BS EN ISO 11665-5:2015

BSI Standards Publication

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

Part 5: Continuous measurement method of the activity concentration

National foreword

This British Standard is the UK implementation of EN ISO 11665-5:2015. It is identical to ISO 11665-5:2012. It supersedes BS ISO 11665-5:2012 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee NCE/2, Radiation protection and measurement.

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Measurement of radioactivity in the environment -Air: radon-222 - Part 5: Continuous measurement method of the activity concentration (ISO 11665-5:2012)

Mesurage de la radioactivité dans l'environnement - Air: radon 222 - Partie 5: Méthode de mesure en continu de l'activité volumique (ISO 11665-5:2012)

Ermittlung der Radioaktivität in der Umwelt - Luft: Radon-222 - Teil 5: Kontinuierliches Messverfahren für die Aktivitätskonzentration (ISO 11665-5:2012)

This European Standard was approved by CEN on 12 June 2015.

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European foreword

The text of ISO 11665-5:2012 has been prepared by Technical Committee ISO/TC 85 “Nuclear energy, nuclear technologies, and radiological protection” of the International Organization for Standardization (ISO) and has been taken over as EN ISO 11665-5:2015 by Technical Committee CEN/TC 430 “Nuclear energy, nuclear technologies, and radiological protection” the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2016, and conflicting national standards shall be withdrawn at the latest by March 2016.

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Endorsement notice

The text of ISO 11665-5:2012 has been approved by CEN as EN ISO 11665-5:2015 without any modification.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 11665-5 was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiological protection*.

ISO 11665 consists of the following parts, under the general title *Measurement of radioactivity in the environment — Air: radon-222*:

— *Part 1: Origins of radon and its short-lived decay products and associated measurement methods*

— *Part 2: Integrated measurement method for determining average potential alpha energy concentration of its short-lived decay products*

— *Part 3: Spot measurement method of the potential alpha energy concentration of its short-lived decay products*

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

— *Part 5: Continuous measurement method of the activity concentration*

— *Part 6: Spot measurement method of the activity concentration*

— *Part 7: Accumulation method for estimating surface exhalation rate*

— *Part 8: Methodologies for initial and additional investigations in buildings*

The following parts are under preparation:

— *Part 9: Method for determining exhalation rate of dense building materials*

— *Part 10: Determination of diffusion coefficient in waterproof materials using activity concentration measurement*

Introduction

Radon isotopes 222, 220 and 219 are radioactive gases produced by the disintegration of radium isotopes 226, 224 and 223, which are decay products of uranium-238, thorium-232 and uranium-235 respectively, and are all found in the earth's crust. 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.

Radon is today considered to be the main source of human exposure to natural radiation. The UNSCEAR (2006) report[2] 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. For this reason, references to radon in this part of of ISO 11665 refer only to radon-222.

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

The values commonly found in the continental environment are usually between a few becquerels per cubic metre and several thousand becquerels per cubic metre. Activity concentrations of one becquerel per cubic metre or less can be observed in the oceanic environment. Radon activity concentrations inside houses can vary from several tens of becquerels per cubic metre to several hundreds of becquerels per cubic metre[3]. Activity concentrations can reach several thousands of becquerels per cubic metre in very confined spaces.

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 part of ISO 11665 deals with continuous measurement methods for radon-222.

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 5:
Continuous measurement method of the activity concentration

1 Scope

This part of ISO 11665 describes continuous measurement methods for radon-222. It gives indications for continuous measuring of the temporal variations of radon activity concentration in open or confined atmospheres.

This part of ISO 11665 is intended for assessing temporal changes in radon activity concentration in the environment, in public buildings, in homes and in work places, as a function of influence quantities such as ventilation and/or meteorological conditions.

The measurement method described is applicable to air samples with radon activity concentration greater than 5 Bq/m^3.

2 Normative references

The following referenced documents are indispensable for the application 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, *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 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*

IEC 61577-2, *Radiation protection instrumentation — Radon and radon decay product measuring instruments — Part 2: Specific requirements for radon measuring instruments*

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.

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
$u_{\mathrm{rel}}(\ )$	relative standard uncertainty
μ	quantity to be measured
μ_0	background level
ω	correction factor linked to the calibration factor and climatic correction factors

4 Principle

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

a) continuous in situ sampling of a volume of air previously filtered and representative of the atmosphere under investigation;

b) continuous detection of radiations emitted by radon and its decay products accumulated in the detection chamber.

Several measurement methods meet the requirements of this part of ISO 11665. They are basically distinguished by the type of physical quantity and how it is detected. The physical quantity and its related detection may be as follows, for example:

- ionization current produced by several tens of thousands of ion pairs created by each alpha particle emitted by the radon that is present in the detection chamber and its decay products formed therein (see Annex A);
- charges produced in a solid [semi-conductor medium (silicon)] by ionization from alpha particles of radon and its decay products; the charges are detected by related electronics.

Measurement results are instantly available. A mean or integrated value can be obtained through appropriate processing based on an integration interval compatible with the phenomenon studied but in all cases less than or equal to one hour.

In order to monitor the temporal variation of radon activity concentration, the measurement period must be compatible with the dynamics of the phenomenon studied. For example, the minimum significant period for detecting daily variations is approximately one week.

Continuous monitoring allows for the assessment of temporal changes in radon activity concentration. For measurements performed outdoors, the season and climatic conditions shall be taken into account.

For measurements performed inside a building, the lifestyles of its inhabitants, the level at which the measurement place is located (basement, ground floor, upper levels) and the natural ventilation characteristics (condition of doors and windows, open or closed) shall be taken into account.

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, a device to pump the air for sampling if active sampling is necessary, and the detection chamber;

b) a measuring system adapted to the physical quantity to be measured.

The instrument used for measurement shall satisfy the requirements of IEC 61577-2.

An example of the equipment (ionization chamber) for a specific measurement method is given in Annex A.

6 Sampling

6.1 Sampling objective

The sampling objective is to place an air sample representative of the atmosphere under investigation in continuous contact with the detector.

6.2 Sampling characteristics

Sampling may be passive (natural diffusion) or active (pumping).

Sampling shall be performed through a filtering medium which prevents access of aerosol particles present in the air at the time of sampling, especially radon decay products.

The filter shall not trap radon gas.

The sampling system shall be used under conditions that do not cause clogging of the filter (this would result in a modification of the measurement conditions, e.g. decrease of gas quantity sampled due to pressure drop in measurement chamber).

In case of clogging during sampling by pumping, the pressure drop might increase, leading to a degradation in the performance of the measurement system, and possibly resulting in the perforation of the filter.

Clogging during sampling by natural diffusion can lead to the non-renewal of air in the detection chamber.

6.3 Sampling conditions

6.3.1 General

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

6.3.2 Installation of sampling device

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

6.3.3 Sampling duration

For continuous sampling, the sampling duration corresponds to the measurement period, which shall be compatible with the dynamics of the phenomenon studied.

6.3.4 Integration interval

The integration interval determines the time resolution of the measurement. Different parameters such as the expected radon activity concentration or dynamics of radon level changes need to be taken into account when selecting the appropriate integration interval.

6.3.5 Volume of air sampled

For active sampling, the volume of air sampled shall be measured by a flow-meter corrected for the temperature and pressure variation (expressed in cubic metres at a standard pressure and temperature of 1,013 hPa and 0 °C respectively).

For passive sampling, direct measurement of the air volume sampled is not necessary; a calibration factor (activity per unit volume) shall be used.

7 Detection

Detection shall be carried out using a suitable method as outlined in ISO 11665-1.

8 Measurement

8.1 Procedure

The measurement procedure is specific to the detection method used.

An example of a measurement procedure using an ionization chamber is given 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) temperature, humidity and atmospheric turbulence; these variables are taken into account when choosing a location for the device;

b) background radiation;

c) instrumental background noise;

d) electromagnetic field;

e) increase in pressure drop due to clogging of the intake filter;

f) possible presence of other alpha emitters (radium, radon isotopes, actinides, etc.) in the detection volume; if the presence of other radon isotopes is suspected, it shall be ruled out using an appropriate system, e.g. ageing chamber;

g) possible presence of other gamma emitters in the detection volume.

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

8.3 Calibration

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

The relationship between the physical parameter measured by the detection device (number of electric charges, count rate, 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.

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

9 Expression of results

9.1 Radon activity concentration

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

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

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):

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

9.3 Decision threshold and detection limit

The characteristic limits associated with the measurand shall be calculated in accordance with ISO 11929. An example of the calculations of uncertainties and characteristic limits is given 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 shall be calculated using Formulae (3) and (4) (see ISO 11929):

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

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

where

$\omega = \Phi\left[y/u(y)\right]$, 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:

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

$\gamma = 0{,}05$ 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 part of ISO 11665, i.e. ISO 11665-5:2012;

b) measurement method (continuous);

c) sampling characteristic (passive or active);

d) sampling time (date and hour);

e) duration of sampling;

f) sampling location;

g) units in which the results are expressed;

h) test result, $C \pm u(C)$ or $C \pm U$, 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 $(1-\gamma)$;

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), 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 11665-1:2012, Annex C.

Annex A
(informative)

Measurement method using a vented ionization chamber and a current ionization chamber

A.1 General

This annex deals with an ionization chamber method, which is one of several methods meeting the requirements of this part of ISO 11665. The vented and current ionization chambers are intended to operate at atmospheric pressure.

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

$\bar{E}$	mean energy released by the radiation in the air of the chamber for a temperature T (K) and pressure p (hPa), in joules
e	electron charge, in coulombs ($e = 1{,}602 \times 10^{-19}$ C)
F_{c}	calibration factor, in becquerels per cubic metre per ampere
f_{p}	correction factor for atmospheric pressure, dimensionless
f_{T}	correction factor for temperature, dimensionless
I	ionization current due to radon, in amperes
I_{g}	ionization current for the vented ionization chamber, in amperes
I_{γ}	ionization current due to gamma radiations, in amperes
I_0	background ionization current, in amperes
p_{e}	atmospheric pressure when calibrating the chamber, in hectopascals
p_{m}	atmospheric pressure when operating the chamber, in hectopascals
T_{e}	temperature of the air when calibrating the chamber, in kelvins
T_{m}	temperature of the air when operating the chamber, in kelvins
V_{ch}	volume of air present in the chamber, in cubic metres
ω_{air}	mean energy expended to produce an ion pair in the air of the chamber, in joules

A.2 Principle of the measurement method

The continuous measurement of radon activity concentration using a current ionization chamber is based on the following elements.

a) Active air sampling with a sampling pump: Sampling is carried out continuously through filters to prevent the radon decay products from entering the ionization chamber and using an ageing chamber to eliminate the interference of the radon-220 isotope.

b) Circulating the air sample in the measurement ionization chamber at known pressure and temperature, between two electrodes with different voltages: The presence of radon gas in the detection volume of the ionization chamber causes the emission of 5,5 MeV alpha particles, among others. As they travel in the air contained in the detection volume, these particles release all or part of their energy. The released energy is converted into ion pairs (positive and negative charges), with each 5,5 MeV alpha particle contributing to the formation of approximately $1,6 \times 10^5$ ion pairs in the air. Each ion type is then collected by the corresponding electrode.

c) Measuring the electric current (ionization current) produced by the collection of the ions formed in the detection volume of the ionization chamber.

d) Determining the contribution of the ambient ionizing radiation, particularly gamma radiation, to the measured electric current: The influence of gamma radiation on the radon measurements is determined using a closed compensation chamber in conjunction with the measurement chamber. The response of the closed chamber is only proportional to the ambient gamma radiation. The response to a gamma dose rate from a 10 l metallic chamber is 10^{-16} A/nGy/h (in France, for example, the dose rate varies from 30 nGy/h to 230 nGy/h[6]).

e) Determination of the activity concentration from the measured ionization current corrected from the gamma radiation contribution: The ionization current delivered by the vented ionization chamber is proportional to

   1) the number of radon atoms present in the detection chamber in which the sampled air circulates,

   2) the mean energy released in the air of the chamber by the radiation resulting from alpha disintegrations, and

   3) the mean ionization energy of the air in the chamber.

NOTE The mean ionization energy in the air varies little with the gas medium characteristics and incident particle type and energy (see Table A.1). The typical value is approximately 35 eV[5]. A beta or gamma particle emitted by radionuclides other than radon and its decay products present in the detection volume can disturb the measurements by creating $0,05 \times 10^5$ to $0,15 \times 10^5$ ion pairs.

Table A.1 — Response of a 10 l ionization chamber to various radionuclides as compared to radon[1][5]

Radionuclide	^{3}H	^{14}C	^{41}Ar	^{85}Kr	^{133}Xe	^{222}Rn
Mean energy of incident particles, keV	5,7	49,4	464	251	101	5 500
Response as compared to ^{222}Rn, %	0,1	0,9	8,4	4,5	1,8	100

A.3 Equipment

The apparatus shall include the following elements (see Figure A.1).

a) A sampling system including a sampling head, intake pre-filter and air dehydrator. In cases where significant concentrations of suspended particles are to be expected, a pre-filter shall be placed in or immediately after the sampling head. The pre-filter shall be made of a material with good resistance to humidity and a very low pressure drop, and it shall not trap radon.

b) An ageing chamber, in case of interference from the radon-220 isotope. To eliminate radon-220, the residence time of the air in the ageing chamber shall be at least equal to five times the radioactive half-life of radon-220.

c) A filter with a low pressure drop at the inlet of the detection volume. This filter is intended to trap all solid radon decay products contained in the sampled air immediately prior to analysis. It shall be placed as close as possible to the ionization chamber. Since the size of the aerosol particles carrying the solid radon decay products is generally less than 1 µm, the filter shall be of absolute filter class.

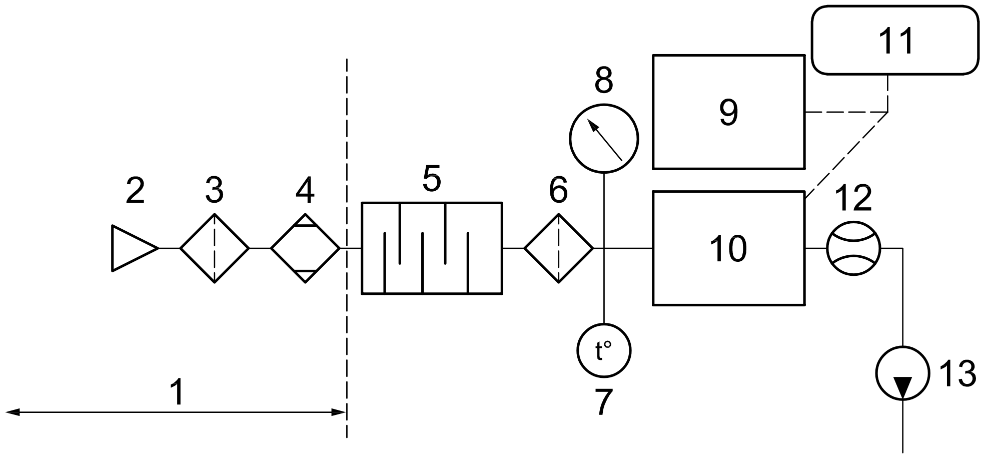
d) A vented ionization chamber constituting the detection volume (measurement chamber). It consists of a metallic enclosure whose detection volume can range from a few cubic centimetres to several tens of litres.

e) A closed ionization chamber used to compensate for ambient gamma radiation (compensation chamber). The compensation chamber shall have characteristics identical to those of the measurement chamber with which it is used.

f) Appropriate electronics, which shall allow direct measurement of very weak ionization currents (approximately 10^{-12} A to 10^{-15} A).

g) An air pump with operating characteristics appropriate for the volume of the ionization chamber (flow-rate that ensures sufficient air renewal within the detection volume). The air pump shall be installed upstream or downstream of the measurement chamber.

h) In certain cases: flow-rate, pressure and temperature detectors.



Key

1	sampling system
2	sampling head
3	pre-filter
4	air dehydrator
5	ageing chamber
6	decay product filter
7	thermometer
8	manometer
9	closed ionization chamber
10	vented ionization chamber
11	associated electronics
12	flow-meter
13	pump

The volume of the ionization chamber and associated electronics shall be compatible with the expected range of radon activity concentration.

Figure A.1 — Basic diagram of a radon activity concentration measurement system with vented and current ionization chambers (pump installed downstream)

A.4 Sampling

The sampling conditions shall be in accordance with Clause 6.

If sampling is performed outdoors, the sampling head shall include a weather shelter device (see ISO 11665-1).

The pre-filter and the filter shall be replaced regularly, especially if they show signs of clogging.

Active sampling shall be carried out continuously with a sampling pump whose characteristics are compatible with the volume of the ionization chamber. It is recommended that the air in the detection volume be renewed one to three times per minute. For a 10 l ionization chamber, a sampling rate of 20 l/min represents a good compromise. The pump can be installed upstream or downstream of the ionization chamber. Its operation shall not pollute the latter.

The pressure deviation between the ionization chamber and the sampling place shall be kept within an acceptable range (±50 hPa) in order to ensure measurement accuracy and system integrity. This pressure deviation is verified by monitoring the pressure drop at the filter boundaries (where Δp_{min} = pierced filter and Δp_{max} = clogged filter).

The system must be leak tight to ensure that radon measurements are only carried out in the air sampled through the sampling head.

A.5 Influence quantities

Besides the influence quantities specified in 8.2, the following shall be taken into account.

a) The two ionization chambers shall be placed in an identical and homogeneous radiation field. The presence of a source of radioactivity near either chamber shall be avoided as far as possible.

b) The air to be monitored shall have a relative humidity of less than 80 %. If the humidity conditions of the sampled air are incompatible with the proper operation of the ionization chamber, the relative humidity should be reduced (for example, by increasing the air temperature in the detection chamber). Nevertheless, the temperature of the ionization chamber shall remain below 60 °C.

c) During measurement, if temperature and pressure deviations exceed ±20 °C and ±50 hPa, respectively, a correction shall be made.

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

A.6 Expression of results

A.6.1 Radon activity concentration

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

$$C = \left(I - I_0\right) \cdot \omega \quad \text{with} \quad \omega = F_{\text{c}} \cdot f_{\text{p}} \cdot f_{\text{T}} \quad \text{and} \quad I = I_{\text{g}} - I_{\gamma} \tag{A.1}$$

where

$$F_{\text{c}} = \frac{1}{V_{\text{ch}}} \cdot \frac{\omega_{\text{air}}}{\bar{E} \cdot e} \tag{A.2}$$

$$f_{\text{p}} = \frac{p_{\text{e}}}{p_{\text{m}}} \tag{A.3}$$

$$f_{\text{T}} = \frac{T_{\text{m}}}{T_{\text{e}}} \tag{A.4}$$

In practice, it is possible that the measured temperature, T_{m}, and pressure, p_{m}, will not differ significantly from the calibration values, T_{e} and p_{e}. In this case, 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):

$$u(C)=\sqrt{\omega^2\cdot\left[u^2\left(I_\mathrm{g}\right)+u^2\left(I_0\right)+u^2\left(I_\gamma\right)\right]+C^2\cdot u_\mathrm{rel}^2(\omega)}=\sqrt{\omega^2\cdot k_I\cdot\left(I_\mathrm{g}+I_0+I_\gamma\right)+C^2\cdot u_\mathrm{rel}^2(\omega)} \tag{A.5}$$

where

$$u_\mathrm{rel}^2(\omega)=u_\mathrm{rel}^2\left(F_\mathrm{c}\right)+u_\mathrm{rel}^2\left(f_\mathrm{P}\right)+u_\mathrm{rel}^2\left(f_\mathrm{T}\right) \tag{A.6}$$

the uncertainty of the calibration temperature, T_e, and the calibration pressure, p_e, are considered negligible;

$$u^2\left(I_\mathrm{g}\right)=k_I\cdot I_\mathrm{g} \tag{A.7}$$

$$u^2\left(I_0\right)=k_I\cdot I_0 \tag{A.8}$$

$$u^2\left(I_\gamma\right)=k_I\cdot I_\gamma \tag{A.9}$$

k_I is a constant provided by the manufacturer.

In Formula (A.5), the uncertainties of the values associated with the instrumentation (temperature and pressure sensors, etc.) are known.

For the calculation of the characteristic limits in accordance with ISO 11929, $\tilde{u}(\tilde{C})$ is required, i.e. the standard uncertainty of C as a function of its true value, calculated using Formula (A.10):

$$\tilde{u}(\tilde{C})=\sqrt{\omega^2\cdot\left[k_I\cdot\left(\frac{\tilde{C}}{\omega}+2\cdot I_0+I_\mathrm{c}\right)\right]+\tilde{C}^2\cdot u_\mathrm{rel}^2(\omega)} \tag{A.10}$$

A.6.3 Decision threshold

The decision threshold, C^*, is obtained from Formula (A.10) for $\tilde{C}=0$ (see ISO 11929).

This yields Formula (A.11):

$$C^*=k_{1-\alpha}\cdot\tilde{u}(0)=k_{1-\alpha}\cdot\sqrt{\omega^2\cdot k_I\cdot\left(2\cdot I_0+I_\mathrm{c}\right)}=k_{1-\alpha}\cdot\omega\cdot\sqrt{k_I\cdot\left(2\cdot I_0+I_\mathrm{c}\right)} \tag{A.11}$$

$\alpha = 0{,}05$ with $k_{1-\alpha} = 1{,}65$ is often chosen by default.

A.6.4 Detection limit

The detection limit, $C^\#$, is calculated as given in Formula (A.12) (see ISO 11929):

$$\begin{aligned}C^\#&=C^*+k_{1-\beta}\cdot\tilde{u}\left(C^\#\right)\\&=C^*+k_{1-\beta}\cdot\sqrt{\omega^2\cdot\left[k_I\cdot\left(\frac{C^\#}{\omega}+2\cdot I_0+I_\gamma\right)\right]+C^{\#^2}\cdot u_\mathrm{rel}^2(\omega)}\end{aligned} \tag{A.12}$$

$\beta = 0{,}05$ with $k_{1-\beta} = 1{,}65$ is often chosen by default.

The detection limit can be calculated by solving Formula (A.12) for $C^\#$ or, more simply, by iteration with a starting approximation $C^\#=2\cdot C^*$ in terms of the right side of Formula (A.12).

One obtains $C^{\#}$ with $k_{1-\alpha} = k_{1-\beta} = k$:

$$C^{\#} = \frac{2 \cdot C^{*} + k^{2} \cdot \omega \cdot k_{I}}{1 - k^{2} \cdot u_{\text{rel}}^{2}(\omega)} \tag{A.13}$$

Values $\alpha = \beta = 0{,}05$ and therefore $k_{1-\alpha} = k_{1-\beta} = 1{,}65$ are often chosen by default.

Bibliography

[1] Nuclear Data Base issued from the Decay Data Evaluation Project. Available at: http://www.nucleide.org/DDEP_WG/DDEPdata.htm

[2] UNSCEAR 2006 Report: *Effects of ionizing radiation* (Vol. 1, report to the General Assembly and two scientific annexes). United Nations Publication, New York, 2008

[3] Institut de Protection et de Sûreté Nucléaire — Direction Générale de la Santé. Campagne nationale de mesure de l'exposition domestique au radon. Bilan et représentation cartographique des mesures au 1 Janvier 2000

[4] NEUILLY M. *Modélisation et estimation des erreurs de mesure. Technique et documentation*. CETAMA, Éditions Lavoisier, Paris, 1993

[5] ICRU 31, *Average energy required to produce an ion pair*. International Commission on Radiation, Units and Measurements, 1979

[6] *Bilan de l'état radiologique de l'environnement français en 2007. Synthèse des résultats des réseaux de surveillance de l'IRSN*. Report DEI/SESURE-2008-48, 2008

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

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