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Measurement of radioactivity in the environment — Air: radon-222 —

Part 6: Spot measurement methods of the activity concentration

Mesurage de la radioactivité dans l'environnement — Air: radon 222 —

Partie 6: Méthodes de mesure ponctuelle de l'activité volumique

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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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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

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

This second edition cancels and replaces the first edition (ISO 11665-6:2012), of which it constitutes a minor revision. The changes compared to the previous edition are as follows:

— update of the Introduction;

— update of the Bibliography.

A list of all the parts in the ISO 11665 series can be found on the ISO website.

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.

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Introduction

Radon isotopes 222, 219 and 220 are radioactive gases produced by the disintegration of radium isotopes 226, 223 and 224, which are decay products of uranium-238, uranium-235 and thorium-232 respectively, and are all found in the earth's crust (see ISO 11665-1:2019, Annex A, for further information). Solid elements, also radioactive, followed by stable lead are produced by radon disintegration[1].

When disintegrating, radon emits alpha particles and generates solid decay products, which are also radioactive (polonium, bismuth, lead, etc.). The potential effects on human health of radon lie in its solid decay products rather than the gas itself. Whether or not they are attached to atmospheric aerosols, radon decay products can be inhaled and deposited in the bronchopulmonary tree to varying depths according to their size[2][3][4][5].

Radon is today considered to be the main source of human exposure to natural radiation. UNSCEAR[6] suggests that, at the worldwide level, radon accounts for around 52 % of global average exposure to natural radiation. The radiological impact of isotope 222 (48 %) is far more significant than isotope 220 (4 %), while isotope 219 is considered negligible (see ISO 11665-1:2019, Annex A). For this reason, references to radon in this document refer only to radon-222.

Radon activity concentration can vary from one to more orders of magnitude over time and space. Exposure to radon and its decay products varies tremendously from one area to another, as it depends on the amount of radon emitted by the soil and building materials, weather conditions, and on the degree of containment in the areas where individuals are exposed.

As radon tends to concentrate in enclosed spaces like houses, the main part of the population exposure is due to indoor radon. Soil gas is recognized as the most important source of residential radon through infiltration pathways. Other sources are described in other parts of ISO 11665 and ISO 13164 series for water[7].

Radon enters into buildings via diffusion mechanism caused by the all-time existing difference between radon activity concentrations in the underlying soil and inside the building, and via convection mechanism inconstantly generated by a difference in pressure between the air in the building and the air contained in the underlying soil. Indoor radon activity concentration depends on radon activity concentration in the underlying soil, the building structure, the equipment (chimney, ventilation systems, among others), the environmental parameters of the building (temperature, pressure, etc.) and the occupants' lifestyle.

To limit the risk to individuals, a national reference level of 100 $Bq \cdot m^{-3}$ is recommended by the World Health Organization[5]. Wherever this is not possible, this reference level should not exceed 300 $Bq \cdot m^{-3}$. This recommendation was endorsed by the European Community Member States that shall establish national reference levels for indoor radon activity concentrations. The reference levels for the annual average activity concentration in air shall not be higher than 300 $Bq \cdot m^{-3}$[5].

To reduce the risk to the overall population, building codes should be implemented that require radon prevention measures in buildings under construction and radon mitigating measures in existing buildings. Radon measurements are needed because building codes alone cannot guarantee that radon concentrations are below the reference level.

The activity concentration of radon-222 in the atmosphere can be measured by spot, continuous and integrated measurement methods with active or passive air sampling (see ISO 11665-1). This document deals with radon-222 spot measurement methods.

NOTE The origin of radon-222 and its short-lived decay products in the atmospheric environment and other measurement methods are described generally in ISO 11665-1.

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Measurement of radioactivity in the environment — Air: radon-222 —

Part 6: Spot measurement methods of the activity concentration

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1 Scope

This document describes radon-222 spot measurement methods. It gives indications for carrying out spot measurements, at the scale of a few minutes at a given place, of the radon activity concentration in open and confined atmospheres.

This measurement method is intended for rapid assessment of the radon activity concentration in the air. The result cannot be extrapolated to an annual estimate of the radon activity concentration. This type of measurement is therefore not applicable for assessment of the annual exposure or for determining whether or not to mitigate citizen exposures to radon or radon decay products.

The measurement method described is applicable to air samples with radon activity concentration greater than 50 $Bq \cdot m^{-3}$.

NOTE For example, using an appropriate device, the radon activity concentration can be spot measured in the soil and at the interface of a material with the atmosphere (see also ISO 11665-7[8]).

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 11665-1, *Measurement of radioactivity in the environment — Air: radon-222 — Part 1: Origins of radon and its short-lived decay products and associated measurement methods*

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

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

IEC 61577-1, *Radiation protection instrumentation — Radon and radon decay product measuring instruments — Part 1: General principles*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11665-1 apply.

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

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

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

3.2 Symbols

For the purposes of this document, the symbols given in ISO 11665-1 and the following apply.

C	activity concentration, in becquerels per cubic metre
C^*	decision threshold of the activity concentration, in becquerels per cubic metre
$C^\#$	detection limit of the activity concentration, in becquerels per cubic metre
$C^\triangleleft$	lower limit of the confidence interval of the activity concentration, in becquerels per cubic metre
$C^\triangleright$	upper limit of the confidence interval of the activity concentration, in becquerels per cubic metre
U	expanded uncertainty calculated by $U = k \cdot u(\ )$ with $k = 2$
$u(\ )$	standard uncertainty associated with the measurement result
$u_{\text{rel}}(\ )$	relative standard uncertainty
μ	quantity to be measured
μ_0	background level
ω	correction factor linked to the calibration factor

4 Principle

Spot measurement of the radon activity concentration is based on the following elements:

a) active grab sampling of a volume of air previously filtered and representative of the atmosphere under investigation at time t; this pre-filtered sample is introduced into the detection chamber;

b) measurement of the physical variable (photons, pulse counts and amplitude, etc.) linked to the radiation that is emitted by the radon and/or its decay products present in the detection chamber after sampling.

Several measurement methods meet the requirements of this document. They are basically distinguished by the type of physical quantity and how it is measured. The physical quantity and its related measurement may be as follows, for example:

— photons emitted by a scintillating medium, such as ZnS(Ag), when excited by an alpha particle (see Annex A);

— gamma emission rates of the decay products ^{214}Pb and ^{214}Bi produced by the radon that is present in the sampled air volume.

The measurement results can be available immediately or after a certain period of time. Due to the great variability of the radon activity concentration in time and space, the measurement result is representative of the radon activity concentration at the sampling time and the sampling place only.

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5 Equipment

The apparatus shall include the following:

a) a sampling device, including a filtering medium, for taking the air sample in the detection chamber; the role of the filtering medium is to stop the aerosols present in the air at the time of sampling, especially the solid radon decay products;

b) a device to pump the air for sampling if active sampling is required;

c) the detection chamber;

d) a measuring system adapted to the physical quantity.

The necessary equipment for a specific measurement method is specified in Annex A.

6 Sampling

6.1 Sampling objective

The sampling objective is to introduce an ambient air sample into the detection chamber of the device during a short period of time of less than 1 h.

6.2 Sampling characteristics

Sampling is active and may be carried out via pumping or suction in a detection chamber under vacuum.

Grab sampling is representative of the radon activity concentration at a given moment and a given place. An air sample adapted to the detection chamber of the measuring device used is taken directly in the atmosphere by pumping and filtering.

The filtering medium shall stop the aerosol particles present in the air at the time of sampling, especially the radon decay products.

The sampling device shall not include components that trap radon (desiccants, etc.).

6.3 Sampling conditions

6.3.1 General

Sampling shall be carried out as specified in ISO 11665-1. The sampling location and time (date and hour) shall be recorded.

6.3.2 Location of sampling place

Grab sampling may be carried out in the atmosphere, inside a building, in the ground or at the interface between a material and the atmosphere, etc.

The choice of each sampling location depends on the objectives sought (for example, verification of the homogeneity of the activity concentrations in an environment or a search for anomalies, etc.).

6.3.3 Sampling duration

Sampling is carried out over a short period of time. The sampling duration shall be less than 1 h.

6.3.4 Volume of air sampled

The volume of air sampled shall be determined accurately with a flowmeter corrected for the temperature and pressure variation (expressed in cubic metres at a standard pressure and temperature

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of 1,013 hPa and 0 °C respectively) or by deducing it from a pressure measurement when sampling is carried out via suction (see Annex A).

7 Detection

Detection shall be carried out using silver-activated zinc sulphide ZnS(Ag) scintillation or gamma-ray spectrometry, as described in ISO 11665-1.

8 Measurement

8.1 Procedure

Measurement shall be carried out as follows.

a) Determine the background of the detection chamber.

b) Select and locate the measuring place.

c) Using grab sampling, collect an air sample representative of the atmosphere under investigation.

d) Record the location and time (date and hour) of sampling.

e) Wait until short-lived decay products are in equilibrium with radon in the detection chamber (3 h).

f) Measure the physical quantity emitted in the detection chamber with a suitable measuring chain.

g) Record the time (date and hour) of measurement.

h) Determine the activity concentration by calculation.

The measurement procedure for the scintillation method is detailed in Annex A.

8.2 Influence quantities

Various quantities can lead to measurement bias that could induce non-representative results. Depending on the measurement method and the control of usual influence quantities specified in IEC 61577-1 and ISO 11665-1, the following quantities shall be considered in particular:

a) the instrumental background noise;

b) the presence of other gaseous radionuclide alpha-emitters or gamma-emitters in the detection chamber, including other radon isotopes and their decay products.

Manufacturer recommendations in the operating instructions for the measuring devices shall be followed.

8.3 Calibration

The entire measuring instrument (sampling system, detector and related electronics) shall be calibrated as specified in ISO 11665-1.

The relationship between the physical quantity measured by the detection device (count rate, etc.) and the activity concentration of the radon in the air sample shall be established based on the measurement of a radon-222 reference atmosphere. The radon-222 activity concentration in the reference atmosphere shall be traceable to a primary radon-222 gas standard.

An instrument calibration result shall allow traceability of the measurement result against a primary standard.

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9 Expression of results

9.1 Radon activity concentration

The radon activity concentration shall be calculated as given in Formula (1):

$$C = (\mu - \mu_0) \cdot \omega \tag{1}$$

9.2 Standard uncertainty

In accordance with ISO/IEC Guide 98-3, the standard uncertainty of C shall be calculated as given in Formula (2):

$$u(C) = \sqrt{\omega^2 \cdot \left[u^2(\mu) + u^2(\mu_0) \right] + C^2 \cdot u_{\text{rel}}^2(\omega)} \tag{2}$$

9.3 Decision threshold and detection limit

The characteristic limits associated with the measurand shall be calculated in accordance with ISO 11929 (all parts). An example of the calculations of uncertainties and characteristic limits is detailed in Annex A for a specific measurement method.

9.4 Limits of the confidence interval

The lower, $C^{\triangleleft}$, and upper, $C^{\triangleright}$, limits of the confidence interval are calculated using Formulae (3) and (4) [see ISO 11929 (all parts)]:

$$C^{\triangleleft} = C - k_p \cdot u(C);\ p = \omega \cdot (1 - \gamma/2) \tag{3}$$

$$C^{\triangleright} = C + k_q \cdot u(C);\ q = 1 - \omega \cdot \gamma/2 \tag{4}$$

where

$\omega = \Phi[y/u(y)]$, Φ being the distribution function of the standardized normal distribution;

$\omega = 1$ may be set if $C \geq 4 \cdot u(C)$, in which case:

$$C^{\triangleleft\triangleright} = C \pm k_{1-\gamma/2} \cdot u(C) \tag{5}$$

$\gamma = 0{,}005$ with $k_{1-\gamma/2} = 1{,}96$ are often chosen by default.

10 Test report

10.1 The test report shall be in accordance with the requirements of ISO/IEC 17025 and shall contain the following information:

a) a reference to this document, i.e. ISO 11665-6:2020;

b) measurement method (spot);

c) identification of the sample;

d) sampling characteristic (active);

e) sampling time (date and hour);

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f) duration of sampling;

g) sampling location;

h) units in which the results are expressed;

i) test result, $C \pm u(C)$ or $C \pm U$, with the associated k value.

10.2 Complementary information can be provided such as the following:

a) purpose of the measurement;

b) probabilities α, β and $(1-\gamma)$;

c) the decision threshold and the detection limit; depending on the customer request, there are different ways to present the result:

   1) when the radon-222 activity concentration is compared with the decision threshold [see ISO 11929 (all parts)], the result of the measurement shall be expressed as $\leq C^*$ if the result is below the decision threshold;

   2) when the radon-222 activity concentration is compared with the detection limit, the result of the measurement shall be expressed as $\leq C^{\#}$ if the result is below the detection limit or, if the detection limit exceeds the guideline value, it shall be documented that the method is not suitable for the measurement purpose;

d) any relevant information likely to affect the results:

   1) weather conditions at the time of sampling;

   2) ventilation conditions for indoor measurement (mechanical ventilation system, doors and windows open or shut, etc.) prior to sampling (over a period of a few hours) and at the time of sampling.

10.3 The results can be expressed in a similar format to that shown in ISO 11665-1:2019, Annex C.

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Annex A
(informative)

Measurement method using scintillation cells

A.1 General

This annex deals with the scintillation cell method, which is one of several methods that meet the requirements of this document.

For the purpose of this annex, the symbols given in Clause 3 and following apply.

F_c calibration factor per alpha for counting carried out with a radioactive equilibrium between the radon and its short-lived decay products, in pulses per second per becquerel

f_d correction factor for the decay of radon in the detection volume, dimensionless

f_p correction factor for atmospheric pressure, dimensionless

N_s number of gross counts

N_0 number of background counts

$\bar{N}_s$ average number of gross counts

$\bar{N}_0$ average number of background counts

n number of countings of each sample

$n_\alpha(t)$ number of alpha emitters present in the cell per becquerel of radon after a waiting time between filling and counting the cell (n_α is approximately equal to 3 at a waiting time of 3 h for 1 Bq of radon)

p_v pressure measured in the cell once under vacuum, in hectopascals

p_r pressure measured in the cell after sampling, in hectopascals

t_c counting duration (common to N_s, N_0), in seconds

V_{sc} cell volume, in cubic metres

λ decay constant of radon-222, per second

Δt elapsed time between the end of the sampling ($t = 0$) and the cell counting, in seconds

A.2 Principle of the measurement method

Measurement of the radon activity concentration using scintillation cells is based on the following elements:

a) active air sampling by filling a scintillation cell in which a vacuum is created prior to use; sampling is carried out via suction in the cell through a filter placed in a filter holder;

b) waiting until a radioactive equilibrium between the ^{222}Rn and its short-lived decay products (^{214}Po, ^{218}Po) is achieved in the scintillation cell (the alpha particles produced by the disintegration of the

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radon and its short-lived decay products transfer their energy as they travel to the scintillation medium; by returning to their ground state, the electrons energized in the scintillation medium emit photons);

c) detecting the photons emitted in the scintillation cells using a photomultiplier, converting them into electric pulses that are counted by a counting chain;

d) determining the radon activity concentration from the number of gross counts, the number of background counts, the sample volume, the counting duration and the calibration factor.

A.3 Equipment

The apparatus shall include the following:

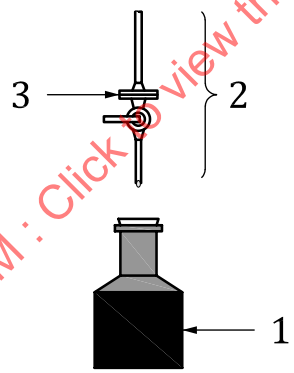
a) a device with a filtering medium placed in a filter holder for taking the air sample in the detection chamber (see Figure A.1);

b) a detection chamber made up of a scintillation cell used to take an air sample representative of the atmosphere under investigation; a scintillation cell is a hermetically-sealed glass flask with defined geometry and volume in which the internal surface, apart from the bottom, is covered in silver-activated zinc sulphide [ZnS(Ag)];

c) a device to create the vacuum in the cell;

d) a device to measure the pressure in the cell;

e) a counting chain equipped with a photomultiplier.



Key

1 scintillation cell
2 sampling device
3 filter

Figure A.1 — Example of a spot measuring system

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A.4 Sampling

A.4.1 Sampling characteristics

A vacuum shall be created in the scintillation cell prior to use.

For optimal filling of the cell, the residual pressure in the cell before sampling shall be controlled and shall be lower than 40 hPa. Once sampling is terminated, the pressure inside the cell shall be controlled and shall be equal to the atmospheric pressure.

Sampling shall be carried out via suction in the cell through a filter placed in a filter holder.

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A.4.2 Sampling conditions

The sampling duration, equal to the time required for the scintillation cell to be filled when it reaches the atmospheric pressure, shall be less than 1 h.

The volume of air sampled shall be determined by measuring the pressure in the cell after the vacuum is created and after the sampling is terminated.

In order to improve the accuracy of the measurement, two scintillation cells with identical characteristics may be used for sampling the air at the same place.

A.5 Measurement procedure

Measurement shall be carried out as follows.

a) Before using the cells, determine the background of each scintillation cell by counting the photons emitted before sampling for a suitable duration using a pre-calibrated photomultiplier placed in a lightproof enclosure.

b) Create a vacuum in the scintillation cells.

c) Measure the residual pressure in the cells and ensure the pressure stays below 40 hPa.

d) Select and locate the measuring place.

e) Take one or more air samples per sampling site using the scintillation cells.

f) Measure the pressure after filling the cells and ensure the pressure is equal to the atmospheric pressure.

g) Record the location and time (date and hour) of sampling.

h) Wait until a radioactive equilibrium between the ^{222}Rn and its short-lived decay products (^{214}Po, ^{218}Po) is achieved in the cell. For optimal counting, 3 h shall elapse after sampling in order to achieve radioactive equilibrium.

i) Count the number of photons emitted by the scintillation medium when excited by the alpha particles that are produced by the disintegration of the radon and its short-lived decay products present in the cells. A pre-calibrated photomultiplier placed in a lightproof enclosure shall be used for counting.

j) Determine the radon activity concentration by calculation.

It is assumed that the sample counting duration and the background counting duration are the same.

It is assumed that these counting durations are short compared with the radon half-life.

The accuracy sought shall dictate the counting duration and the number of countings for the sample.

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A.6 Expression of results

A.6.1 Radon activity concentration

The spot radon activity concentration, C, is obtained from Formula (1). This yields Formula (A.1):

$$C = \frac{(\bar{N}_s - \bar{N}_0)\cdot f_p}{t_c \cdot F_c \cdot n_\alpha(t)\cdot V_{sc}\cdot f_d} = (\bar{N}_s - \bar{N}_0)\cdot \omega \tag{A.1}$$

where

$$\bar{N}_s = \frac{\sum_{j=1}^{n} N_{s_j}}{n} \text{ and } \bar{N}_0 = \frac{\sum_{j=1}^{n} N_{0_j}}{n}$$

$$\omega = \frac{f_p}{t_c \cdot F_c \cdot n_\alpha(t)\cdot V_{sc}\cdot f_d} \tag{A.2}$$

where

$$f_p = \frac{p_r}{p_r - p_v} \tag{A.3}$$

$$f_d = \exp(-\lambda\cdot\Delta t) \tag{A.4}$$

In practice, f_p is close to 1 and, for an optimum count, the cell counting should be performed 3 h after sampling, at which time the radioactive equilibrium between radon and its decay products is achieved. Therefore, $n_\alpha(t)\cong 3$ and Formula (A.1) may be simplified.

A.6.2 Standard uncertainty

The standard uncertainty of C is obtained from Formula (2). This yields Formula (A.5):

$$u(C) = \sqrt{(\bar{N}_s + \bar{N}_0)\cdot\frac{\omega^2}{n} + C^2\cdot u_{rel}^2(\omega)} \tag{A.5}$$

The relative standard uncertainty of ω is calculated using Formula (A.6):

$$u_{rel}^2(\omega) = u_{rel}^2(F_c) + u_{rel}^2(V_{sc}) \tag{A.6}$$

where the uncertainties of the counting duration, the decay constant, the number of alpha emitters and the pressure are considered negligible.

Calculation of the characteristic limits [see ISO 11929 (all parts)] requires calculation of $\tilde{u}(\tilde{C})$, i.e. the standard uncertainty of C as a function of its true value, calculated as given in Formula (A.7):

$$\tilde{u}(\tilde{C}) = \sqrt{\left(\frac{\tilde{C}}{\omega} + 2\cdot\bar{N}_0\right)\cdot\frac{\omega^2}{n} + \tilde{C}^{\,2}\cdot u_{rel}^2(\omega)} \tag{A.7}$$

A.6.3 Decision threshold

The decision threshold, C^*, is obtained from Formula (A.7) for $\tilde{C} = 0$ [see ISO 11929 (all parts).

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