B example might be applied if the principle study question was deciding if the site related contaminant environmental monitoring data distribution was indistinguishable from the background distribution. Application of this scenario is considered when the background distribution indicates significant variability, where the range on the variability is such that a sufficient minimum detectable difference between background and contamination cannot be established. For this case, the most severe consequence would be deciding that contamination is present when it is not and the results are due to random variation of background. Therefore, the assumed base condition (H_0) is that environmental monitoring data are indistinguishable from background.

Hypothesis testing can be performed using parametric statistics when the distribution of the data is known (e.g., normal, lognormal or fit some other distribution), and nonparametric statistics when the distribution is unknown. In parametric statistics, the observations need to be independent and obtained from a known group. Additionally, the sample variances are assumed to be identical. Alternatively, the general requirements for nonparametric statistics are that the observations are independent and that the variable of interest has continuity (e.g., can be ranked). The advantages of using nonparametric statistics are that there is no assumption about the sample distribution, the calculations are typically simpler, and the outliers do not influence the test. Table 8-3 presents examples of statistical tests that may be selected for multiple hypothesis goals.

TABLE 8-3: Examples of Statistical Tests for Multiple Hypothesis Goals (ORAU 2013)

Goal of Hypothesis	Continuous Data		Discrete Data
	Parametric	Nonparametric	
Compare one group to a hypothetical value	One-sample t test	Sign test or Wilcoxon	Chi-square or binomial
Compare two unpaired groups	Unpaired t test or Welch's test (unequal variances)	Wilcoxon rank sum (Mann-Whitney)	Chi-square (Fisher's for small samples)
Compare two paired groups	Paired t test	Wilcoxon signed-rank	McNemar's test
Compare three or more unpaired groups	One-way ANOVA	Kruskal-Wallis	Chi-square
Compare three or more paired groups	Repeated measures ANOVA	Friedman Test	Cochran's Q
Quantify association between two variables	Pearson correlation	Spearman correlation	Contingency coefficients
Predict value from another variable(s)	Regression	Nonparametric regression	Logistics/Poisson regression
Trend Detection	Regression	Mann-Kendall or Seasonal Kendall (when seasonal variation exists)	--

The objective for obtaining reliable estimates of radionuclide concentrations at environmental sampling locations is to compare those values to regulatory or administrative control standards or values at control stations to determine whether action needs to be taken to reduce the radionuclide levels to minimize potential exposures to members of the public and to protect the environment.

Environmental data often follows a lognormal probability distribution; and, as such, the geometric mean and geometric standard deviation are used to describe the data. Log-normally distributed environmental data appear approximately normal when the data are plotted on a logarithmic scale. In this particular case, parametric hypothesis testing can be carefully applied when the environmental data is converted to logarithmic scale. It is important to note that data conversion may introduce unwanted errors to the data due to round-offs. On the other hand, nonparametric tests would limit the introduction of unwanted errors because the data do not need to be converted and because no assumption for the data probability distribution is necessary to apply nonparametric statistics.

A determination is necessary regarding whether the hypothesis test be a two-tailed or one-tailed evaluation of the distribution(s). For example, in situations where the principle study question is to decide whether the sample data represents a population concentration that exceeds an established action level, a one-tailed test of the mean/median would be used—in this example the upper tail of the distribution is critical to the decision. More specifically, the hypothesis test is designed to determine if the mean/median concentration at a specified confidence level is above or below the action level threshold. When comparing two or more sample populations, either a one-tailed or two-tailed test could be used, dependent upon the specific study question. An example would be if the study was to answer whether two samples come from the same population distribution, perhaps a background distribution, then a two-tailed test would be considered. Alternatively, if the study question was to establish if a specific sample population mean was greater than or less than a second sample population, a one-tailed test would be applied.

The following are brief descriptions for the application of the parametric and nonparametric tests summarized in Table 8-3 that may be used for data comparison with regulatory or administrative control standards, or control data. Additional statistical tests not indicated here also may be used for data comparison and compliance verification as necessary.

8.6.1 Parametric Tests

8.6.1.1 One-Sample t Test

The One-Sample t test compares the sample data mean, $\bar{x}$, to a limiting/decision value such as a cleanup guideline, or the true, but unknown population mean (μ). The null hypothesis for the one sample t test is defined as:

$$H_o: \overline{x} = \mu$$

If the test statistic T value is greater than $t_{1-\alpha}(n-1)$, the null hypothesis is rejected.

Where the one-sample t test is used when the mean of the population is specified as part of the null hypothesis, the two-sample t test (Student's t test) assumes as the null hypothesis that the means of two populations being compared are equal but is only used when the variances of the populations can be assumed equal. The Welch's Test discussed below is applied when the variances of the data groups cannot be assumed to be equal. The unpaired t test is used to compare two independent populations such as those from an impacted areas (those that may be affected by DOE activities) and a non-impacted areas (background locations) while the

paired t test is for populations expected to have a logical pairing of observations with the same means and distribution (e.g., analysis of split sample).

8.6.1.2 Unpaired t Test (Welch's Test)

The unpaired t test is used to compare the mean values ($\bar{x}$) of two distinct groups. The null hypothesis of the unpaired t test is defined as: H_0, the means of the two groups are equal,

$$\bar{x}_A - \bar{x}_B = 0$$

where A and B represent the two groups of interest. Two important assumptions in the unpaired t test are that the group distributions and their means are normally distributed.

If the T value exceeds $t_q(v)$ for the Student's t-distribution (Figure 8-5), the null hypothesis is rejected.

8.6.1.3 One-Way Analysis of Variance (ANOVA)

Multiple samples (three or more) can be compared among themselves with a one-way ANOVA to determine if the means of the populations (μ_i) represented by the samples are the same or different. The null hypothesis is that the samples from the multiple groups are from populations with the same means. Like the previously described parametric tests, the one-way ANOVA test assumes that: (1) the observations are obtained under identical conditions; (2) the observations are independent; (3) the variance is the same for all groups; and (4) the groups are normally distributed. The one-way ANOVA test can be employed independently of the number of observations on each group. However, when the number of observations of each group is the same, the power of the one-way ANOVA test is higher. The null hypothesis in the one-way ANOVA test is defined as: H_0, the means of all groups are equal. That is:

$$H_0 = \mu_1 = \mu_2 = \cdots \mu_k$$

whereas H_A is that at least one of means are unequal; however, it may not be known which mean resulted in the rejection of H_0 and additional tests may be required to determine which of the means are statistically different. NUREG-1475, Chapter 16 provides procedural steps for performing the one-way ANOVA test.

8.6.2 Nonparametric Tests

8.6.2.1 Kruskal-Wallis

The Kruskal-Wallis test is the nonparametric analog to the ANOVA. The Kruskal-Wallis test may be applied when a decision is required to access background variability among several background reference populations that may then be used for the comparison with site environmental monitoring sample populations. The test may be a necessary component to determine indistinguishability from background. For this situation, the test evaluates whether significant variability exists between several (three or more) different sample background populations and if the medians of multiple groups are statistically different or not. Thus the null hypothesis, H_0, assumes that no significant variability exists between the groups and may be written as illustrated for the ANOVA H_0.

As with any nonparametric test, Kruskal-Wallis test can be performed regardless of the group distribution or lack thereof although the test assumes the population distributions are identical. NUREG-1475 and NUREG-1505, *A Nonparametric Statistical Methodology for the Design and Analysis of Final Status Decommissioning Surveys* (NRC 1998) provide procedural steps for performing the Kruskal Wallis test. NUREG-1505 provides the steps for assessment of the site data using additional statistical tests, the Wilcoxon Rank Sum and Quantile tests, to assess indistinquishability from background. NUREG-1475 provides procedural steps for performing the Kruskal-Wallis test.

8.6.2.2 Sign Test

The Sign test may be used to evaluate sample results to make a decision regarding the difference of the medians either relative to the sample population median as it relates to an action level (a one-sided Sign test) or a two-sided Sign test for paired sample evaluations. The null hypothesis for the one-sided Sign test may be stated as:

H_0: the median concentration ≥ the action level

The alternative hypothesis would then be:

H_A: the median concentration < the action level

MARSSIM recommends this approach for comparing sampling results with a guideline concentration value, and any background contribution to the sample is considered inconsequential. The test is relatively simple to perform and measures the number of positive or

negative differences between the paired data (where the paired data for this example consist of the action level value and the sample population). The magnitude of the difference between the pairs is not considered. To illustrate the basics of the test, if the differences between the action level and all sample results were negative, then strong evidence has been gathered to reject H_0 as clearly each result is less than the action level. However, when both positive and negative differences exist, a critical level is established for comparison with the Sign test statistic and deciding whether H_0 may be rejected. The critical level is a function of sample number (n). When the difference between data points equals zero, and therefore cannot be assigned either a positive or negative value, the n is reduced accordingly and the new associated critical level is used. To minimize zeroes, it is recommended to retain all significant figures provided with the analytical results when applying the test. This same strategy of retaining all significant figures should be considered for any of the tests discussed in this section that involve either the evaluation of differences or ranking of data.

The two-sided Sign test may be applied for two populations of independent paired measurements to determine if the medians are equal, or unequal (where one population is either > or < the second population). Similar to the one-sided Sign test, the paired sample results from one population are subtracted from the second population. For populations that are similar, one would expect, with a sufficient n, an equal number of positive and negative differences. Evidence that the two population medians are not equal is generated when the differences become increasingly more positive or negative. Dependent upon how the hypothesis statements are established will determine whether the number of positive or negative differences is compared with the critical value.

Additional information and examples concerning the application of the Sign test can be found in MARSSIM, MARSAME, and NUREG-1505.

8.6.2.3 Wilcoxon Rank Sum Test

In contrast to the Sign test, the Wilcoxon Rank Sum (WRS) or Mann-Whitney test is used to evaluate the results from independent data when the contaminant (e.g., a radionuclide) is present in background by comparing the results to measurements from an appropriately chosen background reference sample population. For comparison of these two groups, the WRS test (EPA 2010a) is a robust nonparametric alternative to the Student's two-sample t test.

Rather than a direct test of means, the WRS test is computed based on rank sums of the data from the two sample populations to detect differences between the means. Because of this,

outliers and non-detects do not present the serious problem encountered when using parametric tests. As a general rule, the WRS test can be used with up to 40 percent non-detect measurements present in either population sample. The test is applied by pooling the data from the two sample populations then ranking the sample concentrations from highest to lowest, tied data are assigned the average value of the ranks.

There are two forms of the test, Test Forms 1 and 2. With Test Form 1, the base condition is that the concentration difference between the site and background population is essentially zero. H_0 and H_A for Test Form 1 would be stated as follows:

> H_0: the mean/median contaminant concentration in environmental monitoring samples is ≤ the concentration in background samples
>
> H_A: the mean/median contaminant concentration in environmental monitoring samples is > the concentration in background samples

Test Form 2 also assumes the opposite base condition, where the contaminant concentration is assumed to exceed background. However, rather than assuming the difference in the means/medians as zero, Test Form 2 allows for a comparing the site data to the background data plus some investigation level (+S). S, also referred to as the “substantial difference” may be an action level, a release guideline, a percentile above the background mean concentration, or other variable. H_0 and H_A for Test Form 2 would be stated as follows:

> H_0: the mean/median contaminant concentration in environmental monitoring samples is > the background concentration +S (where S is the allowable substantial difference)
>
> H_A: the mean/median contaminant concentration in environmental monitoring samples is ≤ the concentration in background samples +S

Test Form 1 uses a more conservative investigation level but relaxes the burden of proof by requiring overwhelming evidence to reject H_0. With Test Form 2, the burden of proof is strict the investigation level is relaxed by allowing for the substantial difference between the means/medians.

Additional information and an example concerning the application of the WRS or Mann-Whitney tests can be found in MARSSIM, MARSAME, NUREG-1505, and EPA 540-R-01-003.

8.6.3 Regression and Trend Analysis

In addition to hypothesis testing, other statistical tests and approaches may be used to analyze environmental data and make decisions based on the statistical results. The detection and assessment of temporal or spatial trends are a critical objective of environmental monitoring and trend detection serves to identify the presence of new releases, when additional effluent release controls are required, to evaluate the effectiveness of controls or other contaminant release mitigation projects. The following approaches are suggested based on their application to effluent and environmental monitoring and are available to investigate trends. Detailed descriptions of tests for trends can be found in EPA QA/G-9S (EPA 2006).

8.6.3.1 Graphical Representations

Graphical representation of the effluent or environmental data over time can assist the user in identifying trends. Diurnal and nocturnal concentrations of radon, radiation exposure, or dose measured in a specific environmental location, and concentrations of airborne effluent releases are some practical examples of measurements that could represented as a time plot. A time plot can be used to identify temporal trends and potential outliers. It may also be used for comparing multiple data groups (e.g., background or baseline with operational measurements). When multiple measurements are obtained simultaneously, the results can be superimposed on a site or facility map to evaluate spatial trends during a sampling period or for multiple sampling periods.

NUREG-1475 and EPA QA/G-9S provide guidance for the application and construction of the variety of charts useful for analyses of both single and multi-variable data sets including the use of confidence intervals and/or action levels for trend analyses.

8.6.3.2 Linear Regression

Linear regression is a parametric method to test for the presence of trends and/or model (predict) trends over time using the slopes of the data regression line as an estimate of the strength of the trend (EPA QA/G-9S). The regression may be applied to two or more variables when data suggest a linear change with time and the data are normally distributed. The linear regression trend test relies on a variety of assumptions (e.g., normality and no non-detects or outliers) that require verification. A least squares method is used to develop a best-fit line of the data, e.g., concentration vs. time. A statistical test, such as the t test may then be applied to assess whether the slope of the line departs from zero, indicative of trend. Linear regression

includes simple regression for a single independent variable and multiple linear regression for more than one independent variable. Uses and applications for linear regression are provided in NUREG-1475, Gilbert 1987, and other referenced sources.

8.6.3.3 Mann-Kendall Test

The Mann-Kendall test, a nonparametric test for detecting trends, is based on a measure of the correlation of the sample values with time. The Mann-Kendall trend test may be used to test for a significant trend in any time series of four or more independent data points. Unlike linear regression, the time series may include non-detects, missing values, and/or outliers.

As with other non-parametric tests previously discussed, the Mann-Kendall test evaluates the relative magnitude of the data instead of the measurement result directly. The test is conducted by comparing each observation with all previous observations to determine if it is larger, smaller, or the same. If larger (or smaller), a score of +1 (or -1) is assigned; for ties the score is 0. The test statistic, S, is the sum of the scores for all comparisons. Positive (or negative) values of S indicate a positive (or negative) slope. The absolute value of S is compared with tabulated critical values of the test statistic determined if the slope is statistically significant. For large sample sizes ($n > 10$) a normal approximation for the Mann-Kendall test is available (EPA QA/G-9S). Corrections may be necessary during the evaluation period when periodic cycles in the dataset are identified (i.e., seasonality). A detailed description of the Mann-Kendall test can be found in EPA QA/G-9S. When seasonal cycles are evident in the data and need to be accounted for, the user is referred to the Seasonal Kendall Test (Gilbert 1987).

8.6.3.4 Thiel-Sen Slope Estimator

The Thiel-Sen slope estimator is a follow-on to the Mann-Kendall test that provides a nonparametric estimate of the value of the slope (an alternative to the parametric linear regression and least-square slopes) (Helsel 2005). As the Thiel-Sen Slope Estimator is non-parametric, the result shows how the median concentration changes with time.

An equal number of positives and negatives slopes may be interpreted as a lack of a trend in the dataset, while either a greater proportion of either positive or negative values are indicative of a respective positive or negative slope (increasing or decreasing concentrations over time). A detailed description of the Thiel-Sen's slope estimator can be found in Helsel 2005.

8.7 Computational Tools

In recent decades computer tools have been developed to assist in the implementation of statistical analyses. This chapter discusses several computer tools that have been widely used for developing environmental sampling plans, data analysis, graphical representations of data, and uncertainty propagation. Additional tools are available commercially and their versatilities vary between developers and intended uses. It is important to mention that computer tools used for verification of regulatory compliance should be verified and validated prior to use. A discussion regarding verification and validation is included in this chapter.

The following computational tools were selected based on their wide use, regulatory acceptance, and availability.

8.7.1 Visual Sample Plan

Visual Sample Plan (VSP)[10] was developed at Pacific Northwest National Laboratory. VSP is a software tool that supports the development of a defensible sampling plan based on statistical sampling theory and the statistical analysis of sample results. VSP helps ensure that the right type, quality, and quantity of data are gathered and provides statistical evaluations of the data with decision recommendations. VSP has many parametric and non-parametric statistical sampling design modules including random, systematic, sequential, adaptive cluster, collaborative, stratified, transect, multi-increment, combined judgment/probabilistic, and ranked set sampling. Sampling designs can be geo-referenced and may be applied to soils, sediments, surface water, streams, groundwater, and buildings. The software also includes statistical analysis/data quality assessment modules for performing the various hypothesis tests.

8.7.2 ProUCL Software

The ProUCL software package[11] was developed by EPA (EPA 2013a, EPA 2013b) and designed to do many of the statistical tests/analyses identified in this Handbook. A trend analysis module includes regression analysis, the Mann-Kendall trend test, and the Thiel-Sen estimate of the slope. Also included is a variety of other parametric and nonparametric

[10] http://vsp.pnnl.gov/

[11] http://www.epa.gov/osp/hstl/tsc/software.htm

statistical methods, including modules for plotting the data, identifying the type of probability distribution, parameter estimation and tolerance limits, and outlier tests.

8.8 Quality Assurance

As they apply to data analysis and statistical treatment activities, the general QA program provisions of Chapter 11 should be followed. Specific QA activity requirements for data analysis and statistical treatment activities at a site should be incorporated in the QA plan for the facility.

8.8.1 Software Validation and Verification

Multiple effluent and environmental guidance incorporate EPA's QA/G-4, *Guidance for the Data Quality Objectives Process* (EPA 2000c), and QA/G-9, *Guidance for Data Quality Assessment* (EPA 2000d), processes. As part of an adequate quality assurance program, it is customary to verify and validate computer tools used in the analysis and representation of data. Site- or project-specific computer tools may be developed as needed (e.g., spreadsheet programs) or commercially available software may be obtained to streamline the data analysis process. Requirements for validation of software will normally follow a graded approach. Custom designed software of extensively modified off-the-shelf software would generally necessitate a formal validation and verification plan prior to authorizing use of the application, whereas commercial software, government-funded software, and similar applications should have the verification and validation documentation available for the user and validation may be as simple verifying proper installation and running of test scripts that ensure functionality.

DOE-approved computational tools may be used without restrictions. User-developed computational tools should be verified and validated prior to use to ensure proper function, particularly when used to demonstrate compliance with regulatory requirements. Verification and validation may be performed by performing data analysis using known data that meet the characteristics for the statistical evaluation. The results from software or user-developed tools can be verified against independent verifications of the results (e.g., results from hand calculations or other approved software).

9 DOSE CALCULATIONS

For DOE sites, DOE O 458.1 and DOE O 231.1B describe the annual reporting requirements for releases of radioactive materials to the environment. In addition to the summary of airborne and liquid effluents released to the offsite environment, these Orders require the reporting of estimates of the effective doses to the population and to the MEI or representative person. The dose estimates require detailed knowledge (or estimates) of the concentrations of radionuclides in the facility effluents and emissions and in various environmental media resulting from site operations. Samples of air, soil, water and vegetation, and direct readings of external radiation can also be used to determine these concentrations. However, in most cases these concentrations are very low and challenge the sensitivity of the analytical techniques used. As a result, estimates of environmental concentration and human exposure and the resulting estimated radiation dose are frequently made using mathematical models that represent various environmental pathways. For situations where available environmental data are sufficiently accurate to determine radionuclide concentrations, their use in the dose assessment process is encouraged. For the purposes of this Handbook, the following basic definitions are used:

- Model – A mathematical formulation or description of a physical, ecological, or biological system, which includes specific numeric values or parameters.
- Computer program – The logical computer language statements in an executable form on a digital computer that represents the model (mathematical formulation) and appropriate data.

A lines of inquiry approach is provided in Appendix B that may be used to conduct self-assessments and to verify that the program is effective and in compliance with the appropriate requirements and to ensure continuous improvement of the program. For situations where available environmental data are sufficiently accurate to determine radionuclide concentrations, use them in the dose assessment process.

9.1 Key Requirements

The following regulations and directives apply to dose calculations:

- DOE O 458.1, *Radiation Protection of the Public and the Environment*, requires dose evaluations to demonstrate compliance with the public dose limit and to assess collective dose.

- DOE O 231.1B, *Environment, Safety and Health Reporting*, requires that information provided in the ASERs on individual, population, and biota radiation exposures, doses, and potential impacts should accurately portray the information required by DOE O 458.1, or other applicable regulations and requirements, such as 40 CFR Part 61, Subpart H, and State regulatory and administrative codes. To support consistent data collection and reporting under DOE O 231.1B, the DOE Office of Environment, Health, Safety and Security provides *Guidance for the Preparation of Department of Energy (DOE) Annual Site Environmental Reports (ASERs)*.

9.2 Required Performance Standards for Public Dose Calculations

Models and methods used for documenting compliance with radiation protection standards and regulations have evolved and matured, often driven by revised regulations and standardized reporting requirements. However, key to the preparation of the compliance documentation is having quality site-specific data collected for each DOE site, facility, or activity.

Except where mandated otherwise (e.g., compliance with 40 CFR Part 61), the assessment models selected for all environmental dose assessments should appropriately characterize the physical and environmental situation encountered. In some cases, the specific assessment model may be mandated (e.g., compliance with 40 CFR Part 61 Subpart H, or use of RESRAD for site restoration). The information used in dose assessments should be as accurate and realistic as possible. Complete documentation of models, input data, and computer programs should be provided in a manner that supports the ASER or other application.

9.3 Documentation and Conformance with Other Requirements

Default pathway analysis values used in model applications should be documented and evaluated to determine appropriateness to the specific modeling situation. Those values may be replaced with site-specific information when adequate data are available and appropriate.

When performing human food chain assessments, a complete set of human exposure pathways should be considered, consistent with current methods (IAEA 1982; NCRP 1984; NRC 1992b; Yu et al. 2001).

Documentation of pathway analysis models, input data, and computer programs should be provided in a manner that supports the ASER. Parameter sensitivities and uncertainties in modeling results should be documented whenever possible.

Surface- and ground- water modeling should be conducted, as necessary, to conform to the applicable requirements in DOE O 458.1 and to applicable requirements of the State government and the regional EPA office.

9.4 Pathway Analysis Modeling

Pathway analysis modeling is used to assess the immediate potential consequences of chronic routine releases or accidental releases, or potential future consequences for site remediation or waste management evaluations. Exposure pathways are the routes of radiation exposure to human beings or biota. They generally include external exposure to penetrating radiation, inhalation, and ingestion.

Within each type of exposure pathway, several separate mechanisms may be at play as shown in Table 9-1 and described in the following:

- External exposure may include exposure to contaminated ground surfaces or buried sources, submersion in an airborne plume of radioactive material, or submersion (swimming) in contaminated water. However, in most cases, air or water submersion will be secondary in magnitude compared with exposure to contaminated ground or buried sources.
- Inhalation can occur during submersion in a contaminated plume, or following resuspension of radioactive material in the soil.
- Ingestion pathways include ingestion of food products contaminated by radioactive material deposited from the air or through root uptake of radionuclides in soil, direct ingestion of radionuclides in soil, ingestion of radionuclides in water, or ingestion of radionuclides incorporated in aquatic foods.

Mathematical modeling for pathway analysis of radiation doses to members of the public caused by radioactive materials in the environment has become complex to meet the challenges encountered. However, the rule of thumb is that the simplest model that will adequately address the situation always should be applied first (NCRP 1984). Simple models often are highly conservative, but they rely on fewer data than complex models.

TABLE 9-1: Potential Pathways to Be Considered in Environmental Pathway Analyses

Exposure Category	***Environmental Pathway***
External	Direct Facility Radiation Submersion in an Airborne Plume Contaminated Land Aquatic Recreation (Swimming/Shoreline/Boating)
Inhalation	Submersion in an Airborne Plume Re-suspended Materials
Ingestion of Terrestrial Foods	Vegetables: Potatoes Other Root Vegetables Leafy Vegetables, Other Vegetables, Fruits Cereal Grains Animal Products: Liquid Milk Cheese Meat and Meat Products (Beef, Pork, Poultry, Game Animals) Eggs
Ingestion of Aquatic Foods	Fish Seafood (Shellfish) Waterfowl Reptiles Amphibians
Ingestion of Soil	Grazing Animals Humans (Children)
Ingestion of Drinking Water	Surface Water (Raw or Treated) Well Water (Raw or Treated) Rain Water

(Source: RESidual RADioactivity (RESRAD) Manual (Yu et al. 2001).

9.5 Misuse of Models

According to the National Council on Radiation Protection and Measurements (NCRP), the three most common misuses of these types of models are: 1) "overkill," 2) inappropriate prediction, and 3) misinterpretation (NCRP 1984).

"Overkill" occurs when the level of available data or the use of the results do not support the sophistication of the model selected. NCRP (1984) was responding to "overkill" in models used for radiological assessments in the following comment:

> *In recent years, the trend has been toward more complex models; however, the increased complexity has not necessarily improved the accuracy of estimates of dose and, in certain cases, has had the opposite effect.*

Inappropriate prediction occurs when sophisticated models and detailed analyses are used too early in the assessment process. Initial assessments should be conducted with very simple models; more detailed models and more detailed assessments should be made as data and knowledge of the system being modeled improve.

Misinterpretation of modeling results can occur when inappropriate boundary conditions or assumptions have been used. The results of any modeling application should be viewed as estimates of reality, and not reality itself. In many cases, seemingly minor changes in assumptions or input can cause drastic changes in the results obtained (NCRP 1984).

9.6 Transport Models

Models that are used to estimate the concentrations of radionuclides at locations that are distant from the point of release of a source are termed transport models. Transport models include transport by air, surface water, and ground water as discussed below.

The first level of model verification can be done by comparing the program results for sample problems against either documented sample problem results or against hand calculations.

> DOE encourages the use of realistic data (best estimate) that are not likely to underestimate doses or exposures. The goal is to minimize conservatism but provide reasonable assurance that doses or impacts are not underestimated.

Limited comparisons against field or laboratory data typically are conducted during development of a computer program because complete validation of all models usually is not feasible due to the size of some datasets and the inability to fully characterize most sites. Modifications then can be made to key parameter values to make the results compare more closely to measured conditions. This comparison process is called “model calibration” and often is used when site-specific model applications are desired.

In many situations, site-specific data are not available, so default parameters or datasets can be used in the transport calculations. These default values often are obtained from generic datasets and are designed to give conservative dose overestimates.

9.6.1 Atmospheric Transport and Dispersion Models

Atmospheric dispersion models typically are applied to model the transport of airborne releases of radioactive materials. These releases may be through active stacks or distributed area sources, such as those encountered during environmental remediation or waste management.

Atmospheric dispersion models and meteorological data will vary in sophistication and complexity from relatively simple spreadsheet computations, to extensive computations that require computers. Use of simple compliance assessment models such as the NCRP (1996)

screening model based on conservative assumptions and little or no meteorological data, could be sufficient for some DOE facilities. As the potential magnitude of the release increases, more detailed models used with site-specific data become necessary to assess the potential consequences.

Selection of an adequate atmospheric dispersion model first requires the determination of site-specific data for a variety of parameters. These data typically are collected through meteorological monitoring as described in Chapter 5. The types of parameters required include horizontal and vertical diffusion parameters, wind data, plume-rise parameters, and plume deposition and depletion factors (Randerson 1984).

For the purposes of routine dose assessment, it is assumed that: (1) the atmospheric releases occur over a long period of time (i.e., they are chronic releases from routine facility operation and not short-term accidental releases); (2) the purpose of estimating ground-level concentrations is to conduct annual public dose assessments; and (3) local terrain is not a complicating factor.

40 CFR Part 61 Subpart H establishes radiation dose limits for the maximally exposed member of the public from all airborne emissions and pathways, and requires that effective dose equivalent values to members of the public be calculated using EPA approved sampling procedures, computer models CAP88 or AIRDOS-PC, or other procedures for which EPA has granted prior approval. Other approved methods could include the use of environmental data in the evaluation.

9.6.2 Surface and Ground Water Transport Models

Information on DOE operations and activities reported annually on liquid releases needs to include: (1) statements concerning the quantity and type of radioactive materials discharged to receiving streams or aquifers, and (2) assessments of the potential radiation dose to the public that could have resulted from these discharges during the previous calendar year. Decisions about which transport model (or models) will be used in performing a specific assessment depend on the local site conditions, the receiving stream or aquifer characteristics, the duration of the release, the potential exposure pathways, the magnitude of the potential doses that result, and other factors.

There is much uncertainty in modeling surface- and ground- water systems, and many unanswered questions about radionuclide transport through surface- and ground- water

systems remain. Additional questions about surface- and ground- water dispersion models have arisen from the need to identify the parameters that can be measured in the field that correspond to the parameters used in the models. For ground water modeling, where the results are largely prospective, these uncertainties are magnified. Modeling should use site-specific data, taking into consideration the important characteristics of the site.

9.7 Environmental Restoration

The RESRAD (Yu et al. 2001) modeling code was developed by DOE and the NRC to support the evaluation of radiation doses and risks from residual radioactive materials in soil at sites undergoing remediation. RESRAD has undergone extensive review, benchmarking, verification, and validation and has been used widely by DOE, NRC, EPA, the U.S. Army Corps of Engineers, industrial firms, universities, and foreign government agencies and institutions. It is the preferred method for determining derived concentration guideline limits (DCGLs) for site cleanup using MARSSIM or MARSAME. An overview of the pathways and components evaluated in RESRAD is shown in Figure 9-1.

In addition to RESRAD[12], an entire family of codes[13] has been developed to respond to specific situations. Currently supported codes include:

- RESRAD Build – designed to estimate radiation doses to individuals in buildings following decontamination.
- RESRAD Recycle – designed to estimate radiation doses to industrial workers and other members of the public following release and recycle of metals.
- RESRAD Biota – designed to estimate radiation doses to biota consistent with DOE guidance.
- RESRAD Offsite – designed to estimate doses and risks to individuals down wind, down stream, or down plume from sources of radionuclide discharges to the environment.
- RESRAD RDD – designed to facilitate the implementation of operational guidelines and protective action guides for radiological or nuclear incidents.

[12] RESRAD may also be identified as RESRAD-Onsite to distinguish it from other members of the RESRAD family of codes.

[13] The RESRAD family of codes is available at: www.ead.anl.gov/RESRAD.

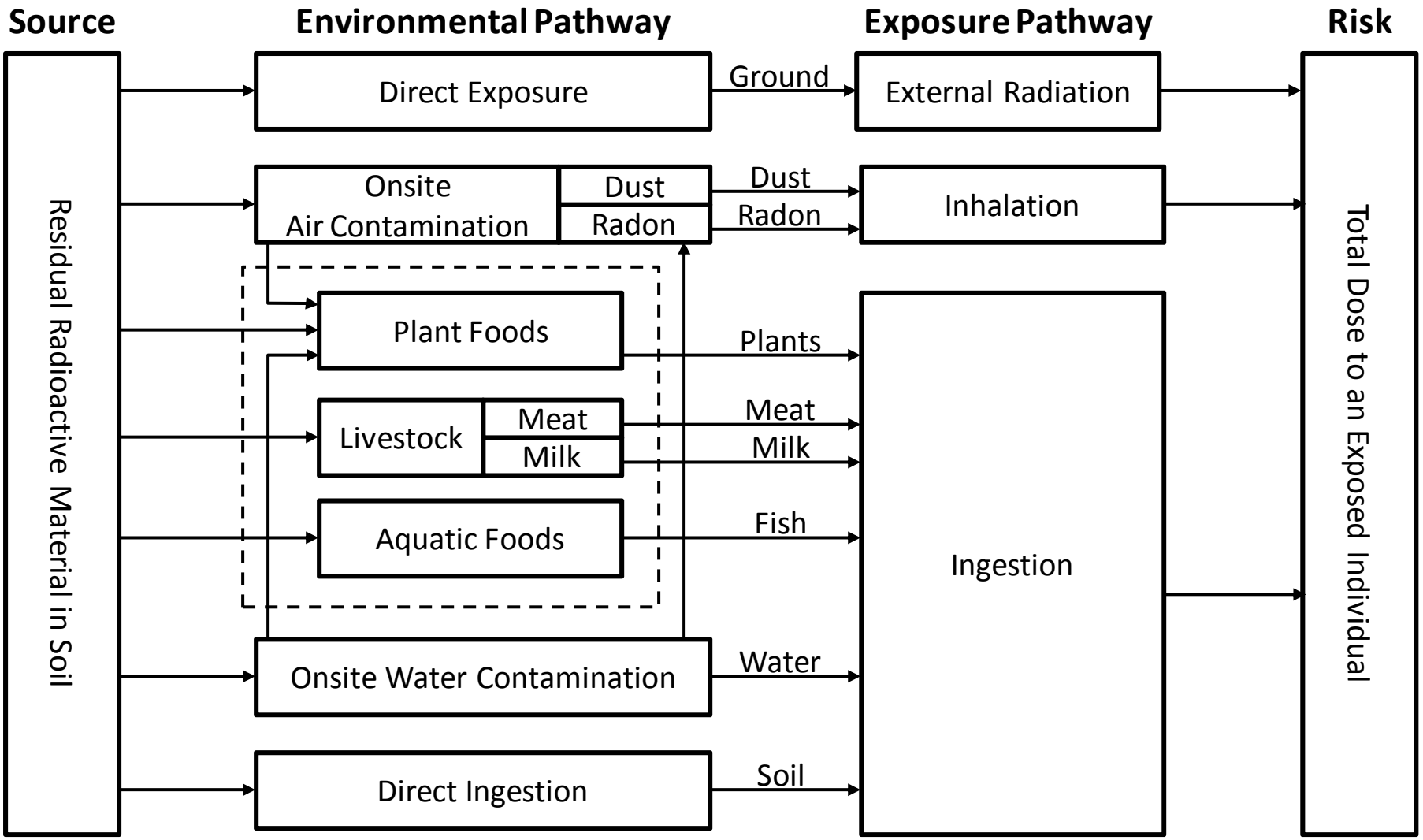

FIGURE 9-1: Pathways Considered in the RESRAD Family of Codes

9.8 Protection of Biota

DOE O 458.1 requires radiological activities that have the potential to impact the environment to be conducted in a manner that protects populations of aquatic animals, terrestrial plants, and terrestrial animals in local ecosystems from adverse effects due to radiation and radioactive material released from DOE operations.

When actions taken to protect humans from radiation and radioactive materials are not adequate to protect biota then evaluations are conducted to demonstrate compliance with paragraph 4.j.(1) of DOE O 458.1 in one or more of the following ways:

- Use DOE-STD-1153-2002, A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota.
- Use an alternative approach to demonstrate that the dose rates to representative biota populations do not exceed the dose rate criteria in DOE-STD-1153-2002, Table 2.2.
- Use an ecological risk assessment to demonstrate that radiation and radioactive material released from DOE operations will not adversely affect populations within the ecosystem.

Because of the diversity of biota and the variety of pathways and radionuclides that need to be considered, it is not possible to develop a single generalized model that can be assumed to cover all possible conditions. Instead, DOE developed DOE-STD-1153-2002 (DOE 2002a) that provides the methods, models, and guidance within a graded approach that DOE and its contractors may use to evaluate radiation doses to populations of aquatic animals, terrestrial plants, and terrestrial animals from DOE activities. The intent is to provide a means of meeting the DOE requirements for protection of biota.

> DOE O 458.1 requirements and tools are to help protect the health of the ecosystems around DOE sites, and are not intended to be applied to individual organisms.

The DOE graded approach includes a screening method and three detailed levels of analysis for demonstrating compliance. RESRAD-BIOTA is the preferred or recommended computer program to use to meet DOE-STD-1153-2002.

9.9 Dose Coefficients

DOE O 458.1 requires that DOE-approved dose coefficients be used to evaluate doses resulting from DOE radiological activities. Use of alternative dose coefficients need to be approved in accordance with DOE O 458.1.

Derived concentration guidelines (DCG) were issued in DOE 5400.5. Since then, the radiation protection framework on which Derived Concentration Standards (DCSs) are based has evolved with more sophisticated biokinetic and dosimetric information provided by the ICRP, thus enabling consideration of age and gender.

DOE-STD-1196-2011 establishes DCS values reflecting the current state of knowledge and practice in radiation protection. This Technical Standard also addresses radionuclides encountered at accelerator facilities. DCSs are radiological quantities used in the design and conduct of radiological environmental protection programs at DOE facilities and sites. These quantities provide reference values to control effluent releases from DOE facilities and may be used in implementing the ALARA process for environmental programs.

The DCSs are based on age-specific effective dose coefficients computed in the manner of ICRP (1996) and Federal Guidance Report 13 (EPA 1999), using revised gender-specific physiological parameters for members of the public set forth in ICRP Publication 89 (ICRP 2002), and the nuclear decay data of ICRP Publication 107 (ICRP 2008).

The DCSs represent the concentration of a given radionuclide in either water or air that results in a member of the public receiving 1 millisievert (mSv) (100 mrem) total effective dose (TED) following continuous exposure for one year for each of the following pathways: ingestion, submersion in air, and inhalation.

The tables of dose coefficients for an adult or Reference Person provided in Appendix A of DOE-STD-1196-2011 for ingestion, inhalation, and submersion can be used in estimating doses to the public for demonstrating compliance with DOE O 458.1. It should be noted that the adult dose factors are appropriate for worker related dose assessments and Reference Person factors should be used when assessing compliance of exposures to a representative person that is based on an age and gender average reference person and to the general population that may include members of the public of all ages.

9.10 Quality Assurance

The general QA provisions of Chapter 11 should be followed as they apply to performing calculations that assess dose impacts. Specific QA activity requirements for performing dose calculations for a facility/site are to be contained in the QA Plan associated with the facility.

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10 RECORDS, RETENTION AND REPORTING

The successful operation of any radiological effluent monitoring and environmental surveillance program relies upon well-documented and effective recordkeeping, retention and reporting programs. This chapter identifies the recordkeeping and reporting requirements of DOE Orders and major regulations applicable to the radiological effluent monitoring and environmental surveillance at DOE sites. These regulations represent only part of the total environmental requirements that are applicable to DOE sites. Environmental statutes and regulations can be amended or superseded. The listing in this chapter should not be considered all inclusive, and should be updated as necessary.

Proper recordkeeping and reporting is essential to DOE's overall compliance strategy. Timely notification of occurrence and information involving DOE and its contractors should be made to the appropriate DOE officials and to other responsible authorities. Auditable records relating to environmental surveillance and effluent monitoring should be maintained. Calculations, computer programs, or other data handling should be recorded or referenced.

A lines of inquiry approach is provided in Appendix B that may be used to conduct self-assessments and to verify that the program is effective and in compliance with appropriate requirements and to ensure continuous improvement of the program.

10.1 Key Requirements

DOE O 458.1, *Radiation Protection of the Public and the Environment*, identifies recordkeeping, retention and reporting requirements for effluent monitoring and environmental surveillance activities.

DOE O 231.1B, *Environment, Safety and Health Reporting,* contains requirements for reporting information pertaining to DOE O 458.1 in the ASER.

DOE O 232.2, *Occurrence Reporting and Processing of Operations Information,* includes reporting criteria associated with DOE O 458.1 on the following: releases of radionuclides from a DOE facility; spread of radioactive contamination; and radiation exposure.

DOE O 243.1B, *Records Management Program*, sets forth requirements and responsibilities for creating, maintaining, and preserving records.

10.2 Recordkeeping, Retention and Reporting Activities

The following activities support an effective records, retention and reporting program:

- Identify and comply with all relevant records, retention and reporting requirements;
- Notify appropriate DOE officials and other responsible authorities in a timely manner of occurrences involving DOE and its contractors;
- Notify the appropriate level of DOE management as prescribed by the DOE site of occurrences for the purpose of investigation and evaluation of causes, and to identify appropriate measures to prevent recurrences;
- Maintain auditable records relating to environmental surveillance and effluent monitoring;
- Record and reference calculations, computer programs and other data handling methods;
- Provide a basis for the improvement of codes, guides, and standards used in the DOE and contractor operations;
- Monitor, evaluate, and report onsite discharges, liquid and airborne effluents, and environmental conditions in the vicinity of DOE sites to assess the levels of radioactive contaminants and their impact on the public and the environment; and
- Identify trends in areas of concern for DOE and contractor operations.

10.3 Quality Assurance

As they apply to recordkeeping, retention and reporting activities, the general QA program provisions of Chapter 11 should be followed.

11 QUALITY ASSURANCE

Quality control is generally performed by the line organization as part of its design or implementation functions. Quality assurance is, in part, an evaluation function that should be performed by an independent organization or by independent individuals or groups within an organization. Verification of the quality of a product or service is an evaluation function that is performed by persons or organizations not directly responsible for performing the work. Even though these two functions (QA and QC) can be considered separately, they are both necessary parts of a quality program. A QA Plan should be prepared and included as a section of the Environmental Monitoring Plan and should cover the monitoring activities at each site.

11.1 Key Requirements and Supporting Documents

DOE O 458.1, *Radiation Protection of the Public and the Environment,* requires that Authorized Limits be based on the applicable dose constraint, supported by a complete exposure pathway analysis using appropriate methodologies, techniques, parameters and models (such as the RESRAD family of codes) that meet QA requirements under DOE O 414.1D, *Quality Assurance*. DOE O 458.1 requires that all radiological monitoring or surveys performed to support clearance of property meet measurement quality objectives (MQOs).

DOE O 414.1D, *Quality Assurance,* contains requirements for the development and implementation of a QA program using a graded approach by DOE elements.

DOE G 414.1-2B, *Quality Assurance Program Guide* suggests that analytical laboratories providing analyses on behalf of DOE should participate in an approved proficiency testing program such as DOE's corporate Mixed Analyte Performance Evaluation Program (MAPEP)[14]. MAPEP serves as a valuable quality assurance tool and provides QA oversight for environmental analytical services across the DOE complex. It is also a proficiency testing program that includes radiological, stable inorganic, and organic constituents (i.e., mixed analytes) in the same single-blind sample for analytical performance evaluation. The samples use various matrices including soils, water, vegetation, and air filters.

[14] Additional information can be found at http://www.inl.gov/resl/mapep

11.2 QA Program Implementation

This section provides information for implementing a QA program. The information is organized according to management, performance, and assessment criteria. Additional QA and QC information is provided in MARLAP.

11.2.1 Management

- Develop data quality objectives (DQOs) for the radiological effluent monitoring and environmental surveillance program to ensure that data needs are clearly identified. A properly executed DQO process should provide a level of data and information that is appropriate to the magnitude of the monitoring and surveillance program (NCRP 2010).
- Develop MQOs to assist in determining analytical protocols and methods.
- Design the sampling and analytical program to ensure that samples are collected and analyzed in a manner that meets the DQOs and MQOs.
- Ensure that plans are developed to define how samples are collected and analyzed and the data are evaluated. At a minimum these should include:
  - QA Plan;
  - Sampling and Analysis Plan;
  - Data Validation Plan; and
  - Data Quality Assessment Plan.

11.2.2 Performance

- Use DOE/EPA approved/recognized analytical procedures whenever possible.
- Analyze sufficient numbers of quality control samples (blanks, duplicates, spikes, etc.) to determine the bias and precision of the analytical process.
- Calibrate radiation measuring equipment, including portable instruments, environmental dosimeters, in situ monitoring equipment, and laboratory and analytical equipment according to the manufacturer's recommendations and NIST-traceable calibration standards.
- Participate in a DOE approved quality assessment program (sample exchange) to ensure quality of the analytical process.
- Participate in an approved accredited proficiency testing program (e.g., DOE Radiological and Environmental Sciences Laboratory (RESL) – Mixed Analyte Performance Evaluation Program (MAPEP) for radionuclide, inorganic, and organic constituents).

11.2.3 Assessment

- Perform management assessment of effluent monitoring and environmental surveillance management processes.
- Periodic assessments or audits should be performed to verify compliance with documented standard operational procedures, QC procedures, and all aspects of the QA program.
- Independent assessments should be performed in accordance with documented procedures or checklists by personnel or an organization with no direct responsibility for performing or monitoring the activities being assessed (e.g., DOE Consolidated Assessment Program [DOECAP], *DoD/DOE Consolidated Quality Systems Manual (QSM) for Environmental Laboratories*).
- Consider participating in “blind” and “double blind” QA programs for field sampling.
- Verify the usefulness of the data through the data validation process.
- Assessment or audit results should be documented and reported to, and reviewed by, responsible management. Follow-up action should be taken where indicated.

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APPENDIX A: Acronyms and Technical Definitions

ACRONYMS

Acronym	Definition
AIRDOS-PC	Clean Air Act Compliance Software for Personal Computers
ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
ASER	Annual Site Environmental Report
ASOS	Automated Surface Observing System
ASTM	American Society for Testing and Materials
AWOS	Automated Weather Observing System
BAT	Best Available Technology
CAA	Clean Air Act
CAM	Continuous Air Monitor
CAP88	Clean Air Act Assessment Package - 1988
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)
CFR	Code of Federal Regulations
Ci	Curie
CRD	Contractor Requirements Document
DCG	Derived Concentration Guide
DCS	Derived Concentration Standard
DOE	U.S. Department of Energy
DOECAP	Department of Energy Consolidated Assessment Program
DQA	Data Quality Assessment
DQO	Data Quality Objectives
ED	Effective Dose
EML	Environmental Measurement Laboratory
EMP	Environmental Monitoring Plan
EPA	U.S. Environmental Protection Agency
ERPP	Environmental Radiological Protection Program
FAA	Federal Aviation Administration
GI	Gastrointestinal
GM	Geiger-Muller
HPS	Health Physics Society
HTO	tritiated water (liquid or vapor)

Acronym	Definition
IAEA	International Atomic Energy Agency
IEC	International Electrochemical Commission
INL	Idaho National Laboratory
ISO	International Organization for Standardization
LIDAR	Light Detection and Ranging
LLD	Lower Limit of Detection
MAPEP	Mixed Analyte Performance Evaluation Program
MARLAP	Multi-Agency Radioanalytical Laboratory Analytical Protocols
MARSAME	Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	Minimum Detectable Concentration
MEI	Maximally Exposed Individual
MQO	Measurement Quality Objectives
mrem	millirem
mSv	millisievert
NARAC	National Atmospheric Release Advisory Center
NCRP	National Council on Radiation Protection and Measurements
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NIST	National Institute of Standards and Technology
NNSA	National Nuclear Security Administration
NNSS	Nevada National Security Site
NRC	U.S. Nuclear Regulatory Commission
NSS	Non-Settleable Solids
OSLD	Optically Stimulated Luminescence Dosimeters
PIC	Pocket Ionization Chamber
QA	Quality Assurance
QAP	Quality Assurance Plan or Quality Assurance Program
QC	Quality Control
RASS	Radio Acoustic Sounding System
RCRA	Resource Conservation and Recovery Act
RESRAD	Residual Radioactive (A computer model used to calculate risks and estimate radiation doses from residual radioactive material)
SCG	Screening Concentration Guidelines
SODAR	SOund Detection and Ranging

Acronym	Definition
TED	Total Effective Dose
TLD	Thermoluminescent dosimeter
TRU	Transuranic
TSS	Total Suspended Solids

TECHNICAL DEFINITIONS

Absorbed Dose (D): the average energy imparted by ionizing radiation to the matter in a volume element per unit mass of irradiated material. The absorbed dose is expressed in units of rad (or gray) (1 rad = 0.01 gray).

Accuracy: the degree of agreement between a measured value and an accepted reference or true value. Two principal attributes of accuracy are precision and systematic error (bias). An accurate measurement is achieved with high precision and low systematic error (bias). .

Activity: synonym for radioactivity.

Aerosol: a gaseous suspension of very small particles of liquid or solid.

Alpha Radiation: the emission of alpha particles during radioactive decay. Alpha particles are identical in makeup to the nucleus of a helium atom and have a positive charge. Alpha radiation is easily stopped by materials as thin as a sheet of paper and has a range in air of only an inch or so. Despite its low penetration ability, alpha radiation is densely ionizing and therefore very damaging when ingested or inhaled. Naturally occurring radioactive elements such as radon emit alpha radiation.

Ambient Air: the surrounding atmosphere, usually the outside air, as it exists around people, animals, plants, and structures. It does not include the air immediately adjacent to emission sources.

As Low As Reasonably Achievable (ALARA): an approach to radiation protection to manage and control releases of radioactive material to the environment, and exposure to the work force and to members of the public so that the levels are as low as is reasonably achievable, taking into account societal, environmental, technical, economic, and public policy considerations. As used in DOE O 458.1, ALARA is not a specific release or dose limit but a process which has the goal of optimizing control and management of releases of radioactive material to the environment and doses so that they are as far below the applicable limits of DOE O 458.1 as reasonably achievable.

As Low As Reasonably Achievable (ALARA) Process: a graded process for evaluating alternative operations, processes, and other measures, for optimizing releases of radioactive material to the environment, and exposure to the work force and to members of the public, taking into account societal, environmental, technical, economic, and public policy considerations to make a decision concerning the optimum level of public health and environmental protection. A graded approach provides the flexibility to perform qualitative or quantitative ALARA analyses. For situations where potential doses are low, qualitative evaluations normally will suffice. In general, care should be taken to ensure that the cost of implementing the ALARA process does not exceed the value/benefit of the doses it may reduce or avert.

Atmospheric Dispersion: the process by which gaseous or particulate matter is spread into the atmosphere by turbulent motion in the atmosphere, horizontal transport, and vertical mixing.

Background Radiation: radiation from: (1) naturally occurring radioactive materials which have not been technologically enhanced (i.e., background radiation does not include TENORM); (2) cosmic sources; (3) global fallout as it exists in the environment (such as from the testing of nuclear explosive devices); (4) radon and its decay products in concentrations or levels existing in buildings or the environment which have not been elevated as a result of current or prior activities; and (5) consumer products containing nominal amounts of radioactive material or producing nominal amounts of radiation.

Becquerel (Bq): the unit of radioactive decay equal to one disintegration per second. The Becquerel is the basic unit of radioactivity used in the international system of radiation units, referred to as the "SI" units. 37 billion (3.7×10^{10}) becquerels = 1 curie (Ci).

Best Available Technology (BAT): the preferred technology for treating a particular activity, selected from among others after taking into account factors related to technology, economics, public policy, and other parameters. As used in this Handbook and DOE O 458.1, BAT is not a

specific level of treatment, but is the conclusion of a selection process in which several alternatives are evaluated.

Best Available Technology (BAT) Selection Process: the evaluation of candidate alternative technologies to select the BAT after considering: technology; economics; the age of equipment and facilities involved; the process employed; the engineering aspects of the application of various types of control techniques; process changes; other environmental impacts (including energy requirements); safety considerations; and policy considerations.

Beta Radiation: beta radiation is composed of charged particles emitted from a nucleus during radioactive decay, with a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron. Beta radiation is slightly more penetrating than alpha, but may be stopped by materials such as aluminum or Lucite panels. Naturally occurring radioactive elements such as Potassium-40 emit beta radiation.

Calibrate: adjustment of flow, temperature, humidity or pressure gauges, and the determination of system accuracy using approved equipment.

Calibration: comparison of the response of a measurement device with a standard or instrument of higher accuracy to quantify the relation between the standard and the response. Calibration procedures may also provide the proper correction factors.

Characterization: facility or site sampling, monitoring and analysis activities to determine the extent and nature of contamination. Characterization provides the basis of necessary technical information to select an appropriate cleanup alternative.

Collective Dose: the sum of the total effective dose to all persons in a specified population received in a specified period of time. For clearance of property the collective dose refers to the population potentially exposed to the cleared property. Collective dose is expressed in units of person-rem (or person-sievert).

Committed Effective Dose (E_{50}): the sum of the committed equivalent doses to various tissues or organs in the body ($H_{T,50}$), each multiplied by the appropriate tissue weighting factor (w_T) – that is, $E_{50} = \Sigma w_T H_{T,50} + w_{Remainder} H_{Remainder,50}$, where $w_{Remainder}$ is the tissue weighting factor assigned to the remainder organs and tissues and $H_{Remainder,50}$ is the committed equivalent dose to the remainder organs and tissues. Committed effective dose is expressed in units of rems (or sieverts).

Committed Equivalent Dose ($H_{T,50}$): the equivalent dose calculated to be received by a tissue or organ over a 50-year period after the intake of a radionuclide into the body. It does not include contributions from radiation sources external to the body. Committed equivalent dose is expressed in units of rems (or sieverts).

Composite Sample: a sample of an environmental media where multiple individual sample increments have been combined into a single sample. Composite may be formed from either spatial or temporal increments. Spatial examples might include composite samples that represent land area soils, water sources or outfalls, and air monitoring stations. A temporal composite represents samples collected over a period of time. The samples may be collected from the same or different locations. They may or may not be collected at equal time intervals over a predefined period of time (e.g., 24 hours).

Confidence Interval: a numerical range within which the true value of a measurement or calculated value lies. ANS/HPS N 13.1-1999 §E.4 indicates that sample results should be estimated at the 95 percent confidence level, corresponding to a ±2σ interval for variability in a sample (i.e., there is a 95 percent probability that the true value of a measurement or calculated value lies within the specified range).

Contamination: unwanted radioactive and/or hazardous material that is dispersed on or in equipment, structures, objects, air, soil, or water.

Continuous Sampling: both non-interrupted sampling and repetitive, sequential collection of a small sample obtained automatically at intervals short enough to yield a representative sample for the entire sampling period.

Curie (Ci): a quantitative measure of radioactivity. One Ci of activity is equal to 3.7×10^{10} decays per second.

Daughters: nuclei formed by the radioactive decay of different (parent) nuclides.

Decay Correction: an adjustment used to account for the probability that in a given time interval a certain fraction of the nuclei present in a radioactive isotope will gradually decrease in activity.

Decay Product: a nuclide resulting from the radioactive disintegration of a radionuclide, being formed either directly or as a result of successive transformations in a radioactive series. A decay product may be either radioactive or stable.

Decontamination: the removal or reduction of radioactive or hazardous contamination from facilities, equipment, or soils by washing, heating, chemical or electrochemical action, mechanical cleaning, or other techniques to achieve a stated objective or end condition.

Deposition: removal of a gaseous or particulate species from the atmosphere by the process of gravitational settling, by rain or snow, or by contact with surface features such as grass, trees, buildings, etc.

Derived Concentration Standard (DCS): a derived concentration value for a radionuclide in water that would result in a dose of 100 mrem in a year to a gender– and age-weighted reference person using DOE approved dose coefficients and assuming continuous exposure.

Detector: any device for converting radiation flux to a signal suitable for observation and measurement.

Diffuse Source: a source or sources of radioactive contaminants (emissions) released into the atmosphere that do not have a defined point (origin) of release (i.e., a non-point source). Such sources are also known as area sources.

Direct Radiation: radiation, as used here, typically gamma rays, but occasionally neutrons or beta particles, that is emitted by a source and impinges upon an object.

Dose: a general term for absorbed dose, equivalent dose, effective dose, committed equivalent dose, committed effective dose, or TED.

Dosimeter: a portable detection device for measuring the total accumulated exposure to ionizing radiation.

Effective Dose (E): the summation of the products of the equivalent dose received by specified tissues or organs of the body (H_T) and the appropriate tissue weighting factor (w_T)--that is, $E = \Sigma w_T H_T$. It includes the dose from radiation sources internal and/or external to the body. For purposes of compliance with DOE O 458.1, equivalent dose to the whole body may be used as effective dose for external exposures. The effective dose is expressed in units of rems (or sieverts).

Effluent: gaseous or liquid waste streams released to the environment.

Effluent Monitoring: the collection and analysis of samples of liquid and gaseous effluents, or measurements of liquid and gaseous effluents performed to characterize and quantify radiological

contaminants and process stream characteristics, assess radiation exposures of members of the public, and demonstrate compliance with applicable standards and permit requirements.

Environmental Impact: any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products, or services.

Environmental Surveillance: the collection and analysis of samples of air, water, soil, foodstuffs, biota, and other media at the DOE site and surrounding environs and the measurement of external radiation to demonstrate compliance with applicable standards, assess radiation exposure of members of the public, and assess effects, if any, on the environment.

Equivalent Dose (H_T): the product of average absorbed dose ($D_{T,R}$) in rad (or gray) in a tissue or organ (T) and a radiation (R) weighting factor (w_R). For external dose, the equivalent dose to the whole body is assessed at a depth of 1 cm in tissue; the equivalent dose to the lens of the eye is assessed at a depth of 0.3 cm in tissue, and the equivalent dose to the extremity and skin is assessed at a depth of 0.007 cm in tissue. Equivalent dose is expressed in units of rems (or sieverts).

Exposure: a measure of the amount of ionization produced by x-rays or gamma rays as they travel through air. The unit of radiation exposure is the roentgen (R).

Fallout: radioactive material made airborne as a result of aboveground nuclear weapons testing that has been deposited on the Earth's surface.

Fugitive Emissions: materials discharged into the air from point or diffuse sources.

Gamma Radiation: gamma radiation is a form of electromagnetic radiation, like radio waves or visible light, but with a much shorter wavelength. It is more penetrating than alpha or beta radiation, capable of passing through dense materials such as concrete.

Gamma Spectroscopy: this analysis technique identifies specific radionuclides. It measures the particular energy of a radionuclide's gamma radiation emissions. The energy of these emissions is unique for each nuclide, acting as a "fingerprint" to identify a specific nuclide.

Grab Sample: a single sample or measurement collected at a specific time or over as short a period as feasible.

Ground Water: water found beneath the surface of the ground (subsurface water). Ground water usually refers to a zone of complete water saturation containing no air.

Half-life: the time required for one half of the atoms of any given amount of a radioactive substance to disintegrate; the time required for the activity of a radioactive sample to be reduced by one half.

Hazardous Waste: toxic, corrosive, reactive, or ignitable materials that can negatively affect human health or damage the environment. It can be liquid, solid, or sludge, and include heavy metals, organic solvents, reactive compounds, and corrosive materials. It is defined and regulated by the Resource Conservation and Recovery Act (RCRA), Subtitle C.

In Situ Monitoring: Monitoring where the detection and quantification of contaminants are performed in place in the environment.

Ion Chamber: a radiation detection device that collects electrons created by the passage of ionizing radiation, records the produced electric charge or current, and can be read in terms of radiation dose or dose rate.

Ionizing Radiation: any radiation capable of displacing electrons from atoms or molecules, thereby producing ions. Some examples are alpha, beta, gamma, x-rays, neutrons, and light. High doses of ionizing radiation may produce severe skin or tissue damage.

Isokinetic: a condition which prevails when the velocity of air entering a sample probe or the collector when held in the airstream is identical to the velocity of the airstream being sampled at that point.

Isotope: two or more forms of a chemical element having the same number of protons in the nucleus (or the same atomic number), but having different numbers of neutrons in the nucleus (or different atomic weights). Isotopes of a single element possess almost identical chemical properties.

Low-Level Waste (LLW): radioactive waste that is not high-level radioactive waste, spent nuclear fuel, transuranic fuel, or byproduct material as defined in sections 11(e)(2), (3) or (4) of the Atomic Energy Act of 1954, as amended.

Maximally Exposed Individual (MEI): a hypothetical individual who – because of realistically assumed proximity, activities, and living habits – would receive the highest radiation dose, taking into account all pathways, from a given event, process, or facility.

Measurement Quality Objectives: a statement of a performance objective or requirement for a particular method performance characteristic.

Member of the Public: an individual who is not a general employee. An individual is not a member of the public during any period in which the individual receives an occupational dose.

Monin-Obukhov Length: the height over the ground, where mechanically produced (by vertical shear) turbulence is in balance with the dissipative effect of negative buoyancy.

Monitoring: the measurement of radiation levels, discharges or environmental releases, residual radioactive levels, quantities of radioactive material, or exposure to members of the public and the use of the results of these measurements to evaluate radiological discharges or releases or potential and actual dose resulting from exposure to radioactive material or radiation.

Nozzle: a device used to extract a sample from an effluent flow and transfer the sample to a transport line or collection device. Within the nozzle there will be a transition zone where the sample stream adjusts to the conditions in the transport line.

Nuclide: a species of atom characterized by the number of protons and neutrons in the nucleus.

Off-line: systems in which an aliquot is withdrawn from the effluent stream for collection or conveyance to a detector assembly.

On Site: the area within the boundaries of a site that is controlled with respect to access by the general public.

Optically Stimulated Luminescence Dosimeter (OSLD): a radiation monitoring device similar to the thermoluminescent dosimeter but using aluminum oxide to absorb the energy of x-rays and a laser light instead of heat to release the stored energy and measure the dose of ionizing radiation received.

Pathway Analysis: determination of the unique sequence of steps or mechanisms by which an individual or population becomes exposed to a chemical or radioactive contaminant after its release into the environment.

Pathway of Exposure: a course a chemical or radioactive contaminant takes from a source to an exposed organism.

Pressurized Ionization Chamber (PIC): an instrument used for measurement of low levels of environmental levels of gamma and x-radiations. The units are positioned at locations surrounding a site and provide integrated exposure levels over time.

Point Source: the release of a chemical or radioactive substance from a point.

Precision: the degree of agreement among measured values. It represents an error among repeated measures of the same property under identical conditions, but not systematically in the same direction or of the same magnitude. High precision measurements will have minimal dispersion around a central value but not necessarily around an accepted reference or true value.

Public Dose: the dose received by members of the public from exposure to radiation and to radioactive material released by a DOE radiological activity whether the exposure is within a DOE site boundary or offsite. Public dose is expressed in units of person-rem (or person-sievert).

Quality Assurance (QA): in environmental monitoring, any action to ensure the reliability of monitoring and measurement data. Aspects of QA include procedures, inter-laboratory comparison studies, evaluations, and documentation.

Quality Control (QC): in environmental monitoring, the routine application of procedures to obtain the required standards of performance in monitoring and measurement processes. QC procedures include calibration of instruments, control charts, and analysis of replicate and duplicate samples.

Radiation Weighting Factor (w_R): the modifying factor used to calculate the equivalent dose from the average tissue or organ absorbed dose; the absorbed dose (expressed in rad or gray) is multiplied by the appropriate radiation weighting factor.

Radioactivity: the property or characteristic of radioactive material to undergo spontaneous transformations (disintegrations or decay) with the emission of energy in the form of radiation. It is measured by the rate of spontaneous transformations of a radionuclide. The unit of radioactivity is the curie, Ci (or becquerel, Bq). ($1\ Ci = 3.7 \times 10^{10}\ Bq$).

Radionuclide: a radioactive element characterized by the number of protons and neutrons in the nucleus. There are several hundred known radionuclides, both artificially produced and naturally occurring.

Reference Person: a hypothetical aggregation of human (male and female) physical and physiological characteristics arrived at by international consensus for the purpose of standardizing radiation dose calculations.

Rem: stands for “roentgen equivalent man,” a unit by which human radiation dose is assessed. This is a risk-based value used to estimate the potential health effects to an exposed individual or population.

Representative Person: an individual receiving a dose that is representative of the more highly exposed individuals in the population. This term is the equivalent of, and replaces, 'average member of the critical group." (Source: ICRP Publication 103).

Residual Radioactive Material: any radioactive material which is in or on soil, air, water, equipment, or structures as a consequence of past operations or activities of the Department or its predecessors.

Sampling: the extraction of a prescribed portion of an effluent stream or of an environmental medium for purposes of inspection and/or analysis.

Sensitivity: the minimum amount of an analyte that can be repeatedly detected by an instrument.

Sequential Sampling: timed aliquots of a liquid effluent stream, collected for laboratory analysis. Can be proportional if the stream flow is constant or other automated features are used and representative if changes in radionuclide concentrations are minimal and slow.

Settleable Solids: (i) that matter in waste water which will not stay in suspension during a preselected settling period, such as one hour, but settles to the bottom; (ii) in the Imhoff cone test, the volume of matter that settles to the bottom of the cone in one hour; or (iii) suspended solids that can be removed by conventional sedimentation processes.

Sievert (Sv): the SI (international system) unit for dose equivalent equal to 1 Joule/kilogram. 1 sievert = 100 rem.

Source Term: the amount of radionuclides or chemicals released from a site to the environment over a specific period of time, expressed as a rate of release over a given duration of release.

Stripping: a process used to remove volatile contaminants from a substance.

Surveillance: the collection and analysis of samples of air, water, soil, foodstuffs, biota, and other media and the measurement of external radiation for purposes of demonstrating compliance with applicable standards, assessing radiation exposures of members of the public, and assessing effects, if any, on the local environment.

Thermoluminescent Dosimeter (TLD): a device used to measure radiation dose to occupational workers or radiation levels in the environment. It is made of material that when heated emits light in amounts proportional to the amount of the radiation dose it received.

Tissue Weighting Factor (w_T): the fraction of the overall health risk, resulting from uniform, whole body irradiation, attributable to specific tissue (T). The equivalent dose to tissue, (H_T), is multiplied by the appropriate tissue weighting factor to obtain the effective dose (E) contribution from that tissue.

Total Effective Dose (TED): sum of the effective dose (for external exposures) and the committed effective dose.

Tritium: the heaviest and only radioactive nuclide of hydrogen, with a half-life of 12.3 years and a very low energy radioactive decay (beta emitter).

Tritiated Water: water molecules that contain atoms of the ^3H nuclide.

Type I Error: In a hypothesis test, the error made by rejecting the null hypothesis when, in fact, the decision should have been to fail to reject the null hypothesis. A Type I error can also be referred to as a false positive.

Type II Error: In a hypothesis test, the error made by failing to reject a null hypothesis when, in fact, it is false. A Type II decision error is also called a false negative.

Uncertainty: (1) the range of values within which the true value is estimated to lie; (2) the best estimate of possible inaccuracy due to both random and systematic errors.

Validation: confirmation by examination and provision of objective evidence that the particular requirements for a specified intended use are fulfilled.

Verification: the act of reviewing, inspecting, testing, checking, auditing, or otherwise determining and documenting whether items, processes, services or documents conform to specified requirements.

Wake: the region of turbulence immediately to the rear of a solid body caused by the flow of air over or around the body.

Wildlife: animals in a natural, undomesticated state.

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APPENDIX B: Considerations for Self-Assessments of Environmental Monitoring and Surveillance Programs

The following lines of inquiry and approach are provided as examples for conducting self-assessments and performance assessments to verify that the environmental monitoring and surveillance programs are effective and in compliance with the appropriate requirements. Additionally, they are provided as a mechanism to monitor and document the existence of continuous improvement of the environmental monitoring and surveillance programs. The development of site- or facility-specific lines of inquiry is encouraged to provide site- or facility-specific verification of compliance and/or identification of areas for improvement that are tailored to site operations. The following lines of inquiry are illustrative and may not be applicable to some DOE operations or activities.

Chapter 2: DESIGNING, REVIEWING, AND UPDATING RADIOLOGICAL ENVIRONMENTAL MONITORING

1. Is there an integrated environmental monitoring program and associated documentation in place? How is it systematically reviewed to ensure monitoring needs associated with specific program or site operations are being addressed in a holistic, cost-effective, and efficient manner? How are program redundancies and gaps identified and addressed?
2. How are environmental monitoring and associated quality assurance and assessment data appropriately tracked, reviewed, and trended to ensure that changes in environmental conditions are fully identified and reported? Are procedural controls consistent with line management expectations established for trending and reporting anomalous conditions?
3. Are environmental monitoring data reviewed regularly to determine if modifications or improvements to the overall design (sampling methods, location, and analysis) are needed to meet data quality objectives or overall program performance?
4. How are environmental sampling and analysis methods and approaches systematically reviewed and evaluated to ensure they are sufficient to demonstrate compliance with applicable limits and provide an adequate technical basis for the environmental monitoring program?
5. Is a program in place to evaluate unplanned releases and assess the impacts of such releases on the public and the environment?
6. What processes are employed in notifying responsible managers and stakeholders of environmental monitoring implementation and results?

7. How is information gained through routine radiological monitoring efforts used to support the ALARA process and evaluate its effectiveness?
8. Are formalized reporting procedures and criteria for monitoring results in place?
9. Are programs in place to ensure the overall precision of radiological effluent monitoring data?

Chapter 3: LIQUID RADIOLOGICAL EFFLUENT MONITORING AND SAMPLING

1. Is there an integrated environmental monitoring program and associated documentation in place? How is it systematically reviewed to ensure monitoring needs associated with liquid radiological effluent monitoring are being addressed in a holistic, cost-effective, and efficient manner? How are program redundancies and gaps identified and addressed?
2. Are self- and performance assessments of different parts of the liquid radiological effluent monitoring program completed periodically to document acceptable performance and continuous improvement in the effluent monitoring program?
3. How are environmental monitoring and associated quality assurance and assessment data appropriately tracked, reviewed, and trended to ensure that changes in environmental conditions are fully identified and reported? Are procedural controls consistent with line management expectations established for trending and reporting anomalous conditions?
4. Are environmental monitoring data reviewed regularly to determine if modifications or improvements to the overall design (sampling methods, location, and analysis) are needed to meet data quality objectives or overall program performance?
5. How are environmental sampling and analysis methods and approaches systematically reviewed and evaluated to ensure they are sufficient to demonstrate compliance with applicable limits and provide an adequate technical basis for the environmental monitoring program?
6. Is a program in place to evaluate unplanned releases and assess the impacts of such releases on the public and the environment?
7. What processes are employed to notify responsible managers and stakeholders of environmental monitoring implementation and results?
8. How is information gained through routine liquid effluent monitoring efforts used to support the ALARA process and evaluate its effectiveness?
9. Are formalized reporting procedures and criteria for monitoring results in place?
10. Are programs in place to ensure the overall precision of liquid effluent monitoring data?

11. Are programs in place to ensure that representative samples are obtained and that all factors germane to proper sample collection are identified and incorporated into sampling activities?
12. What systems are in place for performing and recording calibration and maintenance activities associated with field and laboratory instrumentation?
13. Is a validated and consistent approach for sampling and analysis of radionuclide samples applied to ensure laboratory data meet program-specific needs and requirements within the framework of a performance-based approach for analytical work?
14. What systems are in place to ensure corrective actions are implemented during malfunctions of field and laboratory instrumentation?
15. Is a program in place to conduct a pre-operational assessment prior to start up of all facilities (new or modified) with the potential to expose the public or environment to radiation or radioactive material to determine the types and quantities of effluents to be expected?
16. Are measures in place to obtain representative liquid flow rate data necessary to assess the impact of routine and accidental releases of radioactivity? How well do they provide the data needed to help determine the transport and fate of radionuclides released to uncontrolled aquatic environment and the assessment of their impacts to public health and the environment?
17. Are all potential routes of liquid effluents from facilities on site identified and evaluated on a periodic basis to ensure that the monitoring program for all liquid radiological effluents is complete and up-to-date?
18. Have provisions for monitoring liquid effluents during non-routine situations been considered in the overall monitoring program needs?
19. Is continuous monitoring required when a significant potential exists for approaching or exceeding the Derived Concentration Standards (sum-of-fractions)? Do these systems have alarms that provide timely warnings to signal the need for corrective actions?
20. Does the documentation of the site's radiological effluent monitoring program include the rationale for the design and selection of monitoring locations, procedures and equipment used, frequency and analyses required for each sample extraction, detection limits of the monitoring system (e.g., LLD, MDA or MDC) and uncertainty, quality assurance components, and investigation and alarm levels?
21. Are the recommended criteria in Table 3-1 used to establish the liquid radiological effluent monitoring program at the site?

22. Have all of the important characteristics of the liquid effluent system, other pertinent structural information, the pertinent characteristics of the process control systems, and the sampling and measurement systems been documented? Have evaluation reports of the operational systems been retained?
23. Are the proper methods used to measure liquid stream characteristics adequately?
24. Have sample-transport lines been designed and installed with the characteristics needed to obtain a representative sample at the sampling or monitoring point?
25. Are liquid flow measurements for the effluent and sample streams accurate to ± 10 percent by documented calibration, unless extenuating circumstances exist?
26. Are flow-measuring devices used for compliance determinations located downstream from the collector when possible or feasible?
27. Are the detectors used relatively insensitive to environmental conditions and do they seldom need attention or adjustment?

Chapter 4: AIRBORNE RADIOLOGICAL EFFLUENT MONITORING AND SAMPLING

1. Is there an integrated environmental monitoring program and associated documentation in place? How is it systematically reviewed to ensure monitoring needs associated with point and diffuse source air effluents and emissions are being addressed in a holistic, cost-effective, and efficient manner? How are program redundancies and gaps identified and addressed?
2. Is a program in place to conduct a pre-operational assessment prior to start up of all facilities (new or modified) with the potential to expose the public or environment to radiation or radioactive material to determine the types and quantities of effluents expected?
3. Are the criteria in Table 4-1 (or equivalent) used to establish the airborne radiological effluent monitoring program at the site?
4. How is information gained through routine air effluent sampling and monitoring efforts used to support the ALARA process and evaluate its effectiveness?
5. Have all of the important characteristics of the exhaust handling system, other pertinent structural information, the pertinent characteristics of the process-effluent control systems, and the sampling and measurement systems been documented? Have evaluation reports of the operational systems been retained?
6. What systems are in place for performing and recording calibration and maintenance activities associated with field and laboratory instrumentation?

7. What systems are in place to ensure corrective actions are implemented during malfunctions of field and laboratory instrumentation?
8. Are self- and performance assessments of different parts of the radiological air effluent monitoring program completed periodically to document acceptable performance and continuous improvement in the effluent monitoring program?
9. Are all potential routes of airborne effluents and emissions from facilities on site identified and evaluated on a periodic basis to ensure that the monitoring program for all airborne radiological effluents and emissions is complete and up-to-date? Is the loss of effluent controls considered when assessing the potential to exceed emissions performance standards?
10. Does the air effluent monitoring program consider minimum dose sensitivity, release conditions, and particle size?
11. Has the effectiveness of effluent treatment and controls been evaluated in their capability in reducing effluents? If they were not adequate, how were they changed to ensure acceptable levels of effluents?
12. Have the air moving systems, including pumps and mechanical components been designed to operate continuously under anticipated operating conditions? Is preventive maintenance scheduled periodically and repair performed and documented when necessary?
13. Are the detectors used relatively insensitive to environmental conditions and do they seldom need attention or adjustment?
14. Are flow measurements accurate to $\pm$ 10 percent by calibration with NIST standards, unless extenuating circumstances exist?
15. Are the record flow-measuring devices located downstream from the sample extraction point?
16. Are programs in place to ensure that representative samples are obtained and that all factors germane to proper sample collection are identified and incorporated into sampling activities?
17. Does the documentation of the site's radiological air effluent monitoring program include the rationale for the design and selection of monitoring locations, procedures and equipment, frequency and analyses for each sample extraction, minimum detectable concentration and uncertainty, quality assurance components, and investigation and alarm levels?
18. Is continuous monitoring addressed when a significant potential exists for approaching or exceeding a large fraction of the emission standard (e.g., 20 percent)? Do these

systems have alarms that provide timely warnings to signal the need for corrective actions?

19. Are systems and methods in place that can adequately monitor or sample the concentrations of gases, vapors, and particulates that are potentially in the effluents?
20. Are the proper EPA and ANSI methods used to measure gas-stream characteristics adequately?
21. Is a validated and consistent approach for sampling and analysis of radionuclide samples applied to ensure laboratory data meet program-specific needs and requirements within the framework of a performance-based approach for analytical work?
22. Are the sampling and monitoring methods discussed in ANSI/HPS N13.1-1999 used when a new or modified facility or process is involved? Otherwise, are the methods in ANSI N13.1-1969 referenced and used? As appropriate, do program plans include updating ANSI N13.1-1969 systems to meet ANSI/HPS N13.1-1999 criteria?
23. Have sample-transport lines been designed and installed with the characteristics needed to minimize the loss of material in the line prior to reaching the monitor?
24. Radionuclide-specific Considerations:
    a. Are radioiodine monitors designed in such a way that the replacement of sorbent and filter does not disturb the geometry between the collector and detectors?
    b. Are the instrumentation and sampling methods for radioiodine adequate to measure the radioisotope alone or when other radionuclides are present? Have minimum levels of detectability been measured and documented for various iodine isotopes?
    c. Have studies been performed to measure the composition of noble gases present so that measurements can be interpreted correctly?
    d. Does the minimum detection level for radioactive noble gases and particulates meet ANSI N42.18-2004?
    e. Is tritium removal performed before other measurements are made when significant amounts of tritium are present?
    f. Does the minimum detection level for tritium meet ANSI N42.18-2004?
    g. Has the detection level of tritium been determined when other radionuclides are present?
25. Have studies been performed (either by the site or by the instrument manufacturer) that document the collection efficiency of the particle collection/retention devices used over the range of 0.01 to 10.0 μm?

26. Are formalized reporting procedures and criteria for monitoring results in place?
27. Are programs in place to ensure the overall precision of airborne radiological effluent monitoring data?
28. Can the levels of gross beta and gross alpha emitters be measured with the accuracy identified by IEC 60761 standards?
29. Is the monitoring of diffuse sources included in the site's radiological effluent monitoring program and, if so, are the computational models and/or downwind arrays of samplers arranged and operated to adequately determine the release? Has the rationale for choosing the computational models or monitoring equipment used been documented?
30. Is a program in place to evaluate unplanned releases and assess the impacts of such releases on the public and the environment?
31. Have provisions for monitoring radioactive airborne effluents and emissions during non-routine situations been considered in the overall monitoring program needs?

Chapter 5: METEOROLOGICAL MONITORING

1. Is there an integrated environmental monitoring program and associated documentation in place? How is it systematically reviewed to ensure monitoring needs associated with meteorological conditions are being addressed in a holistic, cost-effective, and efficient manner? How are program redundancies and gaps identified and addressed?
2. Is there a program in place to obtain representative meteorological data necessary to assess the impact of routine and accidental releases commensurate with the level of site activities? How well does it provide the data needed to help determine the transport and fate of radionuclides released to the atmosphere, and the assessment of their impacts on the public and the environment?
3. Has the meteorological monitoring program been established using site specific information? Does it take into consideration the specific activities at the site, topographical characteristics of the site, distance to each of the critical receptors, and planned future uses of the site?
4. Is the scope of the program based on an evaluation of the applicable regulatory requirements and a determination of meteorological data needed to support various analyses including facility operations, environmental impact assessments, environmental surveillance activities, safety analyses, environmental restoration activities, and the consequence assessment element of emergency preparedness and response?

5. Has the meteorological monitoring program been documented appropriately, such as in a site environmental monitoring plan or an environmental radiological protection program?
6. Do the onsite meteorological measurements include wind direction and speed, temperature, and a direct or inferential measure of atmospheric turbulence?
7. Does the meteorological monitoring program make use of measurements obtained from offsite sources? If so, are the data spatially representative of conditions at the site and are they consistent with onsite monitoring requirements?
8. Are the meteorological monitoring program requirements incorporated into the effluent monitoring and the environmental surveillance programs?
9. Are meteorological measurements made in locations that, to the extent practicable, provide data spatially representative of the atmospheric conditions into which material will be released and subsequently transported?
10. Are the instruments used in monitoring capable of continuous operation within the normal range of atmospheric conditions at the facility?
11. Have any special meteorological monitoring requirements imposed by other agencies (i.e., outside of DOE) been taken into consideration when designing the meteorological measurement systems and establishing measurement locations?
12. Has an uninterruptible power supply and an alternate source of power been included in the meteorological monitoring system?
13. Are wind speed and wind direction measurements made at a sufficient number of heights to adequately characterize the wind (including turbulence) at potential release heights?
14. Have the temperature monitoring levels been selected and spaced so that the profile is representative and characterizes the magnitude of atmospheric turbulence (if being inferred through vertical temperature differences) and/or to estimate plume buoyancy at the potential release heights?
15. Are wind measurements made at locations and heights that avoid airflow modification by obstructions?
16. Are air temperature and relative humidity measurements made in such a way as to avoid airflow modification by heat and moisture sources?
17. Was the location of the meteorological monitoring tower chosen to avoid being on or near man-made surfaces such as concrete or asphalt?

18. Does the onsite meteorological monitoring system use an electronic digital data acquisition system housed in a climatically controlled environment as a primary data recording system? Is there a backup recording system available for use if needed?
19. Are the digitally recorded data (except for wind direction (σ_Θ) and precipitation) averaged over at least 30 samples taken at intervals not to exceed 60 seconds?
20. Are the accuracies of the monitoring measurements consistent with those listed in Table 5-2 of this Handbook?
21. Does the monitoring program provide for routine inspection of the data and scheduled calibration and maintenance of the meteorological instrumentation and data acquisition system based on the calibration frequency recommendations of the manufacturers?
22. Are the inspections and calibrations conducted in accordance with written procedures and are the logs of the inspections, maintenance, and calibrations kept and maintained as permanent records?
23. Is the meteorological instrument system capable of providing data recovery of at least 90 percent quality-assured data on an annual basis?
24. Are the monitoring and data recording systems protected from lightning-induced electrical surges and electrical faults, and severe environmental conditions?
25. Have functional checks been made and properly documented of instrumentation after exposure to extreme meteorological conditions or other events that have or may have compromised system integrity?
26. Does every facility on site have a valid and accurate meteorological database which can be utilized by the analyst and codes to evaluate environmental impacts and consequence assessments? Was pre-operational data obtained for at least one year?
27. Are meteorological monitoring data collected as 15-minute averages for use in emergency response applications and combined into hourly averages for use in consequence assessments? Are these data examined and entered into permanent archive at least monthly?
28. If required, are the meteorological data being made available to NARAC in support of emergency response consequence assessments?
29. Are meteorological data retained for a period of at least five years and validated data retained for the life of the facility?
30. Does the Quality Assurance documentation meet the guidance provided in Section 7.4 of ANSI/ANS-3.11-2005 (R2010) and Section 8 of EPA-454/R-99-005 (EPA 2000a)?
31. Has the QA Plan been reviewed and updated as needed every 5 years or when a substantive change to the meteorological program was made?

Chapter 6: ENVIRONMENTAL SURVEILLANCE

1. Are an integrated environmental surveillance program and associated documentation in place? How is the environmental surveillance program systematically reviewed to ensure needs associated with specific program or site operations are being addressed in a holistic, cost-effective, and efficient manner? How are program redundancies and gaps identified and addressed?
2. Are self-and performance assessments of different parts of the environmental surveillance program performed periodically to document acceptable performance and continuous improvement?
3. How are environmental surveillance and associated quality assurance and assessment data appropriately tracked, reviewed, and trended to ensure that changes in environmental conditions are fully identified and reported? Are procedural controls consistent with line management expectations established for trending and reporting anomalous conditions?
4. Are environmental surveillance data reviewed regularly to determine if modifications or improvements to the overall design (sampling methods, location, and analysis) are needed to meet data quality objectives or overall program performance?
5. How are environmental sampling and analysis methods and approaches systematically reviewed and evaluated to ensure they are sufficient to demonstrate compliance with applicable limits and provide an adequate technical basis for the environmental surveillance program?
6. Has trending and tracking of ground water monitoring data been established to ensure that changes in ground water contamination conditions are fully identified and reported?
7. Have all ground water plumes, including those containing lower concentrations of contaminants, been monitored through direct measurement to determine the full nature and extent of the contamination?
8. Are settleable solids being analyzed?
9. Are sediment sampling locations and rigor sufficient to detect contamination and evaluate trends?
10. Has the site relied too heavily on gross alpha and beta analyses and not on analyses of specific radionuclides? Did the site routinely establish proper data quality objectives in support of environmental radiological sampling and decision-making?
11. Is a program in place to evaluate unplanned releases and assess the impacts of such releases on the public and environment?

12. What processes are employed in notifying responsible managers and stakeholders of environmental monitoring implementation and results?
13. Are formalized reporting procedures and criteria for monitoring results in place?
14. Are programs in place to ensure the overall precision of the environmental surveillance data?
15. Are programs in place to ensure that representative samples are obtained and that all factors germane to proper sample collection are identified and incorporated into sampling activities?
16. What systems are in place for performing and recording calibration and maintenance activities associated with field and laboratory instrumentation?
17. Is a validated and consistent approach for sampling and analysis of radionuclide samples applied to ensure laboratory data meet program-specific needs and requirements within the framework of a performance-based approach for analytical work?
18. What systems are in place to ensure corrective actions are implemented during malfunctions of field and laboratory instrumentation?
19. Have the minimum criteria for determining the need for environmental surveillance listed in Table 6-1 been used to help establish the environmental surveillance program?
20. Is the environmental surveillance program able to distinguish site radiation contributions from other local sources adequately?
21. Has the particle size of effluent particulates been measured or considered in the establishment of the environmental surveillance program?
22. What provisions for emergency monitoring has been planned and how do they fit into the routine environmental surveillance program?
23. Are all potential exposure pathways covered in the environmental surveillance program?
24. Is the proper instrumentation used to make the external radiation measurements in terms of precision, sensitivity for the measurements needed, and suitability for use in the field?
25. Have the sampling and measurement locations, number of samples, and frequency of data acquisition been justified adequately and documented in the environmental surveillance plan or other appropriate record?
26. How have the background radiation levels been considered during the process of identifying locations of samples and measurements?
27. What other precautions (besides background radiation levels) related to environmental sampling and monitoring were considered during the process of establishing the

environmental surveillance program and during the implementation of the program? Are the precautions adequate?

28. Are radon isotopes and their daughters potential interferences in the analyses of the samples or the measurements made on site? If so, how are their interferences taken into account or compensated for?
29. Is the process of obtaining the environmental samples and measurements on site controlled such that the samples can be easily identified and followed through their analyses and the samples maintained in such a way that the integrity of the sample is preserved adequately prior to analyses?
30. Are there chain-of-custody procedures for the samples?
31. Is the analysis equipment used in the environmental surveillance program adequate to identify and measure the presence of all of the radionuclides of concern in the local environment with the appropriate level of precision?
32. Are all of the sampling and monitoring procedures used to implement the environmental surveillance program documented adequately and followed by the personnel obtaining the data?

Chapter 7: SAMPLE HANDLING, PREPARATION, AND ANALYSIS PROCEDURES

1. Are standard operating procedures (SOPs) in place to guide sampling, sample handling, sample preparation, sample analysis, and quality assurance verifications?
2. Are self- and performance assessments of sample handling, preparation, analysis, and quality assurance procedures performed periodically to document acceptable performance and continuous improvement in the processes?
3. Are deviations from procedures documented and investigated?
4. Is a system in place to properly identify samples throughout handling, preparation, analytical processes and data reporting?
5. Are chain-of-custody protocols used and documented?
6. Are sample preservation techniques properly used?
7. Are contamination controls adequately implemented during sampling?
8. Is appropriate instrumentation used for analysis?
9. Are the instruments used for quantification calibrated and their operation routinely verified?
10. Are systems in place for performing and recording calibration and maintenance activities associated with field and laboratory instrumentation?

11. Are the sample preparation and analytical procedures used adequate for the sample matrices, radionuclides of interest, and potentially required concentrations?
12. Is a validated and consistent approach for sampling and analysis of radionuclide samples applied to ensure laboratory data meet program-specific needs and requirements within the framework of a performance-based approach for analytical work?
13. How are analytical methods and results systematically reviewed and evaluated to demonstrate compliance with applicable limits and provide an adequate technical basis for the environmental monitoring program?
14. How are program redundancies and gaps identified and addressed?
15. Are protocols in place to ensure corrective actions are implemented?

Chapter 8: DATA ANALYSIS AND STATISTICAL TREATMENT

1. Are the justification and rationale for the data analysis and statistical treatments current and described in appropriate program plans, procedures, and protocols?
2. Is a system in place for selecting and validating appropriate methods and models used for data analysis and statistical treatments?
3. Are SOPs in place to guide sample analysis, statistical treatments, and quality assurance verifications?
4. Are deviations from procedures documented and investigated?
5. Are analytical results, their uncertainty and associated statistical treatments properly documented and readily available?
6. Are backup systems implemented to minimize potential losses of data?
7. Are procedural controls consistent with line management expectations established for trending and reporting anomalous conditions?
8. Are programs in place to ensure overall precision of radiological effluent monitoring and environmental surveillance data?
9. Does the data analysis and statistical treatment program appropriately track, review, and trend the data to ensure that changes in environmental conditions are fully identified and reported?
10. Are data analysis and statistical treatments and approaches periodically reviewed and evaluated to ensure they are sufficient to demonstrate compliance with applicable limits and provide an adequate technical basis for the environmental monitoring program and to meet the overall data quality objectives?

11. Is a system in place to ensure that data analysis and statistical treatments are supported with updated and accurate information, which includes identification and documentation of values of assumed default or site-specific parameters used in calculations?
12. How are program redundancies and gaps identified and addressed?
13. What protocols are in place to ensure corrective actions are implemented?
14. Are environmental monitoring data reviewed regularly to determine if modifications or improvements to the overall design (sampling methods, location, and analysis) are needed to meet data quality objectives or overall program performance?

Chapter 9: DOSE CALCULATIONS

1. Has a system been established for evaluating doses to the public and the environment considering relevant exposure modes and pathways from DOE activities? Are doses less than DOE's all-pathways limit of 100 mrem/year and ALARA? Are doses through the air pathway less than 10 mrem/year?
2. Is a system in place to ensure that dose evaluations are supported with updated and accurate information, which includes identification and documentation of values of assumed default or site-specific parameters used in calculations?
3. Is a system in place for selecting and validating appropriate methods and models used for evaluating doses to the public and the environment?
4. Is the information used to calculate doses to the public (e.g., including the extent and use of affected air, land, and water media data) identified, documented, reported, and periodically re-evaluated?
5. Do the assessment models used for all environmental dose assessments appropriately characterize the physical and environmental situations existing at the site?
6. Is surface and ground water modeling conducted as necessary to conform to the applicable requirements of the State government and the regional EPA office?
7. Are data/information used in the dose assessment models or resulting from the modeling consistent with the data obtained from the site's ASER?
8. Are all external exposures, inhalation, and ingestion pathways taken into account in the dose assessment modeling?
9. Are parameter sensitivities and uncertainties in modeling results properly justified and documented?
10. Are controls or reviews established in the dose assessment process to prevent the occurrence of "overkill", inappropriate prediction, and misinterpretation of the data?

11. Do parameters used in the atmospheric transport and dispersion models include horizontal and vertical diffusion parameters, wind data, plume-rise parameters, and plume deposition and depletion factors?
12. Is the RESRAD family of codes or another environmental transport code used to model and evaluate radiation doses and risks? If so, are the parameters/inputs and results documented properly?
13. With regard to protection of biota and the evaluation of radiation doses to populations of aquatic animals, terrestrial plants, and terrestrial animals, is a graded approach used such as the one discussed in DOE-STD-1153-2002? Are all assumptions and input parameters justified and properly documented?
14. Are dose coefficients used in the dose assessment process referenced, justified, and properly documented?
15. Have results obtained through computer programs been compared and evaluated against field or laboratory data? How did they compare and how were differences justified?

Chapter 10: RECORDS, RETENTION AND REPORTING

1. Have all relevant reporting requirements been identified?
2. Was compliance with all identified reporting requirements achieved?
3. Is a documented program in place to ensure that appropriate DOE and other responsible authorities will be, or have been notified of all occurrences and information involving DOE and its contractors in a timely manner in accordance with the identified requirements?
4. Have auditable records relating to environmental monitoring and surveillance been maintained?
5. Have calculations, computer programs and other data handling methods been recorded and referenced appropriately?
6. Have record disposition and disposals been conducted in accordance with approved plans, procedures, and DOE records management requirements?
7. Have records documenting the source of input parameters including the results of all measurements upon which they are based, the calculations and/or analytical methods used to derive values for input parameters, and the procedure used to determine effective dose been generated? Are the records sufficient to allow an independent auditor to verify determinations made concerning the facility's compliance with the

standard? Are the records kept at the site of the facility for at least five years and, available, upon request, for inspection by appropriate authorities?

8. Was an ASER issued?
9. Does the program systematically plan, document, execute, and evaluate the management of DOE radioactive waste and assist in planning, executing and evaluating the management of DOE radioactive waste in accordance with DOE O 435.1, *Radioactive Waste Management*?
10. Does the facility NESHAPS document meet the requirements of 40 CFR Part 61?

Chapter 11: QUALITY ASSURANCE

1. Are environmental monitoring and surveillance data reviewed regularly to determine if modifications or improvements to the overall design (sampling methods, location, and analysis) are needed to meet data quality objectives or overall program performance?
2. Are programs in place to ensure that representative samples are obtained and that all factors germane to proper sample collection are identified and incorporated into sampling activities?
3. What systems are in place for performing and recording calibration and maintenance activities associated with field and laboratory instrumentation?
4. What systems are in place to ensure corrective actions are implemented during malfunctions of field and laboratory instrumentation?

APPENDIX C: Radiological Control and Release of Game for Human Consumption

C.1.0 INTRODUCTION

C.1.1 Purpose

This appendix provides information on radiological control, and release of game for human consumption. This appendix describes an approach where game taken by hunters is monitored and the results are compared to calculated radionuclide Screening Concentration Guidelines (SCG). These guidelines can be used to control the release of game to assure that the doses to humans from consumption of game will not exceed a dose constraint of 25 mrem/year and will be well below DOE's public dose limit of a 100 mrem/year (DOE O 458.1).

C.1.2 Background

Hunting of indigenous game (e.g., deer, rabbits, birds) is permitted at or around several DOE sites. The practice of allowing hunting of deer and other game is part of an ecosystem approach to local wildlife management and conservation efforts, to restore and sustain the health, productivity, and biological diversity of a well-balanced ecosystem.

DOE O 458.1 establishes standards and requirements for DOE operations to protect the public and the environment from undue risk of radiation. The objective of the Order is to ensure that doses to the public resulting from DOE controlled activities are maintained within limits ALARA, and that DOE facilities monitor releases and assess potential doses from these releases. Potential doses resulting from human consumption of game that might have ingested or been in contact with radioactive materials at DOE sites could be a contributing pathway. In accordance with DOE O 458.1, this pathway must be considered in ensuring compliance with DOE public dose limits and ALARA process requirements.

C.1.3 Approaches for Monitoring or Evaluating Doses from Consumption of Game

Although the DOE O 458.1 requirements are applicable to the hunting pathway, it contains no specific requirements for monitoring or evaluating doses from hunting. For DOE sites where the pathway exists, as with other sources of exposure, DOE line management is responsible for ensuring the pathway is appropriately evaluated and compliance is achieved. The selected approach and level of effort should be commensurate with the importance of the pathway, and

sites and facilities are responsible for documenting and implementing an approach. The choice of approach depends on the degree of confidence needed to report valid and reliable data. The selected approach should provide the site with reasonable assurance that the dose attributable to consumption of game will not exceed the DOE dose constraint of 25 mrem/year from a single pathway, and will be well below the public dose limit of a 100 mrem/year.

Approaches may entail:

- A process or site-wide knowledge approach: This approach uses knowledge of radionuclides and their concentration levels in the environment (air, water, soil, and plants) to assess potential doses to humans resulting from consumption of game from the evaluating area using empirically derived or modeled concentration factors for game;
- A selective or statistical sampling approach: This approach uses radionuclide concentrations in game from the evaluating area to estimate the range of doses to hunters; and
- A direct measurement approach: This approach uses radionuclide concentrations in tissue of game taken by hunters and measured or estimated based on radiological measurement and modeled or compared to predetermined screening criteria to ensure DOE dose constraints and limits are met.

C.1.4 Rationale for the Recommended Approach

The approach detailed in this document is the *Direct Measurement and Uses Screening Concentration Guidelines (SCG)*. The approach is dependent upon measurement of radioactivity levels or radionuclide content of game taken on DOE lands. It presumes that individuals hunting on DOE land should have permission; therefore, their access and egress to and from the site are controlled. They can be required as a condition of the hunting permit to bring any game taken on the reservation to check stations for tagging and monitoring. Although measurements can be used to calculate estimated doses, in general the use of screening criteria based on a dose constraint will simplify the process. If the measurement indicates the screening criteria are met, the animal may be released.

This approach provides a high level of confidence that the hunting pathway doses comply with DOE requirements. It can be implemented in the field and is similar to the process used at most sites permitting hunting on DOE lands. In addition, because it requires each hunter to check in their game, the approach readily permits DOE to confirm that hunters have not strayed out of the permitted hunting areas into areas that pose a risk of direct contamination.

C.1.5 Selecting a Dose Constraint

As specified in DOE O 458.1, the public dose limit from DOE facilities for a member of the public is 100 mrem (1mSv) effective dose in one year. This dose limit applies to the radiation dose from all sources and pathways except natural background radiation and dose received from medical applications. It should not be used exclusively for setting allowable radionuclide levels from consumption of game.

To ensure multiple sources will not result in doses exceeding the DOE public dose limit of 100 mrem/year, DOE recommends potential doses from a single pathway be constrained so as not to exceed 10 percent to 25 percent of the public dose limit of 100 mrem per year. This recommendation is consistent with established radiation protection practices and policies articulated by the NCRP, the ICRP and the International Atomic Energy Agency (IAEA), as well as proposed Federal Guidance for Radiation Protection. These documents recommend the projected dose attributable to any single source, practice, or activity should be some fraction less than the applicable overall public dose limit.

Depending on the particular source of concern DOE, EPA, NRC, and others typically have established single-source or pathway constraints or limits[15] from less than 10 to over 50 percent of the public dose limit for protection of the public (i.e., 100 mrem/year) from any particular source. For the purposes of this Handbook, DOE used a dose constraint of 25 mrem/year for developing screening criteria.

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[15] Examples include: 10 CFR Part 20 Appendix B concentrations (based on 50 mrem or 0.5 mSv if ingested) and Subpart E license termination limits (25 mrem or 0.25 mSv); 40 CFR Part 190 fuel cycle facility dose limits (25 mrem); 40 CFR Part 191 dose limit for management of spent fuel and high-level waste (25 mrem) and for disposal (15 mrem or 0.15 mSv); 40 CFR Part 192 uranium mill tailings limits (radon daughter and external gamma rate levels); DOE M 435.1-1 dose limit for management and disposal of low-level waste (25 mrem); 40 CFR Part 61 dose limit for air emissions (10 mrem); NCRP Report No. 129 screening limits for soil (0.25 mSv or 25 mrem); and IAEA Safety Guide No. WS-G-2.3 default constraint for control of discharges to the environment (300 microSv or 30 mrem) and upper bound constraint (800 microSv or 80 mrem).

C.1.6 Use of Other Constraints

Site-specific screening criteria may be established using lower dose constraints and the procedures discussed in this Handbook, but if constraints used with this methodology are higher than the 25 mrem/year value, their use should be justified and documented to explain how such values provide reasonable assurance that the potential doses from this pathway and others will not cause the all-sources/all-pathways limit to be exceeded. In any case, in addition to reporting game releases and associated radiological control procedures in the site's annual report, DOE sites permitting hunting should make information on DOE control procedures, constraints, and screening criteria available to the public, especially to those permitted to hunt game on DOE sites.

It is noted that the 25 mrem/year dose constraint was selected and is reasonable for the direct measurement approach discussed in this Handbook. However, if site management chooses to use a different method (e.g., statistical sampling or site-wide knowledge approaches), comparison to the 25 mrem/year constraint may not be a sufficient test to ensure compliance with DOE O 458.1. For example, incomplete characterization of a site's radiological condition, uncertainty in the movement of game, and other factors increase uncertainty in dose estimates where the actual game taken are not monitored. Hence, to achieve the same level of confidence as the direct measurement approach, an increased margin of safety may be needed.

The dose constraint used in this Handbook is appropriate for demonstrating compliance with DOE O 458.1 requirements. DOE sites may have agreements or requirements under other regulations that necessitate the use of other constraints. The screening concentration guidelines approach outlined here may be adjusted and modified to address external needs and still be used for compliance with DOE O 458.1, so long as the approach can be shown to ensure that doses to the public are below DOE dose limits and maintained ALARA. This Handbook is focused on compliance with DOE requirements and is not intended to change, address or resolve local or regional regulatory issues external to DOE requirements.

C.1.7 Other approaches and sampling considerations

This Handbook is focused on an approach for the hunting pathway where access to the site and hunting is controlled. Such control is not always possible. It is also recognized that hunting big game (e.g., deer and hogs) is just one of several "sportsman" or "wild food" pathways. DOE sites or their surrounding properties are used for other activities (e.g., fishing, camping, and public gatherings). In most cases, the potential doses associated with such activities are

modeled and reported in DOE ASERs. The data and modeling for such activities is site-specific, and is not addressed in this Handbook. They typically involve the site-wide knowledge or selective sampling approaches discussed earlier where potential doses are estimated based on environmental surveillance data collected around the sites. In some cases, the hunting pathway may be addressed in a similar fashion. As noted previously, this approach does not preclude the use of other approaches for ensuring compliance with DOE O 458.1 requirements. This approach is applicable to sites using the direct measurement SCG approach for hunting and it is not practical for pathways such as fishing and fish consumption. It may even be impractical for some hunting pathway assessments, for example, where the primary radionuclide of interest is difficult to measure in the field. In such cases, prospective modeling using the selective sampling or site-wide knowledge may be the only options. This is also the case where it is not practical for DOE to control access to the areas being hunted.

The assumptions and procedures used in this Handbook are generally conservative and provide reasonable assurance of compliance with DOE requirements for most situations. However, there may be site-specific situations (possibly due to regional regulations, land characteristics or local practices) that produce either overestimated or underestimated doses based upon the assumptions recommended in this Handbook. DOE sites are responsible for ensuring that these assumptions are reasonable for their site and situations, and are responsible for adjusting or modifying the assumptions and procedures as necessary and documenting these changes.

DOE recommends a graded approach for addressing this pathway consistent with the risk (potential doses). Where it can be demonstrated that potential doses are very low, resources necessary to implement a direct measurement approach such as the SCG approach would not be commensurate with the risk. In such cases, selective sampling or site-wide knowledge approaches should be considered.

The direct measurement SCG approach discussed in this Handbook is most useful when the significant radionuclides of interest are gamma emitters, or when the mix of radionuclides are such that their concentration can be estimated using a gamma measurement as a surrogate for any beta or alpha emitters present. Gamma emitters may be detected using field gamma spectrometers (e.g., cesium would be expected to concentrate in the muscle tissue and thus be amenable to this technique). Note that external contamination of fur and skin, and internal contamination present in the GI tract may include radionuclides that are not likely to be consumed by humans and therefore are not good indicators of potential dose. Dose estimates

and measurements compared to screening guidelines should be based on edible portions of the animal (e.g., muscle tissue).

Although gamma measurements alone may be used to estimate alpha and beta contributions when radionuclide concentration ratios are generally uniform, if a consistent ratio (e.g., Cs:Sr) cannot be demonstrated from available data, then specific analyses may be necessary to measure concentrations of the alpha and beta emitting radionuclides. If there is a large spatial variation in the isotopic mix found at different locations on a large multi-purpose site, it may not be practical to estimate the concentrations of alpha and beta emitting radionuclides based only upon measurements of associated gamma emitting radionuclides. The extent of such sampling and analysis should be commensurate with the potential dose. If potential doses associated with beta and alpha emitters are low (i.e., a small fraction of the gamma emitters) or a small fraction of the dose constraint (whether or not there is variability in the ratios), they need not be measured regularly. Some sampling, however, (e.g., through the environmental surveillance program) will likely be needed to confirm their significance or insignificance.

Tritium may be analyzed in a separated blood specimen and its content in meat estimated by assuming the same specific activity (pCi ^{3}H per gram of stable hydrogen). It is recommended that wet chemical analyses for tritium, strontium or other beta emitting radionuclides be performed primarily. Because strontium concentrates in the bone, strontium may be measured in non-edible tissue for screening purposes. If the concentrations are very low or non-detectable, no muscle tissue need be analyzed. Because it is difficult to estimate muscle concentrations and dose from consumption of the meat from analysis of non-edible tissue, analysis of strontium in edible tissue samples may be necessary only when analysis of the non-edible portions (e.g., bone) indicates the significant presence of the radionuclide.

C.2.0 SCREENING CONCENTRATION GUIDELINES (SCG) FOR RELEASE OF GAME FOR POSSIBLE HUMAN CONSUMPTION

This section lists possible SCG for release of game for human consumption (see Table C.1. below). The methodology used to develop the values in Table C.1 is explained in the next section. Screening criteria in this Handbook are based on a 25 mrem/year dose constraint, a value consistent with national and international recommendations and past practices. This value provides reasonable assurance that this pathway will not cause the all-sources/all-pathways public dose limit to be exceeded when using a direct measurement approach. Furthermore, the screening concentrations are sufficiently conservative that for most individuals

consuming meat from game, doses will amount to much less than the constraint. It is also noted that records from DOE sites indicate that very few, if any, animals taken on these sites will contain residual radioactive material at these levels. Most contain quantities of radionuclides that are well below constraints. Another important criterion is that the concentration guideline (or other measurable quantity) needs to be ready for practical application in the field. It should be determined if the game in question can be taken by the hunter during the hunt, not days or weeks later. Site-specific values may also be developed using the methods and assumptions described in this Handbook.

If local or regional data on the intake of meat from game are used for estimating doses rather than the data in this document, the methods of collection should be documented and approved by the appropriate DOE field organizations. The use of alternative guidelines should be reported in the ASER together with the data on radionuclide concentrations and estimated radiation dose.

C.2.1 Example for Calculation of Radionuclide Screening Calculation Guidelines

The following example demonstrates how the Radionuclide Screening Calculation Guidelines (SCG) are calculated using an annual dose constraint of 25 mrem and an annual consumption of 100 kg. This method can be used to calculate Radionuclide SCG for radionuclides not included in Table C-1 by substituting the appropriate ingestion dose conversion factor from Table A-1, “Effective Dose Coefficients for Ingested Water” in DOE STD-1196-2011. If other dose conversion factor documents are used (e.g., FGR No. 13), they should be documented and approved by DOE.

TABLE C-1: Radionuclide Screening Concentration Guidelines(SCG)

That Yield a 25 mrem TED for a Meat Intake of 100 Kg/year

Nuclide	Ingestion Dose Coefficient (mrem/pCi intake) (F)	Radionuclide Screening Concentrations Guidelines (pCi/g) (SCG)
Tritium (H-3)	1.69E-07	1.48E+03
Beryllium-7	1.29E-07	1.94E+03
Carbon-14	2.34E-06	1.07E+02
Sodium-22	1.44E-05	1.74E+01
Sodium-24	2.02E-06	1.24E+02
Phosphorus-32	1.25E-05	1.99E+01
Sulfur-35	3.85E-06	6.50E+01
Chlorine-36	4.59E-06	5.45E+01
Chromium-51	1.86E-07	1.34E+03
Manganese-54	3.29E-06	7.59E+01
Iron-55	2.04E-06	1.23E+02
Cobalt-58	3.74E-06	6.69E+01
Iron-59	1.01E-05	2.47E+01
Cobalt-60	2.03E-05	1.23E+01
Nickel-63	7.33E-07	3.41E+02
Copper-64	5.88E-07	4.25E+02
Zinc-65	1.76E-05	1.42E+01
Strontium-89	1.34E-05	1.87E+01
Strontium-90	1.33E-04	1.88E+00
Yttrium-90	1.37E-05	1.83E+01
Zirconium-95	4.66E-06	5.36E+01
Niobium-95	2.78E-06	9.01E+01
Technetium-99	3.33E-06	7.51E+01
Technetium-99^{m}	1.08E-07	2.32E+03
Ruthenium-103	3.48E-06	7.18E+01
Ruthenium-106	3.55E-05	7.05E+00
Antimony-125	5.44E-06	4.60E+01

Nuclide	Ingestion Dose Coefficient (mrem/pCi intake) (F)	Radionuclide Screening Concentrations Guidelines (pCi/g) (SCG)
Iodine-129	4.48E-04	5.58E-01
Iodine-131	1.16E-04	2.16E+00
Tellurium-132	1.98E-05	1.26E+01
Cesium-134	6.92E-05	3.61E+00
Cesium-137	4.92E-05	5.08E+00
Barium-140	1.34E-05	1.86E+01
Lanthanum-140	9.88E-06	2.53E+01
Cerium-144	2.68E-05	9.32E+00
Neodymium-147	5.48E-06	4.57E+01
Promethium-147	1.34E-06	1.86E+02
Europium-154	9.66E-06	2.59E+01
Lead-210	3.77E-03	6.62E-02
Polonium-210	6.48E-03	3.86E-02
Radium-226	1.68E-03	1.49E-01
Radium-228	5.92E-03	4.22E-02
Thorium-230	9.36E-04	2.67E-01
Thorium-232	1.03E-03	2.43E-01
Uranium-232	1.49E-03	1.67E-01
Uranium-234	2.15E-04	1.16E+00
Uranium-235	2.03E-04	1.23E+00
Uranium-238	1.94E-04	1.29E+00
Plutonium-238	9.73E-04	2.57E-01
Plutonium-239	1.07E-03	2.35E-01
Plutonium-240	1.07E-03	2.35E-01
Plutonium-241	1.93E-05	1.30E+01
Plutonium-242	1.01E-03	2.47E-01
Americium-241	8.81E-04	2.84E-01

Cobalt (Co-60):

The ingestion dose factor for Co-60 expressed in Sv/Bq is

$$5.49E-09\,Sv/Bq$$

Multiply by 3.7E+09 to convert from Sv/Bq to mrem/μCi

$$5.49E-09\ \times 3.7E+09 = 2.03E+01\,mrem/\mu Ci$$

Multiply by 1E-06 to convert from μCi to pCi

$$2.03E+01\ mrem/\mu Ci\ \times 1E-06 = 2.03E-05\ mrem/pCi$$

Co-60 Screening Concentration Guideline (SCG)

$$= \frac{25\ mrem\ TED\ (dose\ constraint)}{Ingestion\ Dose\ Factor\ \ mrem/pCi\ \times Intake\ of\ meat\ (g)}$$

$$\frac{25\ mrem}{2.03E-05\ \ mrem/pCi\ \times 1.0E+05g} = 1.2E+01\ \ pCi/g$$

$$Co-60-SCG = 1.2E+01\,pCi/g = 12.3\ \ pCi/g$$

C.2.2 Implementation Considerations and Lessons Learned from DOE Site Monitoring Programs

Monitoring data from DOE ASERs indicates that the primary radionuclides typically detected in the edible portions of game include alpha, beta, and gamma emitting radionuclides such as Pu-239, Sr-90, Cs-137, and tritium. Gamma emitters may be detected using field gamma spectrometers. If the results of analyses of samples from game killed in accidents or hunted by licensed hunters according to state permits confirm the presence of any radionuclide above the screening criteria or dose constraint, game should not be released for human consumption. Dose could also be received from external tissues (e.g., fur, skin) that may include radionuclides that are not likely to be consumed by humans. These radionuclides would likely be an insignificant fraction of the dose from ingestion. Therefore, doses for these media were not calculated.

Estimates of game consumption doses typically reported are generally conservative. For example, one site reported the taking of multiple deer and hogs by a single hunter and reported the potential dose assuming one individual consumed all of the game. Such an assumption is considered extremely conservative and while given the uncertainties in estimating how much of

the game was consumed per individual, it is understandable that one may calculate and present this unrealistic result as a bounding estimate, the extreme conservatism should be noted and a less conservative estimate based on more realistic consumption should be given. Others have combined the dose estimates to the MEI for air pathway and water pathway with the MEI estimate for game consumption to estimate the total MEI dose when it is highly unlikely or even impossible that the same individual could receive the maximum dose from all three pathways. This should be avoided if possible but placed in context if not.

C.3.0 REFERENCES

10 CFR Part 20, Code of Federal Regulations, Title 10, Part 20, *Standards for Protection Against Radiation*.

40 CFR Part 61, *Emission Standards for Hazardous Air Pollutants*.

40 CFR Part 61, Subpart H. *National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities*.

40 CFR Part 190, *Environmental Radiation Protection Standards for Nuclear Power Operations*.

40 CFR Part 191, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*.

40 CFR Part 192, *Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings*.

DOE G 435.1-1, *Implementation Guide for Use with DOE M 435.1-1.* U.S. Department of Energy, Washington, DC, July 9, 1999.

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EPA-520/1-88-20, *Federal Guidance Report No. 11, Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion and Ingestion*, U.S. Environmental Protection Agency, Washington, DC, September 1988.

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