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Surveillance of the activity concentrations of airborne radioactive substances in the workplace of nuclear facilities

Surveillance de l'activité volumique des substances radioactives dans l'air des lieux de travail des installations nucléaires

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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The committee responsible for this document is ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiological protection*.

Introduction

Sampling of airborne radionuclides and monitoring of activity concentration in workplaces are critically important for maintaining worker safety at facilities where dispersible radioactive substances are used. Specifically, air sampling and monitoring are critical for evaluation of containment integrity, evaluation of effectiveness of contamination control programs and work practices, providing measurements for qualitative dose assessment, providing a general assessment of the level of the airborne hazard in a room, and for providing workers an immediate warning when the activity concentration exceeds safe levels.

This document sets forth guidelines and performance criteria for sampling airborne radioactive substances and monitoring activity concentration in the workplace of nuclear facilities. Emphasis is on health protection for workers in indoor environments. This document provides best practices and performance-based criteria for the use of sampling devices and systems, including delayed radioactivity measurement samplers and continuous air monitors. Specifically, this document covers air sampling program objectives, design of sampling and monitoring programs to meet program objectives, methods for air sampling and monitoring in the workplace, and quality assurance to ensure system performance toward protecting workers against unnecessary inhalation exposures. Taken together, these activities constitute the sampling or surveillance program.

The primary purpose of the surveillance of airborne activity concentrations in the workplace is to evaluate and mitigate inhalation hazards to workers in facilities where these may become airborne. Results often provide the basis for development and evaluation of control procedures and may indicate if engineering controls or operational changes are necessary.

The surveillance can consist of two general techniques. The first is retrospective sampling, in which constituents of the air are sampled, the collection medium is removed and taken to a radiation detector system and analysed for radioactive substances, and the activity concentration results made available at a later time. In this context, the measured activity concentrations are evaluated retrospectively. The second approach is real-time monitoring, in which activity concentrations are continuously monitored so that workers can be warned that a significant release of airborne activity may have occurred. In implementing an effective sampling program, it is important to achieve a proper balance between the two general approaches of the program. The specific balance depends on the hazard level of the work and the characteristics of each facility.

When designing a surveillance program, the optimization of worker protection minimizes internal and external exposures while balancing social, technical, economic, practical, and public policy considerations that are associated with the use of the radioactive substance.

A comprehensive surveillance program should also consider that the monitoring program is only one element of a comprehensive radiation protection program. Therefore, individuals involved with the monitoring program should interact with personnel working in the other elements of the radiation protection program, such as contamination control and internal dosimetry.

Surveillance of the activity concentrations of airborne radioactive substances in the workplace of nuclear facilities

1 Scope

This document provides guidelines and performance criteria for sampling airborne radioactive substances in the workplace. Emphasis is on health protection of workers in the indoor environment.

This document provides best practices and performance-based criteria for the use of air sampling devices and systems, including retrospective samplers and continuous air monitors. Specifically, this document covers air sampling program objectives, design of air sampling and monitoring programs to meet program objectives, methods for air sampling and monitoring in the workplace, and quality assurance to ensure system performance toward protecting workers against unnecessary inhalation exposures.

The primary purpose of the surveillance of airborne activity concentrations in the workplace is to evaluate and mitigate inhalation hazards to workers in facilities where these can become airborne. A comprehensive surveillance program can be used to

— determine the effectiveness of administrative and engineering controls for confinement,

— measure activity concentrations of radioactive substances,

— alert workers to high activity concentrations in the air,

— aid in estimating worker intakes when bioassay methods are unavailable,

— determine signage or posting requirements for radiation protection, and

— determine appropriate protective equipment and measures.

Air sampling techniques consist of two general approaches. The first approach is retrospective sampling, in which the air is sampled, the collection medium is removed and taken to a radiation detector system and analysed for radioactive substance, and the concentration results made available at a later time. In this context, the measured air concentrations are evaluated retrospectively. The second approach is continuous real-time air monitoring so that workers can be warned that a significant release of airborne radioactivity may have just occurred. In implementing an effective air sampling program, it is important to achieve a balance between the two general approaches. The specific balance depends on hazard level of the work and the characteristics of each facility.

A special component of the second approach which can apply, if properly implemented, is the preparation of continuous air monitoring instrumentation and protocols. This enables radiation protection monitoring of personnel that have been trained and fitted with personal protective equipment (PPE) that permit pre-planned, defined, extended stay time in elevated concentrations of airborne radioactive substances. Such approaches can occur either as part of a planned re-entry of a contaminated area following an accidental loss of containment for accident assessment and recovery, or part of a project which involves systematic or routine access to radioactive substances (e.g. preparing process material containing easily aerosolized components), or handling objects such as poorly characterized waste materials that may contain radioactive contaminants that could be aerosolized when handled during repackaging. In this special case, the role of continuous air monitoring is to provide an alert to health physics personnel that the air concentrations of concern have exceeded a threshold such that the planned level of protection afforded by PPE has been or could be exceeded. This level would typically be many 10's or 100's of times higher than the derived air concentration (DAC) established for unprotected workers. The monitoring alarm or alert would therefore be designed not to be confused with the normal

monitoring alarm, and the action taken in response would be similarly targeted at the specific site and personnel involved.

The air sampling strategy should be designed to minimize internal exposures and balanced with social, technical, economic, practical, and public policy considerations that are associated with the use of the radioactive substance.

A comprehensive air sampling strategy should also consider that the air sampling program is only one element of a broader radiation protection program. Therefore, individuals involved with the air sampling program should interact with personnel working in other elements of the radiation protection program, such as contamination control and internal dosimetry.

This document does not address outdoor air sampling, effluent monitoring, or radon measurements.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11929, *Determination of the characteristic limits (decision threshold, detection limit and limits of the confidence interval) for measurements of ionizing radiation — Fundamentals and application*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
accuracy
closeness of agreement between a measured value and a true value

3.2
aerodynamic diameter
D_a
diameter of a sphere with density 1 000 kg·m^{-3} that has the same sedimentation velocity in quiescent air as the actual particle of arbitrary shape and density

3.3
aerosol
dispersion of solid or liquid particles in air or other gas

Note 1 to entry: An aerosol is not only the aerosol particles.

3.4
airborne radioactive substance
radioactive substance dispersed in the air in the form of dusts, fumes, particulates, mists, vapours, or gases

3.5
air contamination area
area accessible to individuals where the measured activity concentrations of an airborne radioactive substance exceeds or is likely to exceed the applicable national criteria

3.6
air sampler
device designed to pass a known volume of air containing a radioactive substance through a filter or other media and thereby trapping the airborne radioactive substance on the sampling media

3.7
annual limit on intake
ALI
derived limit for the amount of radioactive substance (in Bq) taken into the body of an adult worker by inhalation or ingestion in a year

3.8
breathing zone
BZ
uniform description of the volume of air directly around the worker's upper body and head, which may be drawn into the lungs during the course of breathing

Note 1 to entry: An air sample representative of the breathing zone is usually considered to be representative if drawn from within about 30 cm of the worker's head.

3.9
breathing zone sampler
BZA
air sampler located in the breathing zone

Note 1 to entry: Other common terms include "personal air sampler" (PAS), "personal air monitor" (PAM), "lapel air samplers" or "fixed air sampler".

Note 2 to entry: In the case of workers using PPE which includes full face (or even whole body suit) respirator equipment and supplied air, as when preparing for entry into high levels of airborne radioactive substances, special BZA or protective equipment samplers may be needed. Such BZAs are not always mandated then, but the decision should be based on the contaminant levels and types of PPE involved and the potential for contamination entering the suit or air immediately surrounding the suit just as PPE are being doffed.

3.10
continuous air monitor
CAM
instrument that continuously monitors the airborne activity concentration on a near real-time basis

3.11
continuous monitoring
active and continual monitoring of activity concentration in room air in near real time

Note 1 to entry: This approach uses continuous air monitors to assess activity concentration in air and can alarm when predetermined levels are exceeded.

3.12
derived air concentration
DAC
concentration of a radionuclide in air that, if breathed over the period of a work year, would result in the intake of one ALI for that radionuclide

Note 1 to entry: The DAC is calculated by dividing the ALI by the volume of air breathed by reference man under light-activity work during a working year (in $Bq \cdot m^{-3}$).

Note 2 to entry: The parameter values recommended by the International Commission on Radiological Protection for calculating the DAC are a breathing rate of $1,2\ m^3 \cdot h^{-1}$ and a working year of 2 000 h (i.e. 2 400 m^3).

Note 3 to entry: The air concentration can be expressed in terms of a number of DAC. For example, if the DAC for a given radionuclide in a particular form is $0,2\ Bq \cdot m^{-3}$ and the observed concentration is $1,0\ Bq \cdot m^{-3}$, then the observed concentration can also be expressed as 5 DAC (i.e. 1,0 divided by 0,2)

Note 4 to entry: The derived air concentration-hour (DAC-h) is an integrated exposure and is the product of the concentration of a radioactive substance in air (expressed as a fraction or multiple of DAC for each radionuclide) and the time of exposure to that radionuclide, in hours.

[SOURCE: References [5] and [10], modified]

3.13
detection limit
L_D
smallest true value of the measurand which ensures a specified probability of being detectable by the measurement procedure

Note 1 to entry: For a given type-I error (or false alarm probability, i.e. typically 0,05), L_D is the lowest net count (or rate) with the desired probability of detection, i.e. typically 0,95 (otherwise stated as a type-II error of 0,05 or a missed detection probability of 5 %).

Note 2 to entry: The measurand is the quantity subject to measurement.

3.14
grab sample
air sample of a sufficient volume drawn over a relatively short duration

3.15
intake
activity of a radionuclide taken into the body in a given time period or as a result of a given event

[SOURCE: ISO 20553:2006, 3.10]

3.16
personal air monitor
personal air sampler
breathing zone sampler

3.17
personal protective equipment
PPE
equipment designed to limit worker exposure to contaminants in the air or that are easily resuspended from contaminated surfaces

Note 1 to entry: Includes partial or full-face respirators, face masks, gloves, boots, whole body anti-contamination coveralls, and self-contained breathing apparatus (SCBA), depending on conditions.

3.18
potential missed exposure
PME
time-integrated activity concentration or maximum activity concentration, as applicable, that can acceptably be missed

Note 1 to entry: The detection limit of the method of measuring the activity concentration shall be less than or equal to the selected PME, which is defined according to ALARA/ALARP principles, and below legal limits.

3.19
sampling
collection of a radioactive substance on media such as filters, absorbers or adsorbers that is analysed for radioactive content after collection

3.20
standard reference conditions
conditions of temperature and pressure to which measurements are referred for standardization

Note 1 to entry: For this document, the standard reference conditions are 25 °C temperature and 101 325 Pa pressure.

Note 2 to entry: Used to convert air densities to a common basis. Other temperature and pressure conditions may be used and should be applied consistently.

3.21
surveillance
air monitoring and sampling, and the evaluation of the activity concentration measurement

4 Symbols

A activity, in Bq

C activity concentration, defined as activity per volume, in $Bq \cdot m^{-3}$

D_a aerodynamic aerosol particle diameter, in µm

$E(\tau)$ committed effective dose, in Sv

e_{inh} dose coefficient for inhalation, in $Sv \cdot Bq^{-1}$ (committed effective dose per unit intake such as those in Reference [9])

L annual dose limit, in Sv (an annual limit on the total effective dose equivalent to an individual)

q flowrate, in $m^3 \cdot s^{-1}$ or $m^3 \cdot h^{-1}$

Q_B breathing rate, in $m^3 \cdot s^{-1}$ or $m^3 \cdot h^{-1}$

R_N net count rate from the assay system, in s^{-1}

T_E annual exposure time, in s

T_S sampling time span, in s

ε_C collection efficiency

ε_r counting (measurement) efficiency of the assay system for a reference standard, in $Bq^{-1} \cdot s^{-1}$

ε_S efficiency modification factor for counting (measuring) an actual sample as opposed to the reference standard (e.g. the dimensionless alpha self-absorption factor for particulate alpha on glass fiber filters)

5 Developing the surveillance program

5.1 Reasons for conducting a surveillance programme

5.1.1 General

The specific techniques used in a sampling or surveillance program are based on the purpose(s) of the sampling. Even if airborne concentrations are very low, sampling may be conducted routinely due to the potential for high exposures and doses, should releases occur (e.g. in facilities with glove boxes). Sampling in the workplace can be used to determine the following parameters:

— effectiveness of engineering and administrative controls for the confinement of radioactive substances;

— measurement of activity concentrations of airborne radioactive substances in the workplace for assessment of inhalation risk;

— estimation of worker intakes when bioassay methods are deficient or unavailable;

— confirmation of appropriate air contamination area posting requirements;

— appropriateness of PPE;

— provision of early warning or detection of the release of radioactive substances in the workplace.

5.1.2 Sampling when respiratory protective equipment is used

A special component of the second approach which can apply, if properly implemented, is the preparation of continuous air monitoring instrumentation and protocols which enable radiation protection monitoring of personnel that have been trained and are using PPE that permit pre-planned, defined, extended stay time in elevated concentrations of airborne radioactive substances. Such applications can occur either as part of a planned re-entry of a contaminated area following an accidental loss of containment for accident assessment and recovery, or part of a project which involves systematic or routine access to radioactive substances (e.g. preparing process material containing easily aerosolized components), or handling objects such as poorly characterized waste materials that may contain radioactive contaminants that could be aerosolized when handled during repackaging. In this special case, the role of continuous air monitoring is to provide an alert to health physics personnel that the air concentration(s) of concern have exceeded a threshold such that the planned level of protection afforded by PPE has been or could be exceeded. This level would typically be 10's or 100's of DAC. The monitoring alarm or alert would therefore be designed not to be confused with the normal monitoring alarm, and the action taken in response would be similarly targeted at the specific site and personnel involved.

5.1.3 Sampling to establish air contamination areas

Air samplers located to sample general room air or at a specific work location can be used as an aid to evaluate the need for posting the area as an airborne radioactivity area. Areas should not be posted as airborne radioactivity areas on the basis of unlikely accidents; rather, airborne radioactivity areas should be established based on the radioactivity levels normally encountered or on levels that can reasonably be expected to occur when work is being performed.

5.1.4 Air sampling as a basis for determining worker intakes

Air sampling is a tool for internal dosimetry primarily to help identify when an intake may have occurred, and is an indication of the magnitude of an intake. It is not usually the primary tool for individual worker intake and dose assessment, but may be used as such by internal dosimetry programs in the absence of appropriate bioassay data. Specifically, the estimation of internal dose shall be based on bioassay data rather than air concentration values unless bioassay data are 1) unavailable, 2) inadequate, or 3) internal dose estimates based on air concentration values are demonstrated to be as or more accurate. Some regulatory bodies accept air sample results as being appropriate for assigning intakes when circumstances indicate that this would be the most reliable option. There is nothing in this document that is contrary to this practice, provided that use of air sampling, which is generally less accurate for assigning intakes than bioassay, is justified.

5.1.5 Air monitoring for early warning of elevated air concentrations

Air monitors can provide early warning to workers regarding elevated radioactivity concentrations. This real-time monitoring can be an effective method to reduce or eliminate exposures to the airborne radioactive substance or gas.

5.2 Graded approach to sampling

The extent and type of sampling should be based on estimates of worker intakes and on estimated activity concentrations of airborne radioactive substances as illustrated in Table 1. Estimates of intakes and concentrations may be based on historical sampling or bioassay data if these data are available. If the data are not available, a survey program should be established based on likely radiological conditions, probability of change in conditions, and area occupancy factors. Considerations for this evaluation may include the following:

a) quantity of radioactive substance being handled;

b) ALI of the substance;

c) release fraction for the radioactive substance based on its physical form and use;

d) type of confinement for the substance;

e) other factors appropriate for the specific facility (such as national regulations or license requirements).

The estimated prospective intake levels given in Table 1 are an illustration that may be used to guide decisions regarding sampling resources used in different situations. Alternatively, a sampling resource allocation scheme may be based on containment classes (see ISO 17873[1] and ISO 26802[3]) or according to other local or national guidelines. The person in charge of the radiation safety program should use all appropriate information, professional judgment, and historical experience to perform sampling appropriate for the specific situation in keeping with the as low as reasonably achievable/practicable (ALARA/ALARP) principle.

Table 1 — Example of sampling recommendations based on ALI and airborne concentrations expressed as fractions of the ALI

Annual intake as a fraction of ALI	Sampling recommendations
<0,02	Sampling is generally not necessary. However, monthly or quarterly grab samples or some other measurement (e.g. surface contamination) may be appropriate to confirm that airborne levels are indeed low.
≥0,02 and <1,0	Sampling is appropriate. Intermittent or grab samples are appropriate near the lower end of the range depending on the nature of the work being performed. Continuous sampling is appropriate if activity concentrations are likely to cause an exposure exceeding 12 DAC-h during a time period of a week or longer. A demonstration that the samples are representative of the breathing zone air is appropriate if intakes of record are based on sampling. Additional investigation by bioassay methods may be considered.
≥1,0	Perform continuous monitoring with alarm capability, as necessary, provided there is a reasonable potential for concentrations to cause an exposure exceeding 40 DAC-h during a time period of a week or less. Samples should be analysed before work resumes the next day, and results should be available before the next shift ends. Credit may be taken for protection factors if respiratory protection is used.