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ENVIRONMENTAL RADIOLOGICAL MONOTORING & SURVEILLANCE - VOL 1 OF 3

Main Category:	Nuclear Engineering
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Course Content:	71 pgs
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NUC-118 EXAM PREVIEW

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Exam Preview:

1. Monitoring and sampling systems should be recalibrated at least annually and routinely checked with known sources to determine that they are consistently functioning properly.
   a. True
   b. False
2. According to the reference material, there are four basic types of liquid effluent sampling systems. Which of the following sampling systems matches the description: samples of effluent streams are taken periodically, composited if desired, and submitted for laboratory analysis?
   a. Continuous sampling
   b. Time proportional sampling
   c. Periodic sampling
   d. Flow proportional sampling
3. The environmental monitoring program updates should not be considered with the potential impact on the overall site budget.
   a. True
   b. False
4. Variability in the flow rate of liquid effluents may be the most significant factor in sample calculations. Liquid effluent flow rates should be measured with an uncertainty of no more than __ percent and recorded.
   a. 5
   b. 10
   c. 15
   d. 20

5. An unshielded in-line monitoring system should be sufficient to quantify the beta-emitting radionuclides in the liquid effluent line, if low ambient dose-rate conditions exist.
    a. True
    b. False
6. According to the reference material, aerosol transport lines should not have sharp bends. Changes in direction should be minimized and be made with radii of curvatures of at least _____ tube diameters and no greater than 10.
    a. 5
    b. 4
    c. 3
    d. 2
7. Using TABLE 4-2. Collection Methods for Specific Radioactive Effluent, which of the following radioactive effluents would be collected using the following method: Ethylene glycol bubbler, silica gel, molecular sieves, and condensers?
    a. Noble Gases
    b. Tritium Oxide
    c. Particulates
    d. Radon
8. 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 inlet should be at a distance at least ___ times the tower horizontal width away from the nearest point on the tower.
    a. 1.5
    b. 2.0
    c. 2.5
    d. 3.0
9. According to the reference material, aerosol transport lines should be flexible and should be electrically grounded to the point where the particles are collected or accumulated.
    a. True
    b. False
10. Which of the following DOE supporting documents provides practical screening and analysis methods that can be used to demonstrate compliance with the DOE O 458.1 requirements for protection of biota?
    a. DOE O 232.2
    b. DOE-STD-1196-2011
    c. DOE O 231.1B
    d. DOE-STD-1153-2002

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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.

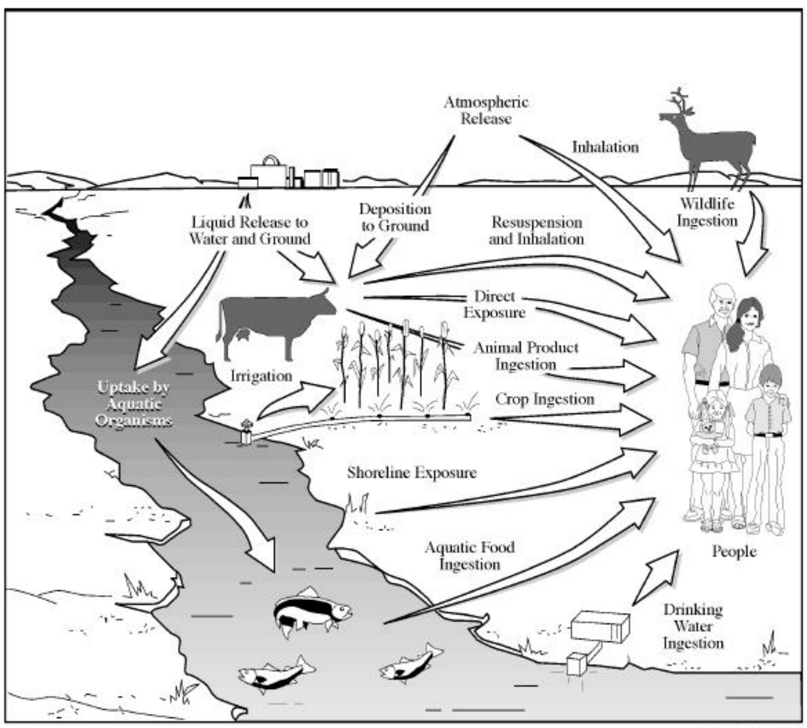

FIGURE 2-1. Potential Radiation Exposure Pathways to Man

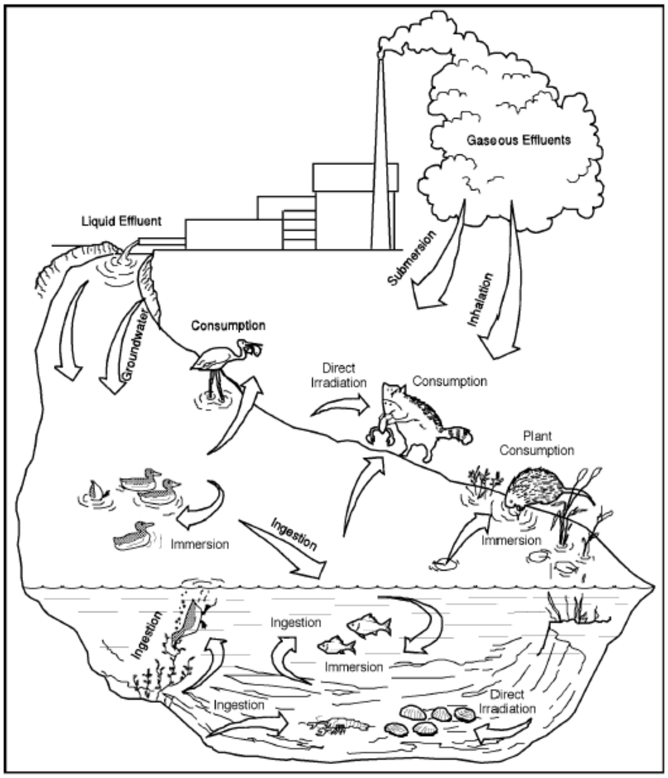

FIGURE 2-2. Potential Radiation Exposure Pathways to Biota

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

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

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.

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-

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[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 *or* 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

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[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 σ_{Θ}, 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.

12 REFERENCES

1. Title 42 U.S.C. 2011, et seq., *Atomic Energy Act of 1954*, as amended.

2. Title 42 U.S.C. 7401 et seq., *Clean Air Act*, as amended.

3. 40 CFR Part 60, Appendix A, *Test Methods.*

4. 40 CFR Part 61, *National Emission Standards for Hazardous Air Pollutants*.

5. 40 CFR Part 61, Subpart H. *National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities*.

6. 40 CFR Part 61, Subpart I, *National Emission Standards for Radionuclide Emissions from Federal Facilities Other Than Nuclear Regulatory Commission Licensees and Not Covered by Subpart H*.

7. 40 CFR Part 61, Appendix B, *Method 114, Test Methods for Measuring Radionuclide Emissions from Stationary Sources*.

8. 40 CFR Part 61, Appendix D, *Methods for Estimating Radionuclide Emissions*.

9. 40 CFR Part 61, Appendix E, *Compliance Procedures Methods for Determining Compliance with Subpart I.*

10. 40 CFR Part 192, *Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings*.

11. Allen, D.E., "Determination of MDA for a Two Count Method for Stripping Short-Lived Activity Out of an Air Sample," *Health Physics,* 73:512-517, 1997.

12. American National Standards Institute (ANSI), *Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities,* ANSI N13.1-1969, American National Standards Institute, New York, NY, 1970 (Reaffirmed 1982).

13. American National Standards Institute (ANSI), *Performance Criteria for Instrumentation Used for Inplant Plutonium Monitoring,* ANSI N317-1980, American National Standards Institute, New York, NY, 1980.

14. American National Standards Institute (ANSI), *Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities,*

ANSI/HPS N13.1-1999, American National Standards Institute and Health Physics Society, New York, NY, 1999 (Reaffirmed in 2011).

15. American National Standards Institute (ANSI), *Specification and Performance of Onsite Instrumentation for Continuously Monitoring Radioactivity in Effluents*, ANSI N42.18-2004, American National Standards Institute, New York, NY, 2004.

16. American National Standards Institute/ American Society for Quality (ANSI/ASQ), *Quality Systems for Environmental Data and Technology Programs: Requirements with Guidance for Use*, ANSI/ASQ E4-2004, American National Standards Institute, New York, NY, 2004.

17. American National Standards Institute (ANSI), *Determining Meteorological Information at Nuclear Facilities*, ANSI/ANS-3.11-2005; R2010, American National Standards Institute and American Nuclear Society, Washington, DC, 2005 (Reaffirmed in 2010).

18. American Public Health Association (APHA), *Methods of Air Sampling and Analysis,* 3rd ed., American Public Health Association, New York, NY, 1988.

19. American Public Health Association (APHA), *Standard Methods for the Examination of Water and Wastewater* (22nd ed.), E.W. Rice, R.B. Baird, A.D. Eaton and L.S. Clesceri (Eds.), American Public Health Association; American Water Works Association; and Water Environment Federation, Washington, DC, 2012.

20. American Society for Testing and Materials (ASTM), *Standard Practice for Calibration of Type S Pitot Tubes,* ASTM Standard D3796-90(2004), ASTM International, West Conshohocken, PA, 2004, www.astm.org.

21. American Society for Testing and Materials (ASTM), *Standard Test Method for Average Velocity in a Duct (Pitot Tube Method),* ASTM Standard D3154-00(2006), ASTM International, West Conshohocken, PA, 2006, www.astm.org.

22. American Society for Testing and Materials (ASTM), *Standard Test Method for Average Velocity in a Duct Using a Thermal Anemometer,* ASTM Standard D3464-96(2007), ASTM International, West Conshohocken, PA, 2007, www.astm.org.

23. American Society for Testing and Materials (ASTM), *Standard Practice for Sampling Surface Soils for Radionuclides,* ASTM Standard C998-05(2010)e1, ASTM International, West Conshohocken, PA, 2010a, www.astm.org.

24. American Society for Testing and Materials (ASTM), *Standard Practice for Soil Sample Preparation for the Determination of Radionuclides*, ASTM Standard C999-05(2010)e1, ASTM International, West Conshohocken, PA, 2010b, www.astm.org.

25. American Society for Testing and Materials (ASTM), *Standard Practice for Rotameter Calibration,* ASTM Standard D3195/D3195M-10, ASTM International, West Conshohocken, PA, 2010, www.astm.org.

26. American Society for Testing and Materials (ASTM). *Standard Test Method for Radiochemical Determination of Plutonium in Soil by Alpha Spectroscopy*. ASTM Standard C1001. ASTM International, West Conshohocken, PA, 2011, www.astm.org.

27. Anspaugh, L.R., J.J. Koranda, W.L. Robison, and J.R. Martin, *The Dose to Man Via Food-Chain Transfer Resulting from Exposure to Tritiated Water Vapor in Tritium*, Messenger Graphics, Las Vegas, NV, 1973.

28. Arndt, M.F. and L. West, "A Study of the Factors Affecting the Gross Alpha Measurement, and a Radiochemical Analysis of some Groundwater Samples from the State of Wisconsin Exhibiting an Elevated Gross Alpha Activity," Michael F. Arndt, Ph.D., Assistant Researcher, Radiochemistry Unit and Inorganic Chemistry Unit, Wisconsin State Laboratory of Hygiene, Lynn West, Radiochemistry Unit, Wisconsin State Laboratory of Hygiene, http://digital.library.wisc.edu/1711.dl/EcoNatRes.ArndtStudy http://www.slh.wisc.edu/ehd/radiochem/dnr_reports/dnrfinal.pdf, 2004.

29. Barnett, J.M. and W.E. Davis, "Six Methods to Assess Potential Radioactive Air Emissions From a Stack," *Health Physics*, 71(5):773-778, 1996.

30. Barnett, J.M., V.I. Cullinan, D.S. Barnett, T.L.T. Trang-Le, M. Bliss, L.R. Greenwood, and M.Y. Ballinger, "Results of a Self-Absorption Study on the Versapor 3000 47-mm Filters for Radioactive Particulate Air Stack Sampling," *Health Physics,* 97(5): S161-S168, 2009.

31. Bellamy, R.R., "Elemental Iodine and Methyl Iodide Adsorption on Activated Charcoal at Low Concentrations," *Nuclear Safety*, Volume 1516, pages 711-723, U.S. Atomic Energy Commission Technical Information Center, Oak Ridge, TN, 1974.

32. Beres, D.A., *The Clean Air Act Assessment Package – 1988 (CAP-88): A Dose and Risk Assessment Methodology for Radionuclide Emissions to Air*, U.S. Environmental Protection Agency, Office of Radiation Programs, Washington DC, 1990.

33. Briggs, G.A., “Plume Rise and Buoyancy Effects,” in: D. Randerson (Ed.), *Atmospheric Science and Power Production*, DOE/TIC-27601, Technical Information Center, U.S. Department of Energy, Oak Ridge, TN, 1984.

34. Denham, D.H., “Environmental Radiological Surveillance in Perspective: The Relative Importance of Environmental Media as a Function of Effluent Pathway and Radionuclides,” *Health Physics,* 36: 273-281, 1979.

35. Denham, D.H., D.A. Waite, and J.P. Corley, *Summary of Selected AEC Contractor Environmental Surveillance Techniques and Capabilities,* BNWLB-384, Pacific Northwest Laboratory, Richland, WA, 1974.

36. Department of Defense (DoD) and Department of Energy (DOE), *Consolidated Quality Systems Manual (QSM) for Environmental Laboratories*, 2013.

37. Department of Energy (DOE), *A Guide for Environmental Radiological Surveillance at U.S. Department of Energy Installations*, DOE/EP-0023, Washington, DC, 1981.

38. Department of Energy (DOE), *Radiological and Environmental Sciences Laboratory, Analytical Chemistry Branch Procedures Manual,* DOE/IDO-12096, 1982.

39. Department of Energy (DOE), *Enewetak Radiological Support Project- Final Report,* NVO-213, Nevada Operations Office, Las Vegas, NV, 1982.

40. Department of Energy (DOE), *A Guide for Effluent Radiological Measurements at DOE Installations,* DOE/EP-0096, Washington, DC, 1983.

41. Department of Energy (DOE), *Procedures for Sampling Radium-Contaminated Soils,* Grand Junction Projects Office, Colorado, GJ/TMC-13 (UC-70A), 1985.

42. Department of Energy (DOE), *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*, DOE/EH-0173T, Washington, DC, 1991.

43. Department of Energy (DOE), Radiation Protection of the Public and the Environment, DOE 5400.5, Change 2, Washington, DC, 1993.

44. Department of Energy (DOE), U.S. Department of Energy and U.S. Environmental Protection Agency, *Memorandum of Understanding Between the U.S. Environmental Protection Agency 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 and T,* joint DOE/EPA agreement, 1995.

45. Department of Energy (DOE), *Radioactive Waste Management*, DOE O 435.1 Chg 1, Washington, DC, 2001.

46. Department of Energy (DOE), *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*, DOE STD-1153-2002, Washington, DC, 2002a.

47. Department of Energy (DOE), *Performance Analysis of the Environmental Monitoring, Surveillance, and Control Programs within the U.S. Department of Energy*, Office of Independent Oversight and Performance Assurance, Washington, DC, 2002b.

48. Department of Energy (DOE), *Comprehensive Emergency Management System*, DOE O 151.1C, Washington, DC, 2005.

49. Department of Energy (DOE), Radiological Control, DOE-STD-1098-2008, Washington DC, 2008.

50. Department of Energy (DOE), *Radiation Protection of the Public and the Environment*, DOE O 458.1, Washington, DC, February 11, 2011.

51. Department of Energy (DOE), *Derived Concentration Technical Standard*, DOE-STD-1196-2011, Washington, DC, April 2011.

52. Department of Energy (DOE), *Quality Assurance,* DOE O 414.1D, Washington, DC, April 25, 2011.

53. Department of Energy (DOE), *Environment, Safety and Health Reporting*, DOE O 231.1B, Washington, DC, June 27, 2011.

54. Department of Energy (DOE), *Quality Assurance Program Guide*, DOE G 414.1-2B, Washington, DC, August 16, 2011.

55. Department of Energy (DOE), *Occurrence Reporting and Processing of Operations Information*, DOE O 232.2, Washington, DC, August 30, 2011.

56. Department of Energy (DOE), *Records Management Program*, DOE O 243.1B, Washington, DC, 2013.

57. dePlanque, G., T.F. Gesell, and K. Becker, "Second International Inter-comparison of Environmental Dosimeters Under Field and Laboratory Conditions," In *Proceedings of the Tenth Midyear Topical Symposium of the Health Physics Society*, pages 555-574, Rensselaer Polytechnic Institute, Troy, NY, 1976.

58. Eastern Research Group, *Methods for Estimating Fugitive Air Emissions of Radionuclides from Diffuse Sources at DOE Facilities*, Report prepared for the U.S. Environmental Protection Agency, http://www.epa.gov/radiation/neshaps/pubs.html), 2004.

59. Eisenbud, M. and T. Gesell, *Environmental Radioactivity*, Academic Press, 1997.

60. Environmental Protection Agency (EPA), *Environmental Radioactivity Surveillance Guide,* EPA ORP/SID 72-2, Office of Radiation Programs, Washington, DC, 1972.

61. Environmental Protection Agency (EPA), *Prescribed Procedures for Measurement of Radioactivity in Drinking Water*, EPA 600/4-80-032, Environmental Monitoring and Support Laboratory, Cincinnati, OH, 1980a.

62. Environmental Protection Agency (EPA), Method 901.1 (modified), *Gamma Emitting Radionuclides in Drinking Water*, EPA 600/4/80.032, Environmental Monitoring and Support Laboratory, Cincinnati, OH, 1980b.

63. Environmental Protection Agency (EPA), *Methods for Chemical Analysis of Water and Wastes,* EPA-600/4-79/020, Environmental Monitoring and Support Laboratory, Cincinnati, OH, 1983.

64. Environmental Protection Agency (EPA), Turner, J., M. Branscome, R. Chessin, A. Damle, and R. Kameth, *Method for Estimating Fugitive Particulate Emissions from Hazardous Waste Sites*, EPA-600/2-87/066, Washington, DC, 1987.

65. Environmental Protection Agency (EPA), *User's Guide for CAP88-PC Version 1.0*, EPA 402-B-92-001, Las Vegas, NV, 1992.

66. Environmental Protection Agency (EPA), Federal Guidance Report No. 13, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*, EPA 402-R-99-001, Washington DC, 1999.

67. Environmental Protection Agency (EPA), *Meteorological Monitoring Guidance for Regulatory Modeling Applications*, EPA 454/R-99-005, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 2000a.

68. Environmental Protection Agency (EPA), *Updated User's Guide for CAP88-PC, Version 2.0*, EPA 402-R-00-004, Environmental Protection Agency, Office of Radiation and Indoor Air, Washington DC, 2000b.

69. Environmental Protection Agency, *Guidance for the Data Quality Objectives Process*, QA/G-4. Washington, DC, 2000c.

70. Environmental Protection Agency, *Guidance for Data Quality Assessment*, QA/G-9. Washington, DC, 2000d.

71. Environmental Protection Agency (EPA), Radionuclide NESHAPs Subpart H Inspection Manual, available at: http://www.epa.gov/radiation/docs/neshaps/nshpinspman_092702.pdf, 2002a.

72. Environmental Protection Agency (EPA), *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites*. EPA 540-R-01-003/OSWER 9285.7-41, 2002b.

73. Environmental Protection Agency (EPA), *Data Quality Assessment: Statistical Methods for Practitioners, EPA QA/G-9S*. EPA/240/B-06/003, Office of Environmental Information, Washington, DC, 2006.

74. Environmental Protection Agency (EPA), *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities: Unified Guidance*, EPA 530/R-09-007, 2009.

75. Environmental Protection Agency (EPA), *ProUCL Version 5.0.00 User Guide - Statistical Software for Environmental Applications for Data Sets with and without Nondetect Observations*. EPA/600/R-07/041, Office of Research and Development, Washington, DC, 2013a.

76. Environmental Protection Agency (EPA), *ProUCL Version 5.0.00 Technical Guide - Statistical Software for Environmental Applications for Data Sets with and without Nondetect Observations*. EPA/600/R-07/041, Office of Research and Development, Washington, DC, 2013b.

77. Gifford, F.A., "Turbulent Diffusion-Typing Schemes: A Review," *Nuclear Safety* 17(1):68-86, 1976.

78. Gilbert, R.O., *Statistical Methods for Environmental Pollution Monitoring,* Van Nostrand Reinhold Co., New York, NY, 1987.

79. Gilbert, R.O. and R.R. Kinnison, "Statistical Methods for Estimating the Mean and Variance from Radionuclide Data Sets Containing Negative, Unreported or Less-Than Values," *Health Physics,* 40: 377-390, 1981.

80. Gilbert, T.L., C. Yu, Y.C. Yuan, A.J. Zielen, M.J. Jusko, and A. Wallo III., *A Manual for Implementing Residual Radioactive Material Guidelines.* ANL/ES-160, DOE/CH/8901, Argonne National Laboratory, Argonne, IL, 1989.

81. Griffin, W.R., J.A. Cochran, and A.A. Bertuccio, *A Sampler for Nonaqueous Tritium Gases*, U.S. Environmental Protection Agency, Office of Radiation Programs, Winchester, MA, 1972.

82. Grossman, R.F. and R.W. Holloway, "Concentrations of Krypton-85 near the Nevada Test Site," *Environmental Science and Technology*. 19:1128-1131, 1985.

83. Guthrie, E.B., N.C. Shen, and B.B. Bandong, *Isotope Exchange and Fractionation Corrections for Extraction of Tritiated Water in Silica Gel by Freeze-Drying Techniques,* Lawrence Livermore National Laboratory Report UCRL-ID-148610, 2001.

84. Hanna, S.R., G.A. Briggs, J. Deardorff, B.A. Egan, F.A. Gifford, and F. Pasquill, "AMS Workshop on Stability Classification Schemes and Sigma Curves – Summary of Classification Recommendations," *Bulletin of the American Meteorological Society* 58:1305-1309, 1977.

85. HASL-195, *The Radiation Field in Air Due to Distributed Gamma-Ray Sources in the Ground,* New York Operations Office (Atomic Energy Commission) New York Health and Safety Laboratory, New York, NY, 1968.