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Concepts for Environmental Radioactive Air Sampling and Monitoring

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1. Introduction

Environmental radioactive air sampling and monitoring is becoming increasingly important as regulatory agencies promulgate requirements for the measurement and quantification of radioactive contaminants. While researchers add to the growing body of knowledge in this area (Byrnes, 2001; Till & Grogan, 2008), events such as earthquakes and tsunamis demonstrate how nuclear systems can be compromised. The result is the need for adequate environmental monitoring to assure the public of their safety and to assist emergency workers in their response. Two forms of radioactive air monitoring include direct effluent measurements and environmental surveillance.

Direct effluent radioactive air sampling is typically conducted at the exhaust point. The considerations for analysis should include particulates and gases in use; one cannot neglect short-lived radioisotopes or hard-to-detect (HTD) radionuclides. An emission point may be in the form of an actively exhausted stack or vent. Emissions may come from several industries, such as medical isotope production, hospital use, research institutes, and industrial processes.

Environmental surveillance is conducted when emissions emanate from a fugitive pathway such as a waste pile, abandoned building, or contaminated land mass or breather tank. Monitoring stations are often located at near the facility boundary or nearby public areas in the affected directions. Often, a combination of direct effluent (point source) sampling and post release environmental monitoring is employed to assure the public, demonstrate low emissions of radioactive material, and comply with regulations.

This chapter presents basic concepts for direct effluent sampling and environmental surveillance of radioactive air emissions, including information on establishing the basis for sampling and/or monitoring, criteria for sampling media and sample analysis, reporting and compliance, and continual improvement.

2. Basis for sampling and/or monitoring

Releases of airborne radionuclides into the environment are typically managed so that they are minimized, utilizing the As Low As Reasonably Achievable (ALARA) concept. These releases encourage the need to demonstrate that the environment is protected, which is usually accomplished through direct effluent sampling at the point of exhaust and/or through environmental surveillance at locations both on and off the site (Fig. 1). A

combination of both methods may be employed depending on the facility needs and regulatory requirements.

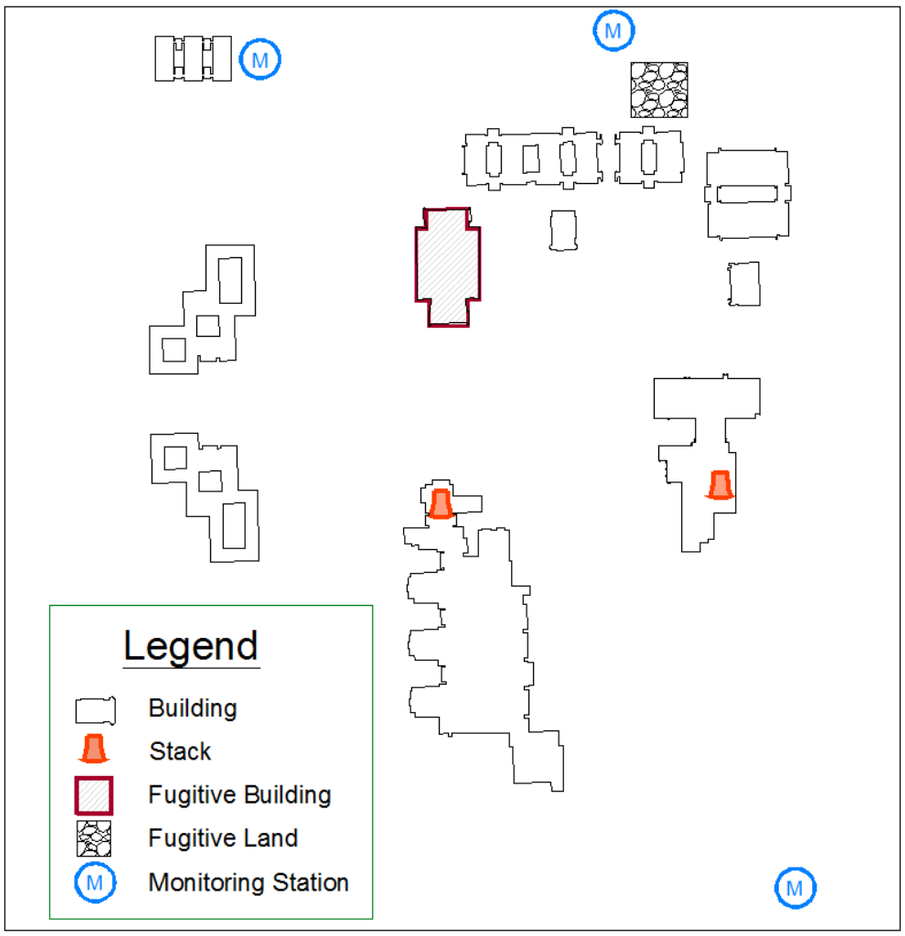


Fig. 1. Example facility showing stacks, fugitive emissions, and on-site monitoring station locations

Exposure to humans from the release of radioactive materials into the atmosphere would generally occur through the inhalation or ingestion pathway; an open wound would be another possible way for internal deposition. Additional exposure comes from immersion, material deposited on the soil and vegetation, and through the resuspension of material when disturbed. Hence, the categories for consideration in establishing radioactive air sampling systems include particulate radionuclides, gases (e.g., tritium and carbon-14), and special categories such as radioiodines and other HTD radionuclides (e.g., those with a short half-life or very weak radiation emission). In-depth implementation methods are available in established standards such as *Sampling Airborne Radioactive Materials From the Stacks and Ducts of Nuclear Facilities* (International Organization for Standardization [ISO], 2010) and *Sampling and Monitoring Releases of Airborne Radioactive Substances From the Stacks and Ducts of Nuclear Facilities* (American National Standards Institute [ANSI], 2011) as well as in *Radioactive Air Sampling Methods* (Maiello & Hoover, 2010). When sampling/monitoring is not conducted, releases may be estimated.

2.1 Sampling point source releases of radioactive substances

Over 40 years ago, proscriptive sampling methods were normative, with an emphasis on the isokinetic sampling of airborne radioactive material from exhaust points (ANSI, 1970). Since then, advances in sampling techniques and improved technology have yielded a new approach to representative sampling (ANSI, 2011; ISO, 2010). Because of these advances, the goal of achieving an unbiased, representative sample now results in a standards-based approach with definitive criteria to establish the sampling at a well-mixed location.

Point sources are discrete, well-defined locations (such as a stack, vent, or other functionally equivalent structure) from which radioactive air emissions originate (Washington Administrative Code [WAC], 2005; U.S. Environmental Protection Agency [EPA], 2002a). Point sources are actively ventilated or exhausted. Emissions from a point source may be captured, treated, monitored, sampled, and/or controlled. At some threshold, direct effluent sampling must be conducted to verify low emissions, and a graded approach based on potential emissions is recommended. Table 1 shows the ANSI N13.1-2011 approach to direct effluent sampling and monitoring requirements based on the U.S. limit of 0.1 mSv/yr (10 mrem/yr) (EPA, 2002a).

Potential Impact Category	Monitoring and Sample Analysis Procedures	Potential Fraction of Allowable Limit
1	Continuous sampling for a record of emissions and in-line, real-time 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

Table 1. Graded approach to sampling and monitoring (ANSI N13.1-2011)

Using a graded approach to determine direct effluent sampling and monitoring needs (Table 1) and to design a robust sampling system (whereby the sample is extracted at a homogeneous location within the point source) requires an evaluation of the sample environment, transport mechanisms, and collection materials. The criteria for the homogeneous sampling location includes a determination of the angular or cyclonic flow, uniformity of the air velocity profile, gas concentration profile, and particle concentration profile (ISO, 2010; Table 2). Scaled tests may be utilized to demonstrate compliance with these criteria; however, as technology improves, modeling techniques such as computational fluid dynamics may be used to validate a well-mixed location without the necessity of field tests conducted in the stack or vent (Recknagle et al., 2009).

Characteristic	Methodology	Recommendations
Measurement to determine if flow in a stack or duct is cyclonic	ISO 10780:1994.	The average resultant flow angle should be less than 20 degrees.
Velocity profile	Selection of points across a section based on the guidance in ISO 10780 for the center 2/3 of the area may be added to adequately cover the region.	The coefficient of variance (COV) should not exceed 20% over the center region of the stack that encompasses at least 2/3 of the stack cross-sectional area.
Tracer gas concentration profiles	Selection of points across a section based on the guidance in ISO 10780 for the center 2/3 of the area of the stack or duct. Additional points or area may be added to cover the region adequately.	The COV should not exceed 20% over the center region of the stack that encompasses at least 2/3 of the stack cross-sectional area.
Maximum tracer gas concentration deviations	Selection of points across a section based on the guidance in ISO 10780 for the entire cross-sectional area.	At no point on the measurement grid should the tracer gas concentration differ from the mean value by more than 30%.
Aerosol particle concentration profile	Selection of points across a section based on the guidance in ISO 10780. Additional points or area may be added to cover the region adequately.	The COV should not exceed 20% over the center region of the stack that encompasses at least 2/3 of the stack cross-sectional area.

Table 2. Summary of recommendations for a stack sampling location (ISO 2889:2010)

2.1.1 Direct effluent sampling

Once the sampling location has been identified and qualified, attention to the sample system design is necessary. A typical stack effluent sampling system includes an in-line sample probe within the stack/vent, a sample transport line to the sample media (e.g., filter paper or cartridge), a rotameter, and vacuum gauge with feedback controls. The sample collection and transport are affected by the nozzle design, performance, and specific sampling use (e.g., particulates, gases/vapors). For reporting purposes, the bulk stream flow through the emission point is also required.

During the sampling process, losses – particle losses in particular – should be minimized. The most effective way to accomplish this is to limit the number of bends and horizontal sections of the sample line and to minimize the total sample line length. For harsh sampling environments such as those containing corrosive gases and vapors, construction material should be resistant to degradation. Because some loss is inevitable, required maintenance activities such as inspection, cleaning, and testing can help maintain effective operations.

The collection media is equally important to obtaining a valid sample. Sampler filters are usually adequate for collecting particulate radioactive air media (Fig. 2). Commercial particulate filters are made of glass fiber, acrylic copolymer, or other robust material and vary in size from 25 mm to 20 cm in diameter. Other potentially necessary specialized

collection media include silica gel (Fig. 3) or molecular sieves for tritium collection, activated charcoal or silver zeolite cartridges for radioiodines, and bubblers for other gases. For collection media selection, detection criteria for the measurement of alpha, beta, and gamma radiation must also be established to meet lower limits of detection. The sample volume affects the criteria for detection limits, sample size, sampling frequency, and materials used.



Fig. 2. Fixed head radioactive air stack sampler with 47-mm diameter filter in place

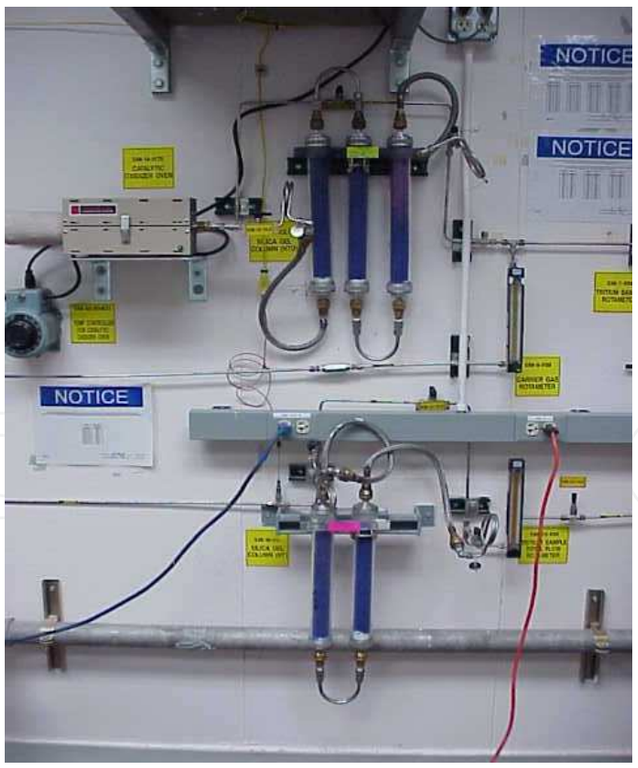


Fig. 3. Silica gel columns in use for tritium sampling system; three columns are used for collecting water vapors, and then the dry gas goes through a catalyst to form the water vapor collected using the two columns (Barnett et al., 2004)

Optimization of the sampling system is the final component of the program development. Balancing the effects and requirements along with a graded approach will generally result in an adequate sample. These considerations are also germane to environmental surveillance sample collection stations and equipment.

2.1.2 Direct effluent monitoring

As identified in the graded approach of Table 1, continuous air monitoring may be required at a point source for real-time analysis and feedback. A continuous air monitor (CAM) provides timeliness in assessing the release of radionuclides to the environment. Fig. 4 shows a combination particulate and gas CAM. While the system specifications require the user to balance the sensitivity, energy response, response time, and accuracy, the CAM should also have alarm capabilities with established thresholds to alert the user to significant releases (DOE, 1991).



Fig. 4. Combination continuous air monitor for particulates and gases

The requirements of sampling at a well-mixed location apply equally to a stack CAM. However, additional maintenance, repair, and calibration are required for a CAM. Maintenance activities can include periodic checks of the system responses to inputs that generate alarms that verify normal operations. Repairs can include replacement of electronics, detectors, or other system components that wear out or become damaged. Finally, an annual calibration is required that covers all aspects of the CAM operations. Calibration activities would include background checks and measurements, source responses to reference standards of given radioisotopes, leak tests, electronics validations, and alarm responses.

A CAM is particularly useful in laboratory work where releases are expected and can be observed and managed, either in normal or upset/accident conditions. For routine work, staff may observe a release to limit the overall activity or bound daily releases. In an upset condition, staff have a near real-time assessment of releases and potentially a second filter for future analysis to confirm releases and potential exposures.

2.2 Airborne radioactive material environmental surveillance

The primary benefits of environmental surveillance for airborne radioactive material are that it identifies emissions from fugitive (and point) sources and provides detailed impacts to the public and the environment. When establishing a site monitoring program, utilization of a data quality objective (DQO) process is recommended, this determines the environmental monitoring needs for routine radiological air emissions to the atmosphere from the emissions/sources of the site in response to regulatory requirements. Assistance with preparing a DQO is available from *Guidance on Systematic Planning Using the Data Quality Objective Process* (EPA, 2006); additionally, the Pacific Northwest National Laboratory (PNNL) used the DQO process to establish three site monitoring locations (Barnett et al., 2010). The development of the DQO includes the following aspects:

1. Stating the problem
2. Establishing goals
3. Assessing inputs
4. Setting boundaries
5. Establishing decision rules
6. Evaluating decision errors
7. Optimizing the results

Besides a DQO, processes such as an implementation plan, sampling and analysis plan, a site environmental monitoring plan, and a data management plan complete a well-managed monitoring program.

Identifying and clearly stating the problem is the first step in the DQO process. This section discusses the background and scope, states the requirements, establishes the problem statement, and identifies the participants and schedule. Once the problem statement is firmly established, the goals of the DQO can be identified, usually a series of supportive questions and actions that specifically address the problem statement.

Assessing inputs and setting boundaries are the next steps in the DQO process. The inputs are used to answer the questions formulated from the goals; include information necessary to meet performance and acceptance criteria; and provide direction for the monitoring, sampling, and analysis methods. Additionally, the boundaries discuss the logistics of implementing the goals and objectives. To provide a viable monitoring program, all seven aspects of a DQO must be considered.

In establishing and evaluating the decision rules and errors, goals and inputs are vital. The decision rules are the answers to questions posed during the goal-setting process, and they utilize the data inputs for the decisions that follow. Decision errors evaluate and discuss potentially incorrect decisions and determine the possible consequences.

The final step in setting up the monitoring program for a facility or site is optimization, which may include requirement compliance, using commercial off-the-shelf equipment, and implementing standard analytical methods. However, when optimized, the goal is to make the operations and systems work efficiently.

Commercial monitoring stations are readily available (Fig. 5), the weather-protected equipment is housed in a small metal portable or stationary cabinet consisting of a pump, flow totalizer, adjustable vacuum gauge, and other equipment and/or electronics as necessary (Fig. 6). The unit's power may be a hard-wired electrical outlet, batteries, or a renewal energy source such as an array of solar panels.

Depending on system and design needs, the filter/sample media may be either inside the monitoring cabinet or external to it. Basic filter papers (Fig. 2) can be fixed to a sample head on the exterior of the cabinet; cartridges (e.g., silver impregnated zeolite and/or activated carbon) can also be fixed to an exterior sample head. Other sample media such as the larger silica gel cartridges may need to be housed inside the cabinet.



Fig. 5. Environmental air monitoring station

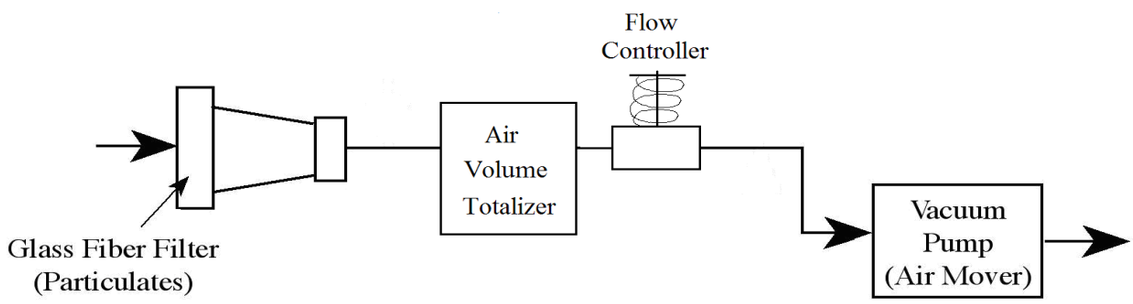


Fig. 6. Air monitoring system schematic for radioactive particulates

2.3 Considerations for assessing hard-to-detect radionuclides

HTD radionuclides have a combination of properties that include a lengthy or very short half-life, low-energy (e.g., weak beta) emissions and detection difficulties, particularly with field instruments but also with laboratory instruments. HTD radionuclides include C-14, Fe-55, I-129, Ni-63, and Tc-99. In the environment, the assessment of HTD radionuclides relies on consideration of alternative approaches such as process knowledge, surrogate/ratio (scaling) measurements, and dose impacts. The overall importance of HTD radionuclides should not be underestimated because they may in fact make a significant contribution to the regulatory dose limit for the public or environment.

The HTD radionuclides are not easily detected because the radiation cannot penetrate outside of its sample matrix or the activity is too low and obscured by background, other radionuclides, or instrument noise. The costs to isolate and analyze for the HTD radionuclides may not be justified when the use of another more readily measurable radionuclide (e.g., Cs-137) can be used to scale the HTD radionuclide measurement. Establishing the scaling factor requires process knowledge about the other radioisotopes available for measurement and the relative quantities of the HTD radioisotopes to the known radioisotopes. Once these are determined, measurement of the HTD radionuclide can proceed as a function of the better known and measured radioisotope.

2.4 Estimating releases in lieu of analytical results

When facility emissions are very low (Potential Impact Category 4, Table 1), an administrative review of the releases to the environment may be used instead of the sampling and monitoring methods described above. This review may employ data logging of actual or estimated releases based on inventory. Emissions may also be conservatively estimated when sampling or monitoring is inadequate.

For gas emissions in particular, the use of data logging is practical and efficient. The facility tracks the known releases of radioactive materials to the environment, and this log becomes the official basis for reporting. In addition to data logging, tracking of a facility's radioactive material inventory can be used to estimate a calculated release (EPA, 1989). In this process, one determines the amount of radioactive material used for the period under consideration. Radioactive materials in sealed packages that remain unopened, and have not leaked during the period are not included. The amount used is multiplied by both a release fraction ([RF]; Table 3) and a decontamination factor ([DF]; Table 4 and Equation 1). If there is more than one abatement control device in series, then multiple DFs are applied. Therefore, it is necessary to know the form of the radioactive material and any abatement controls.

Material Form	Release Fraction (RF)
Gas	1
Liquids	10^{-3}
Particulates	10^{-3}
Solids	10^{-6}

Table 3. Release fractions for estimating radionuclide releases

Abatement Control Device	Type of Radionucides Controlled (i.e., form)	Decontamination Factor (DF)
HEPA filter	Particulates	0.01
Fabric filter	Particulates	0.1
Activated carbon filters	Iodine gas	0.1
Venturi scrubber	Particulates	0.5
Packed bed scrubbers	Gases	0.1
Electrostatic precipitators	Particulates	0.05
Xenon traps	Xenon gas	0.1

Table 4. Typical decontamination factors for estimating radionuclide releases

$$A_{\text{Potentially Released}} = A_{\text{Inventory}} * RF * \pi(DF)_{(i)} \text{ (Bq)} \quad (1)$$

Where:

$A_{\text{Potentially Released}}$ =calculated release in of given isotope in Becquerel
$A_{\text{Inventory}}$ =activity of given isotope in the facility in Becquerel
RF =release fraction for material
$DF_{(i)}$ =decontamination factor for each device used in series

For additional conservatism, one can assign the DF to 1. Also, the EPA (1989) requires that any nuclide heated above 100°C, boils below 100°C, or intentionally dispersed into the environment must have a RF of 1. Other assessment methods include non-destructive assessment, upstream of HEPA filter air concentration measurements, spill release fraction, and back calculation, which may also be used to derive potential radioactive air emissions from a stack (Barnett & Davis, 1996).

3. Criteria for sampling media and correction factors

Sampling media criteria selection must be established. Once the media is selected and evaluated, various correction factors can be applied to the data. For particulate samples, selection of an appropriate filter (paper) is generally acceptable. Sampling for radioactive gases requires special treatment and typically includes the use of activated charcoal, silica gel, or another sampling mechanism based on the characteristics of the gas. Guidance for the selection, optimization, and use of various sampling media are provided (ISO, 2010).

After sampling media selection, subsequent sample collection and analysis are required. In particular, criteria established during the standards based process or DQO process becomes the basis for the analytical laboratory providing results so that meaningful reporting and

data trending can be provided to interested stakeholders. Correction factors are often applied to the analytical data to prevent under reported measurements.

3.1 Sample media selection

Several different filter media are available for the collection of aerosol particles: materials include acrylic copolymers, glass fiber, cellulose, and quartz. While most filters are surface collectors and can readily be analyzed, the user should determine the need to dissolve the filter for composite analysis or further specific isotopic analyses. The range of filter flow rates vary, but for environmental applications, a flow rate between 28 and 85 L min^{-1} during the sample collection period is sufficient to collect an adequate sample for analysis. Finally, the overall media efficiency must be considered.

Often, there is a need to monitor tritium, iodines, carbon-14, radon, and krypton, or other gases. Table 5 shows the various elements and types of extraction considerations used. Aspects to consider when monitoring for these special materials include the ability of the media to capture the sample adequately, chemical forms available for sampling, volume necessary to acquire the sample, and the respective efficiencies of the processes employed.

Element	Sampling Method	Analytical Method
C-14	Carbon	Extraction followed by liquid scintillation
	Activated carbon	Extraction followed by liquid scintillation
	Bubblers	Liquid scintillation
Iodines (e.g., I-131)	Carbon	Gamma spectrometry
	Activated carbon	Gamma spectrometry
Radon	Activated carbon	Gamma spectrometry
	Alpha track strips	Alpha track
Tritium	Silica gel	Extraction followed by liquid scintillation
	Molecular sieves	Extraction followed by liquid scintillation
	Bubblers	Liquid scintillation
Argon, Krypton, and Xenon	Activated carbon	Gamma spectrometry
	Cryogenic condensing	Liquid scintillation
	Compressed gas	Gamma spectrometry

Table 5. Gas sampling methods and analytical processes

Useful resources for implementing environmental monitoring of gases include *Radioactive Air Sampling Methods* (Maiello & Hoover, 2010), *Sampling Airborne Radioactive Materials From the Stack and Ducts of Nuclear Facilities* (ISO, 2010), and *Test Methods for Measuring Radionuclide Emissions From Stationary Sources* (EPA, 2002b). These resources provide detailed information on the sampling methods, media, processes, and analytical approaches.

3.2 Applying sample analysis correction factors

Once the quality status of the data is determined (e.g., valid, suspect, invalid, or validated after review), applicable correction factors can be applied to the reported data. Correction factors are applied so that results are not underreported and a conservative approach to emissions estimates is maintained. Depending on the sample method, a variety of correction factors may be applied, including:

1. Radioactive decay factor
2. Self absorption (for filters)
3. Sampler efficiency
4. Transport efficiency
5. Sample collector media efficiency

The radioactive decay factor accounts for the time between the midpoint of the sample collection period and the sample analysis time. In most cases, the radioactive decay factor can be set to 1 because time lapse between collection and analysis is much shorter than the half-lives of the radioisotopes of concern. For short-lived radioisotopes, a correction may be necessary and can vary according to the time and the specific half-life of the isotope.

Self-absorption factor corrects for the bias caused by the absorption of emitted radiation from the collected particles by dust/particulates and the filter media itself. For filters, this factor is dependent on the amount of material collected and is shown in Fig. 7. Other types of self-absorption factors may need to be calculated, for example, those associated with cartridges.

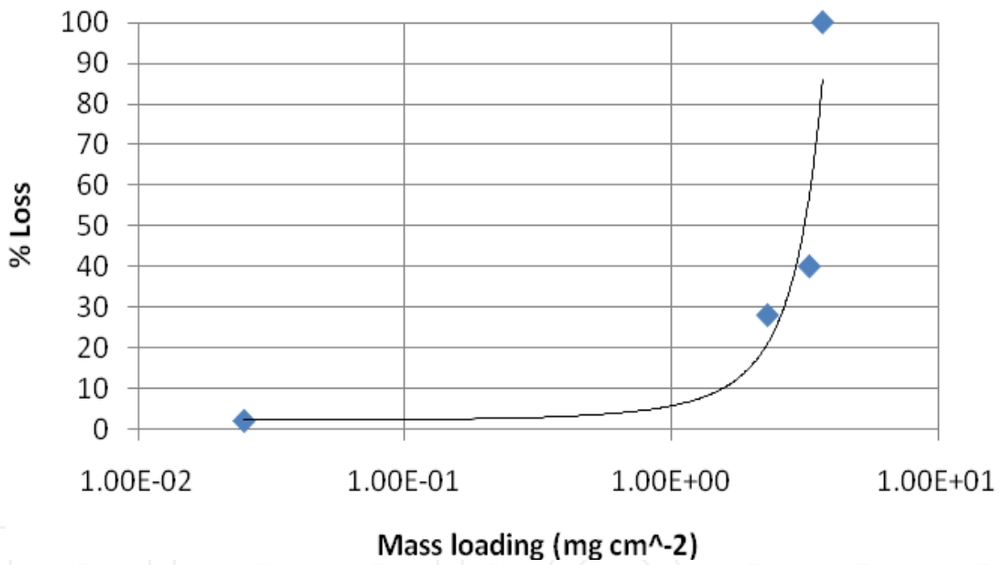


Fig. 7. Percent loss due to self-absorption versus mass loading[1]

The sampler efficiency factor accounts for biases caused by problems with the sampler operation. If the sampler operates without interruption during the sampling period, efficiency is 100% (or 1); however, when operation is incomplete or interrupted, the sampler efficiency factor is determined by the amount of time the sample was collected divided by the entire sample period. If the sampler efficiency factor is too low, an invalid sample may result.

Computer models can be employed to calculate the transportation efficiency correction factor; for example, DEPO has been used in stack monitoring to calculate line losses (McFarland et al., 2000). For environmental monitoring stations that do not have long or complicated transport lines, this factor is often set to 1 and not calculated.

[1] Adapted from Smith et al. (2011) for 47-mm filters when the percent loss is optimized and the exponential function is forced to near zero at very low mass loadings.

The sample collection media efficiency is not to be confused with the total efficiency of the sample media; it is only the part associated with the media itself. Today's filters typically have an efficiency range between 0.8 and 0.9999 for particle sizes in the 0.1 to 10 μm range, depending on the application. Most manufacturers will state rated efficiency for a given range of particle sizes. Silica gel often has 100% retention for tritium sampling until the sample cartridge is fully loaded and breakthrough occurs. In some cases, the unknown media efficiency requires evaluation or estimation.

The calculation and reporting of the final result should include the appropriate correction factors as discussed above. The total activity of a sample is expressed in Equation 2.

$$A_{Total} = A_{Sample} / \pi(E)_{(i)} \text{ (Bq)} \quad (2)$$

Where:

A_{Total} =total activity on sample in Becquerel
A_{Sample} =sample activity in Becquerel
$E_{(i)}$ =efficiency factors, including self-absorption, sampler, transport and media

All data results should be trended against established criteria to evaluate potential changes over time. The repeat measurements at a sampling location can be used to show a normal operating range with the expected statistical deviations. Data trending can also show increasing or decreasing emissions over various cycle times or events. When a data result falls outside of this normal trend, it can then be evaluated. Example causes can be associated with a sampling error (e.g., the wrong sample was reported, or there was a cross contamination of the sample) or a change in the overall emissions characteristics.

4. Reporting and compliance

In many areas, it is mandatory to provide complete and periodic reports to regulatory agencies or customers on the release of airborne radioactive material. The comprehensive report should allow for the discussion of error analysis and provide quantifiable impacts to the public and the environment. Exceeding a regulatory limit, compliance level, or permit condition requires an event notification to the appropriate regulatory agency. Compliance is a cooperative effort between the facility and the local community and regulatory agencies and requires a fully implemented quality assurance (QA) program.

4.1 Annual reporting

An annual report on the emissions of radioactive material has several aspects to consider, and it may be required to include specific information based on applicable regulations or permits and be certified by a responsible individual. Results of reported emissions can then be converted to an off-site dose. Basic elements are identified below:

1. Facility description
2. Emission point description
3. Emissions reporting
4. Input parameters and dose assessment
5. Non-routine releases
6. Supplemental information

A facility description will include historical background on the reporting site, detail the activities conducted resulting in releases of radioactive materials, and offer information on

the buildings where operations are conducted. This section provides information on related nearby facilities and their impacts on the results.

The emission point description is used to brief the type of emission unit and the associated characteristics. For example, an emission unit may be a point source that releases radioactive gases (and potentially particulate materials), while a fugitive emission source may be a contaminated waste pile. Careful itemization and clear description of the emission type are essential elements to reveal the impact to overall operations.

Emissions reporting may be in the form of specific sample analyses or theoretical calculations. Specific analyses can be from point sources collected from a sampling system, or they can equally be from environmental surveillance monitoring stations; a combination of both may be necessary to cover all the types of emissions at a particular site. If environmental surveillance monitoring data is not collected, then theoretical calculations can also be used to supplement the reporting of (potentially) released radioactive materials into the environment. The emissions report is a primary factor in the dose assessment.

Input parameters to the dose assessment include the reported emissions. However, other inputs can include meteorological data for joint frequency wind speed distributions, dose conversion models, and exposure pathway parameters (e.g., inhalation, and food stuffs). Dose models such as CAP88-PC also require information on the clearance type, particle size, a scavenging coefficient, and deposition velocity used (EPA, 2007; Simpkins, 2000).

Non-routine releases from upset conditions such as spills or accidents should be reported separately and may be a permit requirement. Stack sampling or environmental surveillance monitoring stations can sample and detect non-routine releases, which would be included in the dose estimates to the public and/or environment.

Supplemental information to an annual report can include collective (population) dose estimates, results from environmental surveillance measurements, and status of methods confirming emissions. The collective dose differs from the dose to the maximally exposed individual, where the latter receives the maximum dose from the reported emissions and the former is the product of the number of persons in a general area (e.g., within 80 km of the facility) and the average dose per person (ENS, 2003). Results of environmental surveillance sampling and other sampling events can be reported in an appendix or as part of the overall results. Finally, the methods of confirming emissions should be discussed in relation to the emission unit; in such cases, a table indicates whether the emissions were measured by a sample or calculation. If sampling was conducted, it should further be noted whether it was continuous or periodic.

4.2 Event reporting

When compliance with permit conditions, emission or concentration limits, or other requirements are not met, the facility must report the information to the appropriate authority. Additionally, non-routine releases or transient abnormal conditions are reported separately and may also be a required by regulation. Often, the stack sampling or environmental surveillance monitoring stations can sample and detect these events, with the results used for dose estimates to the public and/or environment. Specific event reporting may be governed by internal procedures, licenses, and relevant regulations.

It is a good practice to report events to the appropriate regulatory agency within 24 hrs of discovery. It should cite the specific requirement(s) that is out of compliance and the current status of the situation. Immediate actions taken are reported and may include the shutdown

of work, additional sampling and monitoring, and estimated impacts to the public and environment.

Regulators may request additional information or formal report and may also assign additional actions. Resuming normal work would be coordinated with the regulators. Depending of the severity of the event, additional actions such as a compliance plan submittal, inspections and assessments, more frequent and additional reporting, and assessment of fines and penalties may be initiated. Work with the regulators and management to identify the appropriate actions and cooperatively agree to the resumption of normal work.

4.3 Compliance aspects

Assessment and conformance to the regulations and permit authorization requirements enable the facility to demonstrate compliance. An organization should evaluate its activities and document its baseline compliance. Additionally, compliance requires the implementation of a robust QA program capable of passing an external audit.

There are two applicable standards for continual improvement and quality: *Environmental Management Systems* (ISO, 2004), and *Quality Management Systems* (ISO, 2008). *Sampling and Monitoring Releases of Airborne Radioactive Substances From the Stacks and Ducts of Nuclear Facilities* (ANSI, 2011) also outlines a basic QA program plan, the standard components of which include:

1. Program Aspects
2. Documentation
3. System and Equipment Characterization
4. Training
5. Maintenance and Inspection Requirements
6. Calibration
7. System Performance Criteria
8. Assessment

Shown in Fig. 8, these QA components form a complete, interdependent program.

The QA program describes administrative and organization roles. The program details data handling and procedures that govern data collection and analysis. It also incorporates the organizations proactive and cooperative relations with the regulators and key stakeholders.

Record keeping is integral to the QA program. A management system for the records is necessary and would include the basis for the collection, identification, storage and retention, and retrieval of the documents related to the program. Documentation related to the program must be available for analyses, audits, and archival purposes.

Characterization of system and equipment components as part of a QA program includes the description of the source term under consideration, the characteristics of the system and equipment, and the design and construction features of the program elements. For example, Fig. 6 could be a QA program drawing showing the basic equipment components of a field-deployed air sampling station.

Individuals involved in the program must be trained to conduct the specific role they have in the program. Training may cover many areas including assessment, data collection or analysis, and reporting. The training records would be managed under the documentation requirements of the QA program.



Fig. 8. Basic components of a QA program

Periodic maintenance and inspection requirements may often be prescribed by regulations. However, the QA program should address the frequency by which maintenance and inspections are conducted. These requirements can easily be adapted into a preventive maintenance program.

In addition to periodic maintenance and inspection, measurement and test equipment are to be calibrated periodically. The specific calibration methods utilize prescribed methods and traceable reference standards. Generally, calibrated equipment is labeled with the calibration and expiration dates.

System performance criteria assures overall satisfactory program operation. Performance criteria can cover the operational requirements, transmission factors, and flow ranges, which are used to identify normal system operations. Tracking and trending of data can supplement and monitor the criteria by enabling the user to see outlier data and observe trends in data over time. The tracking and trending of data can also indicate potential changes to program emissions or in equipment operations.

Self-assessment programs are intended to provide a mechanism for continual improvement in programmatic elements (e.g., procedures, management systems) and operational elements (e.g., monitoring systems, permit compliance) of a program. Periodic review of program elements begins with the planning of an assessment. Once the assessment scope and intent are established, criteria can be evaluated, and strengths and weaknesses identified. Corrective actions can then be assigned and implemented to improve areas of weakness or non-compliance. Once actions are complete, an effectiveness review should be conducted to verify adequate corrective action implementation.

Finally, as a part of the overall QA program, the compliance status should be documented in periodic reports and provided to management and/or appropriate regulatory agencies. These reports should include the status of compliance to the specific permit requirements and regulations. When non-compliance is identified, it must be addressed, and corrective actions should be tracked to completion. Notification to regulatory agencies must also be evaluated and may be required.

5. Case studies for continual improvement

In addition to the periodic use of internal and external assessments, the researcher should prepare to embrace opportunities to improve the sampling and monitoring base of knowledge. The assessment process provides for the necessary feedback to make incremental changes in a program to improve the overall result. The reporting of new or unique operations, special studies, or a resolution to a monitoring question provides information valuable to other programs.

Below are two examples of current, evaluative research areas: air sample volume measurements, and the deposition of material on a sample filter paper. However, there are many areas for improvement, and individuals can make their own contributions.

5.1 Air sample volume measurement evaluation

Determination of the sample volume is critical in collecting ambient air samples for environmental monitoring. Errors in the sample volume measurement are directly proportional to errors in the calculated sample concentration (Fritz, 2009). A variety of instruments are available to measure flow and can include rotameters, electronic mass flow controllers, and venturi meters (Wight, 1994). Fritz (2009) reported on the implementation of a dry-gas meter application to air sample volume measurements in lieu of a more cumbersome and less accurate two-point manual airflow measurement and sample duration. The new method showed improved reliability and measurement resolution, reduced error, and more accurate concentration calculations. The evaluation was conducted over two phases that included a system set-up identical to the field configuration and a testing phase where the new dry-gas meters were installed in the actual sampling network.

With reported results, users can apply the basics of their work into their own evaluations applicable to their particular situation. Consider for example that the air sample volume measurement evaluation is being evaluated for an area without adequate electricity or based on filter flow characteristics. In the first case where electricity is necessary to run a sample pump, solar arrays may be an alternative. One could reasonably create a limited project for the facility to determine the appropriateness of such a system and recommend whether to utilize it in a broader program. For this second case, evaluating sample filters for pressure drop (Barnett & Kane, 1993) may be studied to determine if alternative filter sizes are adequate to meet the air sample volume requirements; however, other considerations may impact the final decision such as the ability to reliably analyze the filter, the overall spectral properties of the radioisotope(s), and the ability to ash the filter easily for additional laboratory analyses.

5.2 Sample filter deposition evaluation

Researchers have probed into the major factors affecting the measurements of radioactivity on air samples collected on filters (Stevens & Toureau, 1963; Higby, 1984). These factors

include particles sizes, filter types, filter loading and burial depths, and analysis of energy spectrums. More recently, others have evaluated sample filter deposition characteristics by conducting studies and using computer simulations (Luetzelschwab et al., 2000; Huang et al., 2002; Geryes et al., 2009; Barnett et al., 2009). From recent publications, additional information is now available on the self-absorption that occurs in filters, the measurement losses associated with the filter loading, and the use of Monte Carlo simulations (Fig. 9) to assess the energy spectra in different geometries. Ongoing research in this area is still warranted, given that standards call out a correction factor for self-absorption effects of more than 5% (ISO, 2010; ANSI, 2011).

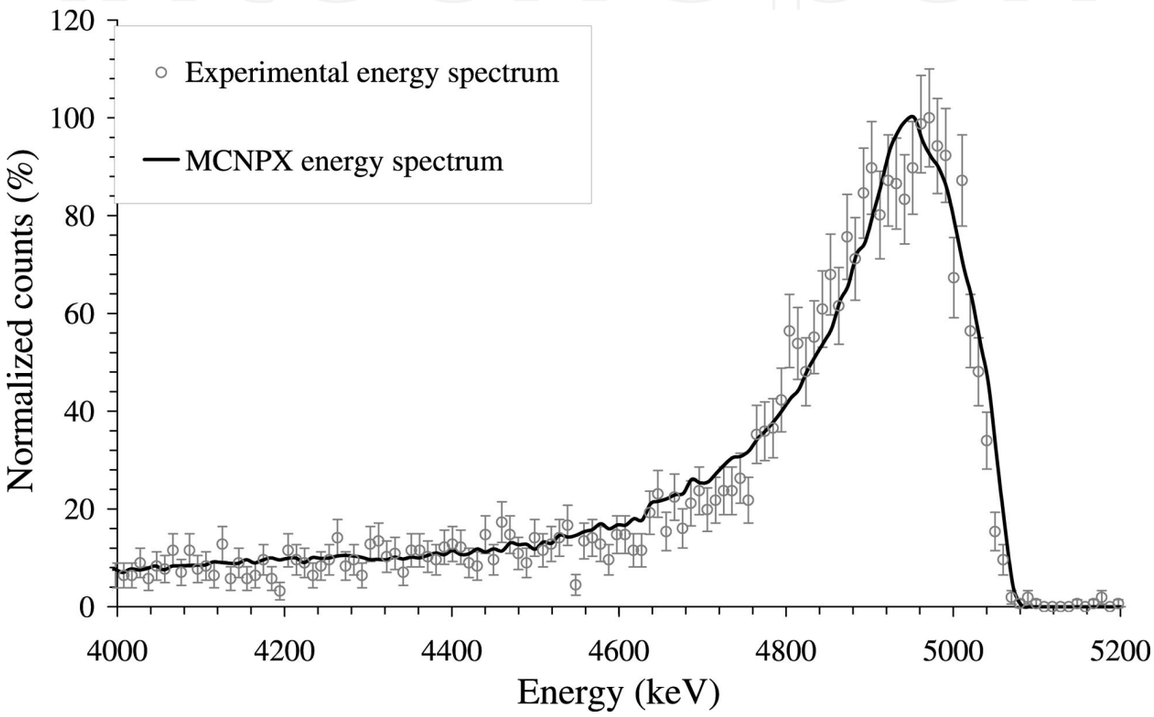


Fig. 9. Comparison of an experimental and simulated energy spectrum in a filter (Geryes et al., 2009)

6. Conclusion

Concepts for environmental radioactive air sampling and monitoring include establishing the basis for sampling/monitoring, criteria for sampling media and analytical requirements, and reporting and compliance. The processes utilized include a standards based and a DQO approach that should be integrated and applied to both direct effluent and environmental surveillance sampling and monitoring. In addition, program improvement can be enhanced through the sharing of knowledge derived from routine operations and the implementation of tested and reviewed ideas. The overall program is used to demonstrated to the stakeholders that the emissions of radioactive materials to the environment is below regulatory limits and that those doses reported from such emissions are reasonably and conservatively accurate.

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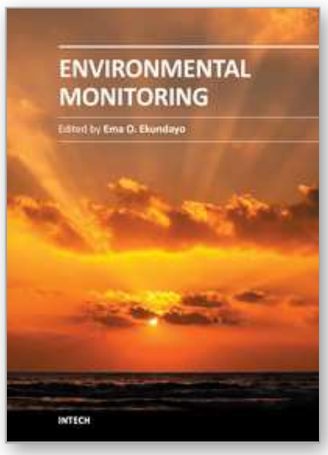
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