



American National Standard

ANSI/HPS N13.1-2011

**Sampling and Monitoring Releases
of Airborne Radioactive Substances
from the Stacks and Ducts of Nuclear Facilities**

Approved: March 30, 2011

American National Standards Institute, Inc.



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Abstract

American National Standard N13.1 sets forth guidelines and performance criteria for sampling the emissions of airborne radioactive substances in the air discharge ducts and stacks of nuclear facilities. Emphasis is on extractive sampling from a location in a stack or duct where the contaminant is well mixed. At such a location, sampling may be conducted at a single point. This standard provides performance-based criteria for the use of air sampling probes, transport lines, sample collectors, sample monitoring instruments, and gas flow measuring methods. This standard also covers sampling program objectives, quality assurance issues, developing air sampling action levels, system optimization, and system performance verification. Workplace, containment, and environmental air monitoring are not addressed. Specific sample analysis methods and the reporting or interpreting of results are also not addressed.

Foreword

(This foreword is not part of American National Standard ANSI/HPS N13.1-2011.)

This version of the standard is identical to the previous (1999) version and is a re-affirmation of the earlier standard. The text of the standard is unchanged. The errata below are included as part of this foreword and are not part of the standard.

Page	Erratum
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- | | |
|----|---|
| 11 | <p>To correct a subscript error in the definition of the Dean number, De, the definition is changed from:</p> <p>Dean number of a flow bend ($De = Re/R_c^{1/2}$), dimensionless</p> <p>to read:</p> <p>Dean number of a flow bend ($De = Re/R_o^{1/2}$), dimensionless</p> |
| 20 | <p>An inconsistency is noted between the confidence level recommended in clause 4.4, paragraph 5 and the confidence level recommended in clause 4.4, paragraph 6; the fifth sentence in 4.4, paragraph 6 is highlighted as follows:</p> <p>The precision shall <u>should</u> be estimated at the 95% confidence level.</p> |
| 21 | <p>To correct a missing verb in clause 4.4.1, paragraph 1, second sentence, the sentence is changed from:</p> <p>There are no hard and fast rules concerning how these levels set.</p> <p>to read:</p> <p>There are no hard and fast rules concerning how these levels are set.</p> |
| 36 | <p>To correct the omission of a minus sign in Equation 7, the equation is changed from:</p> <p>$T_r = A_e(1 \text{ WI})$</p> <p>to read:</p> <p>$T_r = A_e(1 - \text{WI})$</p> |
| 39 | <p>An inconsistency is noted between clause 6.4.1 and the requirement in Table 6; the third sentence of the third paragraph of clause 6.4.1 is highlighted as follows:</p> <p>The penetration of 10 μm AD aerosol particles from the free stream to the collector or analyzer should <u>shall</u> be known and should <u>shall</u> not be less than 50%.</p> |
| 41 | <p>An inconsistency is noted between clause 6.5 and the requirement in Table 6; the sixth sentence of the fourth paragraph of clause 6.5 is highlighted as follows:</p> <p>The minimum transport efficiency for vapor or gas samples from the free stream to the collector/analyzer should <u>shall</u> be 50%.</p> |
| 50 | <p>To correct a typographical error in the last bullet label of clause 7.5, the last bullet is changed from:</p> <p>e. leak tests.</p> <p>to read:</p> <p>f. leak tests.</p> |
| 52 | <p>To correct an inconsistency between the units of the requirement in Table 5, column 2, and the units of the requirement in clause 6.4.6, the units for surface density are changed from:</p> <p>1 g/cm^3</p> |

- to read:
1 g/m²
- 55 **To correct an inconsistency between the requirement in Table 6 and the requirement in the referenced clause 6.3.2, the third item in Table 6 is changed from:**
Sampler nozzle shall have an aspiration ratio that does not exceed 150% for 10 µm AD particles
to read:
Sampler nozzle shall have an aspiration ratio within range of 0.80 to 1.50 for 10 µm AD particles
- 67 **To correct an inconsistency between the 8th input parameter in Table B.1 and the third sentence in clause B.2, the 8th input parameter in Table B.1 is changed from:**
b. shroud diameter should be 52.5 mm
to read:
b. shroud diameter should be 52.8 mm
- 67 **To correct an inconsistency between the 9th input parameter in Table B.1 and the graphical representation of that parameter shown in Figure B.3 on page 66, the 9th input parameter in Table B.1 is changed from:**
Element 2: Tube, 0.2 m long, 0° from horizontal
to read:
Element 2: Tube, 0.2 m long, 90° from horizontal
- 76 **To correct an inconsistency between Equation E-2 and Equation E-1, the left-hand variable name in Equation E-2 is changed from:**
 C_A
to read:
 C_A
- 76 **To correct an inconsistency between the Greek letters used in Equations E-3 and E-4 and the Greek letters used in the last sentence of the page:**
phi's
in the last sentence are changed to:
theta's
- 80 **To correct a cross-reference error in the second sentence of the third paragraph of clause E.4.1:**
annex H
is changed to read:
annex G
- 89, 90 **To correct an inconsistency between the particle diameter notation used in clause G.3 and the particle diameter notation used in the stated references:**
MMD
is changed throughout items 4 and 5 to read:
MMAD

Foreword to the 1999 version

(This foreword is not part of American National Standard N13.1-2011.)

Monitoring of radionuclide emissions from stacks and ducts must provide results that are representative of the content and concentration of the gas stream as a whole. For extractive sampling this requires that a sampling point must be in a region where the contaminant is well mixed with the bulk flow, and that the process of extraction does not bias the sample. In the 1969 version of ANSI N13.1, an attempt was made to meet the mixing goal by prescribing the location in a stack or duct where sampling could be performed in terms of the number of duct diameters from a flow disturbance. With the realization that in many circumstances conformance with a duct length rule would not in itself guarantee achievement of good mixing, another rule was recommended, namely that the extraction process be accomplished with multiple sampling nozzles in any stack or duct with a diameter greater than 150 mm (6 inches). The number of sampling points was dependent on duct diameter. Further, if aerosol particles with sizes greater than 2 to 5 μm could be present in the air stream, it was recommended that the inlet to the sampling nozzle be operated isokinetically. However, the use of multiple isokinetic nozzles to sample aerosol particles can be counterproductive. For a fixed sampling flow rate, as the number of sampling points is increased the inlet diameter of each isokinetic nozzle is decreased, which causes larger losses in the entrance region of the nozzles. It is now known that the early rule-based approach (selection of an acceptable sampling location using a prescribed number of duct diameters from a disturbance, and on the requirement for multi-point isokinetic extraction of particulate samples) does not provide assurance that a sample will be representative.

This revision of ANSI N13.1 differs significantly from the earlier version in that it is now a performance-based standard rather than one based on prescriptive rules. There are two important aspects of performance addressed in the new approach. First, the concept of acquiring a representative sample is not based on rules for sample location and multi-point extraction, but rather on the premise that at any location where the contaminant concentration and the fluid momentum can both be demonstrated to meet numerical criteria for acceptable mixing, a representative sample can be obtained by extraction from a single point in that profile. Thus, the burden has properly shifted from specifying the distance that a sampling location must be from a disturbance to demonstrating compliance with numerical criteria placed on mixing performance. Second, numerical criteria are also used to provide the basis for a decision on whether a sampling system will deliver a representative sample to a collector or detector. Essentially the concept of isokinetic sampling has been replaced by numerical criteria for the sampling performance of extraction nozzle and transport line designs. By eliminating the requirement for multi-point isokinetic sampling and focusing instead on quantitative performance, the design of sampling systems with much lower sample losses is now possible. The complete set of numerical criteria has been shown to be achievable by a new generation of sampling system designs, and these criteria are expected to accommodate the application of any innovative concepts that are based on sound principles of aerosol physics and fluid mechanics. Although the approach to achieving representative effluent sampling presented in this standard represents a substantial departure from the methodology recommended by the previous version of this standard, it is practical and the expected performance is attainable.

Sampling and Monitoring Releases of Airborne Radioactive Substances From the Stacks and Ducts of Nuclear Facilities

0 Introduction

ANSI/HPS N13.1 was first issued in 1969 as a guide to sampling airborne radioactive materials in the ducts, stacks, workplaces, and environs of installations where work with radioactive materials is conducted. Since then, an improved technical basis has been developed for each of the major sampling specialties. Consequently, the scope of this revision has been narrowed to directed airflow situations such as ducts and stacks.

This standard presents a new approach to representative sampling. The goal of achieving an unbiased, representative sample is accomplished by requiring that samples are extracted from airstreams meeting rigorous criteria for being well mixed for potential airborne contaminants. This standard sets forth guidelines and performance criteria for the proper use of air sampling nozzles, transport lines, sample collection and monitoring devices, and gas flow measuring methods in obtaining valid measurements of airborne radioactive materials in ducts or stacks. The guidelines and criteria presented in this standard are covered in the following clauses:

Clause 3 provides a glossary and nomenclature used in this standard to define terms and symbols that are used in the equations.

Clause 4 covers the objectives and approaches for sampling programs.

Clause 5 discusses the requirements for selecting sampling locations.

Clause 6 covers the requirements for designing the sampling system components.

Clause 7 describes the requirements of an acceptable quality assurance program specific for air sampling.

In addition, the following annexes provide information of use to sampling program and system designers:

Annex A provides techniques for measurement of flowrate through a stack or duct.

Annex B outlines modeling of particle losses in transport systems and presents an example of using a computer code to estimate aerosol penetration through a transport system.

Annex C presents special considerations for the extraction, transport, and sampling of radioiodine.

Annex D illustrates criteria for the selection of filters for collecting airborne radioactive particles.

Annex E describes the statistical basis of evaluating effluent sampling errors and uncertainty.

Annex F summarizes when to conduct sampling system performance verification and how this may be accomplished.

Annex G explains transuranic aerosol particulate characteristics and the implications for extractive sampling in nuclear facility effluents.

Annex H discusses tritium sampling and detection. This standard does not cover:

- a. the selection of sampling locations in work areas or containments;

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- b. selection of specific instrumentation for sample collection or on-line monitoring of collected samples;
- c. the analysis of collected samples;
- d. the reporting and interpreting results.

1 Scope

This standard sets forth guidelines and performance-based criteria for the design and use of systems for sampling the releases of airborne radioactive substances from the ducts and stacks of nuclear facilities.

1.1 Relationship to other standards

The potential applications of this standard are diverse, and consequently it is inappropriate to incorporate the many laws, regulations, and guidelines of governmental bodies that have an interest in the measurement of radioactive air emissions. It is incumbent on the user to be familiar with the applicable regulations.

1.2 Application of this standard

The requirements presented in this standard are aimed at sampling programs conducted for regulatory compliance. These requirements may not be universally applicable to all sampling programs, especially those 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 standard.

2 Normative references

The following standards and U.S. Environmental Protection Agency (EPA) test methods contain provisions that, through reference in this text, constitute provisions of this American National Standard. At the time of publication, the editions indicated were valid. All standards and EPA methods are subject to revision, and parties to agreements based on this American National

Standard are encouraged to investigate the implications of the most recent editions of the standards and methods indicated below.

ANSI N13.2-1969 (Reaffirmed 1982), *Administrative Practices in Radiation Monitoring*, outlines administrative practices of a program for monitoring ionizing radiation, including gaseous effluents.

ANSI N42.18-1980 (Reaffirmed 1991) *Specification and Performance of On-Site Instrumentation for Continuously Monitoring Radioactivity in Effluents*, provides performance criteria for instrumentation used for monitoring radioactivity in liquid and airborne effluent streams. How effluent stream characteristics, operating environment factors, and standards and regulations affect the selection of instrumentation for effluent monitoring systems are briefly discussed. Dynamic range; sensitivity; accuracy; precision, physical, mechanical, and electrical requirements; and detection capability are also addressed. Testing procedures are not covered.

ANSI N320 (1979), *Performance Specifications for Reactor Emergency Radiological Monitoring Instrumentation*, addresses the essential performance parameters of monitoring instruments used during an accident event at reactors. The instrument operating environment, operational characteristics, and lower and upper detection limits are also addressed. The general instrument locations inside the reactor plant, at release points, and in the plant environs are addressed.

40 CFR 60, Appendix A, *Method 1, Sample and Velocity Traverses for Stationary Sources*, provides criteria for the number of points and conditions for velocity measurements.

40 CFR 60, Appendix A, *Method 2, Determination of Stack Gas Velocity and Volumetric Flowrate (Type S Pitot Tube)*, provides a methodology for flow measurements.

40 CFR 60, Appendix A, *Method 2C, Determination of Stack Gas Velocity and Volumetric Flowrate in Small Stacks or Ducts (Standard Pitot Tube)*, describes flow

characterization methodology for stacks and ducts less than 300 mm in diameter.

3 Glossary and nomenclature

A system for sampling radionuclides from a stack or duct can consist of several general components, as shown in figures 1a and 1b. A nozzle, placed at a location where a representative sample can be extracted, is used to remove the sample from the bulk flow stream. The transport line generally consists of tubing and connectors. Connectors can be bends, expansions, contractions, flow splitters, or mixing elements. Splitters are used where it is desired to extract a sample from the duct or stack with a single system and then to provide samples

to multiple collectors or monitors. In some situations, a flow conditioning apparatus is used to dilute or concentrate a sample, or to selectively remove constituent gases (e.g., water vapor in order to minimize the risk of condensation). When a sampling system is used with a collector such as an aerosol filter, the sample may be analyzed in a laboratory that is remote from the sampling site. If a continuous monitor is used, the purpose of the monitor is to provide a near realtime signal of the concentration of the radionuclides of interest. The flow control system serves the function of providing the flow through the sampling system, of measuring that flow, and of maintaining its value at a desired level.

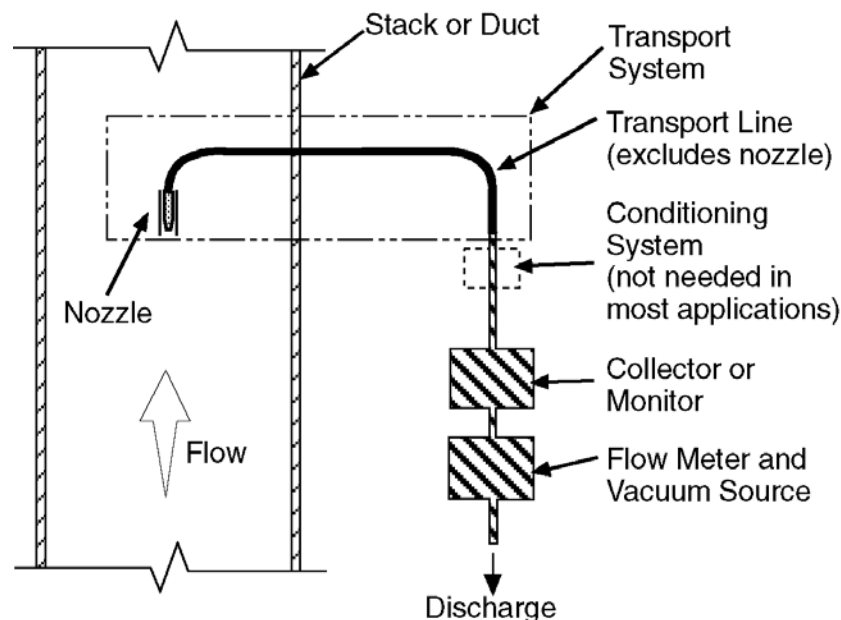


Figure 1a – Generic sampling system, illustrating a flow schematic where components are identified

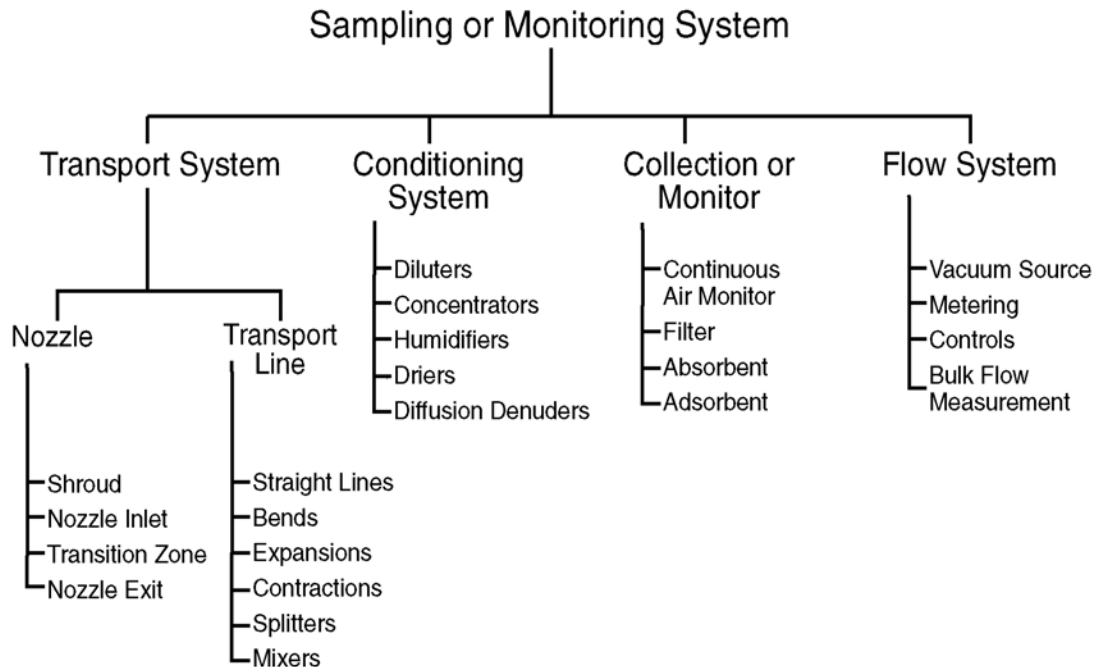


Figure 1b – Generic sampling system, illustrating a component hierarchy of a sampling system S9509031.8

3.1 Definitions

In this standard, the following definitions apply:

AD: See *Aerodynamic diameter*.

AMAD: Activity median aerodynamic diameter. The aerodynamic particle diameter for which 50% of the aerosol radioactivity is associated with sizes less than (or larger than) that particular size.

ANSI: Abbreviation for the American National Standards Institute, Inc.

ASME: Abbreviation for the American Society of Mechanical Engineers.

Accident (Conditions): Upset conditions that can lead to the release of abnormal concentrations of radionuclides from a stack or duct.

Accuracy: The closeness of agreement between a measured value and a true value.

Action Level: The threshold concentration of an effluent at which an appropriate action is to be performed.

Aerodynamic Diameter (AD): The AD of a particle of arbitrary shape and density is the diameter of a spherical water droplet that has the same sedimentation velocity in quiescent air as the arbitrary particle.

Aerosol: A dispersion of solid or liquid particles in air or other gas.

Aerosol, Monodisperse: An aerosol comprised of particles that are all of approximately the same size. In general, the geometric standard deviation of a monodisperse aerosol is less than or equal to 1.1.

Aerosol, Polydisperse: An aerosol comprised of particles with a range of sizes. In general, the geometric standard deviation of a polydisperse aerosol is greater than 1.1.

Analyzer: A device that provides for near realtime data on radiological characteristics of the gas (air) flow in a stack or duct. Usually, an analyzer will evaluate the concentration of radionuclides in a sampled air stream; however, some analyzers are mounted directly in a stack or duct, or are placed on the outside wall of the stack or duct, and have no flow through them.

Aspiration Ratio: Used in conjunction with the performance of a nozzle. It is the ratio of aerosol concentration at a nozzle inlet plane divided by the aerosol concentration in the undisturbed stream at the point where the nozzle is located.

Average Surface Roughness: A measure of the magnitude of fine irregularities of surface texture. The technical definition is the arithmetic average of the absolute values of the measured profile height deviations taken over a length of material and measured from the graphical center line. (See "roughness average" in ANSI/ASME B46.1-1985.)

Bend: A gradual change in direction of a sample transport line. The radius of curvature of a bend should be at least three times the inside diameter of the tubing.

Bulk Stream: The air flow in a stack or duct, as opposed to the sample flowrate.

Burial: The imbedding of a particle into a filter medium or the masking of a particle by subsequent deposits of particulate matter.

Calibrate: Adjustment of a system and the determination of system accuracy using one or more devices that are either traceable to the National Institute of Standards and Technology (NIST) or based on first principles. Includes adjustment of flow, temperature, humidity, or pressure gages and the determination of system accuracy using the NIST-approved or first-

principles equipment.

CFR: Abbreviation for the Code of Federal Regulations.

Coefficient of Variation (COV): A statistic that is the ratio of the standard deviation of a variable to the mean value of that variable. It is usually expressed as a percentage.

Collector: A component of a sampling system that is used to retain radionuclides for analysis, e.g., a filter that is used to remove α -emitting transuranic or other radionuclide aerosol particles from a sample stream.

Concentrator: A device that is used to increase the concentration of contamination in a sample stream.

Conditioning System: Apparatus that could be used to purposefully, in a controlled manner, change the aerosol concentration, gas composition, particle size distribution, temperature, or pressure in a sample stream (see figure 1).

Confidence Interval: The statistical estimate of the bounds on a parameter that provides an interval that is expected, at a specified probability, to contain the true value of the parameter. For example, the 95% confidence interval will contain the true value 95% of the time.

Continuous Air Monitor (CAM): A near realtime sampler and associated detector, which provide data on radionuclides (e.g., concentration of α -emitting aerosol particles) in a sample stream.

Continuous Monitoring: Continuous near realtime measurements of one or more sampling characteristics.

Continuous Sampling: Either uninterrupted sampling or sequential collection of a sample obtained automatically at intervals short enough to yield results that are representative for the entire sampling period. The sample may be analyzed in near realtime (i.e., equivalent to monitoring) or it

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may be analyzed post-sample-collection in a remote laboratory.

Control Equipment: Apparatus used to reduce contaminant concentration in the airflow exhausted through a stack or duct.

Curvature Ratio: The ratio of bend radius to the tube diameter.

Cutpoint: Used in conjunction with a device that causes a separation of aerosol particles by size. It is the aerodynamic particle diameter for which the device will collect 50%, and will transmit 50%, of the aerosol particles.

Depositional Losses: Loss of sample on the internal walls of a sampling system. See also *wall losses*.

Detection Limit: The minimum input signal to an instrument that can be said, with a predetermined confidence level, to exceed the inherent noise of the instrument.

Diffusion Denuder: A device that is used to selectively remove molecular constituents from a sample air stream.

Diluter: A mixing device that is used to reduce the concentration of radionuclides, background contamination, or water vapor in a sample stream. Usually, a sample stream taken from the stack or duct is mixed with dry filtered air in a diluter.

Dryer: A device for removing water vapor from a sample stream.

EPA: Abbreviation for the U.S. Environmental Protection Agency.

Effective Dose Equivalent: The sum of the products of the dose equivalent to the organ or tissue and the weighting factors applicable to each of the body organs or tissues that are irradiated.

Effluent: A waste stream flowing away from a process, plant, or facility to the environment. In this standard, the focus is on effluent air that is

discharged to the atmosphere through stacks and ducts.

Emission: Contamination that is discharged into the environment.

Emit: The process of discharging contaminants into the environment.

Extractive Sampling: See “sampling.”

Fibrous Filter: A filter consisting of a mat of randomly oriented fibers.

Flowrate: The rate at which mass or volume of gas (air) crosses an imaginary cross sectional area in either a sampling system or a stack or duct. The rate at which volume crosses the imaginary area is called the *volumetric flowrate*; the rate at which mass crosses the imaginary area is called either the *mass flowrate* or the *volumetric flowrate at standard conditions*.

Fraction of Allowable Limit (FAL): A multiplier to be applied to an applicable state or federal dose limit for the purpose of developing a graded approach to sampling and monitoring. For each potential impact category, there should be a corresponding fraction of an allowable limit that provides a quantifiable basis for decisions regarding the required monitoring or sampling procedure.

Geometric Mean: If there are N observations of a random variable, x , the geometric mean of the sample, x_g is defined as:

$$\ln x_g = 1/N \sum_{i=1}^N \ln x_i$$

Geometric Standard Deviation: If there are N observations of a random variable, the geometric standard deviation, s_g , is calculated from:

$$\ln^2 s_g = 1/(N-1) \sum_{i=1}^N (\ln x_i - \ln x_g)^2$$

where x_g is the geometric mean of the random variable.

Grab Sample: A single sample removed from a flow stream over a relatively short interval of time.

Graded Approach (to Sampling): A decision process in which the requirements on the system vary with the risk of exposure to radionuclides.

HEPA (High Efficiency Particulate Air) Filter: A filter used for collecting aerosol particles from a flow stream. A HEPA filter collects at least 99.97% of aerosol particles of 0.3 μm diameter and is designed to collect greater fractions of aerosol particles with diameters either larger or smaller than approximately 0.3 μm .

Hydraulic Diameter: A parameter that is equal to the actual diameter of a circular stack or duct and is equal to $(2HW)/(H+W)$ of a rectangular stack or duct, where W = width of the duct cross section, and H = height of the duct cross section.

In-line: A system where the detector assembly is adjacent to, or immersed in, the effluent airstream.

Impaction: A process by which a particle or droplet is removed from an airstream by striking an object in the airstream. Curvature of air streamlines, principally on the front side of the object, cause particles with sufficient inertia to strike the object while the air flow passes around it.

Interception: A process by which a particle is removed from an airstream by an object in the flow, where the trajectory of the particle's center of gravity would miss the object, but the body of the particle strikes the object.

Isokinetic: A condition that prevails when the velocity of air at the inlet plane of a nozzle is equal to the velocity of undisturbed air in a stack or duct at the point where the nozzle inlet is located. *Anisokinetic* is the antonym of isokinetic. *Subisokinetic* refers to the condition where the nozzle inlet velocity is less than the free stream velocity. *Super-isokinetic* refers to the condition where the nozzle inlet velocity is greater than the free stream velocity.

LLD: Abbreviation for the lower limit of detection.

Laminar Flow: The flow regime in stacks or ducts associated with Reynolds numbers less than about 2200. This regime is not usually encountered in effluent air flows. Mixing in laminar flow results from molecular diffusion, which is a much slower process than mixing in turbulent flow.

Mass Size Distribution: A representation of the amount of mass of particulate matter associated with intervals of particle size, over the full size range encountered in a sample. For nuclear aerosol samples, it is a representation of the relative amount of mass (measured mass in a size interval divided by the total mass of the sample) associated with intervals of aerodynamic diameter.

MMAD: Mass median aerodynamic diameter. The aerodynamic particle diameter for which 50% of the aerosol mass is associated with all sizes smaller than (or larger than) that particular size.

May: In regulatory applications implies an action is not mandatory, but is permissible.

Membrane Filter: Filter media consisting of thin organic-based films having a range of selectable porosities and controlled composition. Thin porous metallic filters are sometimes also called membrane filters.

Micrometer: A unit of length equal to 1.0×10^{-6} meters that is commonly used to describe the size of an aerosol particle. It is abbreviated μm .

Mixer: A device that joins two or more sample streams to form a single sample stream. A typical example of a mixer is a Y-fitting where the flow enters the Y-fitting through the two arms of the Y and leaves through the single leg of the Y.

Mixing Element: A device placed in a stack or duct that is used to augment mixing of both contaminant mass and fluid.

Monitor: Measurement of the airborne radioactive constituent or the gross content of radioactive

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material continuously, at a frequency that permits an evaluation of concentration in near realtime, or at intervals that comply with regulatory requirements.

NIST: Abbreviation for the National Institute of Standards and Technology.

Near Realtime: Repetitive or continuous measurement of sample properties.

Nozzle: A device used to extract a sample from an effluent flow and transfer the sample to a transport line or collection device. Within the nozzle there will be a transition zone where the sample stream adjusts to the conditions in the transport line.

Nozzle Exit (plane): An imaginary plane across the cross section of a transport system that divides the nozzle region from the transport line. Frequently, the nozzle is a separate component and the nozzle exit plane is clearly defined as the downstream end of that component. If there is no separate component, the nozzle exit is the end of the transition zone of the nozzle flow.

Nozzle Inlet (plane): The imaginary cross sectional inlet plane of a nozzle where the flow first enters the transport system. In the special case of a shrouded nozzle, the inlet is referenced to the inner nozzle rather than the shroud.

Number Size Distribution: A representation of the number of particles associated with intervals of particle size, over the full size range encountered in a sample. For nuclear aerosol samples, it is a representation of the relative number of particles (measured number of particles in a size interval divided by the total number of particles in the sample) associated with intervals of aerodynamic diameter.

Off-line: A system whereby a sample is withdrawn from the effluent stream and analyzed at a location that is remote from the region where the sampling system is located.

Off-Normal (Conditions): Conditions that are unplanned with unknown consequences. Examples are accidents and equipment failure.

Particle: An aggregate of molecules, forming a solid or liquid, ranging in size from a few molecular diameters to tenths of millimeters (several hundred micrometers).

Particle, Large: A large particle that has a size greater than 10 μm AD.

Penetration: The degree of passage of airborne contaminant through a transport system or transport line.

Potential Effective Dose Equivalent (PEDE): The effective dose equivalent of the most impacted member of the public from a source, which would occur if control equipment on that source were rendered ineffective. In this standard, PEDE is used as a decision tool.

Potential Emissions: Radionuclides that could be released to the environment from a stack or duct in the absence of control equipment.

Potential Impact Category (PIC): A ranking classification of potential radiological impact, based on factors such as potential effective dose equivalent (PEDE). It is used to implement a graded approach to sampling and monitoring. The potential for impact is based on facility source characteristics, assuming loss of containment of radioactive materials that would otherwise be released to the effluent stream under consideration.

Precision: The degree of agreement of repeated measurements of the same property, expressed in terms of the dispersion of test results about the mean result. A value of precision is obtained by repetitive testing of a homogenous sample under specified conditions. The precision of a method is expressed quantitatively as either the standard deviation computed from the results of a series of controlled determinations or as the coefficient of variation of the measurements.

Probe: A term sometimes used colloquially to refer to the equipment inserted into the stack or duct, usually a nozzle and part of the transport line.

Propagated Uncertainty: The uncertainty of a dependent variable of a measurement system as affected by the combined uncertainty of independent variables.

Quality Assurance: Planned and systematic actions necessary to provide confidence that a system or component will perform satisfactorily in service and that the results are both correct and traceable.

Radionuclide: An unstable isotope of an element that decays spontaneously, emitting radiation.

Rake: A probe within a stack or duct to which two or more nozzles are attached.

Record Sample: A sample that is collected for reporting purposes. Generally, record samples are analyzed off-line.

Reference Method: Apparatus and instructions for providing results against which other approaches may be compared. Application of a reference method is assumed to define correct results.

Representative Sample: A sample with the same quality and characteristics for the material of interest as that of its source at the time of sampling.

Sample: A portion of an airstream of interest, or one or more separated constituents, from a portion of an airstream.

Sample Extraction Location: The location in a stack or duct that coincides with the nozzle inlet. Generally, it is taken as a plane that is perpendicular to the longitudinal axis of a stack or duct.

Sampler: A device that collects or analyzes the sampled air flow from a stack or duct.

Sample Stream: Air that flows through a sampling system.

Sampling: The process of removing a sample of the flow stream in a stack or duct and transporting it out of the stack or duct for collection or analysis.

Sampling Environment: The condition of the flow and gas within a stack that can influence the sampling process. Factors include pressure, temperature, and molecular composition of the gas.

Sampling Location: See *sample extraction location*.

Sampling System: With reference to the diagram given in figure 1, a general sampling system consists of a probe, a transport line, a flow conditioning system, and a collector or monitor. Depending upon the application, a flow conditioner may not be used in the sampling system.

Sedimentation Velocity: The terminal (maximum) velocity an aerosol particle attains in quiescent fluid (air) as a result of the gravitational force.

Sensitivity: The change in reading of a mechanical, nuclear, optical, or electronic instrument as affected by changes in the variable being sensed by the instrument. The slope of a calibration curve of an instrument, where a calibration curve shows output values of an instrument as a function of input values.

Shall: In regulatory compliance means an action is mandatory.

Should: In regulatory compliance indicates an action is desirable but not mandatory.

Shroud: An aerodynamic decelerator placed about a sampling nozzle to reduce sampling biases.

Splitter: A device that divides a sample stream into two or more parts. The usual goal in the

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design of a splitter is to have equal concentrations in each of the exit flows from the splitter.

Standard Conditions: Used to convert air densities to a common basis. The standard conditions adopted in this standard are a temperature of 25°C and a pressure of 760 mm Hg.

Swirl: A condition when the velocity vectors of a flow are not aligned with the longitudinal axis of the stack or duct.

Transition Zone. A region in a transport system where the air flow characteristics change. For example, this could be the region where the sampled stream in the nozzle adjusts to the transport line geometry.

Transmission Ratio: Used in quantifying performance of nozzles. It is the ratio of aerosol concentration at the exit plane of a nozzle to the aerosol concentration in the undisturbed flow in the stack or duct at the point where the nozzle is located.

Transport Line: That part of a transport system between the nozzle exit plane and the entrance plane of a collector or analyzer.

Transport System: All components of a sampling system, excluding the collector or analyzer.

Turbulent Flow: The flow regime characterized by bulk mixing of fluid properties. For example, in a tube, the flow is turbulent if the Reynolds number is greater than about 3000 and laminar if the Reynolds number is below about 2200. There is little mixing in the laminar flow regime.

Uncertainty: An estimate of the deviation of a measured value from the true value of a parameter. Typically, the uncertainty is stated at a given statistical level of confidence (e.g., 95%).

Uncertainty Analysis: A procedure for estimating the overall impact on the accuracy or precision of a dependent variable as a result of estimated errors in independent variables.

Vapor: The gaseous form of materials that are liquid or solids at room temperature, as distinguished from non-condensable gases. (Vapors are gases but carry the connotation of having been released or volatilized from liquids or solids.)

Velocity Profile: A map of the velocity values at a given cross section in a stack or duct.

Volatile: Having a high vapor pressure that will allow significant quantities of material to become gaseous at the prevailing temperature. In this standard, the stack temperature would generally be considered as the reference.

Wall Losses: Loss of sample to the internal walls of a transport system. Quantitatively, it is the equivalent concentration lost to the walls of a nozzle, transport line, conditioning system, or transport system divided by the concentration at the inlet plane of the nozzle, transport line, or transport system.

3.2 Nomenclature

Symbols that are used in equations in this standard are defined below.

A	Cross sectional area of a stack or duct, m^2
A_e	Aspiration efficiency of a sampling nozzle, dimensionless
C	Cunningham's slip correction for aerosol particles, dimensionless
C_{af}	Velocity-averaging correction factor for determining flowrate in a stack or duct from a line average velocity taken with an acoustic flow meter, dimensionless
C_P	Pressure coefficient for a pitot tube, dimensionless
C_{pt}	Velocity-averaging correction factor for determining flowrate in a stack or duct

	from a single point reading with a pitot tube, dimensionless	q_a	Volumetric flowrate at actual temperature and pressure conditions, m ³ /s or liter/min
C_{ta}	Velocity-averaging correction factor for determining flowrate in a stack or duct from a single point reading with a thermal anemometer, dimensionless	q_{std}	Volumetric flowrate at standard conditions (25° and 760 mm Hg), m ³ /s
c_e	Radionuclide concentration at the exit plane of a transport system component, mass or activity/m ³	R	Gas constant for a particular gas (R_u/M), kJ/(kg°K)
c_i	Radionuclide concentration at the inlet plane of a transport system component, mass or activity/m ³	R_c	Radius of curvature of a pipe bend, m
c_∞	Radionuclide concentration in the undisturbed free stream at the nozzle location, mass, or activity/m ³	R_o	Curvature ratio ($R_o = R_c/d_t$), dimensionless
D_a	Aerodynamic particle diameter, m or μm	R_u	Universal gas constant, $R_u = 8.314$ kJ/(kmol•K)
De	Dean number of a flow bend ($De = Re/R_c^{1/2}$), dimensionless	Re	Reynolds number of flow in a tube ($Re = \rho U_m d_t / \mu$), dimensionless
d_t	Inside diameter of a transport system component (e.g., tube), m	r	Resuspension rate, time ⁻¹ s ⁻¹
L	Length of a section of tubing, m	S	Signal
M	Mean molar mass of a gas, kg/kmol	Stk	Stokes number, $Stk = C \rho_w D_a^2 U_m / 9 \mu$, dimensionless
N	Number of points or observations	T	Temperature, 1°C or K
P	Overall penetration of sample through a transport system, dimensionless	T_a	Temperature in stack or duct, 1°C or K
P_j	Penetration of sample through the j th component of a transport system, dimensionless	T_{std}	Standard temperature, 25°C or 298 K
p	Pressure, kPa or mm Hg	T_r	Transmission ratio of a nozzle, dimensionless
p_{std}	Standard pressure, 101.3 kPa or 760 mm Hg	t	Time, s
Q_T	Total volume of gas (air) sampled, m ³	U_m	Spatial mean velocity of gas (air) in a flow tube, m/s
q	Volumetric flowrate, m ³ /s or liter/min	V	Velocity, m/s
		V_i	Velocity at the midpoint of the i th element
		V_{std}	Equivalent velocity at standard conditions (25°C and 760 mm Hg), m/s

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v_d	Deposition velocity due to Brownian diffusion or turbulent inertial deposition on the wall of a transport tube, m/s
v_e	Effective deposition velocity of contaminant at the wall of a transport tube, m/s
v_g	Sedimentation velocity of an aerosol particle, m/s
W	Wall losses of aerosols in transport system components, dimensionless
α	Angular coordinate in a tube cross section, dimensionless
Δ	Difference of two values of a parameter
η	Efficiency, dimensionless
θ	Time period over which sampling is performed, s
μ	Dynamic viscosity of a gas, Pa·s
ρ	Density, kg/m ³
ρ_{std}	Density of air at standard conditions (251 and 760 mm Hg), 1.184 kg/m ³
ρ_w	Density of water at 4°C, 1000 kg/m ³
ϕ	Angle of inclination of a tube axis relative to vertical, dimensionless
ε	Surface roughness, m
λ	Decay constant, s ⁻¹

4 Objectives and approaches for sampling programs

A written technical basis shall be prepared for the programs and procedures to sample or monitor the releases of airborne radioactive substances from the ducts and stacks of nuclear facilities. Issues to be addressed shall include the sampling objective, the graded approach for meeting the objectives, the relevant facility operating conditions and

airborne contaminants, and the action levels that signal changing conditions of significance. These issues set the bounds or parameters governing the overall design of sampling system placement, components, and operation as detailed in clauses 5, 6, and 7.

4.1 Defining the sampling objective

There are many possible objectives for an air sampling program. The rationale in choosing a specific objective and approach shall be well documented. Some possible air sampling objectives are:

- meeting regulatory requirements;
- assessing the need for a permanent sampling or monitoring program;
- assisting in evaluating claims of radiation injury by workers or others;
- measuring the release of radioactive materials to the environment through source sampling;
- helping to ensure that people in the surrounding environment are not exposed to levels of airborne materials exceeding established limits;
- helping to assess the possible consequences of non-routine incidents and guiding the selection of appropriate corrective action. This can include the integration of radioactive contamination released to the environment over various time periods.

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. 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 ducts and stacks in a particular facility involve matters of engineering judgement in which conflicting demands arise from consideration of obtaining the most accurate sample, ensuring worker safety, physical plant constraints, and other operational and safety factors that have to be balanced.

The various objectives for sampling are not (or need not be) mutually exclusive in most stack sampling circumstances. A sampling system designed to meet one objective may meet other objectives as well. Likewise, there can be a number of approaches taken to achieve a given objective.

4.2 Developing a graded approach to sampling

The nature of an operation or process which creates the potential for airborne radioactive material influences 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 significant hazard than for a facility handling a less hazardous inventory.

4.2.1 Estimating potential emissions

A survey shall be conducted of the potential sources of radionuclide emissions at a facility to determine 1) the form and radiological inventory of materials being handled, 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.

Facility operators shall consider in their estimates of potential emissions and resultant public exposures, that under adverse conditions the facility effluent controls (e.g., filtration and gas holdup) may be completely eliminated. It would, therefore, be inappropriate 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 shall be assumed that all emission controls are ineffective. Therefore, the limiting factors determining the source term are the inventory, process throughput, and the physical form of the radionuclides being handled. A simple estimation method is the multiplication of the maximum expected radioactive material inventory by a factor that depends on the physical state of the material. The resultant source term can be input to a meteorological dispersion and dose estimation code for purposes of generating annual potential effective dose equivalent rates to a maximally exposed individual at the facility boundary. Table 1 (EPA, 1989) may be used as a guide to aid the estimation process.

Other approaches to estimating potential emissions might include the use of aerosol release fractions for the processes of concern, measurements of the material accumulated on the ventilation filters, or air sampling upstream of the ventilation filters (see DOE, 1994 and Barnett and Davis, 1996). In circumstances where the source term consists of a mixture of radionuclides, the radionuclides that contribute 10% or more to the total potential, or actual, effective dose equivalent from that source should be identified (or as otherwise required by regulation). Facility owners and operators should be aware that this procedure may be subject to state or federal regulation, and if

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so, the requirements of such regulations shall supersede the proposed strategy.

4.2.2 A graded approach to sampling

A graded approach to establishing a sampling and monitoring program should be undertaken. For example, a sampling program design could be

based on the potential that the effluent from a given facility has for contributing to offsite dose. This depends on whether the radioactive source materials being handled are easily dispersed (in gaseous form or finely divided powders), and also on their inherent radiological hazard. A facility stack that has the potential for discharging airborne radionuclides in quantities that could

Table 1 – Generalized strategy for estimating emissions for purposes of designing an appropriate sampling and monitoring program (EPA 1989)

Physical form or state of radioactive inventory available to release	Multiplicative factor to be used in estimating atmospheric emissions
Gases, condensable and noncondensable, and solids or liquids heated to a high enough temperature to be in a volatilized state	1.0
Liquids or particulate solids	0.001
Solids (other than above states)	1.0×10^{-6}

cause radiological doses to a member of the public in excess of a small percentage of federal dose limits would be a candidate for continuous sampling and trending and possibly also continuous monitoring with a sampler fitted with a realtime detector. The decision to utilize realtime monitoring in addition to continuous record sampling would be appropriate for stacks that present the potential for radiological doses well in excess of state or federal dose limits, and would also be appropriate where rapid detection of high levels of contamination during accidental releases is needed. Stacks that have the potential for release of radionuclides to the air in quantities that would contribute less than a small percentage of the regulatory dose limits would typically require only periodic confirmatory measurements.

In the absence of a potential radiological source that could contaminate the effluent, no radioactive air emission sampling would be expected to be required, as in non-radiological stacks at nuclear facilities. However, the absence of a potential source would be subject to periodic review to verify that facility uses have not changed. A possible

situation that should be guarded against is one in which a facility is no longer used for handling, storing, or processing radioactive materials, but has radiologically contaminated ductwork from previous work. Then maintaining the monitoring program may be well advised. Thus, a graded, four-tier program should be developed in which increasingly more sampling and monitoring resources are directed at stacks that have the greatest potential for causing public doses in excess of regulatory limits. Specific state or federal regulations 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 sampling and monitoring of emission points is shown in table 2. This approach employs potential impact categories (PICs) that represent dose consequences (e.g., potential effective dose equivalent) that may occur assuming effluent attenuation or filtration devices present in the effluent stream have no effect.

There is no one graded approach that would be appropriate for all facilities. The fractions of allowable dose limits proposed in table 2 are illustrative, and therefore shall be considered superseded by regulatory requirements. They exemplify how a dose limit standard can be associated with a graded approach to planning for sampling. As indicated, practical considerations involving such additional factors as worker safety and facility constraints should enter into the decision.

4.3 Considerations for different sampling situations

Particular attention should be given to the potential interactions between the operating conditions of the facility, the airborne contaminants, the ventilation components, and the sampling system. General considerations for assessing the interactions of facility operating conditions and the characteristics of the airborne contaminants are discussed in the following subclauses.

4.3.1 Considerations for sampling normal and off-normal conditions

Normal operating conditions are the expected conditions with an expected variability. These are usually the average operating conditions and their variance as defined in statistical terms. The normal operating conditions may have a large range of temperature and flowrates depending on the processes in operation. The effluent sampling system shall be designed to accommodate these conditions. The effluent discharge system may also operate with an effluent control (clean-up) system in place that reduces particulate and gaseous emissions to an acceptable level. Therefore, normal conditions exist for particle size and concentration and effluent reactivity and corrosivity. The effluent monitoring system shall be designed to reliably function under these operating conditions.

Table 2 – Graded approach to sampling and monitoring

Potential impact category	Monitoring and sample analysis procedures	Potential fraction of allowable limit
1	Continuous sampling for a record of emissions and in-line, realtime monitoring with alarm capability; consideration of separate accident monitoring system	> 0.5
2	Continuous sampling for record of emissions, with retrospective, off-line periodic analysis	>0.01 and ≤0.5
3	Periodic confirmatory sampling and off-line analysis	>0.0001 and ≤0.01
4	Annual administrative review of facility uses to confirm absence of radioactive materials in forms and quantities not conforming to prescribed specifications and limits	≤0.0001

Other expected operating conditions may exceed the design conditions for short durations. These conditions may occur during process changes or regular maintenance. Such changes of conditions should be considered design conditions if potential emissions during these periods are unlikely to exceed 10% of the total expected emissions. They should be considered off-normal conditions if they occur for only brief periods on an infrequent basis, such as once every six months, and are likely to involve more than 10% of the total expected emissions.

Off-normal conditions are generally considered to be unplanned with unknown consequences. They may result from:

- a. Accidents such as fires, explosions, spills, or natural disasters;
- b. Incidents, which are planned events whose outcomes were not fully anticipated or in which an accident or error altered the outcome; or
- c. Equipment failures, which 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.

Off-normal conditions may include the following:

- a. Off-normal flow conditions (low or high flowrate in stack or duct);
- b. Off-normal temperature conditions (high or low);
- c. Off-normal gaseous constituents (corrosive, humid, condensing, vaporizing, high concentration, unknown composition);
- d. Off-normal 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 sample should accommodate the conditions or account for the effect and the resulting nonrepresentative sample. If necessary, a back-up system should be provided that can increase the range of sampling conditions.

An effluent sampling system should be able to accommodate or account for off-normal conditions. However, there are limits to the ability to accommodate and account for off-normal conditions, which may be expected to be reached well before the 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 in which the consequences are recognized only after the fact. The effluent sampling system could be the only, or the most immediate, means for recognizing the incident or accident.

A sampling system that is capable of accommodating all off-normal conditions, due to its inherent design or because it is sufficiently controlled to alter its sampling characteristics to fit the altered 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 should monitor the off-normal

conditions sufficiently to institute the back-up or to 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.

4.3.2 Sampling for aerosol particles

A representative sample of aerosol particles should not alter the radiochemical and physical characteristics so that analytical interpretation could be compromised. Special attention should be given to the design of the sampling nozzle and transport line so that excessive sample loss and discrimination between particles of various sizes are minimized. Detailed guidance for particulate extraction and transport line design is provided in clause 6.

Studies may be necessary to establish the size distribution and chemical nature of airborne particles in an effluent as an aid to the sample system design. Changes in the nature of effluent components should be anticipated with changes in operations. The possibility that appropriate sampling equipment modifications may be required should be kept in mind.

The sampling or monitoring system should be designed so that emissions occurring under accidental or off-normal conditions can be adequately sampled and detected. This is especially important if the effluent is filtered prior to discharge. Although the particle size most likely to directly penetrate HEPA (high efficiency particulate air) filter media is in the 0.1 - 0.3 μm diameter range, it is erroneous to assume that the sampling system need only be designed for sub-micrometer particles. Larger-size particles may be transmitted through HEPA filter banks due to small openings in HEPA frames, gasket seals, and filter media defects developing especially after extended periods of use. Downstream particle size distribution is primarily a function of the size distribution of the challenge aerosol (Scripsick 1994). When accidental or off-normal conditions occur, a wide range of particle sizes may be present in the effluent, and this shall be a factor in

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the design. Particles well into the inertial size range (sizes larger than about 2 μm aerodynamic diameter, AD) should be considered to be present.

The off-normal case should consider the consequences of enhanced leakage of particles through filter media, filter seals, and cracks in filter frames. Thus, both normal and off-normal conditions may be characterized by chronic, low-level releases involving particles in size ranges covering nearly the full spectrum of sizes present in the challenge aerosol (Scripsick 1994). The accident case involves failures of potentially much greater consequence, in which high radionuclide concentrations may be present in the effluent. In either case, a polydisperse aerosol (an aerosol with a range of particle sizes) shall be anticipated. But the accident case is much harder to characterize in advance because changes in effluent discharge rate, added dust, smoke, and debris may be expected. However, it should be noted that particles greater than about 100 μm would not be expected to occur in large numbers in a stack effluent due to gravitational settling and inertial impaction removal effects during transport in the accident environment, and in the ductwork leading to the stack. The transport of such large particles in extractive sampling lines is exceedingly inefficient or nonexistent. Therefore, there are upper bounds to particle sizes that need to be evaluated. For typical stack conditions, evaluation with 10 μm AD particles should suffice; for the accident case, consideration of transport of somewhat larger particles is prudent. Annex G should be consulted for a discussion of the particle sizes associated with a variety of source terms and sampling concerns. The facility designer or evaluator should use modeling tools such as those discussed in clause 6 to understand the expected performance of any proposed sampling system under a variety of conditions.

A record sample is collected to minimize sample loss or bias created by complex sample transport line design or by realtime detector chamber design. Consideration should be given to the feasibility of collecting such a 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) provides near realtime detection of radionuclides in the effluent. It is usually desirable to design the sampler to collect as much of the largest size particles as feasible because of the increased activity associated with those large particles (see clause 4.3.3 for what is meant by "large particles," and annex G). However, if there is an unusually high concentration of inert large particles present along with radioactive particles, there may be an offsetting disadvantage to optimizing collection of large particles due to sample burial and radiation attenuation effects. Then, consideration of size-selective sampling techniques that discriminate against larger inert particles is warranted.

The system design chosen to supply aerosol samples to either a continuous air monitor or an in-line record sample filter (or both) shall be designed and evaluated to meet minimum performance objectives under normal, off-normal, and accident conditions with respect to the efficiency of particle transport to the filter, bias with respect to size or kind of particle, and allowable total random error. As discussed in the balance of this standard, performance objectives for these conditions will include many factors in addition to the central concern for providing a representative sample of the effluent.

4.3.3 Concerns for large particles

This document is primarily directed to sampling particles that pose inhalation risks. Thus, the particle sizes of major concern are generally less than or equal to 10 μm AD. If, however, there is a process or source feeding a sampled effluent that can release aerosol particles much larger than these sizes into the effluent stream, a special sampling apparatus located in the duct near the process should be designed that would reliably detect failure of emission controls on that source. The performance of such apparatus should be verified for the range of anticipated particle sizes and sampling conditions (e.g., stream velocity, mixing, etc.) at that location. As previously noted, use of HEPA filtration upstream of the sample withdrawal location does not eliminate all concerns

for large particles due to possible transmission through leaks in frames and seals. However, even nonfilterable radioactive gases and vapors may become associated with large particles by adsorption effects. For example, radioactive vapors or gases penetrating filtration can deposit on downstream stack or duct walls and become incorporated into surface layers, corrosion, or rust. Subsequent 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 to extra-large particle sampling may involve the periodic use of impaction plates or other specialized in-stack samplers or detectors to provide effective and timely samples and detection.

4.3.4 Sampling condensable vapors or reactive gases

The presence of radioactive air contaminants in the form of condensable vapors or reactive gases, such as certain forms of radioiodine, in the effluent stream will create a potential for serious distortions in the sample if precautions are not taken in the design and operation of the sampling system. Deposition in long transport lines and condensation due to temperature changes in the line should be avoided. The inner surfaces of the sampling probe and transport line should be constructed of or coated with nonreactive materials 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 molecular iodine gas into organic iodine vapor, 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 presence of non-radioactive constituents which 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 condensable gases is found in clause 6.

4.3.5 Sampling noncondensable, nonreactive gases

If the radioactive contaminant in the effluent stream is a noncondensable, non-reactive gas (e.g., ^{85}Kr), then it is not as critical to avoid long transport lines as it is for the other types of contaminants described above. In this instance, chemical or phase change interactions will not be a factor for system design.

4.4 Determining action levels

The action levels required of the air sampling system and program shall be considered as part of the design basis. The desired action levels determine the sensitivity requirements of the sampling system and affect design parameters such as sample volume, sampling frequency, the capacity of the collector, and the sensitivity of on- or off-line analyzers.

An action level is an effluent contaminant concentration threshold at which an appropriate action should be performed. The type of action performed depends on the circumstances. The action may entail generation of alarms, diversion of effluent through added effluent treatment, or intervention in the process creating the contaminant. There are inevitable consequences of whatever response is taken. Some are relatively minor, others are much more significant in terms of cost, damage to equipment, and possibly even human health and safety. Consideration shall be given to the setting of an action level for an effluent sampling or monitoring system that takes into account all such consequences. Not only can there be false negative outcomes (i.e., a true release of significance goes uninvestigated), but also false positive outcomes (i.e., worker responses to alarms, risks associated with rapid shutdown, and costs incurred needlessly). Both types should be anticipated, but, depending on the hazard potential of a particular stack effluent and other factors, false positive outcomes may be of more consequence to facility operations and worker safety than false negative ones due to work stoppage and evacuation of areas. Facility administrators should be cognizant of all reasonably anticipated outcomes.

The process of selection of an appropriate action level requires considering 1) the physical and chemical characteristics of the contaminant, 2) the characteristics of the sampling system required to obtain a sample of the contaminant for analysis and counting (e.g., the nozzle design characteristics, the transport line design, or sampling location), and 3) the type, intensity, and variability of interference with the measurement. Each of these considerations can contribute uncertainty to the contaminant concentration estimate, and, therefore, affect the level of confidence that can be assigned to the decision. The selection of an appropriate action level is separate from, and precedes, considerations of the required sensitivity of the sampling and measurement systems.

It is useful in the context of discussing action levels to draw distinctions among the following:

- a. *Control monitoring:* Sampling for purposes of providing adequate warning so that an operator can take action to protect workers and the public from excessive exposure (i.e., continuous monitoring with alarm in Potential Impact Category 1 stacks of table 2);
- b. *System availability:* Tracking sampling system availability and response so the facility operators are alerted if equipment failure takes a system off-line or seriously degrades performance;
- c. *Performance sampling:* Regulatory compliance sampling that will yield data of such quality and type that the facility owner can identify and quantify the most significant radionuclides present in the effluent, and support demonstration of regulatory compliance by meeting all requirements for sample extraction location, instrument calibration and maintenance, sample handling, and chain of custody (this pertains to Potential Impact Categories 1, 2, and 3, table 2).

When determining action levels, consideration should be given to accuracy, precision, and uncertainty. These terms apply to both the process of sampling and the process of

measurement. The concern for accuracy is directed at the elimination of bias in the sampling and measurement processes. Regular calibration of sampling and measuring equipment using accepted procedures and traceable standards is used to establish accuracy. Accuracy should be estimated at the 95% confidence level.

Statistical measures of dispersion of results about a measurement population mean are used to calculate precision. Sampling precision can be determined by replicate samples obtained under the same conditions. Measurement precision is obtained from the statistics of repeated measurements on replicate samples and by detailed analysis and propagation of errors in component measurements. Sampling and measuring precision are combined statistically to obtain an estimate of overall precision. The precision shall be estimated at the 95% confidence level. The concern of precision determinations is the estimation, and where possible, reduction of random errors in the sampling and measuring processes.

The departures of measured values from either the true values (accuracy effects) or from the mean of measured values (precision effects) are measures of error or uncertainty in the sampling and measurement system results. Contributions to uncertainty in sampling or measurement are best determined independently and combined by statistical propagation of error. A detailed discussion of sampling and measurement random errors, and error determination methods leading to an assessment of overall effluent sampling system uncertainty, is found in annex E.

Each facility should set data quality objectives for its particular sampling and measurement systems. A guide to recommended levels of uncertainty, as they pertain to accuracy and precision of sample extraction and transport, and of measurement, is given in table 3. Most of the recommendations for control monitoring in table 3 are not as stringent as the recommendations for record sampling. Near realtime radiation detection by a CAM, for example, usually cannot yield as accurate a measurement as would be expected of a laboratory counting system because variable bias

introduced by the presence of interfering background activity can often be significantly reduced or eliminated in the laboratory. Note that the accuracy and precision recommendations of table 3 are not meant to be absolutes and be equally appropriate in all cases and conditions. For example, effluents containing highly reactive constituents such as radioiodine may be particularly difficult to extract and transport without significant sampling bias, leading to higher estimated sampling accuracy uncertainties than 20%. In contrast, measurement accuracy in some systems may be easily held well below 20% given the characteristics of the instrumentation and measurement processes and should be so reported.

There may be justifiable reasons for sacrificing some degree of measurement accuracy in control systems to achieve higher instrument reliability, extended range of response, more effective background compensation, or other optimization goals. The overall system uncertainty limit values are derived by summing the respective relative variance estimates of the sampling accuracy or precision components. For example, the recommended limit of overall uncertainty in system accuracy for continuous monitors (40%) is the square-root of the sum of squares of the sampling accuracy component (20%) and the measurement accuracy component (35%) of uncertainty. Mentioning these components separately calls attention to the fact that if the sampling nozzle and transport line are not properly designed and properly placed, uncertainty will be created in sampling accuracy, and no amount of attention to measurement accuracy in the system will prevent

the system from generating poor, biased data, and faulty alarm responses.

4.4.1 Action levels for control monitoring

The foregoing discussion provides a basis for incorporating accuracy and precision considerations in the setting of appropriate action levels. (There are no hard and fast rules concerning how these levels set.) It should be kept in mind that there is a trade-off between having high confidence in an alarm being triggered only by a 'true' contaminant release, and having sufficient alarm sensitivity to the presence of the contaminant, albeit at lower confidence. It is in this context that the true costs of false alarms have to weigh into the decision, along with the desire to detect the contaminant at the lowest concentration and shortest integrating time. In some CAM instruments it may be that the net counts are converted to activity concentration estimates by dividing the counts by detector efficiency, volume sampled, and time. All of these factors add uncertainty to the results. However, for alarming purposes, the largest uncertainty will typically derive from the counting error, as shown in annex E. If the costs of false alarms in an effluent monitoring system are large, then a decision may be made to set the alarm threshold at a relatively high level, and accept the risk of not detecting a lower level release in a timely fashion. In some contexts, trending of measurement results can be a useful tool to aid in maintaining control below a chosen action level. The user should determine an action level that can be attained, and design and operate

Table 3 – Guide to uncertainty of sampling and measurement

Factor or consideration	Record sampling	Control monitoring
Frequency of		
a) Sampling	Continuous	Continuous
b) Measurement	Weekly	Near realtime
Relative Uncertainty of Sampling		