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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

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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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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
$\bar{d}_a$
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
$\bar{d}_{a,m}$
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
$\overline{C}$	Averaged activity concentration in the air over the sampling duration	$Bq \cdot m^{-3}$
$\overline{C}^*$	Decision limit of the averaged activity concentration in the air over the sampling duration	$Bq \cdot m^{-3}$
$\overline{C}^\#$	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}

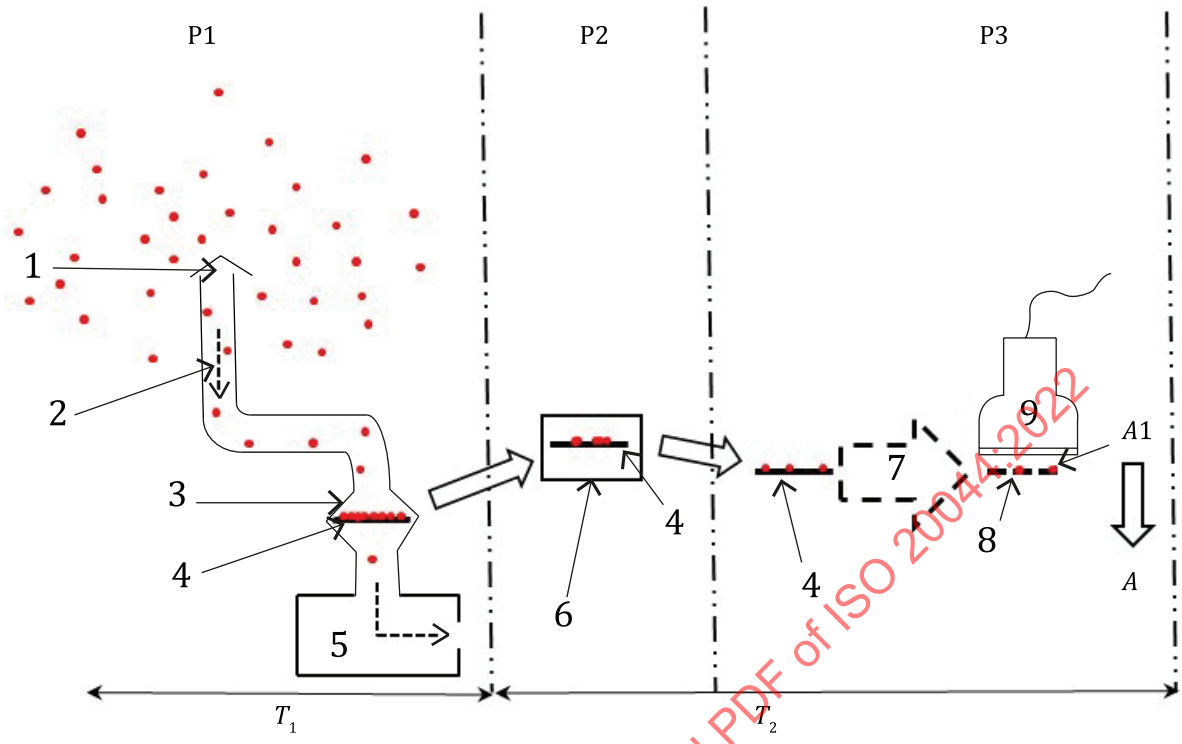
Table 1 *(continued)*

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 $p = 1\text{-}\alpha$, $1\text{-}\beta$ or $1\text{-}\gamma/2$)	—
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;

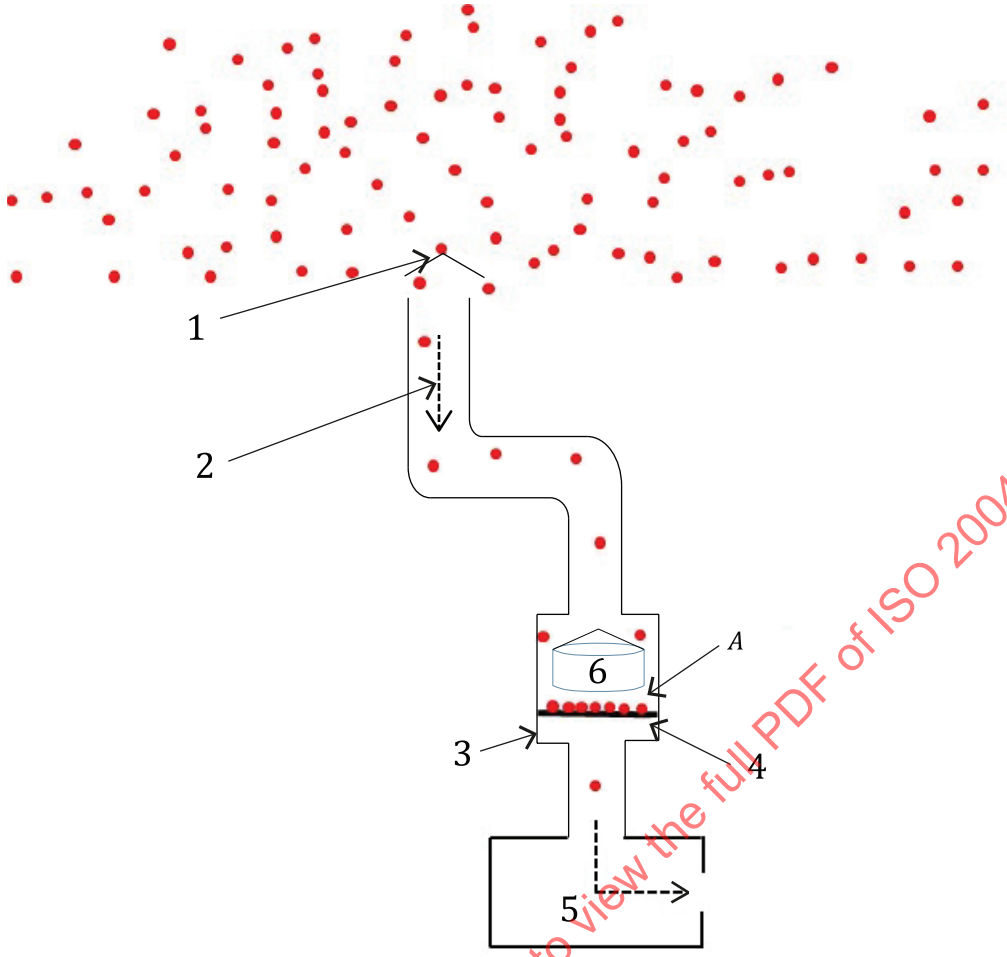


Key

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
$A1$ 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 $A1$)
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).

If it is inadvisable to install the sampling equipment outdoors due to the local weather conditions, the sampling equipment is sheltered by a building or a stable weather-shield. Installing the sampling head outside on a flat roof in a vertical and axisymmetric manner independent of the wind direction offers the optimal solution. In order to minimize the possible influence of turbulences along the edges of the roof, the sampling head shall be installed in the centre of the roof. Setting up a sampling head on a roof may be impossible due to details of the construction. In such a case, mounting the sampling head to an outside wall can be justified in the context of the general monitoring of radioactivity in the environment. The sampling head may also be mounted to an outside wall of the sheltering building and the air is channelled to a filter via a short supply pipe connected to the air transport line.

Other factors for consideration when placing samplers inside a building include the following:

— High-volume samplers are installed in such a way that their exhaust is directed downstream from the sample collector to avoid sampling their own exhaust air.

— If a sampler is operated on a horizontal surface (e.g. a roof), the outlet of air after passing the filter should not be directed to this surface where it could cause localized excessive air concentration from re-suspended surface contamination.

The sampling head design shall allow obtaining a sample as representative as possible of the ambient air regarding the aerosol particle size spectrum. It is recommended that this representativeness be the subject of a characterization at the sampling rate with standard reference conditions (STP) or of an intercomparison of the sampling devices (see Annex C).

The sampling head should be placed on open field representing a surface where obstacles are situated at a minimum distance equal to at least 10 times their height.

An obstacle-free sphere with a diameter of 1 m around the sampling head is recommended.

To minimize the effect of resuspension of aerosol particles deposited on the ground surface, the air intake shall be at a minimum height of 1,5 m from the nearest ground surface.

If samplers are placed in a building the inlet duct should not be at the far side (lee-side) relative to the location of a known emitter, due to the risk of turbulences causing deviations from the representativeness.

A sufficiently large distance between the sampling head and the air outlet is required to prevent exhaust air from being drawn again into the sampler.

The sampling head should be shielded against the intrusion of rain drops or snow flakes. Consideration should be given to installing an insect screen, depending on local conditions. The air vent material and mesh size require careful consideration, usually in consultation with the manufacturer, for example a corrosion resistant grille with a mesh width of 5 mm. The influence of the grille on the collection efficiency has to be taken into account by a calibration procedure. The inlet duct of the air transport line needs to be heatable in order to prevent condensation effects on the pipes and the filter at times of temperatures below the dew point. The corrosion-resistant filter holder has a mechanical strength to cope with pressure drop induced by the filter and accumulated aerosols, has to support the filter and should be fitted with a seal that excludes the possibility of air not filtered to enter the pipe.

In general, the representativeness of sampling is also related to the radionuclide to be measured and the filter used. The particle size distribution of different aerosol particle bound nuclides in the air is different, and the collection efficiency of aerosol particles with different particle sizes is dependent on the filter material. The procedure of collecting samples alters the size distribution of aerosol particles in the air sample compared to their original distribution in the outside air. Key-variables influencing the representativeness of aerosol particle sampling are: air movements in the atmosphere, eddies, the spatial structure of the entire sampling site and its influences on the atmospheric airflow, the distribution of particle sizes, the surface-to-mass ratio of the particles, the geometry of the sampling device, and the volume flow-rate of the sampled air.

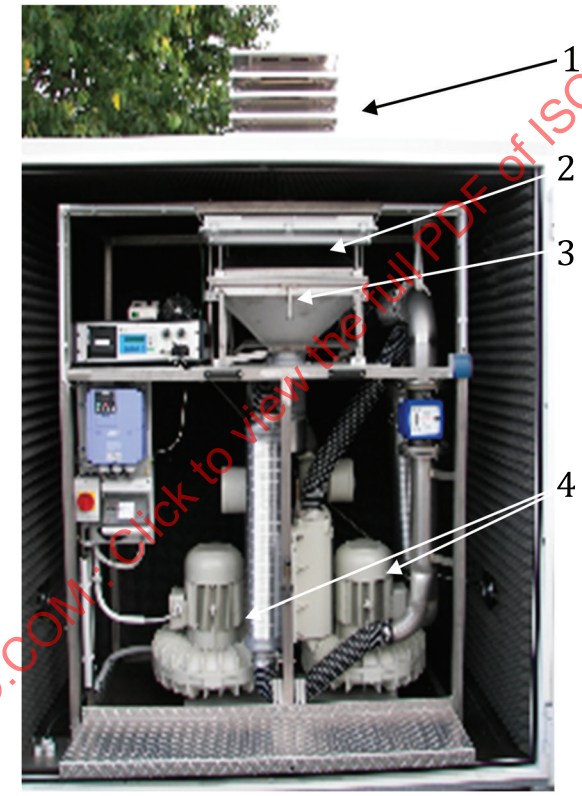
As far as the geometry of the sampling head is concerned, two main options are in principle suitable:

— Sampler with an integrated filter holder (see Figure 3);

— Sampler with a spatially separated filter holder.

To avoid losses in aerosol particle collection, the length of the transport line should not exceed 3 m and should be installed without bends and changes in diameter. The radius of a curvature should not be smaller than three times the transport line inner diameter.

A transport line made from corrosion-resistant steel with a smooth surface should be given preference over other materials. Plastic pipes have the disadvantage of potentially becoming electrostatically charged. Both corrugated hoses and hoses with wire mesh reinforcement act as airborne particulate traps. Welded pipes need to be checked for smooth welding seams. This applies in particular to flange joints.



[SOURCE: Deutscher Wetterdienst (DWD)]

Key

1 sampling head
2 filter
3 filter holder
4 pumps

Figure 3 — Example of a configuration for the sampling of aerosol bound radionuclides with an integrated filter

6.5 Criteria for filter

Ensure that the efficiency of the type of a filter used is characterized at the volume flow rate at standard reference conditions of the sampling site (see Annex D). The efficiency takes also into account the particle size distribution of the expected aerosol particle bound target nuclides.

The filter shall have a mechanical stress resistance that allows for using it in conditions of high air throughput rates for extended time intervals. The efficiency of the filter itself may probably change with the time of storage so that the total uncertainty of the result will become higher.

It is recommended to choose the filter in agreement with the radioactive analysis laboratory to take into account the geometric constraints and specific constraints related to the measurements.

6.6 Criteria for air volume and flow-rate measurement

The sampled air volume shall be measured continuously and expressed in cubic metres at standard reference conditions with a temperature of 273,15 K and a pressure of 1 013,25 hPa in order to be able to compare the results between different sampling locations in time and space.

The measurement of the sampled air volume can be direct or indirect. A volume meter is used for direct measurement. For indirect measurement, a flowmeter (mass or volume) is used, requiring precise knowledge of the sampling duration, moreover it is recommended to use mass flowmeters, giving independent information of environmental conditions (pressure and temperature).

The air flow meter/volume meter shall be installed downstream of the filter.

For non-mass flow meter and volume meter, the temperature and pressure have to be measured nearby so that the calculated density of the air characterizes the mass of the air. The measurement result shall be brought back to the standard reference conditions of temperature and pressure. Temperature and pressure measurement intervals should not exceed 1 h. Moreover, it is the pressure downstream of the filter and near the flowmeter/volume meter that shall be taken into account for the calculation of the air volume expressed in cubic metres.

The overall relative standard uncertainty associated with the measurement of the air volume sampled should be less than 5 % at $k = 1$.

Generally, a laminar flow rate for aerosol particle sampling is recommended to minimize particle losses due to diffusion and inertia over a wide size range, for both, ultrafine and coarse particles. Furthermore, the pressure drop from the inlet to the measuring instruments shall be kept in the range of few hPa. Minimum losses due to particle diffusion in a laminar flow can be achieved by keeping the length of the horizontal pipe as short as possible and the flow rate as high as possible. Particle losses of supermicrometre particles can be minimized by avoiding bends or horizontally orientated sampling pipes (see Annex F).

7 From filter collecting to deferred deposited activity measurement report

At the end of the sampling period, the sampling laboratory:

— collects the filter, checks visually its integrity and the homogeneity of the deposition on the filter, and places it in a packaging and transport box to avoid damage and material loss between the sampling location and the activity measurement laboratory.

NOTE 1 If the presence of “hot particles” in the filter is suspected, prior to sending it to the measurement laboratory, a procedure that provides spatial resolution of the deposited activity on the filter should be carried out. In the simplest scenario, this can be carried out by means of a surface contamination monitor or autoradiographic examination.

— is in charge of the identification of the filter in order to insure its traceability in time and in space from sampling location to corresponding activity measurement results.

The measurement laboratory:

— receives the filter, processes it into a test sample, carries out the appropriate activity measurement and then provides the test report of the activity deposited on the filter.

— is in charge of the traceability of the measurement process related to each identified filter received.

NOTE 2 For certain types of activity measurement techniques, prior processing of the filter is necessary (weighing, drying, mineralization, dissolution, compaction, cutting, ashing, etc.) to obtain the fit for purpose test sample to be measured.

The measurement laboratory test report shall contain the following information:

a) reference to this document, if applicable, or internal method used for the measurement of the activity deposited on the filter;

b) identification of the filter;

c) probabilities α, β and $(1 - \gamma)$ with $\alpha = \beta$;

d) the value of the activity deposited on the filter at the measurement date and its characteristic limits (decision threshold, detection limit, coverage interval) with a given probability of a false positive decision, a given probability of false negative decision and a probability for the coverage interval of the measurand previously defined by the stakeholders (the sampling laboratory and the measurement laboratory);

e) the relative uncertainty of any sample count rates or spectral peak area net count (rates);

f) mention of any relevant information likely to affect the results.

8 Determination of the activity concentration in the air from deferred measurement results

8.1 General

The activity concentration in the air calculated from the deferred measurement results of the activity deposited in the media filter is an average value over the sampling duration, t_1, (see Figure 1). This method does not provide the actual dynamic of activity deposition on the filter during the sampling procedure. Thus, we consider that the deposition of activity in the filter is constant all over the sampling duration. The model of evaluation, the calculation of the uncertainty of measurement, the decision threshold, and the limit of detection shall follow the specifications of ISO 11929-1.

8.2 Model of evaluation

The averaged activity concentration in the air over the sampling duration, is generally expressed as given by Formula (1):

$$\overline{C} = \frac{\lambda \cdot A}{q_{STP} \cdot \varepsilon_S \cdot \varepsilon_F \cdot \left(1 - e^{-\lambda \cdot t_1}\right) \cdot e^{-\lambda \cdot t_2}} \tag{1}$$

While t_1 and t_2 are negligible compared to the half-life for long half-life radionuclides, the averaged activity concentration in the air over the sampling duration is expressed as given by Formula (2):

$$\overline{C} = \frac{A}{q_{STP} \cdot t_1 \cdot \varepsilon_S \cdot \varepsilon_F} \tag{2}$$

8.3 Relative standard uncertainty

The relative standard uncertainties of λ, t_1 and t_2 are considered as negligible, thus the relative standard uncertainty of the measuring result of the averaged activity concentration in the air over the sampling duration is expressed as given by Formula (3):

$$u_r\left(\bar{C}\right)=\sqrt{u_r^2(A)+u_r^2(q_{STP})+u_r^2(\varepsilon_S)+u_r^2(\varepsilon_F)} \tag{3}$$

8.4 Decision threshold

The decision threshold of the averaged activity concentration in the air over the sampling duration is generally expressed as given by Formula (4):

$$\bar{C}^*=\frac{\lambda\cdot A^*}{q_{STP}\cdot\varepsilon_S\cdot\varepsilon_F\cdot(1-e^{-\lambda\cdot t_1})\cdot e^{-\lambda\cdot t_2}} \tag{4}$$

For long half-life radionuclides (t_1 and t_2 are negligible compared to the half-life), the decision threshold of the averaged activity concentration in the air over the sampling duration is expressed as given by Formula (5):

$$\bar{C}^*=\frac{A^*}{q_{STP}\cdot t_1\cdot\varepsilon_S\cdot\varepsilon_F} \tag{5}$$

8.5 Detection limit

The detection limit of the averaged activity concentration in the air over the sampling duration is expressed as given by Formula (6):

$$C^{\#}=\bar{C}^*\cdot\left\{\frac{\frac{A^{\#}}{A^*}\cdot\left[1-k_p^2\cdot u_r^2(w)\right]}{1-k_p^2\cdot\left[u_r^2(w)+u_r^2(q_{STP})+u_1^2(\varepsilon_S)+u_r^2(\varepsilon_F)\right]}\right\} \tag{6}$$

With the following condition $u_r^2(w)+u_r^2(q_{STP})+u_r^2(\varepsilon_S)+u_r^2(\varepsilon_F)<\frac{1}{k_p^2}$, otherwise the method is not suitable for the measurement purpose.

8.6 Expression of activity concentration results

The activity concentration, $\bar{C}$, is compared with the decision threshold $\bar{C}^*$:

a) If $\bar{C} \leq \bar{C}^*$, the result of the measurement is expressed as $\leq \bar{C}^*$.

b) If $\bar{C} > \bar{C}^*$, the result of the measurement is expressed as $\bar{C} \pm k_P \cdot u(\bar{C})$.

An example of calculation of the activity concentration and its associated characteristic limits is given in Annex G.

9 Real time measurement with continuous air monitor[11]

9.1 Context

The determination of the activity concentration in the air from deferred measurement results does not allow a determination of the actual evolution of this activity concentration over the sampling duration.

This knowledge is made a posteriori and, if there is a great potential for an important unsuspected radiological event this would delay the implementation of protective actions.

In that case, the use of a continuous air monitor (CAM) is motivated by the need to be alerted quickly and as reliably as possible when previously defined activity concentration level values are exceeded, in order to take appropriate measures to reduce the exposure of the concerned populations. The performance of a CAM depends both on its metrological aspect, its capability to measure a lowest minimum detectable activity concentration with an acceptable false alarm rate, and also on its capability to react rapidly, which is characterized by the lowest response time. Thus, the ideal performance is to have a minimum detectable activity concentration as low as possible associated with a very short response time, but unfortunately these two criteria are opposite. It is therefore important that the CAM and the choice of the adjustment parameters and the alarm levels be in line with the radiation protection objectives.

It should be noted, however, that the metrological performances (decision threshold, detection limits and uncertainties of the activity concentration) of the CAM never reaches that of determining the activity concentration from the deferred measurement method which is much more sensitive. The first method is carried outdoors in a very changing environment (radon, weather) while the second one is carried out in a laboratory with all influencing parameters being under control. This is why the notion of minimum detectable activity concentration is used for CAM rather than decision threshold. Thus, none of these two methods can replace the other but they complement each other.

There is a new technical report which describes the theory of operation of CAM-types and the determination of activity concentrations, uncertainties and characteristic limits (decision threshold, detection limit, limits of coverage interval) of CAMs in more detail[11].

9.2 Description of CAM

In most of the cases, the CAM is intended to monitor long half-live radionuclides and is usually of two types:

a) **With fixed filter, which means that the activity concentration is determined from the variation of the activity deposited on the filter over time.**

The model of evaluation is expressed as given by Formula (7):

$$C(t) = \frac{A(t, t_C) - A(t - t_I \cdot t_C)}{q_{STP} \cdot t_I} \tag{7}$$

The value of the minimum detectable activity concentration has this following characteristic shown by Formula (8):

$$C_{min} \text{ is proportional to } \frac{1}{t_I} \cdot \sqrt{\frac{1}{t_C}} \tag{8}$$

$A(t, t_C)$ Activity deposited on the filter with a counting time, t_C, at a time t, in Bq;

$A(t - t_I, t_C)$ Activity deposited on the filter with a counting time, t_C, related to the time interval between the end of sampling, t_I, and the time of measurement, t, in Bq;

$C(t)$ Activity concentration measured at a time t, in $Bq \cdot m^{-3}$;

C_{min} Minimum detectable activity concentration, in $Bq \cdot m^{-3}$;

t_C Counting time, in s;

t_I Time interval, in s.

The typical response time of this type of evaluation depends on t_C and t_I as given in Table 2.

Table 2 — Typical response time in min for a fixed filter and long half-life model of evaluation as a function of the counting time, t_C, and the time interval, t_I

t_C min	t_I min								
	1	**5**	**10**	**20**	**30**	**40**	**45**	**50**	**60**
1	1,6	5,0	9,5	18,5	27,5	36,5	41,0	45,5	54,5
5	5,0	7,8	11,8	20,5	29,5	38,5	43,0	47,5	56,5
10	9,5	11,8	15,5	23,7	32,3	41,1	45,5	50,0	59,0
20	18,5	20,5	23,7	31,1	39,0	47,3	51,6	55,8	64,5
30	27,5	29,5	32,3	39,0	46,6	54,5	58,5	62,7	71,0
40	36,5	38,5	41,1	47,3	54,5	62,1	66,0	70,0	78,1
45	41,0	43,0	45,5	51,6	58,5	66,0	69,8	73,8	81,7
50	45,5	47,5	50,0	55,8	62,7	70,0	73,8	77,6	85,5
60	54,5	56,5	59,0	64,5	71,0	78,1	81,7	85,5	93,1

NOTE 1 Formula (8) and Table 2 show that the minimum detectable activity concentration decreases when t_C and t_I increase and so does the response time.

NOTE 2 In case of radionuclides with short half-lives this model of evaluation will provide wrong results.

b) **With continuously moving media filter, which means that the activity concentration is proportional to the activity deposited on the filter over time.**

The model of evaluation is expressed as given by Formula (9):

$$C(t) \text{ is proportional to } \frac{A(t, t_C)}{q \cdot t_T} \tag{9}$$

The response time of this type of evaluation depends on t_C and t_T as given in Table 3.

Table 3 — Response time in minutes of the moving filter model of evaluation of activity concentration as a function of the time transit, t_T, and the counting time, t_C, considering a long half-life radionuclide

t_C min	t_T min								
	1	**10**	**20**	**30**	**60**	**120**	**180**	**240**	**300**
1	1,3	7,4	14,2	21,3	41,5	82,5	123,5	164,4	205,4
5	4,8	9,7	16,3	23,1	43,6	84,5	125,5	166,4	207,4
10	9,3	13,3	19,4	26,0	46,2	87,1	128,0	169,0	210,0
20	18,3	21,6	26,6	32,4	51,9	92,4	133,2	174,2	215,1
30	27,3	30,3	34,7	39,9	58,1	98,0	138,6	179,4	220,3
40	36,3	39,3	43,1	47,9	64,9	103,8	144,1	184,8	225,6
50	45,3	48,3	51,8	56,2	72,2	109,8	149,8	190,3	231,0
60	54,3	57,3	60,7	64,7	79,8	116,1	155,6	195,9	236,5
120	108,3	111,3	114,6	118,0	129,3	159,6	194,6	232,3	271,4
180	162,3	165,3	168,6	171,9	182,0	207,9	239,3	273,8	310,3
240	216,2	219,2	222,6	225,9	235,9	258,6	287,2	319,1	353,3

NOTE 3 Formula (9) and Table 3 show that the minimum detectable activity concentration decreases when t_C and t_T increase and so does the response time.

NOTE 4 Because of the moving filter, the influence of the radon and thoron progenies is less important than for fixed filter.

9.3 Operating use of CAM

In general, each CAM manufacturer has its own specific algorithm process to mitigate more or less the influence of radon and thoron progenies fluctuations. These algorithms are usually black boxes protected by copyrights and the certification tests are generally carried out in test laboratories under well-defined conditions, which do not necessarily reflect the unstable environment in which the CAM is used outdoors. Thus, in order to lessen the false alarm rate, the user of the CAM has to determine empirically the alarm value corresponding to the minimum detectable activity after analysing the CAM response in the absence of the activity concentration under scrutiny over a more or less long period according to the most critical moments where the influence of radon is at its peak. An example of this empirical determination is given in Annex H.

10 Quality assurance and quality control

10.1 General

The quality of sampling procedures has to be assessed in all phases of the program including:

a) Sampling, sample identification, handling and storage;

b) technical operability of sampling equipment;

c) record keeping.

10.2 Sample identification, handling, and storage

All filter samples shall be uniquely identified to ensure that a filter from one location cannot be confused with filters from other locations. Sample designators are placed on all collection envelopes or containers to reduce the possibility of mislabelling a sample. Information included with the sample as a minimum is: the sample date, time period when the sample was collected, the sample volume of air, sample location, and the equipment used to obtain the sample. Additionally, ambient parameters such as wind direction, wind speed and presence of precipitation (rainfall, snowfall, fog) can be useful for further interpretation. An example of sampling information sheet is given in Annex E.

Samples should be handled carefully to prevent cross-contamination and should be placed in appropriately labelled containers to reduce the likelihood for loss. Arrangements should be made for sample storage prior to counting and between counts if multiple counts are required.

10.3 Sampling equipment

The accuracy of the sampling and the calibration of flow meters shall be suitable to ensure accurate and reliable measurement in the presence of radioactive substance.

a) Calibration.

Airflow meters, differential pressure indicators, and other devices used to determine volumetric flow rates should be calibrated to within 15 % of the true reading.

Measurement instruments should have a function check at least annually. Deviation between the measured and function check target values should not exceed 20 %.

b) Operability check.

The operability of continuous sampling equipment should be verified periodically. On a daily basis, job operability checks should include airflow indication and internal check sources if electronic checks are not available.

c) Performance of sampling flow rate measurements.

All samplers used for quantitative measurements should have means to determine the sample volume.

A leak in the sampling system (see Figure 3) can cause the indicated sample flow rate to be erroneous and also cause improper functioning of the sampling system. A sampling system has to be inspected for leaks at the time of installation and at any time when either significant maintenance is performed or during an inspection. The inspection or test methodology should be practical for the installation and documented.

Leakage under flowing conditions should not exceed 5 % of the nominal sampling flow rate.

10.4 Documentation and record keeping

Records shall include the following common elements:

a) Purpose of the activity concentration measurement.

b) Results for activity concentration measurements with associated uncertainty as appropriate for the measurement purpose.

c) Documentation of all parameters used in the calculation of activity concentrations and the associated uncertainties, including flow rate, sampler collection efficiency, filter collection efficiency, self-absorption, sampling period, meteorological conditions and detector counting efficiency.

d) Location of the sample being taken.

e) Model and serial number of the sampler.

f) Records of all calibration, maintenance, repair, and modification data for each instrument. Each record shall be dated and shall identify the individual performing the work. Each record shall be filed with previous records on the same instrument and shall be readily retrievable.

g) Full history and calibration data, including certificates, for all standards and applicable calibration equipment.

h) Documented analysis of the uncertainty of the calibration measurement.

i) All procedures used for providing calibration services.

j) Instruments used to measure activity for quantification of activity concentrations shall be labelled with the following information:

   — date of most recent calibration;

   — initials or other specific identifying mark of the calibrator;

   — date when calibration is due;

   — serial number of instrument or other unique identification number used by the facility to identify a specific instrument.

k) Routine quality control records.

l) Results of all performance tests.

m) Records detailing the training of all staff and supervisory personnel associated with operations within the sampling program.

Annex A
(informative)

Radionuclides in the atmosphere[16]

About 70 radionuclides are present in ambient air. They have either a natural or artificial origin, or, for a small number of them, a double natural and artificial origin (example: ^{3}H, ^{22}Na, ^{85}Kr, ^{14}C, ^{129}I). About 30 are produced directly in the atmosphere and have half-lives ranging from less than one second (^{214}Po) to 15,7 million years (^{129}I).

The majority of the radionuclides present in the ambient air are attached to solid or liquid particles by condensation or by attachment with pre-existing aerosol particles (organic, mineral, sea salts, pollution, etc.) under the effect of various mechanisms such as adsorption, coalescence, the impaction between aerosol particles or electrical attraction. A small number of them, however, remain mainly gaseous either because they do not interact or very little with material or because their lifetime is too short for the kinetics of sorption on ambient aerosol particles to be able to modify the gas /aerosol ratio. Within the framework of this document, only the levels of radionuclides associated with the ambient aerosol particles are detailed.

The highest activity concentration levels in the ambient air are attributable to naturally occurring radionuclides. They represent, for example, most of the value obtained by global beta counting and do not require large volume sampling of air. In comparison, the levels of artificial radionuclides present in the environment or added by discharges from installations in normal operation remain very low and can only be detected or quantified by filtering a large volume of air associated with low-level gamma spectrometry measurement.

The residence time of these radionuclides in the atmosphere varies depending on their half-life and the deposition or resuspension mechanisms.

Among the natural radionuclides present in particulate form in the atmosphere, there are those produced in the upper layers of the atmosphere (cosmogenic origin) and those produced in the earth's crust (telluric origin):

— cosmogenic radionuclides are produced under the action of cosmic radiation (for example ^{7}Be and ^{22}Na)

— telluric radionuclides are on the one hand those resulting from the decay chains of the primordial **uranium and thorium radionuclides and, on the other hand, ^{40}K. The ^{222}Rn gas resulting from the** decay chain of ^{238}U exhales from the emerged surfaces and disperses in the air where it decreases continuously giving rise to a chain of 11 radionuclides including 7 main ones: ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, ^{210}Bi, ^{210}Po.

These radionuclides are deposited on solid or liquid surfaces (gravitational settling and turbulence during dry weather; in-cloud and below-cloud wet scavenging). They are likely to re-integrate the atmospheric compartment by suspended solid particles (dust) or liquids (spray) under the action of the wind or during agricultural practices, open-pit mining, etc., as well as emission processes after integration of radionuclides into biomass: biomass burnings, biogenic aerosols (pollens, spores, etc.). Volcanic eruptions are a separate mechanism because they can emit into the atmosphere, in addition to primordial radionuclides, ^{210}Po formed and accumulated in the magmatic chamber before eruption.

The other large family of radionuclides present in the atmosphere in particulate form concerns those produced artificially during nuclear tests, during nuclear accidents and during the normal operation of nuclear installations. Near certain installations, it is possible to detect ^{129}I carried by the ambient aerosol particles or resulting from heterogeneous nucleation. As part of their normal operation, nuclear power plants (NPP) are authorized to release artificial radionuclides into the atmosphere; among these radionuclides, ^{110m}Ag, ^{60}Co, ^{58}Co are occasionally detectable in minor quantities and in the immediate

vicinity of nuclear facilities. During incidental releases, aerosols associated with ^{106}Ru-^{106}Rh and ^{131}I could be measured. During nuclear accidents (Chernobyl or Fukushima), isotopes of iodine (^{131}I, ^{132}I), cesium (^{134}Cs, ^{136}Cs, ^{137}Cs), tellurium (^{129m}Te-^{129}Te, ^{132}Te), lanthanum (^{140}La) were measured in Europe on a temporary basis.

Witnesses to the fallout from nuclear tests and these accidents, only ^{137}Cs and ^{90}Sr can still be measured at ultra-trace levels in the atmosphere in Europe, as well as ultra-traces of plutonium isotopes by processing samples corresponding to volumes of several hundred thousand m^3 of air.

Table A.1 brings together the main natural and man-made radionuclides present in the form of aerosol particles in the Earth's atmosphere (over a continent), their half-lives and their range of ambient levels.

Table A.1 — Main natural and man-made particulate radionuclides present in the Earth's atmosphere (over a continent)

Radionuclide	Half-life	Activity concentration in the air above the ground $mBq \cdot m^{-3}$	Bibliographical references
^{218}Po	3,07 min	3 000 to 20 000	[17]
^{214}Pb	26,9 min	500 to 3 500	[17]
^{214}Po	162 µs	150 to 3 000	[17][18]
^{212}Pb	10,64 h	200 to 600	[19]
^{210}Bi	5,01 d	0,1 to 2	[20]
^{7}Be	53,3 d	0,5 to 10	[21]
^{210}Pb	22,3 y	0,02 to 4	[21][22]
^{210}Po	138,4 d	0,01 to 0,3	[23]
^{40}K	1,3 x 10^9 y	0,001 to 0,1	[22]
^{232}Th	1,4 x 10^{10} y	0,000 4 to 0,003	[22]
^{238}U	4,5 x 10^9 y	0,000 5 to 0,003	[22]
^{22}Na	2,6 y	0,000 2 to 0,001 2	[24][25]
^{137}Cs	30,05 y	0,000 05 to 0,005	[22][26]
^{90}Sr	28,8 y	0,000 03 to 0,001 4	[22][26]
$^{239+240}$Pu	24 100 y and 6 561 y	0,000 005 to 0,000 2	[27]
^{238}Pu	87,74 y	0,000 000 02 to 0,000 01	[26][28]

Annex B
(informative)

General information on aerosol behaviour

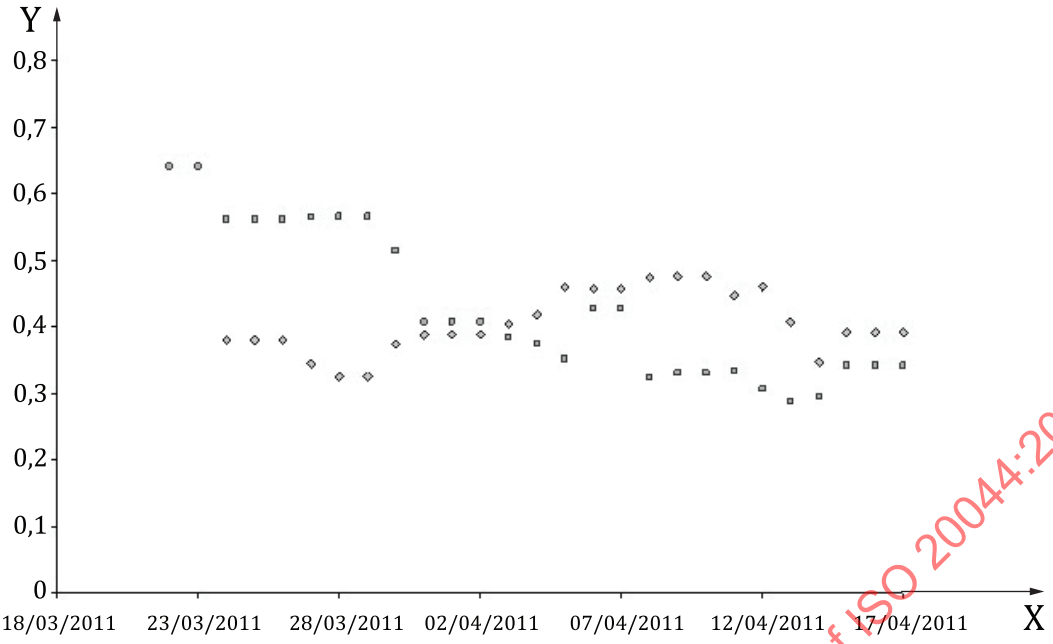
B.1 General

In the context of this document, it is noted that the aerosol particles, for the most part, are polydispersed in size. This distribution, also called the particle size distribution of the aerosol particles, is generally of the log-normal type and is defined by two parameters: the median aerodynamic diameter $\overline{d}_{\mathrm{a}}\,(MAD)$ and its geometric standard deviation $\left(\sigma_{\mathrm{g}}\right)$. However, high proportions of hot particles were also detected on air filters or on the ground, for example after the Chernobyl reactor accident, which, because of their high specific activity, can falsify the assumption of an equally allocated activity concentration in the air after a filter measurement [see Figure B.1].

This median aerodynamic diameter $\overline{d}_{\mathrm{a,m}}$ is generally expressed as a number or as a mass (see 3.15). In the case of radioactive aerosol particles, it is the activity median aerodynamic diameter (AMAD) with $\overline{d}_{\mathrm{a,A}}$ that is generally used (see 3.2).

B.2 Examples of aerosol particle sizes measured in the environment

A few days after the Fukushima accident, 70 % of the radioactive aerosol particles sampled in Western Europe had a particle size distribution of between 0,1 µm and 10 µm (except for ^{131}I) with an average $\overline{d}_{\mathrm{a,A}}$ of 0,6 µm.



Key

X date

Y median aerodynamic diameter in relation to the aerosol activity distribution $\bar{d}_{a,A}$ µm

◇ ^{131}I

■ ^{137}Cs

Figure B.1 — Evolution of the AMAD of particulate ^{131}I and ^{137}Cs in Europe after the Fukushima-Daiichi accident

After its release into the environment, the radionuclide ^{137}Cs is in particulate form. Larger median diameters (0,6 µm to 0,7 µm) were observed with the arrival of air masses. They then decreased over time to values between 0,3 µm and 0,4 µm. These values reflect those higher in Japan just at the beginning of the accident ($\bar{d}_{a,A}$ = 2 µm) and the local downward trend that followed. The lower values observed in Europe are related to deposition by sedimentation and scavenging by rain of the larger aerosol particles during transport.

For iodine, representative diameters were less than 0,4 µm when air masses arrived in Europe. The difference with the representative diameters obtained for ^{137}Cs is due to the fact that

a) the iodine mainly propagated (~ $4/5^{ths}$) in gaseous form;

b) part of the gaseous iodine is gradually attached to aerosol particles by adsorption or converted into aerosol particles by chemical reactions during transport on ambient aerosol particles of all sizes and in particular on fine fractions, thus lowering the representative median diameter.

B.3 Behaviour of aerosol particles

The behaviour of aerosol particles in the environment, a duct or a filter depends essentially on the dimensions of the particles that constitute it in relation to the intermolecular distance of the carrier gas, see References [29] to [44].

When the particle is large (>1 µm), the carrier gas is considered to be a continuous fluid and the behaviour of the particle is linked to fluid dynamics: it is the continuous domain. These particles are

endowed with a great inertia, which favours their deposition in the ducts or the filters during a change of direction of the carrier fluid. In addition, they can sediment under the effect of gravity.

When the particle is small ($<10^{-2}$ µm), the carrier gas constitutes a discontinuous fluid, the diffusion of particles in the gas is linked to the laws of gas kinetics: this is the molecular domain. These particles get trapped quickly, by Brownian diffusion, on walls, on filter fibres or on other particles present in their environment.

When the dimensions of the particle and the intermolecular vacuum are of the same order of magnitude, this is the intermediate domain. The particles located in this area are those that have the greatest penetrating power.

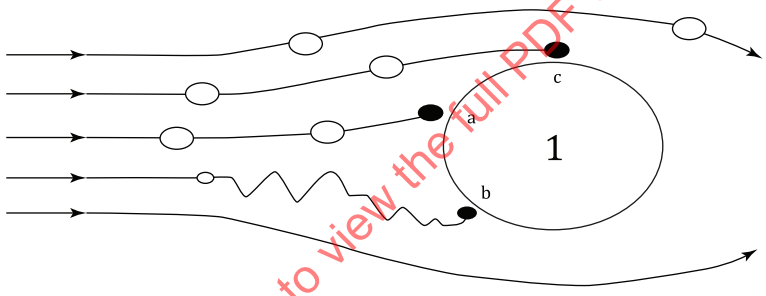
This aerosol particle behaviour explains the mechanism of trapping aerosol particles on the fibre of a filter (see Figure B.2):

— trapping by inertia (1);

— trapping by diffusion (2);

— trapping by interception (3);

— trapping by electric charge effect.



Key

1 fibre

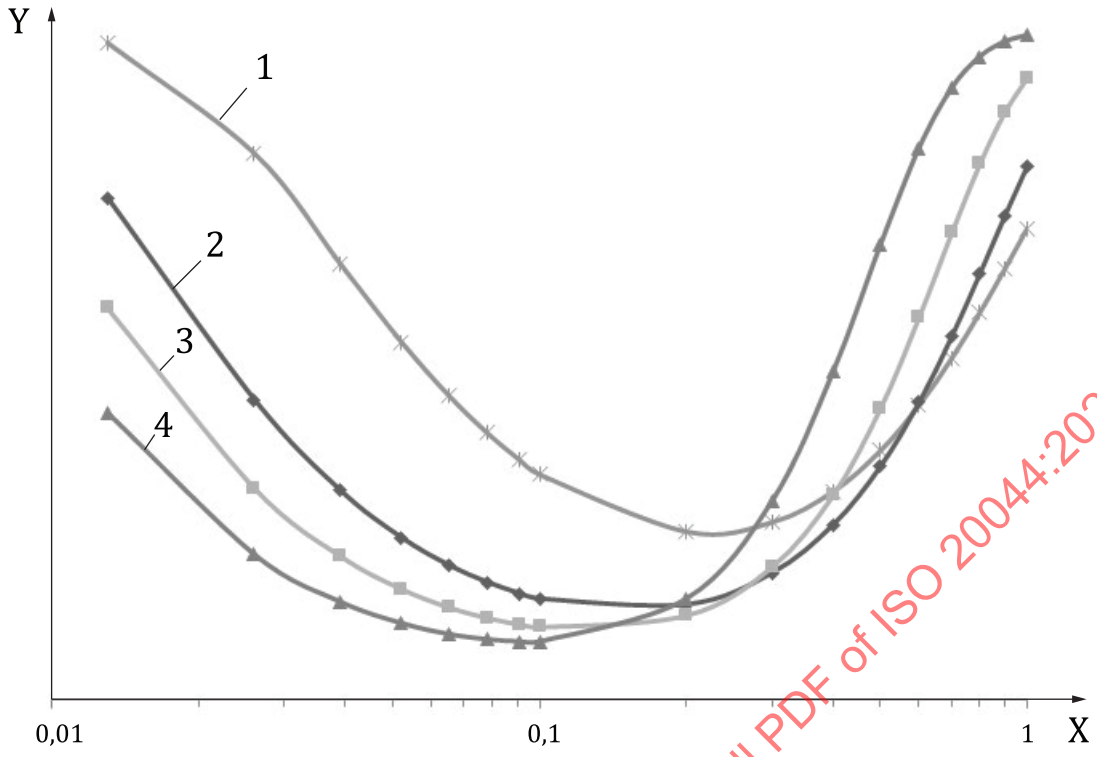
a Trapping by inertia.

b Trapping by diffusion.

c Trapping by interception.

Figure B.2 — Mechanisms for trapping an aerosol particle on a filter

Figure B.3 represents the typical characteristic of the aerosol particle trapping efficiency curves as a function of their particle size and of the air filtration velocity. It should be noted that the minimum filtration efficiency is usually obtained for aerosol particles having an aerodynamic diameter (AD) with d_a of the order of a tenth of a micron, except in the case of electrically charged filters where the capture by electric charge effect brings this minimum down to nanometric sizes.



Key

X aerosol particle diameter (µm)
Y trapping efficiency
1 0,1 m/s
2 0,5 m/s
3 1 m/s
4 2 m/s

Figure B.3 — Influence of aerosol particle diameter and air filtration velocity on the trapping efficiency of a filter

Annex C
(informative)

Example of sampling head and characterizations

C.1 Sampling head example

C.1.1 Test conditions

This annex presents the tests and sampling efficiency values of a sampling head used in France for environmental radiological monitoring.

The purpose of the tests carried out in a wind tunnel is to determine the sampling efficiency of the sampling heads for dry aerosol particles whose size is between 2 µm and 12 µm, and for air velocities of 2 $m \cdot s^{-1}$ and 10 $m \cdot s^{-1}$. Aerosol particles consisting of dry fluorescein as a good indicator for the measurement are generated by a vibrating orifice generator, their geometric standard deviation is 1,1 µm. During the test, the sampling head is positioned in the wind tunnel, its axis perpendicular to the direction of air flow.

The aerosol particles are injected upstream of the blower and then sampled downstream simultaneously by the sampling head to be qualified equipped with a sampling filter on the one hand and an isokinetic sampling probe on the other hand. Analysis of the filter placed downstream of the isokinetic sampling probe makes it possible to calculate the mass concentration of the aerosol particles in the blower.

The sampling efficiency of the sampling head is equal to the ratio between the mass concentration of the aerosol particles taken by the head under test conditions and the concentration in the wind tunnel.

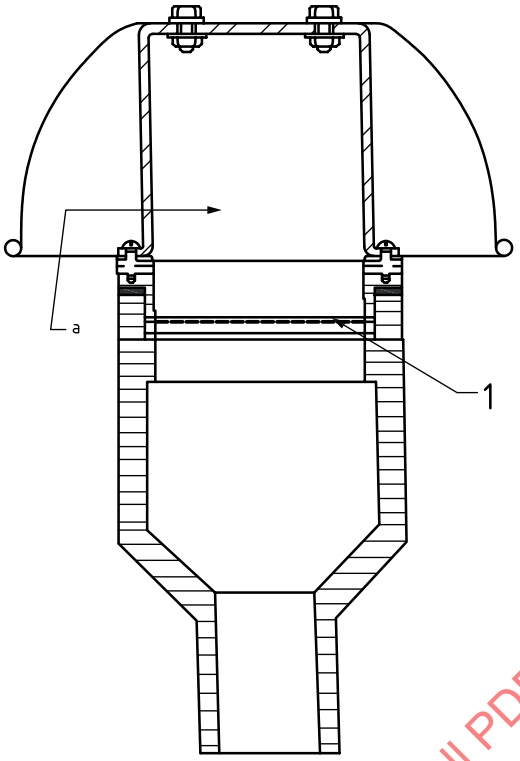
C.1.2 Characteristics of the tested sampling head

In the following example, the sampling head is used with a volume flow rate at standard reference conditions with 100 $l \cdot min^{-1}$ and a 51 mm diameter sampling filter located immediately at the inlet of the head (see Figure C.1). The performances of this head are given in Table C.1.

Table C.1 — Performance of a sampling head on a fixed filter
[SOURCE: Institut de Radioprotection et de Sûreté Nucléaire (IRSN)]

Air velocity m/s	Sampling efficiency of the sampling head	Uncertainty
2	1,18	0,12
	1,08	0,09
	1,03	0,09
	0,95	0,08
	0,87	0,07
10	1,01	0,09
	0,82	0,06
	0,85	0,07
	0,89	0,07
	0,87	0,07

The uncertainty is expressed with an expansion factor k of 2.



Key

1 filter

[a] Air.

Figure C.1 — Example of a sampling head with filter [SOURCE: IRSN]

C.2 Characterization of the sampling device

The sampling efficiency can be quantified according to the size of the aerosol particles and air velocity, either experimentally or via a qualified computer code. Under controlled flow conditions (wind tunnel tests), a sampling efficiency of at least 50 % is used for aerosol particles with an aerodynamic diameter of 10 µm and for an air velocity of 10 $m \cdot s^{-1}$. Note that the sampling efficiency of a sampling head is inversely proportional to the wind speed and the size of the aerosol particles, which implies that the sampling efficiency is better for lower wind speeds and smaller diameters. Failing this, an intercomparison can be made with a sampler for which performance is available.

As the sampling efficiency varies depending on the size of the aerosol particles the sampling head was tested on several aerodynamic diameters, for example 0,4 µm, the most abundant in the environmental spectrum, as well as intermediate sizes up to 10 µm for different air velocities of 2 $m \cdot s^{-1}$ and 10 $m \cdot s^{-1}$ at nominal sampling flow. The sampling efficiency can also be evaluated by a qualified computer code, the results of which have been validated experimentally on at least two distinct aerosol particle sizes.

Intercomparisons between different devices can also be made.

Annex D
(informative)

Examples of some sampling filters characteristics

D.1 Characteristics of some sampling filters

The sampling filters selected in this annex correspond to the most commonly used for samples taken in the environment. Table D.1 presents their general characteristics.

Table D.1 — General characteristics

Reference	A	B	C
Type	Membrane	Fibrous	Fibrous
Nature	Polytetrafluoroethylene (PTFE) and polyethylene support	Fiberglass	Cellulose and fiberglass
Surface mass ($g \cdot m^{-2}$)	50	80	100
Thickness (µm)	125	500	320
Pressure drop (hPa) for a new filter not yet used at 1 $m \cdot s^{-1}$	30 to 40	25	70
Trapping efficiency (%)			
— for 0,15 µm at 1 $m \cdot s^{-1}$ with new filter not yet used	100	80	94
— for 0,15 µm at 1 $m \cdot s^{-1}$ with clogged filter (0,12 $mg \cdot cm^{-2}$)	100	82	98

Some intrinsic properties of these filters are given in Table D.2.

Table D.2 — Examples of intrinsic properties of some filters

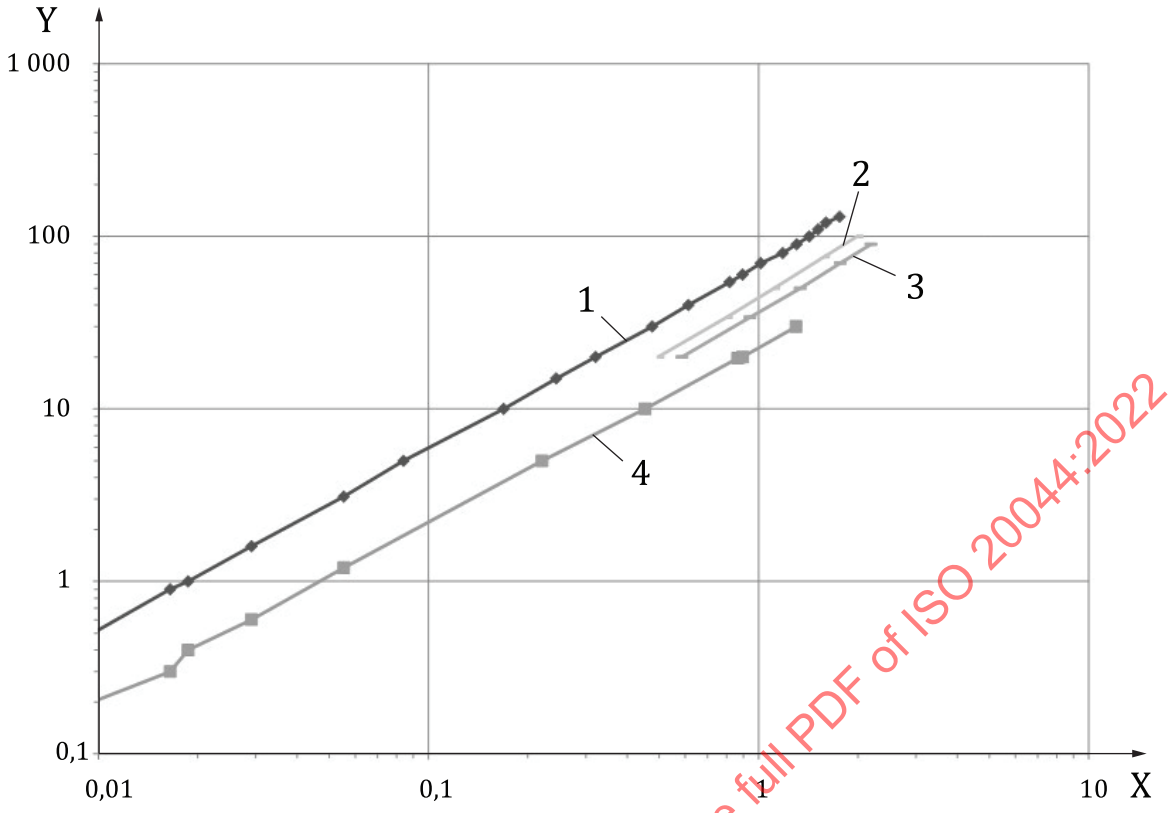
	Aerosol trapping	Mineralization	Humidity	Intrinsic radioactivity
A	at surface	very difficult	not very sensitive	Negligible
B	at surface and depth	not easy	not very sensitive	potassium 40
C		not easy	sensitive	potassium 40

— For measurements based on alpha spectrometry, it is essential to select the membrane to be used by preliminary measurements in order to verify the influence of the attenuation due to the thickness and fibre type.

— Large size filters can be compacted to obtain a geometry suitable for gamma spectrometry measurements.

D.2 Pressure drop

The pressure drop of a filter varies as a function of the square root of the air velocity. The values obtained for some filters are given in Figure D.1.



Key

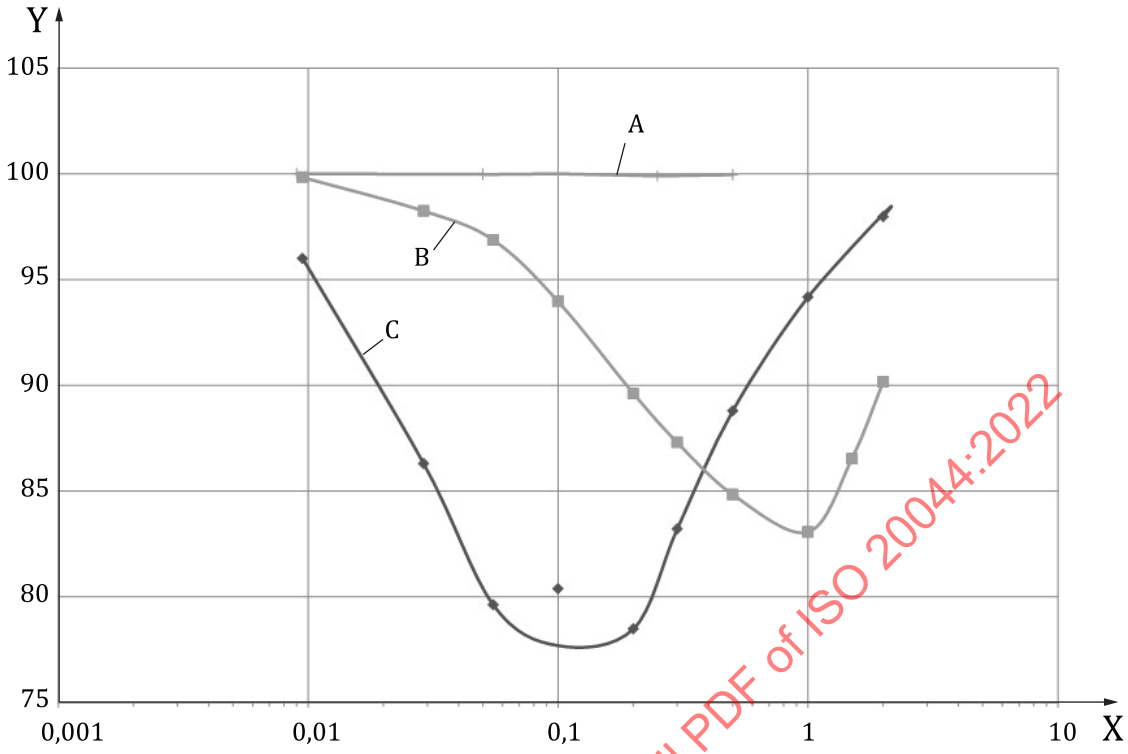
X air velocity (m/s)
Y pressure drop (hPa)
1 C
2 A (lot 2)
3 A (lot 1)
4 B

Figure D.1 — Pressure drop of filters A, B and C as a function of air velocity

D.3 Trapping efficiency

D.3.1 Influence of air velocity

Efficiency varies depending on air velocity. Figure D.2 shows the values obtained with some filters for the uranine (sodium salt of fluorescein) aerosol particles having a mass median aerodynamic diameter (MMAD) with $\bar{d}_{a,m}$ = 0,15 µm.



Key

X air velocity (m/s)

Y filtration efficiency (%)

Figure D.2 — Filtration efficiency of filters A, B and C as a function of air velocity for about 0,15 µm size uranine aerosol particles

D.3.2 Influence of the aerosol particle granulometry

The curve representing the filtration efficiency of a filter as a function of the aerosol particle diameter goes through a minimum for aerosol particles of the order of 0,15 µm. For example, the filtration efficiency of filter B, measured for a filtration rate of 1,2 $m \cdot s^{-1}$, goes from 84 % for aerosol particles of 0,15 µm to 99,5 % for aerosol particles of 0,48 µm and 99,9 % at 0,81 µm.

D.3.3 Influence of clogging

The filtration efficiency of a filter tends to increase as it becomes clogged with solid aerosol particles although it would not be the case for wet environments.

Annex E
(informative)

Example of sampling information sheet

Location of the sampling device:	
Date and time of the start of sampling (UTC)	
Date and time of the end of sampling (UTC)	
Identification of the filter or / and the carrying case	
Volume sampled (or values used to determine this volume)	
Observations on the state of the filter (if necessary)	
Observations on equipment incidents	
Visual observations of the deposit on the filter (pollens, debris, homogeneity, etc.)	
Observations on meteorological and environmental conditions, etc.	
Operator (s): Name (s) / company (s)	
Signatures	

Annex F
(informative)

Characterization of the transport line

The main challenge when transporting the aerosol to collectors and aerosol measuring instruments is to avoid the loss of particles. Particle loss mechanisms are size-depending and are generally caused by particle diffusion, impaction, and sedimentation (see also Annex B). Generally, losses due to particle diffusion are critical for ultrafine particles (smaller than 0,1 µm). In contrast, particle losses due to sedimentation and impaction are related to supermicron particles in horizontal and sloping pipes as well as in bends.

The regime of an air flow in a pipe, laminar versus turbulent, is characterized by its Reynolds number, *Re*. A flow in a pipe is laminar up to a Reynolds number of approximately 2 000. Above this value, the flow becomes gradually more and more turbulent. The Reynolds number can be determined by Formula (F.1):

$$Re = (\rho_G \cdot v_a \cdot d) / \eta_G \quad \text{(F.1)}$$

with the gas density, ρ_G, the air velocity, v_a, the inner diameter of the pipe d, and the dynamic viscosity, η_G.

Advantages of a turbulent sampling configuration are following:

— High aerosol flow rate;

— Short residence time in sampling system;

— Less losses due to sedimentation in horizontal pipes;

Disadvantages:

— Increased losses of ultrafine particles due to enhanced diffusion,

— Increased losses of coarse particles due to enhanced impaction,

— Limited ability to actively dry the aerosol particles by using heaters.

Table F.1 summarizes Reynolds numbers, *Re*, as a result of calculations with different diameters of a tube and different flow rates for air with a temperature of 20 °C and 1 bar.

For example, the conditions for laminar flow are given for an inner diameter of the tube with d = 0,1 m and an airflow velocity of v_a = 0,3 m·s^{-1} meaning a volume flow rate of q = 8,48 m^3·h^{-1}. High-volume samplers with more than v_a = 0,4 m·s^{-1} and an inner diameter d of the tube with 0,1 m have greater Reynolds numbers than 2 000 which means a turbulent flow.

Table F.1 — Reynolds numbers with different air velocities with *T*= 20 °C; 1 013 hPa

d m	v_a m/s	*Re*
0,05	0,1	321
0,05	0,2	653
0,05	0,3	980
0,1	0,1	653

Table F.1 *(continued)*

d m	v_a m/s	Re
0,1	0,2	1 306
0,1	0,3	1 959
0,2	0,1	1 306
0,2	0,2	2 612
0,2	0,3	3 918

Annex G
(informative)

Example of calculation of the activity concentration in the air from deferred measurement

G.1 Description of the monitoring

The monitoring consists in

— collecting the filters daily then measure the deposited gross alpha and beta activities after removal of the short-lived radon progenies, in order to quantify the daily averaged gross alpha and beta activity concentrations. Gross alpha is mostly recommended for facilities dealing with the upstream part of the fuel cycle.

— measuring by gamma spectrometry separately all the filters. In case of values below the decision threshold, filters can be gathered together and measured at once as for instance on a monthly basis in order to quantify the average monthly activity concentrations of the identified radionuclides.

G.1.1 General

The characteristics of the sampling device are given in Table G.1.

Table G.1 — Example of characteristics of a sampling device

Location of the sampling device	Monitoring station N°1
Filtration efficiency of the filter	ε_F = 0,85 $u_r(\varepsilon_F)$ = 3,4 % (k=1)
Collection efficiency of the sampling line	ε_S = 0,92 $u_r(\varepsilon_F)$ = 7,5 % (k=1)
Sampling air flow rate at temperature of 273 K and pressure of 1 013 hPa	q_{STP} = 0,016 3 $m^3 \cdot s^{-1}$ $u_r(q_{STP})$ = 3,3 % (k=1)

G.1.2 Daily sampling

The characteristics of the sampling are given in Table G.2.

Table G.2 — Example of characteristics of a daily sampling

Starting date and time of sampling	20/09/2018 9:00 (UTC)
Ending date and time of sampling	21/09/2018 9:00 (UTC)
Sampling duration	t_1 = 86 400 s $u_r(t_1)$ ~0 %

G.1.3 Monthly sampling

The characteristics of the sampling are given in Table G.3.

Table G.3 — Example of characteristics of a monthly sampling

Starting date and time of the start of sampling	01/09/2018 9:00 (UTC)
Ending date and time of the sampling	01/10/2018 9:00 (UTC)
Sampling duration	t_1 = 2 592 000 s $u_r(t_1)$ ~0 %

G.2 Measurement test report and activity concentration results

G.2.1 Daily sampling

The test report of the daily sampling measurement is given in Table G.4.

Table G.4 — Example of a test report of a daily sampling measurement

Type of measurement	Gross alpha and beta
Date and time of the measurement	27/09/2018 16:40 (UTC)
Duration between the end of sampling and the end of the activity measurement	t_2 = 546 000 s $u_r(t_2)$ ~0 %
Gross beta activity at time of the measurement	A = 0,67 Bq with $u_r(A)$ = 10,5 % (k=1)
Decision threshold of gross beta activity at time of the measurement	A^* =0,05 Bq with $k_{1-\alpha}$ = 1,96
Detection limit of the gross beta activity at time of the measurement	$A^\#$ = 0,11 Bq with $k_{1-\alpha}$ = 1,96
Standard uncertainty of the conversion factor for the measurement of the gross beta activity deposited on the media filter	$u_r(w)$ = 9,5 % (k = 1)
Gross alpha activity at time of the measurement	A = 0,045 Bq with $u_r(A)$ = 40 % (k=1)
Decision threshold of gross alpha activity at time of the measurement	A^* = 0,03 Bq with $k_{1-\alpha}$ = 1,96
Detection limit of gross alpha activity at time of the measurement	$A^\#$ = 0,07 Bq with $k_{1-\alpha}$ = 1,96
Standard uncertainty of the conversion factor for the measurement of the gross alpha activity deposited on the media filter	$u_r(w)$ = 15 % (k = 1)

Then, considering that the detected radioactivity is due to long half-life radionuclides, the Formula (2), (3), (5) and (6) in Clause 8 give the activity concentration results and their associated characteristic limits using the input data given in Table G.1, Table G.2 and Table G.4. The results are given in Table G.5.

Table G.5 — Daily averaged gross alpha and beta activity concentrations

Sampling period	From 20/09/2018 9:00 to 21/09/2018 9:00 (UTC)
Averaged gross beta activity concentration over the sampling period	$\overline{C}$ = 0,59 mBq · m^{-3} with $u_r(\overline{C})$ = 14 % (k = 1)
Decision threshold of the averaged gross beta activity concentration over the sampling period	$\overline{C}^*$ = 0,04 mBq · m^{-3} with $k_{1-\alpha}$ = 1,96
Detection limit of the averaged gross beta activity concentration over the sampling period	$\overline{C}^\#$ = 0,10 mBq · m^{-3} with $k_{1-\alpha}$ = 1,96
Averaged gross alpha activity concentration over the sampling period	$\overline{C}$ = 0,040 mBq · m^{-3} with $u_r(C)$ = 41 % (k=1)
Decision threshold of the averaged gross alpha activity concentration over the sampling period	$\overline{C}^*$ =0,027 mBq · m^{-3} with $k_{1-\alpha}$ = 1,96
Detection limit of the averaged gross alpha activity concentration over the sampling period	$\overline{C}^\#$ = 0,064 mBq m^{-3} with $k_{1-\alpha}$ = 1,96

G.2.2 Monthly sampling

The test report of the monthly sampling measurements is given in Table G.6.

Table G.6 — Example of a test report of a monthly sampling measurement

Type of measurement	Gamma spectrometry
Date and time of the measurement	22/10/2018 17:40 (UTC)
Duration between the end of sampling and the end of the activity measurement	t_2 = 1 845 600 s $u_r(t_2)$ ~ 0 %
^{7}Be activity at time of the measurement ^{7}Be half-life: 53,3 days	A = 120 Bq with $u_r(A)$ = 8 % (k = 1) λ = 1,505 17E-07 s^{-1}
Decision threshold of ^{7}Be activity at time of the measurement	A^* = 0,20 Bq with $k_{1-\alpha}$ = 1,96
Detection limit of ^{7}Be activity at time of the measurement	$A^{\#}$ = 0,42 Bq with $k_{1-\alpha}$ = 1,96
Standard uncertainty of the conversion factor for the measurement of the ^{7}Be activity deposited on all of the filters	$u_r(w)$ = 10 % (k = 1)
^{210}Pb activity at time of the measurement: ^{210}Pb half-life: 22,3 years	A = 15 Bq with $u_r(A)$ = 8,5 % (k = 1) λ = 9,856 3E-10 s^{-1}
Decision threshold of ^{210}Pb activity at time of the measurement	A^* = 0,38 Bq with $k_{1-\alpha}$ = 1,96
Detection limit of ^{210}Pb activity at time of the measurement	$A^{\#}$ = 0,80 Bq with $k_{1-\alpha}$ = 1,96
Standard uncertainty of the conversion factor for the measurement of the ^{210}Pb activity deposited on all of the filters	$u_r(w)$ = 10 % (k = 1)
^{137}Cs activity at time of the measurement ^{137}Cs half-life: 30,05 years	$A \leq A^*$ λ = 7,314 33E-10 s^{-1}
Decision threshold of ^{137}Cs activity at time of the measurement	A^* = 0,24 Bq with $k_{1-\alpha}$ = 1,96
Detection limit of ^{137}Cs activity at time of the measurement	$A^{\#}$ = 0,05 Bq with $k_{1-\alpha}$ = 1,96
Standard uncertainty of the conversion factor for the measurement of the ^{210}Pb activity deposited on all of the filters	$u_r(w)$ = 10 % (k = 1)

Then, the Formulae (1), (3), (4) and (6) in Clause 8 give the activity concentration results and their associated characteristic limits using the input data given in Table G.1, Table G.3 and Table G.6. The results are given in Table G.7.

Table G.7 — Example of monthly averaged gamma emitters activity concentrations

Sampling period	From 01/09/2018 9:00 to 01/10/2018 9:00 (UTC)
Averaged ^{7}Be activity concentration over the sampling period	$\overline{C}$ = 5,66 mBq ·m^{-3} with $u_r(\overline{C})$ = 12 % (k = 1)
Decision threshold of the averaged ^{7}Be activity concentration over the sampling period	$\overline{C}^*$ = 0,009 4 mBq · m^{-3} with $k_{1-\alpha}$ = 1,96
Detection limit of the averaged ^{7}Be activity concentration over the sampling period	$\overline{C}^{\#}$ = 0,020 7 mBq · m^{-3} with $k_{1-\alpha}$ = 1,96
Averaged ^{210}Pb activity concentration over the sampling period	$\overline{C}$ = 0,44 mBq · m^{-3} with $u_r(\overline{C})$= 12 % (k = 1)
Decision threshold of the averaged ^{210}Pb activity concentration over the sampling period	$\overline{C}^*$ = 0,011 mBq · m^{-3} with $k_{1-\alpha}$ = 1,96
Detection limit of the averaged ^{210}Pb activity concentration over the sampling period	$\overline{C}^{\#}$ = 0,025 mBq · m^{-3} with $k_{1-\alpha}$ = 1,96