INTERNATIONAL STANDARD

ISO 20044

First edition
2022-12

Measurement of radioactivity in the environment — Air: aerosol particles — Test method using sampling by filter media

Mesurage de la radioactivité dans l'environnement — Air: particules d'aérosol — Méthode d'essai utilisant l'échantillonnage par un média filtrant

Reference number
ISO 20044:2022(E)

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Foreword

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This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiological protection*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Everyone is exposed to natural radiation. The natural sources of radiation are cosmic rays and naturally occurring radioactive substances that exist in the earth and flora and fauna, including the human body. Human activities involving the use of radiation and radioactive substances add to the radiation exposure from this natural exposure. Some of those activities, such as the mining and use of ores containing naturally occurring radioactive materials (NORM) and the production of energy by burning coal that contains such substances, simply enhance the exposure from natural radiation sources. Nuclear power plants and other nuclear installations use radioactive materials and produce radioactive effluent and waste during operation and decommissioning. The use of radioactive materials in industry, agriculture and research is expanding around the globe.

All these human activities give rise to radiation exposures that are only a small fraction of the global average level of natural exposure. The medical use of radiation is the largest and a growing man-made source of radiation exposure in developed countries. It includes diagnostic radiology, radiotherapy, nuclear medicine and interventional radiology.

Radiation exposure also occurs as a result of occupational activities. It is incurred by workers in industry, medicine and research using radiation or radioactive substances, as well as by crew during air travel. The average level of occupational exposures is generally similar to the global average level of natural radiation exposure[1].

As uses of radiation increase, so do the potential health risk and the public's concerns. Thus, all these exposures are regularly assessed in order to:

— improve the understanding of global levels and temporal trends of public and worker exposure;

— evaluate the components of exposure so as to provide a measure of their relative importance;

— identify emerging issues that may warrant more attention and study. While doses to workers are mostly directly measured, doses to the public are usually assessed by indirect methods using the results of measurements of the activity concentration in or specific activity of waste, effluent and/or environmental samples.

To ensure that the data obtained from radioactivity monitoring programs support their intended use, it is essential that the stakeholders (for example nuclear site operators, regulatory and local authorities) agree on appropriate methods and procedures for obtaining representative samples and for handling, storing, preparing and measuring the test samples. An assessment of the overall measurement uncertainty also needs to be carried out systematically. As reliable, comparable and ‘fit for purpose’ data are an essential requirement for any public health decision based on radioactivity measurements, international standards of tested and validated radionuclide test methods are an important tool for the production of such measurement results. The application of standards serves also to guarantee comparability of the test results over time and between different testing laboratories. Laboratories apply them to demonstrate their technical competences and to complete proficiency tests successfully during interlaboratory comparisons, two prerequisites for obtaining national accreditation.

Today, over a hundred International Standards are available to testing laboratories for measuring the activity concentration or specific activity of radionuclides in different matrices.

Generic standards help testing laboratories to manage the measurement process by setting out the general requirements and methods to calibrate equipment and validate techniques. These standards underpin specific standards that describe the test methods to be performed by staff, for example, for different types of samples. The specific standards cover test methods for:

— naturally-occurring radionuclides (including ^{40}K, ^{3}H, ^{14}C and those originating from the thorium and uranium decay series, in particular ^{226}Ra, ^{228}Ra, ^{234}U, ^{238}U, ^{210}Po and ^{210}Pb) which can be found in materials from natural sources or can be released from technological processes involving naturally occurring radioactive materials (e.g. the mining and processing of mineral sands or phosphate fertilizer production and use);

— human-made radionuclides, such as transuranium elements (americium, plutonium, neptunium, and curium), ^{3}H, ^{14}C, ^{90}Sr and gamma-ray emitting radionuclides found in waste, liquid and gaseous effluent, in environmental matrices (water, air, soil and biota), in food and in animal feed as a result of authorized releases into the environment, fallout from the explosion in the atmosphere of nuclear devices and fallout from accidents, such as those that occurred in Chernobyl and Fukushima.

A reliable monitoring of activity concentration in the air is necessary to assess the potential human exposure, to verify compliance with radiation protection and environmental protection regulations or to provide guidance on reducing health risks. Accurate measurement of the activities of the radionuclides is also needed for homeland security and in connection with the Non-Proliferation Treaty (NPT).

NOTE The Non-Proliferation Treaty (NPT) is a landmark international treaty whose objective is to prevent the spread of nuclear weapons and weapons technology, to promote cooperation in the peaceful uses of nuclear energy and to further the goal of achieving nuclear disarmament and general and complete disarmament.

Many radionuclides are present in ambient air in gaseous form or bound to aerosol particles. They have a natural or artificial origin with half-lives ranging from less than a second (^{214}Po) to 15,7 million years (^{129}I). Examples of activity concentration values of these background levels are presented in Annex A.

If the potential source of release is known, the measurement programme of the environment provides data to compare the activity in the environment with the released radionuclides. In case of an emergency, these measuring programmes provide data to calculate the expected dose.

In all cases, a correction for radon and/or radon progeny interference is taken into account when analysing only the count results, statistics or types of particle, or when no specific information is available, e.g. from spectrometric measurements.

The specific techniques used in a sampling programme are based on the purpose(s) of the sampling. Even if airborne radionuclide concentrations are very low, sampling may be conducted routinely due to the potential for high exposures and doses if an incident or accident release should occur. Sampling in the environment can be used to determine the following parameters:

— controls of the confinement of radioactive substances;

— measurement of activity concentrations of airborne radioactive substance in the environment for assessment of dose calculations and the recommendation of measures;

— environmental monitoring for preparedness for a nuclear/radiological emergency or making radio-ecological investigation

The continuous measurement of radionuclides in the atmosphere enables very fast provision of measurement data in case of an emergency. In the general measurement programme the detection of activity concentrations near to the limit of detection is demanded. The sampling/measuring-sites have to be distributed in such a way that the sum of the results allows an interpretation of the situation which is representative for the area due to the meteorological conditions.

Aims are:

— monitoring of radionuclides in the atmosphere;

— trend detection;

— baseline determination;

— dose assessment in case of air contamination caused by long-distance sources (e.g. Chernobyl, Algeciras, Fukushima, nuclear weapons, etc.);

— data collection for radio-ecological application and research.

Measurement of radioactivity in the environment — Air: aerosol particles — Test method using sampling by filter media

1 Scope

This document provides guidance for

— the sampling process of the aerosol particles in the air using filter media. This document takes into account the specific behaviour of aerosol particles in ambient air (Annex B).

— Two methods for sampling procedures with subsequent or simultaneous measurement:

  — the determination of the activity concentration of radionuclides bound to aerosol particles in the air knowing the activity deposited in the filter;

  — the operating use of continuous air monitoring devices used for real time measurement.

The activity concentration is expressed in becquerel per cubic metre ($Bq\cdot m^{-3}$).

This document describes the test method to determine activity concentrations of radionuclides bound to aerosol particles after air sampling passing through a filter media designed to trap aerosol particles. The method can be used for any type of environmental study or monitoring.

The test method is used in the context of a quality assurance management system (ISO/IEC 17025[2]).

This document does not cover the details of measurement test techniques (gamma spectroscopy, global alpha and beta counting, liquid scintillation, alpha spectrometry) used to determine the activity deposited in the media filter, which are either based on existing standards or internal methods developed by the laboratory in charge of those measurements. Also, this document does not cover the variability of the aerosol particle sizes as given by the composition of the dust contained in ambient air[3][4]. This document does not address to sampling of radionuclides bound to aerosol particles in the effluent air of nuclear facilities [see ISO 2889:2021][5].

The procedures described here facilitate the sampling of aerosol bound radionuclides. It is supposed to conform to the national and international requirements for monitoring programmes safety standards of IAEA[6].

The characteristics of the sampling location (coordinates, type of vegetation, obstacles) need to be documented prior to commencing the monitoring. The guidelines of the World Meteorology Organization (WMO) include the criteria for representative measurements of temperature, wind-speed, wind direction, humidity and precipitation for all the weather stations in the world[7].

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 11929-1, *Determination of the characteristic limits (decision threshold, detection limit and limits of the coverage interval) for measurements of ionizing radiation — Fundamentals and application — Part 1: Elementary applications*

3 Terms and definitions

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

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

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

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

3.1
accuracy
closeness of agreement between a measured quantity value and the true quantity value of the measurand

[SOURCE: ISO 2889:2021, 3.4, modified — Correction of "measured quantity" in "measured quantity value" and "true quantity" in "true quantity value"[5].]

3.2
activity median aerodynamic diameter
AMAD
$\bar{d}_{a,A}$
median aerodynamic diameter (MAD) (3.14) for the airborne activity in a given *aerosol* (3.4)

3.3
aerodynamic diameter
AD
d_a
<for a particle of arbitrary shape and density> diameter of a sphere with density 1 000 kg·m^{-3} that has the same sedimentation velocity in quiescent air as the arbitrary particle

3.4
aerosol
system of solid and/or liquid particles suspended in air or other gas

[SOURCE: ISO 15900:2020, 3.1[8]]

3.5
aerosol particle
solid or liquid particle constituents of an *aerosol* (3.4)

[SOURCE: ISO 2889:2021, 3.11[5]]

3.6
collection efficiency of the sampling line
ratio between the concentration of *aerosol particles* (3.5) arriving on the media filter via the transport line and the outdoor concentration of *aerosol particles* near the sampling head, for a given "size" of *aerosol particles* (3.5) as part of *aerosols* (3.4)

3.7
collection efficiency of the filter
ratio between the amount of *aerosol particles* (3.5) deposited in the filter and the amount of *aerosol particles* (3.5) arriving on the filter

3.8
continuous air monitor
CAM
instrument that continuously monitors the airborne activity concentration on a near real-time basis

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

[SOURCE: ISO 16639:2017, 3.10[9]]

3.9
decision threshold
value of the estimator of the measurand, which when exceeded by the result of an actual measurement using a given measurement procedure of a measurand quantifying a physical effect, it is decided that the physical effect is present

Note 1 to entry: The decision threshold is defined in such a way that in cases where the measurement result exceeds the decision threshold, the probability of a wrong decision, namely that the true value of the measurand is not zero if in fact it is zero, is less or equal to a chosen probability, α.

Note 2 to entry: If the result, A, is below the decision threshold, it is decided to conclude that the result cannot be attributed to the physical effect; nevertheless, it cannot be concluded that it is absent.

[SOURCE: ISO 11929-1:2019, 3.12, modified — The definition and the Notes to entry have been slightly reworded.]

3.10
detection limit
smallest true value of the measurand which ensures a specified probability of being detectable by the measurement procedure

Note 1 to entry: With the decision threshold, the detection limit is the smallest true value of the measurand for which the probability of wrongly deciding that the true value of the measurand is zero is equal to a specified value, β, when, in fact, the true value of the measurand is not zero. The probability of being detectable is consequently $(1 - \beta)$.

Note 2 to entry: The terms detection limit and decision threshold are used in an ambiguous way in different standards (e.g. standards related to chemical analysis or quality assurance). If these terms are referred to, it is necessary to state according to which standard they are used.

[SOURCE: ISO 11929-1:2019, 3.13]

3.11
hot particle
small particle containing a specific activity significantly higher than the rest of the sample

Note 1 to entry: If not detected, the activity of the hot particle would be assigned to the total sample and, therefore, results in a non-representative measurement.

3.12
limits of the coverage interval
values which define a coverage interval

Note 1 to entry: The limits are calculated in the ISO 11929 series to contain the true value of the measurand with a specified probability $(1 - \gamma)$.

Note 2 to entry: The definition of a coverage interval is ambiguous without further stipulations. In this document, two alternatives, namely the probabilistically symmetric and the shortest coverage interval are used.

Note 3 to entry: The coverage interval is defined in ISO 11929-1:2019, 3.4, as the set of quantity values within which the true value of the measurand is contained with a stated probability, based on the information available.

[SOURCE: ISO 11929-1:2019, 3.16, modified — Note 3 to entry has been added.]

3.13
measurand
quantity intended to be measured

[SOURCE: ISO 11929-1:2019, 3.3]

3.14
median aerodynamic diameter
MAD
$\bar{d}_{\mathrm{a}}$
value of *aerodynamic diameter* (3.3) for which 50 % of the quantity in a given *aerosol* (3.4) is associated with particles smaller than the MAD, and 50 % of the quantity is associated with particles larger than the MAD

3.15
minimum detectable activity concentration
time-integrated activity concentration or activity concentration measurements and their associated coverage intervals for a given probability $(1 - \gamma)$ to the detection alarm level

[SOURCE: ISO TR 22930-1:2020, 3.9[11]]

3.16
mass median aerodynamic diameter
MMAD
$\bar{\boldsymbol{d}}_{\mathbf{a},\boldsymbol{m}}$
point in an aerodynamic particle size distribution where half of the mass lies in particles with a diameter less than the MMAD and half in particles with a diameter greater than the MMAD

[SOURCE: ISO 16972:2020, 3.140[12]]

3.17
model of evaluation
set of mathematical relationships between all measured and other quantities involved in the evaluation of measurements

[SOURCE: ISO 11929-1:2019, 3.11]

3.18
response time
time required after a step variation in the measured quantity for the output signal variation to reach a given percentage for the first time, usually 90 %, of its final value

[SOURCE: ISO 2889:2021, 3.64[5]]

3.19
sampling
collection of radioactive substances on filter, absorbers or adsorbers that is analysed for radioactive material

3.20
sampling head
device through which *aerosol particle* (3.5) as part of the *aerosols* (3.4) in the atmosphere contained in ambient air are pumped

3.21
standard reference conditions
STP
conditions of temperature and pressure to which measurements are referred for standardization

Note 1 to entry: Standard reference conditions used in this document are of 273,15 K temperature and 1 013,25 hPa pressure.

[SOURCE: ISO 13443:1996, Clause 3[13]]

3.22
test sample
sample obtained from the collected filter by an appropriate treatment which makes it possible to determine the activity deposited in the filter

Note 1 to entry: If no appropriate treatment is needed, the filter is the test sample.

3.23
transit time
duration corresponding to the complete scrolling of the moving filter in front of the detector, in case of moving filter, and considering that the entire deposition area is viewed by the detector

Note 1 to entry: If v is the moving filter velocity and L the diameter of the circular area of the exposed filter or the length of a rectangular area in the direction of the transported filter tape with a constant width w_D of the exposed area below the detector then the time transit is: $t_T = \frac{L}{v}$ (see Clause 4)

[SOURCE: ISO/TR 22930-1:2020, 3.13[11], modified — Note 1 to entry has been modified with respect to ISO/TR 22930-1:2020, 3.13.]

3.24
transport line
pipe or set of pipes connecting the *sampling head* (3.20) to the media filter

3.25
uncertainty of measurement
parameter associated with the result of measurements that characterizes the dispersion of the values that could reasonably be attributed to the *measurand* (3.13)

Note 1 to entry: The uncertainty of a measurement derived according to the GUM[14] comprises, in general, many components. Some of these components are evaluated from the statistical distribution of the results of series of measurements and can be characterized by experimental standard deviations. The other components, which also can be characterized by standard deviations, are evaluated from assumed or known probability distributions based on experience and other information[15].

[SOURCE: ISO 11929-1:2019, 3.10, modified — Definition and Note 3 to entry were reworded and Notes 1, 2 and 4 to entry were deleted.]

4 Symbols

Symbols used in formulae in this document are defined in Table 1.

Table 1 — Symbols used in formulae

α, β	Probability of a false positive and false negative decision, respectively	—
A	Activity deposited in the filter at the time of measurement	Bq
A^*	Decision threshold of the activity deposited in the media filter at the time of measurement	Bq
$A^\#$	Detection limit of the activity deposited in the media filter at the time of measurement	Bq
a	Cross section area of the suction pipe	m^2
$\bar{C}$	Averaged activity concentration in the air over the sampling duration	$Bq \cdot m^{-3}$
$\bar{C}^*$	Decision limit of the averaged activity concentration in the air over the sampling duration	$Bq \cdot m^{-3}$
$\bar{C}^\#$	Decision threshold of the averaged activity concentration in the air over the sampling duration	$Bq \cdot m^{-3}$
d	Inner diameter of the pipe	m
λ	Radioactive constant decay of the measured radionuclide	s^{-1}

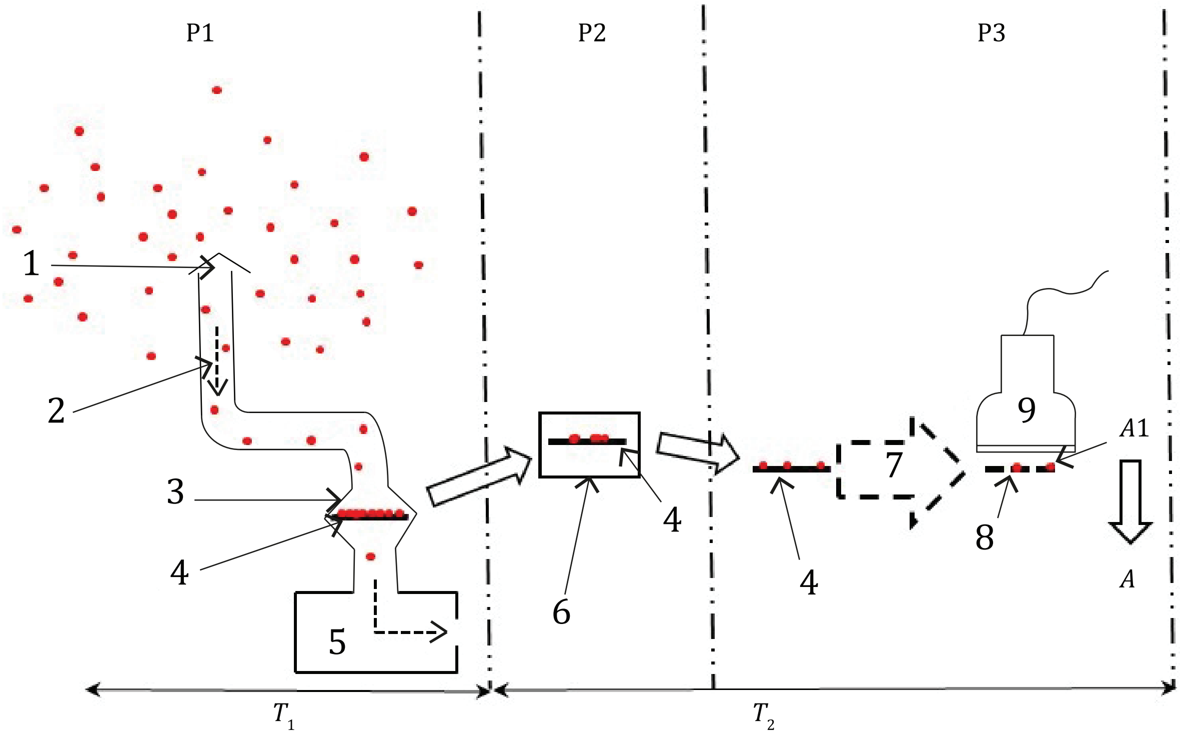
Table 1 *(continued)*

ε_S	Collection efficiency of the sampling line	—
ε_F	Collection efficiency of the filter	—
η_G	Dynamic viscosity	$kg \cdot m^{-1} \cdot s^{-1}$
k_p	Quantile of the standardized normal distribution for the probability p (for instance p = 1-α, 1-β or 1-γ/2)	—
L	Diameter of the circular area of the exposed filter or the length of a rectangular area in the direction of the transported filter tape with a constant width w_D of the exposed area below the detector	m
q_{STP}	Volume flow rate at standard reference conditions with T = 273,15 K and p = 1 013,25 hPa	$m^3 \cdot s^{-1}$
Re	Reynolds number, dimensionless	—
ρ_G	Gas density	$kg \cdot m^{-3}$
t_S (= $T1$)	Sampling duration	s
t_2 (= $T2$)	Period of time from the end of sampling to the end of the measurement	s
t_C	Counting time	s
t_1	Sampling time of CAM	s
t_T	Transit time of the filter	s
$u(x)$	Standard uncertainty of the quantity x	—
$u_r(x)$	Relative standard uncertainty of the quantity x	—
V	Air volume	m^3
v	Moving filter velocity	$m \cdot s^{-1}$
v_a	Air velocity	$m \cdot s^{-1}$
w	Conversion factor for the measurement of the activity deposited on the media filter. It takes into account the detector calibration, the emission intensity and various correction factors useful for the measurement such as, for example, self-attenuation, geometry correction, chemical precipitation efficiency, true coincidences	$s \cdot Bq^{-1}$
w_D	Filter tape width	m

5 Principle

The activity concentration monitoring of the aerosols in the atmosphere consists of passing a known volume of air through a filter placed in a transport line and measuring the activity deposited on this media. In general, two methods are applied:

— A system referred to as continuous sampling and off-line measurement (see Figure 1), in which the filter medium is collected at the end of the batch sampling process and then sent to a laboratory for measurement of the activity deposited on it. The average activity concentrations over the sampling period can be determined only when the measurement result of the activity deposited on the filter is available;

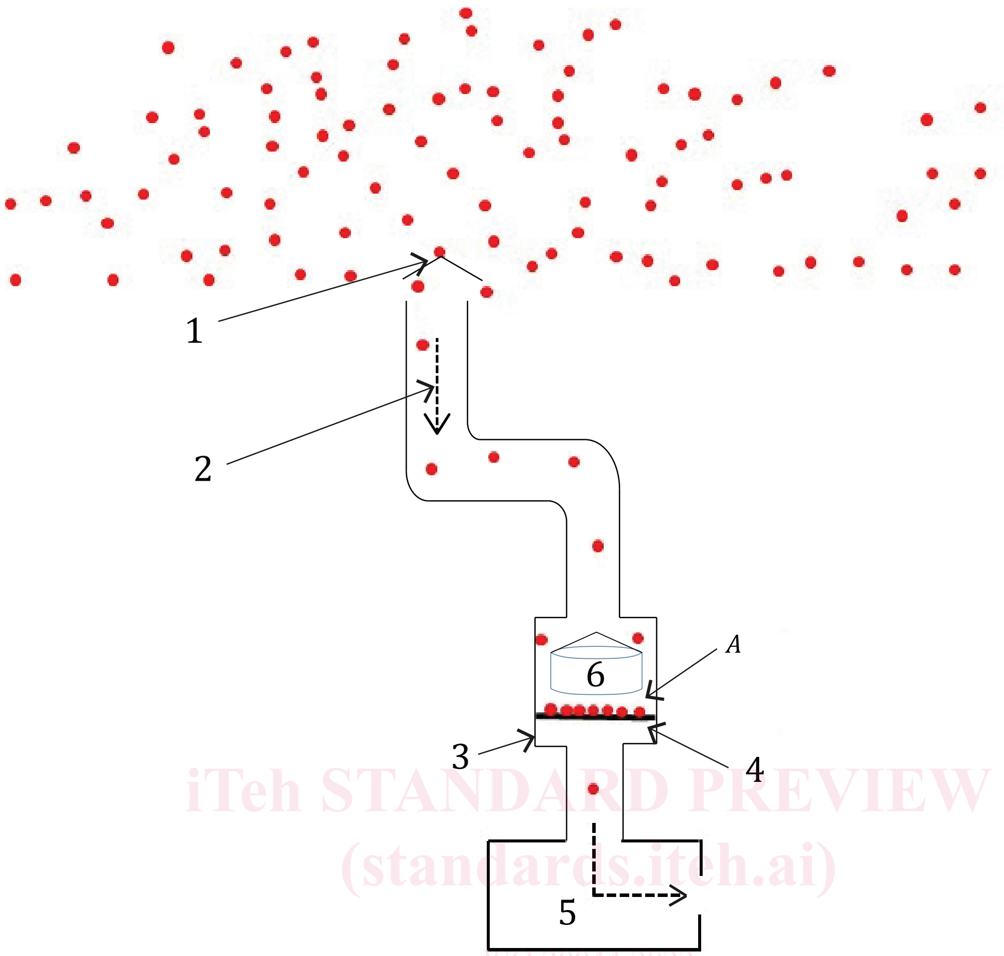


Key

P1 sampling phase
P2 filter collecting, packaging, transfer and conservation phase
P3 filter treatment and activity determination phase
T_1 sampling duration
T_2 period of time from the end of sampling to the end of the measurement
*A*1 activity result of the test sample at the time of measurement
A activity deposited on and in the filter media at the time of sampling (deduced from *A*1)
1 sampling head
2 transport line
3 filter holder
4 filter
5 pump and flow meter
6 filter packaging and transport box
7 treatment of the filter for sampling test
8 test sample
9 activity measurement device

Figure 1 — Principle of continuous sampling with deferred measurement [SOURCE: NF M 60-760][10]

— Another system referred to as real-time measurement using continuous air monitors (CAM) for aerosol particles (see Figure 2), which consists of continuously and simultaneously measuring the volume of air passing through the filter and the activity deposited therein by a radiation detector. The results of the activity concentrations are made available in real time[10][11].



Key

1 sampling head
2 transport line
3 filter holder
4 filter
5 pump and flow meter
6 radiation detector
A activity deposited on the filter

Figure 2 — Principle of continuously sampling and simultaneous detection

The determination of the activity concentration requires the knowledge of the various parameters regarding

— the sampling process: the representativeness of the sampling location, the capture efficiency of the transport line, the trapping efficiency of the filter, the volume of air sampled and their respective uncertainties, and

— the activity measurement process: the treatment efficiency (if needed) of the filter, the activity deposited on the filter at the end of the sampling period and their associated characteristic limits (decision threshold, detection limit and limits of the coverage interval) for the deferred measurement method and the CAM performance for real-time measurement.

6 Sampling

6.1 General

Sampling has to be continuous when measurement is performed simultaneously. In addition, a daily or weekly sampling period may be acceptable (except for very short-lived radionuclides) when measurements are performed after sampling. Monthly or quarterly sampling can be acceptable for areas in which average activity concentrations of airborne radioactive material are expected to be below a few $mBq \cdot m^{-3}$.

6.2 Choice of criteria for sampling location

If the measurement results should be representative for a large area, the directives of the WMO should be taken as a guideline[7] for the choice of a sampling site for aerosol bound radionuclides. The representativeness of an observation is the degree to which it accurately describes the value of the variable needed for a specific purpose. Therefore, it is not a fixed quality of any observation, but results from joint appraisal of instrumentation, measurement interval and exposure against the requirements of some particular application. For instance, synoptic observations should typically be representative of an area up to 100 km around the station, but for small-scale or local applications the considered area can have dimensions of 10 km or less.

Each sampling location, as well as their number, shall be chosen according to environmental monitoring objectives and strategies, in particular:

— monitoring the environment around nuclear sites;

— monitoring of sites with a problem of additional natural radioactivity due to their present or past activities;

— monitoring activity concentration on a national scale (regional background levels, radiological events).

Their location depends on the topography, the climate, types of environment (industrial, agricultural, accessibility, etc.), the potential discharge points, etc.

If a potential source of release is monitored, the sampling locations should be chosen so that the area surrounding the sampling air intake is free of any obstructions. If this condition cannot be met omnidirectionally, it shall be met for the most likely and least likely wind direction from the source of release to be monitored. In case of the continuous release of radionuclides the probability of sampling radionuclides bound to aerosol particles are related to the wind direction. The selection of the sampling site should therefore follow the results of the statistical distribution of wind directions.

6.3 Criteria for sampling duration

The sampling duration should be based on hazard levels, purposes of sampling and required detection limit of the air activity concentration as related to radiation protection goals. If the sample duration is significantly longer than the half-lives of the radionuclides the probability of the detection will be worse meaning high detection limits.

6.4 Criteria for sampling equipment

The sampling equipment consists of a pump for drawing in air, a filter to collect aerosol particles and its holder, a transport line, and the sampling head (see Figures 1 and 2). Compromising influences from walls, roofs, pipes etc. need to be avoided.

The size spectrum of airborne particulate extracted from the air is largely determined by the shape of the sampling head as well as the air intake velocity in the sampling head and the air velocity at the time of sampling. The air sampling shall not disturb the environment to be monitored; it shall allow the collection of the respirable aerosol particles (<10 µm).