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FUNCTIONAL REQUIREMENTS DOCUMENT FOR MEASURING EMISSIONS OF AIRBORNE RADIOACTIVE MATERIALS

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SUMMARY

This document states the general functional requirements for systems and procedures for measuring emissions of airborne radioactive materials from facilities administered by the Westinghouse Hanford Company (WHC).

The following issues are addressed in this document:

- definition of the program objectives
- selection of the overall approach to collecting the samples
- sampling equipment design
- sampling equipment maintenance and quality assurance issues.

The following issues are not addressed in this document:

- air sampling in work areas or containments
- selection of specific on-line sample monitoring instrumentation
- analyzing collected samples
- reporting and interpreting results.

The document provides equipment design guidance that is performance based rather than prescriptive. Locations from which samples are obtained should exhibit mixing of the contaminants with the airstream and acceptable air flow characteristics. Sample collection equipment and effluent and sample flow elements should meet defined performance standards. Quality control and assurance requirements specific to sample collection, equipment inspection, and calibration are presented. Key sample collection performance requirements are summarized in Section 5.4.

The intent of this document is to assist WHC in demonstrating a high quality of air emission measurements with verified system performance based on documented system design, testing, inspection, and maintenance.

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FIGURE

TABLES

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this document is to set forth guidelines and performance-based criteria for the design and use of systems for the measurement of airborne radioactive materials from ducts or stacks under the administration of the Westinghouse Hanford Company (WHC). The guidelines and criteria are presented in the following order:

- setting objectives for sampling and monitoring programs (Section 2.0)
- selecting the design approach (Section 2.0)
- characterizing the sampling environment (Section 3.1)
- determining the appropriate number and placement of sampling locations in ducts and stacks (Section 3.0)
- measuring the effluent flowrate (Section 4.1)
- extracting the sample from the flowing airstream (Sections 4.2 and 4.4)
- transporting the sample to the collection or monitoring device (Sections 4.3 and 4.4)
- selecting the sample collection device (Sections 4.5 and 4.6)
- performing quality control and quality assurance (Section 5.0).

This document does not cover the following details:

- determining the appropriate number and placement of sampling locations in work areas or containments
- selecting specific instrumentation for sample collection or on-line monitoring of collected samples

- analyzing collected samples
- reporting and interpreting results.

1.2 RELATIONSHIP TO OTHER REQUIREMENTS

Internal, U.S. Department of Energy (DOE), U.S. Environmental Protection Agency (EPA), and Washington Administrative Code guidelines and regulations govern the measurement of radionuclide air emissions at WHC. Some of the key documents are as follows:

- WHC-CM-7-5, *Environmental Compliance Manual*
- DOE/EH-0173T, *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*
- 40 CFR 61, Subpart H, "National Emissions Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities"
- WAC 173-480, "Ambient Air Quality Standards and Emission Limits for Radionuclides."

Additionally, the following national consensus standards provide valuable guidance:

- ANSI N13.1 (1969, Reaffirmed 1982), "Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities," which provides design guidance for air sampling hardware in the workplace and environment. Much of the methodology is dated, but the general guidelines are still applicable. This standard is currently in the revision process.
- ANSI N13.2 (1969, Reaffirmed 1982), "Administrative Practices in Radiation Monitoring," which briefly outlines administrative practices for a program to monitor ionizing radiation. The program includes monitoring airborne radioactivity in the workplace and the environment.
- ANSI N42.18 (1980, Reaffirmed 1991, formerly ANSI N13.10), "Specification and Performance of On-site Instrumentation for Continuously Monitoring Radioactivity in Effluents," which provides performance criteria for instrumentation used to monitor radioactivity in liquid and airborne effluent streams. Brief discussions are included of how effluent stream characteristics, operating environment factors, and standards and regulations affect the

selection of instrumentation for effluent monitoring systems. This standard also addresses dynamic range; sensitivity; accuracy; precision, physical, mechanical, and electrical requirements; and detection capability for monitoring radioactivity in effluents. Testing procedures are not included.

1.3 APPLICATION OF THE DOCUMENT

The requirements presented in this document are intended for sampling programs conducted for compliance with 40 CFR 61, Subpart H. However, the information presented here may be useful in the design of sampling systems with more limited objectives, such as process control. When designing systems with objectives other than regulatory compliance, the designer should exercise professional judgement in the application of these requirements and should explicitly document the sampling objectives and the reasons for any exceptions to the requirements of this document.

2.0 OBJECTIVES AND APPROACHES FOR SAMPLING PROGRAMS

2.1 SELECTING THE OBJECTIVE AND DESIGN APPROACH

There are many possible objectives for an effluent sampling program. Likewise, there can be a number of approaches taken to achieve a given objective. The rationale in choosing the objective and approach is required to be well documented. A list of some air sampling objectives follows:

- meet regulatory requirements
- assess the need for a permanent sampling or monitoring program
- provide the supporting documentation of working environments that may be required by regulatory bodies
- assist in supporting or refuting claims of radiation injury by workers or others
- call attention to deteriorating equipment, faulty processes, or other conditions leading to loss of effective control of airborne materials in an operation, and to subsequently determine the effectiveness of corrective measures
- evaluate the efficiency of current plant operation, establish a materials balance for process control, or evaluate the operation of new equipment or procedures
- measure the release of radioactive materials to the environment through source sampling
- assist in evaluating and controlling exposure of the radiation worker at the installation
- ensure that people in the surrounding environment are not exposed to levels of airborne materials exceeding established values
- help assess the possible consequences of non-routine incidents and to help in the selection of appropriate corrective action. This can include the integration of radioactive contamination released to the environment over various time periods.

Many objectives can be identified for stack and duct sampling. Design of a technically defensible extractive sampling program (i.e., removing a

portion of the effluent from the stream for subsequent detection or analysis) requires a clear understanding of these objectives. Many, but not all, objectives are related to worker or environmental protection and regulatory compliance. Other objectives are related to internal management requirements for process control or material balance considerations. Failure to understand the sampling objectives can lead to inappropriate or ineffective system design and implementation. For example, if exploratory sampling data are required to evaluate an uncharacterized or poorly characterized source, it may be appropriate to begin the evaluation using rugged portable equipment. Immediate use of highly sensitive or specialized equipment may lead to costly equipment damage or invalid results. At the same time, if long-term, repetitive sampling and monitoring data are required, efforts should be made to design systems with long-term reliability and ease of operation. The design and implementation of a sampling and monitoring plan for the stacks in a particular facility invariably involve matters of engineering judgement in which conflicting demands arising from considerations of obtaining the most accurate sample, worker safety, physical plant constraints, and other factors have to be balanced.

The various objectives for sampling are not (or need not be) mutually exclusive in most stack monitoring circumstances. A sampling system designed to meet one objective may meet other objectives as well. Regulatory requirements, however, are usually the overriding factor in the design of a sampling system and, accordingly, are the basis for the most appropriate approach to designing a stack sampling and monitoring program.

Multiple factors enter into the design of a sampling program for a facility, including the frequency, duration, and flowrate of sampling, and whether the sample is continuously monitored during sampling by a real-time detector. In most cases a decision regarding these elements is a compromise between ideal values and those which provide safety yet are technically, economically, and conveniently achieved, while at the same time allowing regulatory requirements to be met.

2.2 CONSIDERATIONS FOR A GRADED APPROACH TO SAMPLING

The nature of the operation or process that creates the potential for airborne radioactive material releases may influence the sampling program design and specific response to regulatory requirements. An operation or process being instituted for the first time may require more frequent and extensive sampling than one that is well understood. In addition, a program that requires more comprehensive monitoring is needed for a facility with an inventory of radioactive materials constituting a greater hazard than a facility handling a less hazardous inventory.

A graded approach to establishing a sampling and monitoring program should be undertaken. For example, a graded approach to sampling program design could be based on the potential that given facility stacks have for contributing to offsite dose, which depends on whether the radioactive source materials being handled are easily dispersed (by virtue of being in gaseous form or finely divided powders), and also depends on the inherent radiological hazard. A facility stack that has the potential for discharging airborne radionuclides in quantities that could cause radiological doses to a member of the public in excess of a small percentage of Federal dose limits would be expected to be monitored continuously with a sampler fitted with a real-time detector or sampled continuously. The decision to utilize real-time monitoring in addition to continuous record sampling (rather than using only continuous record sampling) would be prompted by stacks that present the potential for radiological doses in excess of the Federal dose limits. Stacks that have the potential for release of radionuclides to the air in quantities that would contribute less than a small percentage of the Federal dose limits would require only periodic confirmatory measurements. A final category would consist of non-radiological stacks for which no radioactive air emission sampling is required but that would be subject to periodic review to verify that facility uses have not changed from year to year.

Thus a graded, four-tier program could be developed in which increasingly more sampling and monitoring resources are directed at stacks that have

the greater potential for causing public doses in excess of regulatory limits. Specific Federal laws appropriate to the type of nuclear facility stacks identified should be consulted to determine the appropriate basis for determining the potential for release and for dose limit thresholds for each tier. An example of a structure for a graded approach to determining required monitoring of stack emission points is shown in Table 2.1. This approach employs categories of Potential Effective Dose Equivalent (PEDE, the dose to the member of the public nearest a facility from an emission that could occur with no effluent attenuation or filtration devices present at the facility).

As Table 2.1 suggests, a survey must be conducted of the potential sources of radionuclide emissions at a nuclear facility to determine 1) the

TABLE 2.1. Example Graded Approach to Application of Sampling and Monitoring

Potential Effective Dose Equivalent Category	Required Monitoring and Sample Analysis Procedures	Potential Effective Dose Equivalent Range (mrem/y)
1	Continuous extractive sampling for a record of emissions and in-line, real-time monitoring with alarm capability; consideration of separate accident monitoring system	>1
2	Continuous extractive sampling for record of emissions, with retrospective, off-line periodic analysis	>0.1 and ≤1
3	Periodic confirmatory extractive sampling and off-line analysis	>0.001 and ≤0.1
4	Annual administrative review of facility uses to confirm absence of radioactive materials in forms and quantities not conforming to prescribed specifications and limits	≤0.001

form and radiological inventory of materials being handled there, 2) the potential extent of airborne dispersal of this inventory and resultant concentrations at the facility boundary in the event of accidental loss of filtration and control of stack emissions, 3) the potential effective dose equivalent that would be received by a member of the public if such a release occurs, and 4) a comparison of potential doses to appropriate regulatory limits. On the basis of these analyses, the administrator can plan a graded application of sampling and monitoring to all facility stacks. It should be clear that no one plan will be appropriate for all facilities, and that the dose limit criteria proposed in Table 2.1 may not be correct for all applications. They exemplify how a dose limit standard can be associated with a graded approach to monitoring and sampling planning. Once again, practical considerations involving such additional factors as worker safety and facility constraints will enter into the decision.

To estimate potential emissions and resultant public exposures for purposes of developing a sampling and monitoring program using a graded approach, facility administrators must consider that under extremely adverse conditions the facility effluent controls (e.g., filtration and gas holdup) will not be effective. It would be inappropriate, therefore, to use actual measured or reported emissions from a stack as the basis for planning a sampling and monitoring program. To estimate the potential emissions, it must be assumed that all emission controls are ineffective; therefore, the limiting factors determining the source term are the inventory and the physical form of the radionuclides being handled. A simple estimation method is to multiply the maximum expected radioactive material inventory by a factor that depends on the physical state of the material. This can be input to a meteorological dispersion and dose estimation code for purposes of generating annual potential dose effective equivalent rates to a maximally exposed individual at the facility boundary. Table 2.2 provides a guide to aid the estimation process. Facility

TABLE 2.2. Generalized Strategy for Estimating Emissions for Purposes of Designing an Appropriate Sampling and Monitoring Program

Physical Form or State of Radioactive Inventory Available to Release	Multiplicative Factor to be Used in Estimating Atmospheric Emissions
Gases, condensible and non-condensible, and solids heated to high enough temperature to be in a liquid or volatilized state	1.0
Liquids or particulate solids	0.001
Solids (other than above states)	1 E-6

owners and operators should be aware that this procedure may be subject to Federal regulation that could supersede the proposed strategy and specify particular dose models.

In circumstances where the source term consists of a mixture of radionuclides, the radionuclides that contribute 10% or more to the potential effective dose equivalent from that source should be identified.

2.3 CONSIDERATIONS FOR SAMPLING DIFFERENT FORMS OF CONTAMINANTS

When designing the sampling and monitoring systems for a facility, particular attention must be given to the potential interactions between the ventilation components and the sampling system (probe, transport line, and sample collector). These interactions depend on the physical and chemical form of the radioactive constituents.

2.3.1 Sampling for Particles

A representative or valid sample of radiological effluents containing particles should have the same radiochemical and physical composition as the effluent. The sampler must not unduly fractionate by particle size or in other ways distort the physical and chemical properties of the particulate

radioactive constituents. Particular attention must be given to the design of the sampling probe inlet and transport line so that excessive sample loss and discrimination between particles of various sizes are minimized. Detailed particulate sampler and transport line design guidance is provided in Section 4.0.

In many cases, studies may be necessary to establish the size distribution and chemical nature of airborne particulates in an effluent as an aid to the design. Changes in the nature of effluent components must be anticipated with changes in operations, and the possibility that sampling equipment modifications would be required must be kept in mind.

The sampling and monitoring system shall be designed so that emissions occurring under accidental or off-normal conditions can be adequately sampled and detected. This is especially critical when the effluent is filtered before discharge. Although the particle size most likely to penetrate HEPA (high efficiency particulate air) filters is approximately 0.3 μm diameter, it is erroneous to assume that the sampling system need only be designed for sub-micrometer particles. Sub-micrometer particles essentially behave as gases in airborne effluents; therefore, distortions in the sampling process from inertial effects would not be expected to be a concern with such samples. However, when accidental or off-normal conditions are considered, a wide range of particle sizes must be included in the design, including particles well into the inertial size range.

The off-normal case might include situations where filter seals and cracks in filter frames resulting from poor installation or sub-standard materials allow small quantities of larger size particles to leak into the effluent stream. Off-normal conditions are characterized by chronic, low-level releases involving particles in size ranges much larger than the norm. The accident case involves failures of potentially much greater consequence with high radionuclide concentrations in the effluent. In either case, a polydisperse aerosol (an aerosol with a range of particle sizes) can be expected. But the accident case is much harder to characterize in advance

because changes in effluent discharge rate, and added dusts, smokes, and debris may be expected. It should be noted, however, that particles greater than about 100 μm would not be expected to occur in large numbers in stack effluent because of gravitational settling effects during transport in the accident environment. Transport of such large particles in extractive sampling lines is exceedingly inefficient or non-existent; therefore, there are upper bounds to particle sizes that need to be evaluated. It is important, then, to use modeling tools like those discussed in Section 4.3 and to understand the expected performance of any proposed sampling system under a variety of conditions.

The particular sample extraction system design chosen to supply aerosol samples to either a continuous air monitor or an in-line sample filter (or both) should be designed and evaluated to meet minimum performance objectives under normal, off-normal, and accident conditions with respect to efficiency of particle transport to the filter, bias with respect to size or kind of particle, and allowable total random error. Both computational modeling tools and aerosol challenge tests would be appropriate to consider in these endeavors. Practical objectives for each of these categories will include many factors in addition to the central concern for providing an unbiased, error-free sample of the effluent discharge and, hence, should reflect a documented process of optimization.

A record sample is collected with a system intended to minimize sample loss or bias from complex sample transport line design or from real-time detector chamber design. Consideration should be given to the feasibility of collecting the record sample by means of an in-line sampler mounted directly in the stack flow rather than using an extractive system.

A continuous air monitor (CAM) sample is obtained to enable near real-time detection of radionuclides in the effluent to indicate a loss of control in a process. It is usually desirable to obtain a sample containing as much of the largest size particle fraction as is feasible because of the increased activity associated with those large particles (see Subsection 2.3.2 for what

is meant by "large"). However, if there are large quantities of inert large particles along with the radioactive particles, there may be a disadvantage to optimizing collection of large particles because of sample burial and radiation attenuation effects.

2.3.2 Concerns for Large Particles

The guidance presented in this document is primarily directed to sampling particles that pose inhalation risks to people. Thus, the particle sizes of major concern are generally less than or equal to 10-μm aerodynamic equivalent diameter (AED, the diameter of a spherical unit density particle with the same aerodynamic characteristics as the actual particle, i.e., settling velocity, in calm air). If there is a process or source that can produce aerosolized particles much larger than these sizes, special sampling apparatus should be designed for use in ductwork near the process. The performance of such apparatus must be verified for the range of anticipated particle sizes and sampling conditions (e.g., air velocity and temperature). The use of HEPA filtration upstream of the sampling location does not eliminate all concerns for large particles. For example, radioactive vapors or gases that may penetrate the filtration can later deposit on stack or duct walls and become incorporated into surface layers, corrosion, or rust. Flaking or shedding of these layers may lead to the release of large radioactive particles that may go undetected by sampling systems that are optimized for collection of small particles. Alternate approaches may involve the periodic use of impaction plates or real-time aerosol detectors to provide timely detection of large particle releases.

2.3.3 Sampling Condensible Vapors or Reactive Gases

The presence of radioactive air contaminants in the form of condensible vapors or reactive gases, such as certain forms of radioiodine, in the effluent stream creates a potential for serious distortions in the sample if precautions are not taken in the design and operation of the sampling system. Long lengths of transport line and temperature changes in the line must be

avoided. The inner surfaces of the sampling probe and transport line may need to be composed of non-reactive coatings to minimize surface interactions with the sample. The possibility for conversion of a portion of the sample by chemical transformations induced by the sample transport process, such as conversion of tritium gas into tritiated water, should be understood and accounted for in the sampling system design. Conditioning the sample itself may be necessary, such as deliberately changing the temperature or purposefully diluting the sample with a carrier gas. The sampling site or nearby location must accommodate the equipment necessary for analysis or conditioning to decrease the length of sampling lines. This may further require that the location accommodate shielding, air conditioning, easy access, stable electrical supply, and low levels of vibration. The presence of non-radioactive constituents that could undergo phase changes that could cause loss or distortion of the sample, such as the condensation of water vapor, should also be taken into account in sample system design. Further discussion of special considerations related to sampling vapors and condensible gases is found in Section 4.0.

2.3.4 Sampling Non-condensible Gases

If the radioactive contaminant in the effluent stream is a non-condensible, non-reactive gas such as krypton-85, then the concerns to avoid very long transport lines with many bends and horizontal sections, and chemical or phase change interactions induced by the transport line could be relaxed, unless there is a possibility of interactions between the radiological and non-radiological constituents in the sample that could bring about a loss of sample.

2.4 SELECTING APPROPRIATE DETECTION LIMITS AND ACTION LEVELS

An action level is defined as an air concentration at which action is required to be performed. The type of action may vary from producing a record to a physical response that alters the conditions. The consequences of responding require that measurement of the signal at the action level must

be sufficiently accurate to allow response. This means that data quality requirements must be based on sampling representativeness, instrument precision, and method accuracy. It is necessary to perform an uncertainty analysis to ensure acceptable accuracy.

2.4.1 Uncertainty Analysis

A signal (or a measured emission in the context of this document) is detected as a difference, D, of the signal plus background, S, from the mean background, B. The uncertainty of this difference is the sum in quadrature of the uncertainties of B and S. If B and S are obtained in the same manner and are approximately the same magnitude, then the uncertainties are nearly equal and the uncertainty of the difference is

$$\sigma_D = (\sigma_S^2 + \sigma_B^2)^{1/2} \cong 1.4\sigma_B \qquad (1)$$

The relative uncertainty of the difference from background at the detection limit depends on the definition used for the detection limit. If a difference is considered detected when its value is equal to twice the uncertainty of the background, then the relative uncertainty of the difference is

$$\sigma_{D_R} = \frac{\sigma_D}{D} = \frac{1.4\sigma_B}{2\sigma_B} = 0.7 \qquad (2)$$

The uncertainty of the signal or background is the propagated uncertainty of such factors as the extraction, transport, collection, and analysis of the sample. Some of these factors are biases, but the measurement of the bias has an uncertainty associated with it. The propagated uncertainty

associated with the various factors must be summed as the squares of the ratios because the measured emission signal, S, can be represented as

$$S = \frac{F \bullet t}{C_e \bullet D_e \bullet T_e} \tag{3}$$

where F is the flowrate

t is the time of collection

C_e is the collection efficiency

$_e$ signifies an efficiency or bias term that is dimensionless

D_e is the detector efficiency

T_e is the transport efficiency.

The propagated uncertainty is

$$\left[\frac{\sigma_S}{S}\right]^2 = \left[\frac{\sigma_F}{F}\right]^2 + \left[\frac{\sigma_t}{t}\right]^2 + \left[\frac{\sigma_{C_e}}{C_e}\right]^2 + \left[\frac{\sigma_{D_e}}{D_e}\right]^2 + \left[\frac{\sigma_{T_e}}{T_e}\right]^2 \tag{4}$$

This form of propagated uncertainty is particularly sensitive to numerically small factors with large uncertainties because as the value of a factor approaches zero, the uncertainty approaches infinity. This form also assumes that the factors are independent, which is not always the case. Several bias factors (and perhaps their uncertainties) can be affected by changes in flowrate. For instance, a situation in which the transport efficiency for a given particle size is 1% at the mean flowrate, but changes to 3% with a 10% change in the flowrate is an example where the numerical value is both small and dependent on another factor. Thus, the signal uncertainty as a result of the 10% flowrate change exceeds 70%. A similar change in particle collection

filter efficiency can be experienced with flow. Also, some detectors are sensitive to the deposition pattern of particles on the filter, which may be influenced by the flowrate. When any or several efficiency factors are less than 10%, the signal uncertainty is susceptible to large variability, especially when the factors are not independent. Therefore, numerically high biases (greater than 50%) are desirable with small (slowly varying) dependence on the flowrate.

It can be concluded from Equation (4) that to reduce the overall propagated uncertainty, one begins by reducing the largest individual factor's contribution to uncertainty. No appreciable reduction in the propagated uncertainty is achieved by reducing the uncertainty of a factor when its contribution is one-third or less of the largest source of uncertainty.

2.4.2 Action Levels

The strategy for obtaining acceptable accuracy for an action level is to first determine the action level and its consequences, and then examine the possible techniques for arriving at a detection limit that will achieve the required accuracy. Seeking the lowest possible detection limit is not necessarily the best tactic for ensuring acceptable accuracy. Overall control of the system (i.e., reliability) may be the most important factor. A robust but crude system may be preferable to a sensitive but frail one. Propagation of uncertainty and a good uncertainty analysis will reveal the sensitive elements and the limits of control. Ranking of the uncertainties in the analysis will indicate the point of diminishing returns.

Once the action level, required accuracy, and available detection limits are known, two results are possible. The first is that the detection limit is equal to or better than required. The second is that the detection limit is not sufficient to meet the accuracy requirements.

In the case of an acceptable detection limit, the next step is to examine the system reliability. Can the reliability be increased by decreasing the detection limit, in other words, making the system more robust? If the

system is reliable, what is necessary to ensure reliability, i.e., testing, maintenance, and surveillance? These latter techniques ensure that the system uncertainty remains within acceptable bounds.

In the case of an unacceptable detection limit, the next step is to examine methods of reducing the detection limit using either a larger sample size, different detector, better control, different collection media, change in the transport system, or longer sample counting time. Once an acceptable detection limit has been achieved, system reliability should be re-examined.

2.5 SAMPLING OF OFF-NORMAL CONDITIONS

Normal operating conditions are the design conditions of the system. These are the expected conditions with an expected variability. These are not necessarily the average operating conditions and their variance as defined by statistical terms. The normal operating conditions may have a large range of temperature and flowrates depending on the processes in operation. The effluent monitoring system must be designed to accommodate these normal operating conditions. The effluent discharge system also operates with an effluent control (clean-up) system in place that attenuates particulate and gaseous emissions to an acceptable level. Therefore, there are normal conditions of particle size and concentration and effluent reactivity and corrosivity. The effluent monitoring system must be designed to withstand, sample, and record these normal operating conditions.

Other operating conditions are known and expected that may exceed the design conditions for short durations. These conditions may occur during process changes or regular maintenance. These conditions may result at any point in the process from the introduction of feed materials to the effluent control system. Such changes of conditions should be considered design conditions if they occur on a frequent basis, for example, more than once every six months. These conditions may be considered off-normal conditions if they occur less frequently.

Conditions that are generally considered to be off-normal are those that are unplanned with unknown consequences. These conditions may be accidents, incidents, or equipment failure. Accidents are such events as fires, explosions, spills, or natural disasters. Incidents are planned events whose outcomes were not fully anticipated or in which an accident or error altered the outcome. Equipment failures are events that alter the quality of the effluent, particularly such failures of the effluent clean-up system as leaking or damaged filters or loss of fluid to spray systems or traps.

An effluent monitoring system should be able to accommodate or account for the off-normal conditions. There are limits to this ability to accommodate and account for off-normal conditions, and the limits are surely reached well before the very existence of the facility is threatened. Nevertheless, conditions of a low probability may occur that are markedly different from the expected conditions. These conditions may constitute a recognizable emergency or may result from an incident whose consequences are recognized only after the fact. The effluent monitoring system could be the only, or the most immediate, means for recognizing the incident or accident.

Off-normal conditions are conditions of the effluent not expected under design conditions. These conditions may include the following:

- flow conditions (low or high flowrate in stack or duct, laminar rather than turbulent)
- temperature conditions (high or low)
- gaseous constituents (corrosive, humid, condensing, vaporizing, high concentration, unknown composition)
- particle characteristics (high concentration, unusual particle shape, exceptionally large size).

Any one or a combination of these conditions may be possible and may alter the collection characteristics of the sampler. If any of these conditions are possible and probable, then the sampler must accommodate the

conditions or account for the effect and the consequent non-representativeness of the sample. If necessary, a back-up system should be provided that can increase the range of sampling conditions.

A sampling system that is capable of accommodating all off-normal conditions because of its inherent design or because it is sufficiently controlled to alter its sampling characteristics to fit the sampling conditions meets all requirements for off-normal conditions. A sampling system that requires a back-up system or a calculational algorithm to account for the off-normal conditions must monitor the conditions sufficiently to institute the back-up or provide the necessary information for calculation. In any case, off-normal conditions may require alerting necessary personnel and instituting corrective actions in addition to obtaining a representative sample. See Section 4.6 for more information on alarms and warning devices.

3.0 SELECTING APPROPRIATE SAMPLING LOCATIONS

3.1 CHARACTERIZING THE SAMPLING ENVIRONMENT

The sampling environment within a stack or duct must be characterized to design the sampling system for those conditions. A number of critical parameters should be considered in the design process; however, accident or off-normal condition cases must always be kept in mind.

3.1.1 Temperature

The expected temperature range at potential sampling points under normal operating conditions and credible accident conditions should be determined. Often the effluent temperature is very stable. There may be little seasonal variation in temperature because of controls in the facility heating, ventilation, and air conditioning (HVAC) operations. Off-normal conditions in many cases may also have little temperature effect; however, any temperature changes could be critical to the collection of a sample under off-normal conditions. An important consideration of temperature changes is that the volume flowrate of the effluent will change while the mass flowrate may not. The volume flowrate change may also be considerable if a condensible vapor is an appreciable percentage of the effluent.

3.1.2 Effluent Flowrate

The flow velocity is important in any final calculation of the release rate or total release. The range of velocities may also be important in the design and control of the sampling system. The flow velocities may change with a diurnal pattern as processes are increased or decreased, as fans are switched on or off for maintenance, as doors are opened or closed, or as heating or cooling systems add to the exhaust. Off-normal conditions may include occasional planned increases or decreases in the effluent flow as a means of controlling or mitigating unusual process conditions. Facility design basis accident descriptions and accident control and mitigation plans may provide a

basis for estimating changes in flow (including substantially reduced flow) as a result of accident conditions. If available, these should be taken into account in the design of an optimum sampling system for a particular facility. For example, the diversion of flow from one stack through an adjacent stack may be a control option that would be exercised if loss of HEPA filtration were to occur in the first stack.

3.1.3 Duct Geometry

Duct geometry, including shape (circular or rectangular), main stack flow input conditions (e.g., side entry and angled entry at the base), additional lateral entry of contaminated flow, orientation of stack elements with respect to the vertical, and the presence or absence of such flow disturbance elements as bends can all be critical factors in the design of proper sampling systems and their locations in the stack. This information must be fully and carefully documented. Particular attention should be given to the geometry of main flow entry conditions because in many cases the presence of angled inputs from fans or transition elements from rectangular to circular geometry can introduce non-axial velocity components in the flow that can result in swirl and irregularities in aerosol concentration profiles. The discharge of secondary flows of contaminants into a main stack in a manner that injects contaminants into the boundary layer of the stack must be recognized and avoided because this can result in contaminant releases that are not well mixed with the bulk of the flow and, therefore, may not be detected.

3.1.4 Effluent Composition

The composition of a stack effluent under normal and accident conditions must be understood and accounted for when the design of a sampling system for that stack is developed. Radioactive component characteristics to consider are inert and/or reactive radioactive vapors and gases (particularly if condensible), radioactive particle AED distribution, mass and activity distribution by diameter, radioactive labeled organics, and radioactive volatile compounds such as radioiodine. These characteristics must be considered in

each case as appropriate for a particular stack effluent. Non-radioactive components must also be identified whenever they may influence the sampling system design. An important example is the presence of strong acid or caustic fumes in the exhaust that could cause rapid deterioration of the probe or sample transport line unless compensated for by the selection of appropriate materials for construction of those probes and lines. Inert dust loading in the effluent can also be a factor in the design of appropriate probes because of the potential for plugging inlets or interfering in the proper operation of sampling system elements. Moisture content of the effluent can also be critical in the design of sampling systems because of possible interactions with contaminant components, condensation, and plugging of filters.

3.1.5 Particle Size

The efficiency of extracting, transporting, and collecting sampled particles is very sensitive to the size (AED) of the contaminant-bearing particles. Consequently, a knowledge of the contaminant particle size distribution under normal, off-normal, and accident conditions is critical to the design of the entire sampling system and to the setting of reasonable performance expectations. This information can be reasonably obtained for normal and off-normal conditions; however, rarely is it available for accident conditions. Accordingly, the system design will often proceed on the basis of an assumed largest AED particle size that defines the cut-point of the entire sampling system, from probe to sample collection substrate.

3.2 SELECTION OF SAMPLING SITES

3.2.1 General Considerations

Locating a site in a stack or duct where a valid sample can be obtained by extractive methods involves such considerations as the characteristics of the radioactive contaminant, factors associated with equipment placement and support, and worker health and safety. Generally, the sample extraction location should be where the contaminant profile is well mixed and stable, should

be readily and safely accessible, should not present a problem for sampler services and maintenance activities, and should be able to accommodate analysis or collection equipment that does not compromise the quality of the sample.

Sampling lines for radioactive noble gases and activated gases may be long, may lack temperature controls, and may contain many bends and cross-sectional discontinuities without compromising data quality objectives. High radiation fields associated with short-lived activation products or the operation of radiation producing equipment may present a problem with respect to worker safety at the sample extraction location. High ambient temperatures might be a problem in some cases. Either of these situations might dictate longer transport lines than normally needed to locate the sample collection and detection equipment at a properly shielded and air conditioned place. Air leakage must be avoided before the collection or analysis device.

Where the contaminants are in the form of condensible vapors or reactive gases, long transport lines and large temperature changes in the sample or the transport line must be avoided. Heat tracing of the transport line is readily accomplished, but conditioning of the sample may be necessary, such as a deliberate temperature change and purposeful dilution with a carrier gas. The sampling location also may need to accommodate shielding, air conditioning, easy access, and other equipment.

In the case of particulate contaminants, the concerns about losses to the walls of the transport lines by diffusion, gravitational settling, and turbulent deposition dictate keeping sample lines short, minimizing the number of bends, and avoiding horizontal orientation of the line. Abrupt temperature changes and cross-sectional changes should be avoided as well. The sampling location should be such that these constraints can be accommodated. This usually requires that the analysis or collection components be located near the ideal sample extraction point, where the latter is chosen on the basis of completeness of particulate mixing in the effluent stream. The attendant

environmental requirements for the collection or analysis system must be applied. Worker safety issues previously described related to high temperature and radiation fields apply here as well. Concern for worker exposure to hazardous conditions may also arise when considering whether a transport line system can be made shorter or simpler to avoid particulate losses. Clearly, a potential exists for conflicting concerns in such decisions.

Sampler design, support equipment needs, and environmental requirements should be included in the design of the air effluent discharge stack and system and its attendant sample extraction site location. Unfortunately, in the past, samplers have often been forced into the only accessible locations after design, construction, and placement of all other equipment. Therefore, a sampling location was often a default location. In an existing facility, no location in the as-built effluent system may be completely acceptable because the effluent system may not have been designed with the sample extraction location chosen with representative sampling, instrumentation requirements, and worker health and safety in mind.

These general sample extraction location considerations illustrate that the matter of locating the sample probe in a stack is seldom a simple matter of finding the best location based only on complete mixing of contaminants and effluent flow. Often the sample extraction location issue can best be dealt with systematically by a process of optimization.

3.2.2 Qualifying the Sample Extraction Location

Because the intent of sampling and monitoring stack effluents is to measure the contaminant discharge from the source, the sample extraction process should occur downstream of all inputs and contaminant release controls (e.g., filters, precipitating, and scrubbing). Within constraints imposed by more general considerations of extraction site location on a stack, the location must be chosen to provide a valid sample of the entire contaminant discharge from the stack. It is well known that locations near bends, fans, and stack outlets are associated with distortions in the profile of contaminant

concentration and with angularity in the flow that could adversely affect sampling probe performance. Therefore, such locations should be avoided.

Both ANSI N13.1 (1969) and 40 CFR 60, Appendix A, Method 1 set rules for locating the sample extraction plane a required number of duct diameters downstream and upstream of the nearest disturbance in flow. However, because of facility or other constraints, sampling objectives often cannot be met by the application of such rules, and alternative approaches (which appear to violate the rules) sometimes provide superior results. Yet, these rules do provide useful guidance for suggesting possible candidate sampling plane locations, even in constrained situations where inadequate lengths of duct are available. This document requires that candidate sampling plane locations be qualified according to the following performance criteria.

3.2.2.1 Angular or Cyclonic Flow

For a proposed sampling location to be considered acceptable, the flow of particles and gases must not exhibit excessive angularity or swirl. The presence of swirl can adversely affect the mixing of particles in the effluent and degrade the extraction performance of the sample probe inlet and other elements. The criterion of acceptability is that the flow angle shall be less than 20 degrees (relative to the long axis of the stack and probes). An appropriate method for determining if a proposed location meets this criterion is described in 40 CFR 60, Appendix A, Method 1, Section 2.4, "Verification of the Absence of Cyclonic Flow." If there is excessive flow swirl, it can be corrected by using internal elements placed in the stack or duct. In the past it was common practice to use either honeycomb or parallel plate flow straighteners; however, such elements should be used only after suitable mixing of contaminants has been achieved. In some situations excessive flow swirl can be eliminated through the use of static flow mixing elements rather than flow straighteners.

3.2.2.2 Variation in Contaminant Concentration and Velocity Magnitude Profiles

The criterion to be applied in establishing the acceptable uniformity of contaminant mixing and velocity across a large diameter stack is that the coefficient of variation (COV, the standard deviation as a percentage of the mean) of concentration of 10-μm AED tracer aerosol particles and of a tracer gas (e.g., helium or sulphur hexafluoride) shall be less than or equal to 20% across the center two-thirds of the cross-sectional area of the stack or duct. Similarly, the COV of gas velocity shall be within ±20% across the center two-thirds of the area of the stack or duct. Because the velocity is zero at the wall of the duct and gradually increases in the boundary layer of a stack or duct, it is physically impossible to have a perfectly uniform velocity profile even in highly turbulent flow. Ideal velocity profiles monotonically increase from the wall to the center of a duct. An ideal contaminant concentration profile will have a shape similar to the velocity profile and will thus also not be perfectly uniform; however, there should not be any large spike deviations or distortions of the profile shape. Anomalous high concentrations of gases or particulates could occur in stack flows from a variety of causes, chief among them being contaminant injection into the flow boundary layer. Accordingly, an additional mixing criterion is that at no point in a grid setup in accordance with 40 CFR 60, Appendix A, Method 1 shall the concentration of tracer gas exceed 30% of the mean concentration value in that sampling plane. Because of the physical size of the probe, the measurement of the concentration of 10-μm AED aerosol particles is difficult and subject to errors in the vicinity of the wall of a stack or duct. Consequently, the 30% criterion does not need to be verified for aerosol particles.

The above 20% and 30% COV criteria of uniformity are selected to reflect the reality of experimental errors expected in sampling from stacks in the field. The 10-μm AED test aerosol particle diameter was selected based on the need for a test aerosol whose aerodynamic behavior clearly exhibits inertial

effects that could adversely influence mixing because it has been previously used in the performance specification of sample probes and transport lines (Rodgers 1987; McFarland et al. 1989) and because it is relatively easily generated in monodisperse (single particle size) form and dispersed into stack flow.

3.3 METHODS FOR QUALIFYING THE SAMPLE EXTRACTION LOCATION

To meet the contaminant mixing criteria given in Subsection 3.2.2, it is necessary to verify that the stream is well mixed or otherwise sufficiently described in its characteristics to allow a sample to be representative of the effluent. The simplest means to demonstrate the degree of mixing is to introduce an easily measurable tracer gas. The gas should be introduced upstream of the mixing device and at five or more locations across the cross section of the air stream. For a square duct the introduction should be at the center and each corner. For a round duct the introduction should be at the ends of perpendicular diameters and the center. These locations should be the extremes for mixing. If the gas is equally mixed over the cross section at the extraction point, a single inlet sampling probe is preferred. In cases where the mixing device could introduce streaming under circumstances different from the test conditions, these conditions should also be tested.

A failed air filter or absorber can also cause streaming of a contaminant. A test should be made following the filter or absorber at various positions to ensure well-mixed conditions at the extraction point. The tracer gas should be introduced at a minimum of five points upstream of the filter or the absorber. The test conditions should include the range of operating conditions and failure modes for the effluent system.

If a reactive or condensing gas is expected in the effluent, then a reactive or condensing tracer gas should be employed for the tests. The tracer gas should have similar characteristics to the expected effluent gas.

The case of a reactive (or condensing) gas cannot be tested if the test gas is introduced upstream of an operating device designed to remove the gas by its condensing (or reacting) characteristic.

A gas is not sufficient as a tracer for particles of all particle sizes. A gas may be substituted for particles smaller than 5-μm AED but is not sufficient as a tracer for larger particles. The degree of mixing for larger particles should be tested with particles ranging in size from 0.3 μm to the largest size expected. The locations for introduction of the particles is the same as for a gas. As in the case of a gas, the particles are demonstrated to be well mixed by sampling over the cross section at the extraction point. A difference from the case of testing with a gas is that particles should not be introduced upstream of the particle attenuation device.

The testing for the degree of mixing requires sufficient gas or particles to have adequate signal at the extraction point. The method of detection and its detection limit are the important considerations in the amount of material introduced. Sufficient material must be introduced to be detectable after dilution in the effluent stream.

3.4 SAMPLING LOCATIONS OTHER THAN FINAL EFFLUENT STREAMS

Sampling may be required at locations upstream of the final exhaust for purposes of monitoring process conditions, personnel protection, or aiding the interpretation of measurements of the final exhaust. The sampling performance criteria for these situations may be the same as for normal final exhaust sampling; however, these conditions may be more extreme because higher concentrations, larger particle sizes, or more reactive or corrosive gases may be expected. These conditions may be closer to the off-normal conditions for the final exhaust and would, therefore, be governed by the final exhaust off-normal criteria.

3.5 DESIGNING EFFLUENT DISCHARGE SYSTEMS FOR SAMPLER PLACEMENT

Accommodating sampler placement is an effluent system design and construction requirement. Such design must include provision for extracting a representative sample and for supporting transport and collection equipment in a manner that ensures that the extracted sample is transported and collected with minimal loss for all contaminants. The most important requirement for extracting a representative sample is that the sampling plane be located where the effluent is well mixed. Other considerations to include in the effluent discharge design are as follows:

- Do not add another effluent to the stream beyond the sampling point
- Do not locate the final emissions sampling point upstream of any effluent attenuation devices
- Include a section upstream of the sampling plane where corrective devices such as mixing baffles can be installed easily
- Locate the sampling plane downstream of devices that promote mixing of the contaminants
- Avoid the use of flow straighteners except after the contaminants are well mixed and to remedy angular and cyclonic flow
- Locate the sampling plane close to the collection instruments to ensure that transport lines are short and have few bends and transitions
- Provide ample access to service and maintain the sampling system
- Avoid extraction points at such highly inconvenient locations as high above ground on exhaust stacks
- Provide ample access ports for visual probe inspection, flow transmitter verification, and sampler performance testing.

The conditions of the effluent stream may indicate that the stream is well mixed. An obvious indication of being well mixed is that the extraction point is behind a mixing device such as a fan. Under most conditions it is to be expected that placement after particle, chemical, or gaseous attenuation

devices such as filters, scrubbers, or adsorbents would also render the stream well mixed. Other devices that will aid mixing include a series of elbows, a mixing plenum receiving several streams, baffles to promote mixing, or a turbulent stream in a long length of duct. Nevertheless, conditions within the devices or combination of devices may be such that streaming occurs or that separation is induced. Highly cyclonic flow could inertially separate particles, or a temperature profile could cause condensation, Stephan flow, or thermal density effects. Flaws in the attenuation devices or physical or chemical conditions in the devices could induce streaming.

4.0 SAMPLING SYSTEM DESIGN

4.1 BULK STREAM VOLUMETRIC FLOW MEASUREMENT

The flowrate of air exhausted through a stack or duct should be monitored if there is a potential for significant emissions. For effluents that fall into Table 2.1 Category 3 with only a minor potential for emissions, only periodic confirmatory measurements of flowrate may need to be performed.

4.1.1 Requirements

Accurate measurements of the flowrate in stacks and ducts must be monitored for potential emissions of radionuclides because the accuracy of any emissions estimate is directly related to the accuracy of flow measurements. Continuous flowrate monitoring shall be performed unless the source is minor in nature, and the flowrate through the stack or duct is not anticipated to vary by more than ±20% during a year. Such factors as fan maintenance, the opening of doors, and the variations in the number of fans shall be taken into account in determining the need for continuous monitoring of flowrate.

If continuous monitoring of flowrate is not required, annual measurements of flowrate shall be performed following 40 CFR 60, Appendix A, Method 2 or other methods that can be demonstrated to have equivalent or better accuracy. This method will be denoted hereafter as the Reference Method.

For stacks and ducts that must be continuously monitored, the flow measurement and recording system must be able to measure the mass flowrate of gas with an accuracy that is within 10% of that measured with the Reference Method. Here the mass flowrate is defined as the volumetric flowrate based on a pressure of 760 mm Hg (101.3 kPa) and a temperature of 25°C (298 K), and is given in units of m^3_{std}/s.

Any continuous flow monitor must be subjected to annual accuracy audits. Performance of the unit will be compared against the Reference Method. If the

sensor of the continuous flow monitor is based on electronic or acoustical principles, automated daily checks of the instrument zero and span (or linearity) shall be made.

4.1.2 Apparatus and Applications

Three types of systems are currently used for monitoring flowrates in stacks and ducts: thermal anemometers, pitot tubes, and acoustic meters. Other methods may be used if their accuracy is within the limits specified in Subsection 4.1.1.

4.1.2.1 Thermal Anemometers

The use of thermal anemometers is advantageous because it provides a readout that is independent of pressure and temperature and can be used directly to determine mass flowrate. Thermal anemometers should not be used if there is a possibility of condensed vapor being deposited on the sensing element. Also, if there is background aerosol present, the use of thermal anemometry is discouraged; however, a cleaning schedule may be set up if it can be demonstrated that the bias of results will be less than 3% at the end of the interval of the cleaning schedule. Rakes (an array of multiple sensors) of thermal anemometers have been used and that methodology is acceptable; however, the requirements of uniformity of velocity profiles stipulated in Subsection 3.2.2 accommodate the use of single point velocity determinations. When single point anemometry is used, a correction factor must be established to relate average mass flowrate to the reading from the single thermal anemometer element. In some applications, it may be beneficial to deploy redundant (two) single-point thermal anemometry systems.

4.1.2.2 Pitot Tubes

A pitot tube will provide a measurement of the velocity at a given point in the flow. Velocity, V (m/s), is calculated from

$$V = C_p \sqrt{\frac{2\Delta P}{\rho}} \tag{5}$$

where C_p is a pressure coefficient

ΔP is the pressure difference between stagnation pressure and static pressure measured with the pitot tube (in units of Pa)

ρ is the air density (kg/m^3) in the stack or duct.

If a Prandtl-type pitot tube is used, the pressure coefficient is unity; however, if an S-type pitot tube is used, the pressure coefficient must be validated using the procedure stipulated in the Reference Method.

The readings from a single point pitot tube can be correlated with the actual flowrate. Data from a single point pitot tube should be recorded at intervals not to exceed 10 min duration. For reporting purposes, the actual volumetric flowrate through the stack or duct, q_a (m^3/min), should be converted to volumetric flowrate at standard conditions, q_{std}, from

$$q_{std} = q_a \frac{T_{std}}{T_a} \frac{P_a}{P_{std}} \tag{6}$$

where T_{std} is the standard temperature (298 K)

T_a is the temperature in the stack (K)

P_a is the absolute pressure in the stack (kPa)

P_{std} is the standard pressure (101.3 kPa).

If the absolute pressure in the stack does not vary by more than ±5% during the course of a year (exclusive of variations in barometric pressure), and if the temperature in the stack does not vary by more than ±10°C during a year, average values of stack pressure and stack temperature may be used to calculate velocity. If the pressure and temperature variations are outside these ranges, pressure and temperature must be continuously monitored and a value of air density calculated at intervals that do not exceed 10 minutes. Velocity values will be based on the calculated values of density.

A pitot tube should be inspected for the presence of deposits of contamination on an annual basis, or more frequently if the air is not HEPA-filtered. For some applications it may be necessary to perform daily instrument checks for assurance that there is no buildup of material on the ports of the probe. Such checks may be performed by measurement of the pressure associated with a given rate of backflow through the ports. During the annual inspection, the system must be checked for leaks. Leakage at average flow conditions must not affect the results of differential pressure by more than 1%.

4.1.2.3 Acoustic Flowmeters

These devices measure the time for acoustic signals to travel between two transceivers placed on opposite sides of a duct and displaced axially from one another. Acoustic velocity is independent of pressure but does depend on the square root of the absolute temperature in a stack. The acoustic flowmeter should accommodate measurements of temperature and take those values into account when calculating the velocity.

Velocity measured by the device is an average over a single line across the stack and not an area average, where the latter measurement would allow direct calculation of flowrate. Thus, a correction factor must be established between the reading of the instrument and the volumetric flowrate through the stack. When such a correction factor is applied, the result will be the

actual volumetric flowrate through the stack or duct, q_a. Through use of Equation (6), the flowrate is converted to that at standard conditions, $q_{std.}$

If the absolute pressure in the stack does not vary by more than ±5% during the course of a year (exclusive of variations in barometric pressure), and if the temperature in the stack does not vary by more than ±10°C during a year, average values of absolute stack pressure and stack temperature may be used in Equation (6). If the pressure and temperature variations are outside these ranges, pressure and temperature must be continuously monitored. Values of flowrate at standard conditions will be calculated for intervals that do not exceed 10 minutes.

4.2 INLET PROBE DESIGN AND OPERATION FOR PARTICLES

This method is applicable to sampling from stacks and ducts that have the potential to emit aerosol particles. The basic approach is based on the assumption that single point sampling with a properly designed probe, at a location where the flow is well mixed, will provide a representative sample during normal conditions and an adequate sample during accident conditions. If the flow can contain only gaseous contaminants, single point sampling will be used and the probe design is not critical; however, the sampling must take place at a location where the flow is well mixed and meets the criteria of Subsection 3.2.2.

4.2.1 Basic Considerations

Inlet probes serve the function of removing a sample from the free stream of a stack or duct and rendering it compatible with transport to an analyzer or collector. Previously, the ANSI N13.1 (1969) standard recommended probe designs for aerosol sampling as shown in Figure 4.1. However, use of probes that have constant internal cross sections and a 90° elbow of the same cross section is no longer considered good practice because of substantial aerosol particle losses in both the straight entrance region and the elbow and because of errors associated with off-design operational conditions (Fan

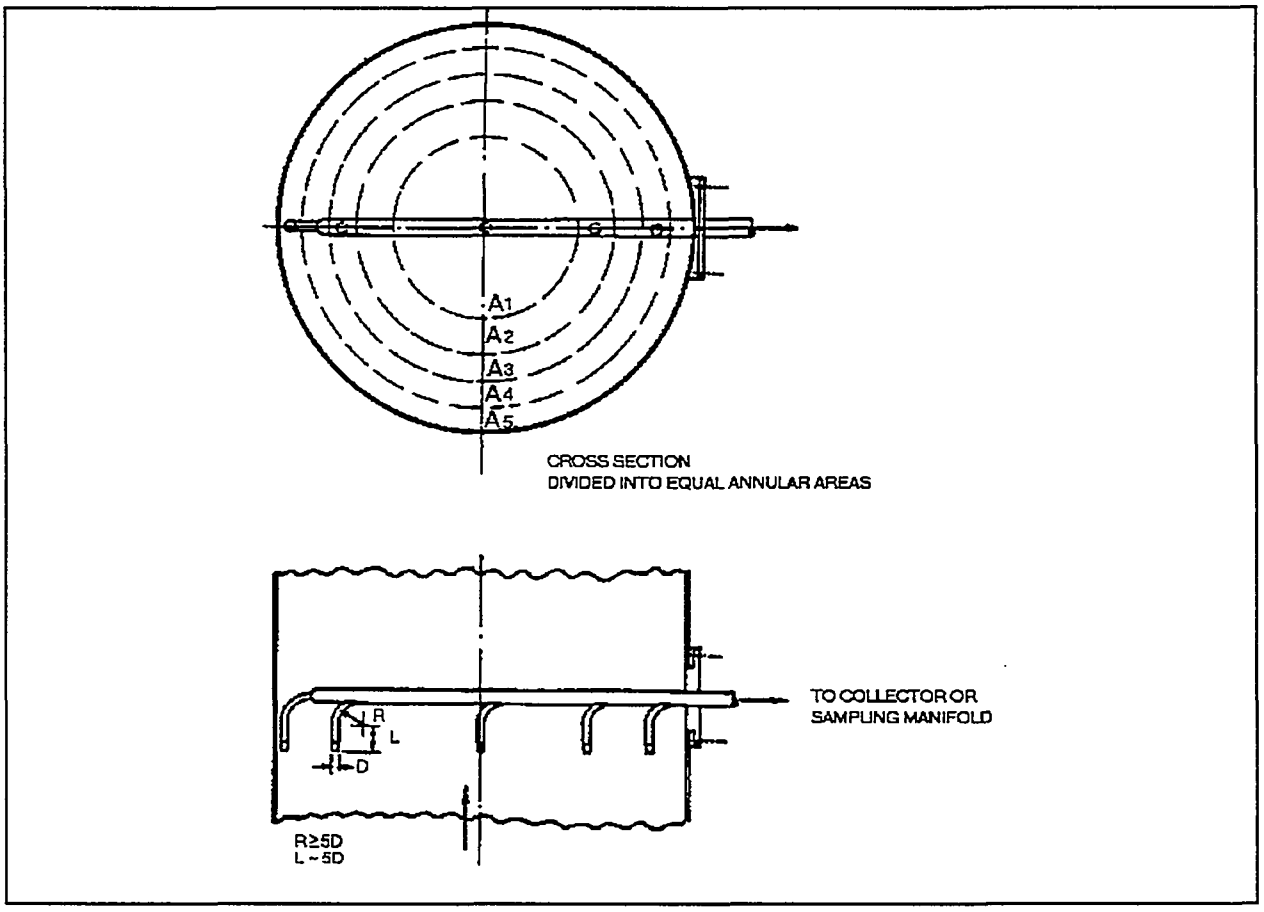

FIGURE 4.1. ANSI N13.1 (1969) Style Sampler Inlet Rake

et al. 1992; McFarland and Rodgers 1993). Also, ANSI N13.1 (1969) recommended the deployment of multiple inlets in circular ducts larger than 6-in. diameter or in rectangular ducts with cross-sectional areas greater than 0.5 ft^2. For larger ducts, as many as 20 inlets were recommended, with rakes (several inlets on a common manifold) of such inlets spanning across the stack or duct. Use of these rakes is no longer considered good practice because for a given flowrate, smaller inlets must be used as the number of inlets is increased to accommodate the ANSI N13.1 (1969) recommendation of isokinetic (inlet air

velocity matching that of the free stream air velocity) sampling. Use of large numbers of small inlets exacerbates sampling deficiencies inherent in the ANSI N13.1 (1969) probe design.

In place of multiple point sampling, single point sampling is recommended provided both fluid momentum and contaminant mass are well mixed at the sampling site. Also, the ANSI N13.1 (1969) recommendation for isokinetic sampling is on longer required. Recent studies have shown that isokinetic operation is not a prerequisite for obtaining representative samples (McFarland and Rodgers 1993).

The design and use of the extractive aerosol sampling probe can have a significant impact on the quality of a sample. There are two basic factors by which an inlet nozzle can produce a non-representative sample: 1) operation in such a manner that the aspiration ratio, A, is not unity, and 2) losses on the internal walls of the nozzle, $W1$. The two terms, aspiration efficiency and wall losses, are defined as

$$A = \frac{C_i}{C_\infty} \tag{7}$$

and

$$W1 = \frac{C_i - C_e}{C_i} \tag{8}$$

where C_i = concentration at the probe inlet plane

C_∞ = aerosol concentration in the free stream

C_e = concentration at the probe exit plane.

In evaluating the effectiveness of a sampling inlet, the aspiration ratio and wall losses should both be considered. Their effects are manifested

in the transmission ratio, T, which is the ratio of the aerosol concentration at the probe exit plane to the aerosol concentration in the free stream, as in

$$T = \frac{C_e}{C_\infty} \tag{9}$$

The transmission ratio, aspiration ratio, and wall losses are related by

$$T = A\ (1 - W1) \tag{10}$$

Although all three parameters are important, the performance of an inlet is best described in terms of its transmission because that parameter provides a measure of the amount of aerosol that actually penetrates from the free stream to the exit plane the inlet.

4.2.2 Inlet Performance

It is recommended that the probe inlet have an aerosol transmission ratio within the range of 0.80 to 1.30 over the entire range of normal or anticipated accident operational conditions for an aerosol particle size of 10-μm AED, or for the range of sizes that could be encountered in normal operating or accident conditions. It is also recommended that the aspiration ratio of a sampling inlet should be within the range of 0.80 to 1.50 for the anticipated range of operating conditions and the previously noted particle size or sizes. Compliance is to be demonstrated with liquid aerosol particles, which will provide conservative transmission values in comparison with solid particles because liquid particles adhere to walls, while solid particles may rebound or be reentrained from a collection surface.

4.2.3 Inlet Designs

When an inlet is operated isokinetically, the aspiration ratio is unity; however, the wall losses can cause the transmission to be considerably lower

than unity. Fan et al. (1992) wind tunnel tested an inlet designed approximately in accordance with ANSI N13.1 (1969) and found the wall loss ratio was approximately 75% for 10-μm AED aerosol particles at isokinetic conditions over a range of stack velocities. In addition, when an inlet is operated at off-design conditions, the transmission ratio can be affected. These conditions can be produced by variations in the free stream velocity, by variations in sampling flowrate, and by an isoaxial orientation of the inlet. The latter factor can be caused by inlet misalignment or flow swirl. Performance of the ANSI N13.1 (1969) inlet and rakes of such inlets are affected by all of these factors.

Modern inlet designs have better performance characteristics than the original ANSI probes. McFarland et al. (1989) and Chandra and McFarland (in press) developed shrouded probe designs that considerably reduce wall losses. In general terms, the wall losses for 10-μm AED aerosol particles are about one-fifth of those of the ANSI N13.1 (1969) probes. The shrouded inlets are designed to be compatible with single-point sampling, where the sampler is operated at a constant flowrate with the flow velocity in the shroud being about 30% that of the nominal stack free stream velocity. The transmission ratio for 10-μm AED aerosol particles is relatively unaffected by variations in stack velocity, flowrate, and angle between the free stream and probe entrance.

Chandra (1992) and Williamson et al. (1987) designed sharp-edged unshrouded inlets that have wall losses of 10-μm AED particles that are approximately half of those of the ANSI N13.1 (1969) inlets.

4.2.4 Application and Performance Considerations

The following factors should be considered in the selection and use of a sampling inlet.

4.2.4.1 Location

Sampling should take place at a location where both the aerosol concentration and fluid momentum (velocity) are well mixed so that a single inlet can be used. The internal wall losses are less for a single inlet than for multiple inlets.

4.2.4.2 Orientation

For aerosol sampling, the inlet axis should be aligned parallel to the temporal mean flow stream direction.

4.2.4.3 Transmission and Aspiration Ratios

The transmission and aspiration ratios of the selected inlet design must be traceable to experimental verification of performance for conditions that include the nominal sampling flowrate and range of anticipated sampling flowrates, the nominal free stream velocity and the range of anticipated free stream velocities, and a particle size of 10-μm AED. If actual testing is used, the means for determining the transmission and wall loss ratios must be documented. If reference to previous testing is employed, the equivalency of the selected design and the design that was tested must be demonstrated.

4.2.4.4 Sampling Flowrate and Free Stream Velocity

During operation of an inlet, the sampling flowrate may be varied to accommodate changes in the free stream velocity, or it may be held constant to accommodate the requirements of the collector or analyzer.

4.2.4.5 Inlet Configuration

The leading edge of the inlet should have a sharp edge with the external cone angle not to exceed 30 degrees. Other configurations can be used if experimental data show either equivalent or superior performance to the sharp-edged inlet. If the sampling inlet is shrouded, the shroud should not have a sharp leading edge. For sharp-edged inlets, the leading edge of the inlet is

to be inspected for damage following installation and subsequent to any maintenance procedures in which the probe could be damaged.

4.2.4.6 Rakes

While use of a sampling rake is discouraged, if one is to be used, it must be tested for wall losses. The tests can be done either *in situ* or in a laboratory environment. For the latter situation, it is acceptable to test the inlets separately with filtered flow passing through those nozzles that are not in the test aerosol environment. Test procedures and results must be documented. If the sampling system is used to collect samples for archival records, the transmission of 10-μm AED aerosol particles from the free stream to the exit of the rake must be within the range of 0.80 to 1.30.

4.2.4.7 Materials of Construction

Probes shall be constructed of materials that do not react with either the aerosol or the vaporous constituents of the gas stream. Surface roughness of the internal regions of probe that contact the sampled stream should not exceed 32 micro-inches. The surface roughness of the external region of the sampling probe from the inlet plane to a distance of two probe inlet diameters from the inlet plane should not exceed 64 micro-inches. A shroud should have a surface roughness that does not exceed 128 micro-inches.

4.2.4.8 Maintenance

The probe must be checked semiannually for alignment, presence of deposits of foreign materials and other factors that could degrade the performance of the sampling system. If there are background aerosols that can produce deposits, a cleaning schedule should be established that will not allow over 5% of the inlet area of a probe to be occluded. For probes that are used to sample HEPA-filtered air, the probe should be cleaned if there are visible deposits of material on either the internal or external regions of the probe.

4.2.4.9 New Concepts

If new approaches are developed for design and operation of inlet probes, such designs can be used in ducts and stacks if it can be demonstrated experimentally that the designs meet the performance specifications given in Subsection 4.2.2. The test conditions should include experiments to determine the wall losses and aerosol transmission at conditions of 1) particle sizes of 3-, 10-, and 20-μm AED at the nominal free stream velocity and nominal flowrate; 2) maximum and minimum operational or anticipated free stream velocities for a particle size of 10-μm AED at the nominal sampling flowrate; and 3) maximum and minimum anticipated sampling flowrates for a particle size of 10-μm AED at the nominal free stream velocity.

4.3 SAMPLE TRANSPORT FOR PARTICLES

The transport of aerosol particles from a sampling probe to a collector or analyzer should take place in such a manner that changes in concentration and size distribution of airborne radioactive materials are minimized within the constraints of current technology.

4.3.1 Depositional Losses

The deposition of particles inside the transport tubing shall be evaluated either through experimental techniques or through use of computer codes (such as Anand et al. 1993) for either 10-μm AED aerosol particles or the size range expected in the particular application under normal, off-normal, and anticipated accident condition.

With respect to general design guidelines, the straight sections of transport tubes, particularly horizontal tubing sections, should be kept as short as possible, and the number of elbows should be minimized within the geometrical constraints of the application. For record samples, it is recommended that not more than one elbow be used although it is recognized that there may be situations where more elbows may be necessary. Elbows should

have a curvature ratio (radius of curvature of the bend divided by the tube diameter) of at least five. Flattening of the elbow caused by a bending process must not exceed 10%, where flattening is defined in terms of the major and minor axes of the tube cross section at the angular midpoint of the elbow. As an example, the diameters of a 90° elbow would be measured at the 45° location. The ratio of the maximum tube diameter to the minimum tube diameter must not exceed 1.10.

In general terms, there will be losses of aerosol particles in transport lines, and any design will entail compromises. The design parameters must be carefully chosen to optimize the utility of the overall system. The penetration of 10-μm AED aerosol particles from the free stream to the collector or analyzer should be known and should not be less than 50%.

4.3.2 Corrosion

The internal walls of the transport system should be constructed of materials that are minimally reactive to inadvertently deposited aerosol particles or to reactive vaporous compounds that could be present in the sample. The materials of construction for external walls and seals between sampling system components must also be compatible with the environment to which they are exposed. Frequently used materials in the nuclear industry are stainless steel for general applications and tetrafluoroethylene for radioiodine.

4.3.3 Electrostatic Effects

When some plastics are used in aerosol transport systems, internal electric fields can cause particle losses (Charuau 1982); in particular, plastic tubing that has been flexed can show abnormally high wall deposits (Liu et al. 1985). A transport system should be constructed of materials such as metals or conductive plastics that will not sustain internal electrostatic fields. In many applications it is useful or convenient to use flexible non-metallic tubing to connect a sampler or analyzer to a transport line, particularly if

there is need to isolate an analyzer from mechanical vibrations in the sample transport line. The inside diameter of the plastic line should not be smaller than the inside diameter of the components with which it is connected and the bend curvature must not be less than a ratio of five, nor may the curvature of a bend cause more than a 10% change in the inside diameter of the tube. If non-conductive flexible tubing is used, the line length exposed to the sample should not exceed two times the internal diameter of the tube.

Of the flexible tubes that can be categorized as non-conductors, neoprene or natural rubber is recommended to minimize electrostatic deposition of particulate matter (Charuau 1982).

4.3.4 Smoothness of Internal Surfaces

Internal surfaces of transport lines should be as hydraulically smooth as possible to minimize aerosol depositional losses and to facilitate decontamination. Drawn tubing or other types of tubes with ϵ/d_t less than approximately 5×10^{-5} are acceptable, where ϵ = height of surface roughness of the internal tube walls and d_t = tube diameter. This criterion requires a surface finish of approximately 64 micro-inches or less for tube sizes that are on the order of 1 in. in diameter. Fittings between tube components should not have steps that cause an abrupt change in diameter in the direction of flow.

4.3.5 Condensation

Condensation of vapors (e.g., water vapor) in transport lines, collectors, and analyzers must be avoided. Condensation takes place when the temperature of air in the transport line is less than the dew point of the vapor of interest. Thermally insulating, or in some cases heating, the transport line may be required to prevent condensation. For situations in which heating of the sampling line may result in unacceptably high temperatures at a collector or analyzer, a dilution system should be considered; however, care must be exercised to ensure that the dilution process does not produce condensation at the mixing location. Experimental or numerical analyses must be

performed to demonstrate the effectiveness of any design provisions that are intended to minimize or preclude the formation of condensation in sample transport systems.

4.3.6 Cleaning Transport Lines

An additional consideration is the need for cleaning transport lines at some facilities. For applications in which the sampled air is HEPA-filtered, there may not be a need for cleaning within the expected lifetime of the installation; however, for applications where background aerosols are present, periodic cleanout may be necessary. As a minimum, for systems that sample HEPA-filtered air, inspections for deposits should be made annually. If there is an indication of deposits inside the probe inlet, then the transport line shall be inspected. If deposits are visible inside the transport line, the line shall be cleaned. For systems that sample non-HEPA-filtered air with background aerosols, if an estimate can be made of the rate of deposition of all aerosol particles on the internal walls of the system, the system should be cleaned when the mean mass of deposited material exceeds 1 g/m^2. Decontamination requirements must be taken into account in any cleaning procedure.

4.4 GAS AND VAPOR SAMPLE EXTRACTION AND TRANSPORT CONSIDERATIONS

Much of the above discussion applies generally for sampling particles and gases; however, special consideration needs to be given to extracting and transporting vapors and gases to determine where special system design is required.

When non-reactive gases and vapors are the only species being sampled, the sampling requirements are considerably simpler than those for particles. The requirements for minimizing particle line-loss are irrelevant. The probe design can be simplified to an open ended or perforated tube. The extraction and transport requirements that still apply include extracting the sample from

a well-mixed location and avoiding water and vapor condensation in the transport and collection system (except perhaps where condensation is being used as the collection method).

When non-reactive gases, vapors, and particles are being simultaneously sampled, the particle sample extraction and transport requirements apply and will ensure adequate delivery of the gas and vapor sample as well. The remaining consideration then is the selection of the appropriate collection devices. It may be appropriate to locate the sample collection device downstream of a particle filter to eliminate particulate radionuclide interferences.

When working with reactive gases and vapors, particular attention must be paid to the sampling system construction materials and to the avoidance of condensation. The construction material shall have minimum reactivity with the gas. Consideration shall be given to the advantages of having a separate sampling system for the gases whenever the construction materials that would be desirable for the transport of the particle and gas samples are incompatible. In situations where even a low level of reactivity cannot be avoided, the transport line length shall be kept to the minimum. The penetration of the gas or vapor through the complete extraction and transport system shall be documented. The minimum transport efficiency for vapor or gas samples from the free stream to the collector/analyzer should be 50%. If long transport lines are unavoidable, consideration must be given to the effect of transport and detection delay time caused by deposition, chemical transformation and subsequent resuspension. Careful consideration must be given to how significant an effect the delay has on the timeliness, interpretation, and usefulness of the resulting data. Although rapid changes in the emission may become smeared over a large time interval relative to the change in emission, the data may still be useful and quantitative when interpreted in that light.

4.5 COLLECTION OF PARTICLE SAMPLES

4.5.1 General Considerations

Filtration is the most widely used technique for collection of aerosol particles because of its low cost and simplicity of use. However, capture of airborne particles by filters is a complex process frequently misunderstood by many users. A common misconception is that filters act as sieves, and that there is a direct relationship between the pore size of a filter and the minimum particle size that can be collected. In reality filters with nominal pore sizes of 5 μm can be efficient collectors of sub-micrometer particles. This occurs because filters capture particles by a combination of physical processes, which include direct interception, inertial deposition, diffusional deposition, electrical attraction, and gravitational sedimentation. Filters typically have a minimum collection efficiency for particles that are approximately 0.3 μm diameter. Filtration efficiency increases above and below this size.

Filters are porous structures with controlled external dimensions such as thickness and cross section normal to the flow. Such materials as fibrous beds of cellulose, glass, quartz, and plastic fibers have been used for filtration. Sintered structures of metals or mineral particles have been used for filters for high temperature filtration. Membrane filters are widely used in sampling radionuclide aerosol particles, particularly in near-real-time continuous monitors.

4.5.2 Filter Media

A large number of filter media are available for use in collection of aerosol particles. Some of these filter media date back many decades and continue to be used because of historical precedents. Users are cautioned to be selective in their choice and re-evaluation of filter media. Selection should be based on careful consideration of such characteristics of the filter media as sample usage, detection methods, cost, durability, handling methods,

and chemical compatibility. For example, if a filter and sample must be separated for a particular analytical method, the user should select a filter medium that can be easily dissolved by a method that would not attack the particles of interest. In another case, it may be imperative that the sample be collected on the surface of the filter rather than imbedded in the filter. Collection efficiency and ability to subsequently analyze the sample contribute to the uncertainty of the monitoring process. These uncertainties should be reduced through informed filter selection. Lippman (1989) provides performance data on a variety of filter media and filter holders, and discusses filtration theory.

4.6 COLLECTION OF GAS AND VAPOR SAMPLES

Airborne radioactive volatile materials and so-called "permanent" gases such as krypton are frequently important contaminants, and their sampling and collection require techniques and methods differing from those used in particle sampling. This topic may be divided into two general methods of sampling: 1) sampling with retention of specific constituents of the airstream, and 2) sampling without constituent separation.

4.6.1 Sampling with Retention of Specific Constituents

Sampling with removal and collection of specific constituents requires a detailed knowledge of the chemical and physical properties of the radioactive material of interest, including possible interfering materials such as particulates and accompanying nonradioactive gases (e.g., acids and organic chemicals). The many possible combinations of the properties of the constituents to be measured and the accompanying airborne materials require careful study to select the optimum collector. Gases and vapor components may be soluble in water, may be highly reactive with certain solutions, may dissolve in specific nonaqueous solvents, or may be retained on specific solid adsorbents or other specifically prepared media. In general, continuous rather than grab samples are taken when separation and removal of a constituent is

required. Sampling rates must be established to ensure adequate sensitivity for the radioassay method selected and must be compatible with the collector performance characteristics. The principal collection methods include solid adsorbents (such as charcoal, zeolites, silica gel, and metal beds), condensation, gas absorption, and catalytic or chemical reaction. More detailed descriptions can be found in Brown and Woebkenberg (1989).

4.6.2 Sampling without Constituent Separation

In some instances a sample of air and all its contained radioactive constituents may be desired for measurement of trends or relative levels of airborne materials. Examples are noble gas isotopes, tritium, and activated gases near a reactor. Volume collection and flow-through detectors are the two main methods for total gas sampling or monitoring.

Because the constituent radioactive materials of interest may not be concentrated with a particular flow-through or volumetric collection device, insufficient sensitivity of detection may limit or preclude their use. Each situation will have to be evaluated individually to determine the feasibility of the gross sample measurement.

Volume collection methods include

- using an evacuated container that can be valved open to the stream of interest, then returned to a laboratory for measurement of gross radioactivity or of separate constituents
- passing the stream through the sample vessel until the vessel is completely purged, then closing the inlet and outlet valves
- pumping the sample stream into deflated bags (of a non-adsorbing material) for later compression and analysis
- compressing the sample stream into a vessel for real-time or subsequent analysis.

A flow-through sample vessel may be an ion chamber whose ion current shows the relative radioactivity of material in the gas. Care must be taken to keep the gas well above its dewpoint in the sampling system and ionization

chamber. Gradual buildup of contamination in the chamber should be expected and will be shown as a gradually increasing response with clean air in the chamber.

Flow-through chamber samplers may be similarly monitored by gamma ray scintillation crystal counters or other detectors held adjacent to or inserted in a well in the chamber wall. Increase of background from contamination must be expected in these samplers, and the chamber must be decontaminated to avoid errors from this source. Prior filtering of the airstream will assist in keeping the chamber clean when gaseous constituents alone are to be measured. A flow-through sampling system that is frequently used at power reactors for accident monitoring involves placement of a high- or wide-range detector mounted directly inside or outside the stack or duct.

4.7 SAMPLE VOLUME MEASUREMENT

The sampled volume of air is another key parameter used in determining emission rates and dose levels. Because sample volume depends on the density of air, a standard density value should be selected for all data that are used to represent or report sample volume data at a facility. It is recommended that the standard density be based on dry air at a pressure of 101.3 kPa (760 mm Hg) and a temperature of 25°C (298 K). The total sampled volume at these standard conditions is represented by the symbol $Q_{T,std}$ (L_{std}). Other pressure and temperature values may be employed in use of the data for calculating exposure levels; however, the density would be non-standard and must be so reported.

4.7.1 Basic Considerations

The flowrate through a sampling system must be measured and an indication of the value must be displayed; however, if the flowrate is controlled at a set value, the display can be an error signal that the control system is out of compliance. The flow detector shall be placed in the flow system in such a manner that it does not cause losses of aerosol particles or reactive

radioactive gases. As a consequence, the flow sensor is generally located downstream of the collector or analyzer. This sensor location generally causes the pressure at the point of measurement to be less than that in the stack or duct. Also, temperature at the point of measurement may differ from that in the stack, duct, or chamber from which samples are being removed.

4.7.2 Volume of Air Sampled

If the sampling flowrate will not vary by more than ±20% over the sampling period, the flowrate, as a minimum, should be recorded at the start and the end of a sampling period. For such a case, the total volume sampled, Q_T (L), is calculated from

$$Q_T = \frac{q_1 + q_2}{2} \Theta \qquad (11)$$

where q_1 (L/min) is the volumetric flowrate indicated by the flowmeter at the start of the sampling period

q_2 (L/min) is the volumetric flowrate at the end of the period

Θ (min) is the time period over which sampling is performed.

Continuous flow monitoring or flow control is encouraged at all sites where significant emissions can occur, and it must be used if the flowrate can vary by more than ±20% during the sampling period. When continuous flow monitoring is employed, the flowrate should be recorded at intervals not to exceed 10 minutes. The total volume of sampled air is based on integration of flow over the entire sampling period. If the time interval between recordings is Δt (min), and the flowrate during the interval (either the true average in

the interval, the average of the initial and final values in the interval, or the value at the interval midpoint) is q_i (L/min), the total volume of air sampled (L) is calculated from

$$Q_T = \frac{1}{\Theta} \sum_{i=1}^{N} q_i \Delta t \qquad (12)$$

Other integration schemes may be used if the numerically induced errors are less than those implicit in Equation (12).

The flowrate Q_T is the total sample volume based on the flowrate indicated by the flowmeter. For many flowmeters, the indicated flowrate is not based on standard conditions, and appropriate corrections must be made to the resulting data.

4.7.3 Flowrate Control

If, based on *a priori* considerations or on experience with the sampling system, the flowrate q_{std} could vary by more than ±20% from the start of a sampling period to the end of the period, flow control or continuous flow monitoring shall be used. The flow controller shall maintain the flowrate within ±15% over conditions that correspond to an initial pressure drop across the collector (usually a filter) or analyzer to a value that is twice the initial pressure drop. The vacuum source used during a test of the controller shall have similar characteristics to the vacuum source used to draw air through the system in the field application.

4.8 ALARM STRATEGIES

There are two reasons for alarming an effluent monitoring system. The first is a problem with the monitoring system that results in the loss of the protection afforded by the system and the loss of information necessary to meet regulatory requirements. The second reason to alarm is that release

criteria have been exceeded and measures must be instituted to ensure protection of the public and environment or to meet regulatory requirements.

4.8.1 System Failure

System failure can take two forms. The first is complete failure. The second is partial failure that either compromises the quality of the output or is sufficient to render the output unusable. Complete failure may be an interruption of power so that the system shuts down or the loss of a vital component that has the same consequence as a loss of power. The complete loss of the system requires an alarm to ensure that action may be taken to restore operation. A complete failure that is the result of the loss of a vital component may require separate alarming because the response may be different. This type of alarm is a diagnostic alarm that indicates the mode of failure. A system that may fail by a variety of means should be equipped with diagnostic alarms. The importance of the alarm and the priority of response should be determined and entered into the facility alarm and response plan.

An incomplete failure may be sufficient to compromise the quality of the information collected, causing the system to be inadequate for safety or regulatory means. This type of failure with its antecedent conditions requires alarm and a graded response. It also requires evaluation criteria because there may be discernible differences in operation that require instrumental interpretation to set off the alarm. The setting up of these types of alarms requires statistical evaluation and a response that requires a decision based on acceptable levels of false positives and false negatives. This type of response will be discussed in the next subsection.

4.8.2 Exceeding Release Criteria

Protection is the reason for having alarms for exceeding release criteria. The basis for such protection comes from two assumptions: 1) the release criteria represent a level of protection, and 2) the monitoring system has the sensitivity that will afford this level of protection. The level of

protection represented by the release criteria should involve both concentration and time. The regulatory requirement should also involve concentration and time. An alarm is set at a level that will prevent a release above, or above a fraction, of the combination of time and concentration. The basis for setting system failure alarms may also be determined indirectly from the release criteria. The system is considered to fail if it cannot offer sensitivity at the required level.

The basis for setting an alarm, whether for system failure or exceeding release criteria, is that an instantaneous or continuous condition exists. Few systems can actually alarm for truly instantaneous conditions; however, even for a short-term average condition, the results should be severe before action is required. An alarm implies that an unsafe condition exists or will exist; therefore, the alarm condition must be highly certain. The chance of an alarm for unsafe conditions to occur when the conditions are actually safe (i.e., a false positive alarm) should be statistically highly unlikely. Two methods for ensuring that a false positive is unlikely are 1) to require two or more redundant alarm systems to simultaneously alarm, or 2) to have a single, highly reliable system that has an alarm set point well above its lower limit of detection.

5.0 QUALITY ASSURANCE AND QUALITY CONTROL

A quality assurance and control program for the collection of air samples of effluents should meet the following objectives:

- identify deficiencies in the sampling equipment and procedures so that corrective action can be taken
- provide assurance to regulatory agencies and the public of the validity of air sampling data.

The tools used to accomplish these objectives include documentation, maintenance, inspection, and calibration.

5.1 DOCUMENTATION

The documentation described below should be maintained in a single location (e.g., file) or the location of the documentation should be identified.

5.1.1 Source Term

Blueprints for the ventilation system(s) serving each monitored stack should be maintained. Modifications to the system performed during construction or anytime thereafter should be described in detail and dated. This includes changes to the ventilation system itself or changes in processes that might affect the effluent.

The nature of the processes serving each stack should be identified. This includes information about the identity of the radionuclides as well as their chemical and physical forms. The air cleaning systems associated with each stack need to be identified as well as the probable nature of releases resulting from the possible failure of these systems.

5.1.2 Effluent Flow Characterization

The results of any efforts to characterize the flow conditions of the effluents should be documented (e.g., particle size distributions, spatial and temporal variations in flowrates across the stack or duct, and checks for

cyclonic flow). The documentation should include the procedures employed, the times and dates of the measurements, the individuals involved, the equipment used, and any pertinent information regarding facility operations.

5.1.3 Design and Construction

Documentation should be available describing the objectives of each stack sampling system and should specify which radionuclides and physical and chemical forms of these radionuclides are to be collected. If a particular component that may be present in the effluent is not to be sampled, the reasons should be identified.

The rationale and any supporting evidence for sampling at a particular point along the duct or stack should be documented. Similarly the rationale for sampling at a particular point(s) within (i.e., across) the stack or duct should be documented. Similar documentation should be available explaining the rationale for the design of the rest of the sampling system. This would include documentation regarding the choice of the probe assembly, the material, diameter and configuration of the sampling lines, and the choice of absorbers, flowmeters, and other equipment. Any evaluation of particulate losses in the sampling lines should be documented. Other design documents to be maintained include engineering change control documents, equipment manuals, and vendor supplied information.

5.1.4 Maintenance and Inspection

Inspection and maintenance procedures should be described in a clear and detailed manner in a procedures manual. Checklists should be employed as part of the inspection protocol, and the checklist can become the permanent documentation of the inspection. The documentation must include the nature of the inspection or maintenance, the reason for the inspection or maintenance, the names of the individuals involved, the time and date, the identity of the equipment employed, and a description of any replacement parts or materials.

All findings made during scheduled inspections should be documented, as well as any deficiencies identified during unscheduled inspections.

5.1.5 Calibrations

Methods for calibrating equipment must be explained clearly and in detail in a procedures manual. The results of all calibrations should be documented. This includes flowmeter calibrations, timer calibrations, and any measurements of collection efficiency. The documentation should include the names of the individuals involved, the time and date, ambient temperatures and pressures, and the type and serial number of the calibration equipment. If an in-service instrument is found to be out of calibration, an analysis shall be performed to determine the impact on the affected data.

5.1.6 Training

Individuals involved in system operation, inspection, audits, and calibrations should receive training in these procedures at a frequency directed by management. This training should be documented.

5.2 MAINTENANCE AND INSPECTION

The requirements for maintenance and inspection will depend to a large extent on the nature of the sampling equipment. Routine scheduled maintenance should be performed as described in the manufacturer's equipment manuals. Typical scheduled maintenance would involve an annual cleaning, lubrication, and replacement of vanes, diaphragms, and gaskets. Maintenance will also be performed as indicated by the results of any inspections.

Regularly scheduled inspections should be performed twice a year and may be concurrent with the semiannual calibrations. Ideally, the same individuals responsible for the calibrations will also be responsible for the inspections.

Inspections should include but not be limited to

- checks of nozzle position and orientation
- measurements of the nozzle opening and evaluation of its edge for wear
- functional checks of instrumentation
- visual inspections for corrosion or damage to the sampling lines and equipment
- checks to ensure the tightness of all fittings/connections
- leak test.

5.2.1 Flowmeter Inspections

Mass flowmeters should be checked at least quarterly with a transfer standard, where a transfer standard is typically a calibrated mass flowmeter placed in series with the unit to be tested. Unscheduled calibrations may be needed if there is maintenance to the sampling system that could affect the performance of the mass flowmeter. The flowrate at which the mass flowmeter is checked shall be at a level that is within ±25% of the nominal design sampling rate of the system. If the flowrate, q_{std}, of the flowmeter being tested differs by more than 10% from the value indicated by the transfer standard, the mass flowmeter shall be removed from service for maintenance and calibration. An analysis shall be performed to determine the impact on the affected data.

Flow through critical flow venturis must be checked before each sampling period by observing the values of ΔP_m (differential pressure across the meter) and ΔP_f (differential pressure across the filter). If the value ΔP_m is less than that needed for critical flow, the vacuum system shall be checked to determine the cause. If the value of ΔP_f is less than 70% of that normally observed when the particular filter or collector is used, the critical flowmeter shall be inspected for blockage, or the sampling system shall be checked for other possible problems. The critical flowmeter will be removed from

service for cleaning and recalibration if it is the cause of the erroneous reading. If the value of ΔP_f is greater than 130% of that normally observed, the filter or collector should be inspected for possible problems.

Rotameters do not need to be checked in the field with transfer standards unless there has been either maintenance or a change to the sampling system that could affect the rotameter accuracy. The rotameter should be inspected at each sampling interval for assurance that there is no foreign matter deposited on the inside surfaces of the measurement tube. If foreign matter is visible, the rotameter shall be removed from service, cleaned, and recalibrated.

5.2.2 Leak Tests

The leak test will involve sealing the nozzle opening with a tight fitting cap or covering it with a short section of plastic tubing sealed at one end. At its simplest, the leak test is a check that the indicated flow has fallen to zero. A more elaborate test involves measuring the static pressure in the lines with a U-tube manometer (or similar device). After sealing the nozzle, a vacuum is generated on the order of 15 in. H_2O below atmospheric pressure. The sampling lines are then closed between the pump and flowmeter and the exact pressure recorded. After one minute, the pressure is measured again. A loss of 0.5 in. H_2O or more indicates a leak.

5.3 CALIBRATION

The principal calibration activities for the collection part of a sampling program involve sample flowrate, sampling time, and effluent flowrate.

5.3.1 Calibration of Flowmeters

All flowmeters must be calibrated at least annually against devices that are either based on first principles or traceable to the National Institute of Standards and Technology (NIST).

The internal sensing region of a flowmeter shall be inspected before calibration. If there is a visual indication of surface deposits, the components of the flowmeter that will be in contact with a flow stream shall be cleaned or replaced.

Mass flowmeters should be calibrated at conditions corresponding to 40%, 70%, 100%, 130%, and 170% of the nominal flowrate in terms of standard conditions. Other values may be used; however, technical justification must be documented to show that the use of the selected points will provide calibration data equivalent to, or superior to, the recommended points. If the flowrate through the sampling system could, under normal conditions, off-normal conditions, or anticipated or accident conditions, exceed the limits recommended for flow calibration, additional calibration points shall be used the encompass the possible flowrate range.

Critical venturi flowmeters need to be calibrated at only a single point that corresponds to operating with a sufficient pressure differential across the meter such that the gas velocity in its throat is sonic. The temperature at the entrance of the critical flowmeter during calibration should be within ±5°C of the average temperature anticipated at that same location during sampling. The absolute pressure at the entrance of the critical flowmeter should be within ±2% of the absolute pressure anticipated at that location.

Rotameters shall be calibrated at flowrate conditions that correspond to the average anticipated flowrate during sampling, and at 75% and 125% of the anticipated sampling flowrate.

The goal of the flowmeter calibration is to help ensure that the uncertainty in the measurement of the total volume of air sampled is below 10%.

The following approach, described in NRC Regulatory Guide 8.25 (NRC 1980) and Hickey et al. (1991), can be employed to calculate the total uncertainty in the volume for air (E_v)

$$E_v = (F_k E_s)^2 + E_c^2 + E_t^2 \quad (13)$$

where E_s = The error (%) in reading the flowmeter scale. This can be estimated by dividing the flowrate by one-half the value of the smallest scale division and multiplying by 100.

F_k = A fluctuation constant. This is set at 1, except for meters that fluctuate during reading (e.g., rotameters); the average of the highest and lowest indicated flows are used for these instruments.

E_c = Error associated with determining the calibration factor i.e., correcting the indicated flow. As an approximation the error associated with the calibration instrument may be used.

E_t = The percent error associated with the measurement of the sampling time.

5.3.2. Calibration of Timing Devices

Timing devices should be calibrated at the same time as the flowmeter, i.e., at least every six months. The maximum acceptable error is 1%.

5.4 SYSTEM PERFORMANCE CRITERIA

Assuring satisfactory sampling system performance requires carefully planned and executed design, inspection, and maintenance. Throughout this document, performance criteria have been included in the discussion of each element. For convenience, they are summarized in Table 5.1. These criteria cover aspects of system design, operation, maintenance, and calibration.

TABLE 5.1. Summary of Performance Criteria

Performance Criterion	Section Cited
PEDE estimates shall identify specific radionuclides that contribute >10%	2.2
Total transport of 10-μm AED particles shall be >50% from the free stream to the collector/analyzer	4.3
Sampler probe inlet shall have aspiration ratios in the range of 80%-150% for 10-μm AED particles	4.2.2
Sampler probe inlet shall transport 80%-130% of 10-μm AED particles	4.2.2
Characteristics of a suitable sampling plane are	3.2.2
a) coefficients of variation over the central 2/3 area of the cross section within ±20% for 10-μm AED particles, gaseous tracer, and gas velocity	
b) flow angle <20° relative to the long axis of the stack and probe inlets	
c) the tracer gas concentration shall not vary from the mean by >30% at any point on a 40 CFR 60, Appendix A, Method 1 velocity mapping grid	
Sampler probe shall transport >50% of gas and vapor species from the free stream to the collector/analyzer	4.4
Continuous effluent flowrate monitoring is required if it varies by > ±20% in a year	4.1.1
Effluent and sample flowrate shall be measured within ±10% of that measured with the Reference Method	4.1.1 & 5.3.1
Continuous sample flowrate monitoring and control is required if it varies by > ±20% during a sample interval. Flow control shall be within ±15%	4.7.2 & 4.7.3
Periodic inspections of probes, transport lines, and sample and effluent flowmeters shall be conducted	5.2
Periodic calibrations of effluent and sample flowmeters, timing devices, CAMs, and sample analysis instrumentation shall be conducted	5.3

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