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

Part 4:
Integrated measurement method for determining average activity concentration using passive sampling and delayed analysis

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

Partie 4: Méthode de mesure intégrée pour la détermination de l'activité volumique moyenne du radon avec un prélèvement passif et une analyse en différé

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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 11665-4:2012), 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.

Introduction

Radon isotopes 222, 219 and 220 (also known as thoron) 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 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 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·m^{-3} is recommended by the World Health Organization[5]. Wherever this is not possible, this reference level should not exceed 300 Bq·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·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 integrated measurement techniques with passive sampling.

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.

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

Part 4: Integrated measurement method for determining average activity concentration using passive sampling and delayed analysis

1 Scope

This document describes radon-222 integrated measurement techniques with passive sampling. It gives indications for determining the average activity concentration of the radon-222 in the air from measurements based on easy-to-use and low-cost passive sampling, and the conditions of use for the sensors.

This document covers samples taken without interruption over periods varying from a few days to one year.

This measurement method is applicable to air samples with radon activity concentrations greater than 5 Bq/m^3.

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 coverage 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

— 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.

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

4 Principle

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

a) continuous, passive sampling of an air sample representative of the atmosphere under investigation, by free convection and natural diffusion for a sensor in an open configuration (open to the air) or by natural diffusion for a sensor in a closed configuration (with an accumulation chamber);

b) simultaneous accumulation of a measurable physical quantity (etched tracks, electrostatic potential drop, radioactive atoms, etc.) on a suitable sensor;

c) measurement of the accumulated physical quantity with a direct link to the average radon activity concentration over the sampling period in question.

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

— "latent tracks" produced in a polymer [solid-state nuclear track detector (SSNTD)] by ionization from alpha particles of the radon and its decay products; these latent tracks are detected and counted (see Annex A);

— charges produced in a solid [semi-conductor medium (silicon)] by ionisation from alpha particles of the radon and its decay products; they are detected by related electronics;

— discharge of an electret (non-rechargeable, positively charged element) by ionisation of the air due to the radioactive disintegration of radon and its decay products; the voltage variation relating to this discharge is measured (see Annex B);

— atoms of ^{222}Rn adsorbed on charcoal; the gamma emission rates of the decay products ^{214}Pb and ^{214}Bi are measured with a gamma spectrometer (see Annex C).

Analysis of the physical quantity might not be immediate and might require laboratory operations.

The result of integrated measurement is the exposure of a sensor to radon over the sampling duration in question. The average radon activity concentration is calculated by dividing the exposure result by the sampling duration.

5 Equipment

The apparatus shall include the following:

a) a sensor which collects the physical quantity (SSNTD, silicon detector, electret detector, activated charcoal, etc.), either alone or with an accumulation chamber made from a conductive plastic material with a known detection volume; in closed configuration, the sensor is placed in a closed accumulation chamber with a filter and in open configuration, the sensor is in direct relation with the atmosphere (no accumulation chamber);

b) a detection system adapted to the accumulated physical quantity.

The necessary equipment for each measurement method is specified in Annexes A, B and C respectively.

6 Sampling

6.1 Sampling objective

The sampling objective is to place the sensor (SSNTD, silicon detector, electret detector, activated charcoal, etc.), within the normal occupied space of the atmospheric medium under investigation.

6.2 Sampling characteristics

Sampling is passive.

In the closed configuration, sampling is performed through a filtering medium, thus only radon alpha particles are detected by the sensor (see Clause 5). Sampling shall be performed in conditions that preclude clogging of the filtering medium, which would result in modified measuring conditions. Clogging during sampling can lead to the non-renewal of air in the accumulation chamber.

Using an open configuration, the sensor simultaneously records the alpha emissions of the radon and those of its decay products near its surface. It also records any alpha emitter present in the analysed atmosphere, in the energy range specified by the manufacturer. This configuration shall be used under conditions that preclude fouling (dust-filled atmosphere, grease deposit, etc.) of the sensor, which would result in modified measuring conditions.

6.3 Sampling conditions

6.3.1 General

Sampling shall be carried out as specified in ISO 11665-1.

6.3.2 Installation of the sensor

Installation of the sensor shall be carried out as specified in ISO 11665-1.

In the specific case of indoor measurement, the sensor should be placed in a normally occupied or occupiable zone on a clear surface between 1 m and 2 m above the ground, i.e. the "breathing zone" under the following conditions:

a) a clear space of at least 20 cm should be left around the sensor to avoid the influence of thoron exhalation from the walls;

b) the sensor should be placed away from any heat sources (radiator, chimney, electrical equipment, television, direct sunlight, etc.) and from areas of traffic, doors and windows, walls and natural ventilation sources;

c) the installation conditions should not be disturbed during measurement (books falling, engineers working, curiosity, etc.); recommendations should be made to occupants in order to prevent the change of sampling conditions;

d) the sensor should also be made secure during measurement, in order to prevent any damage.

6.3.3 Sampling duration

The sampling duration is equal to the time interval between installation and removal of the sensor at the sampling point.

Time of installation and removal of the sensor shall be recorded (date and hour).

The sampling duration shall be adjusted to suit the phenomenon under investigation, the assumed radioactivity and the sensor characteristics (see Table 1).

Table 1 — Examples of sampling characteristics of the various measurement methods meeting the requirements of this document

Sensor	Annex (normative)	Sampling place	Sampling duration/ Exposure time
Solid-state nuclear track detector (open configuration)	A	Indoors	One week to several months
Solid-state nuclear track detector (closed configuration)		Outdoors or indoors	
Electret detector	B		Few days to several months
Activated charcoal	C		Few days

The sampling duration shall be determined on the basis of the intended use of the measurement results.

For example, indoor concentrations vary not only over a day but also between days of the week because of variations in occupancy. In this case, it would be reasonable to sample over a whole week in order to include these variations.

To approach the annual average value of the radon activity concentration in the buildings and not under-estimate it, it is advisable to perform measurements for at least two months (see ISO 11665-8).

Users should be aware of the saturation characteristics of their sensors and should adapt the sampling duration to ensure that saturation does not occur.

6.3.4 Volume of air sampled

For passive sampling, direct measurement of the air volume sampled is not necessary. A calibration factor, in activity per unit volume, shall be used.

7 Detection

Depending on the sensor used, detection shall be carried out using solid-state nuclear track detectors (SSNTD), discharge of a polarized surface inside an ionization chamber, gamma-ray spectrometry or liquid scintillation, as described in ISO 11665-1.

8 Measurement

8.1 Procedure

The measurement procedure for each measurement method shall be as specified in Annexes A, B and C respectively.

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 influence quantities of particular importance for each measurement method described in this document are specified in Annexes A, B and C respectively.

Manufacturer recommendations in the operating instructions for the sensors shall be followed.

8.3 Calibration

The measuring system (sensor and detection system) shall be calibrated annually as specified in ISO 11665-1. Additional requirements for the devices used for particular methods are specified in the relevant annexes (see Annexes A, B and C).

The relationship between the physical quantity recorded by the sensor (number of etched tracks, number of electric charges, pulse count and amplitudes, etc.) and the activity concentration of the radon in the air 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.

In addition to calibration, consideration should be given to regular testing to ensure measurements remain suitable for use. These should include internal blind tests and external proficiency, validation or interlaboratory comparisons.

9 Expression of results

9.1 Average radon activity concentration

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

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

9.2 Standard uncertainty

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

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

9.3 Decision threshold and detection limit

The characteristic limits associated with the measurand shall be calculated in accordance with ISO 11929 (all parts). Examples of the calculations of uncertainties and characteristic limits are detailed in Annexes A, B and C for each respective measurement method described.

9.4 Limits of the confidence interval

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

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

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

where

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

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

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

$\gamma = 0{,}05$ 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) reference to this document, i.e. ISO 11665-4:2020;

b) measurement method (integrated);

c) identification of the type of sensor;

d) identification of the sample;

e) sampling characteristic (passive);

f) sampling times: start and end time (date and hour);

g) duration of sampling;

h) sampling location;

i) units in which the results are expressed;

j) test result, $\bar{C} \pm u(\bar{C})$ or $\bar{C} \pm U$, with the associated k value.

10.2 Complementary information may be provided, such as the following:

a) purpose of the measurement;

b) probabilities α, β and (1-γ);