



BSI Standards Publication

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

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

### National foreword

This British Standard is the UK implementation of EN ISO 11665-2:2015. It is identical to ISO 11665-2:2012. It supersedes BS ISO 11665-2:2012 which is withdrawn.

BSI, as a member of CEN, is obliged to publish EN ISO 11665-2 as a British Standard. However, attention is drawn to the fact that the UK committee voted against its approval as a European Standard.

This was due to the fact that the instructions in Subclauses 5.1, 5.2 and 5.3, on how to design a device to measure the average potential alpha energy concentration of radon short-lived decay products, were considered to be too prescriptive. It is the opinion of the UK committee that the proposed standard restricts the laboratories to only one set-up, and the same results could be achieved using alternative set-ups.

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

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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### Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 July 2012.

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31 October 2015	This corrigendum renumbers BS ISO 11665-2:2012 as BS EN ISO 11665-2:2015

EUROPEAN STANDARD

**EN ISO 11665-2**

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English Version

**Measurement of radioactivity in the environment - Air:  
radon-222 - Part 2: Integrated measurement method for  
determining average potential alpha energy concentration  
of its short-lived decay products (ISO 11665-2:2012)**

Mesurage de la radioactivité dans l'environnement -  
Air: radon 222 - Partie 2: Méthode de mesure intégrée  
pour la détermination de l'énergie alpha potentielle  
volumique moyenne de ses descendants à vie courte  
(ISO 11665-2:2012)

Ermittlung der Radioaktivität in der Umwelt - Luft:  
Radon-222 - Teil 2: Integrierendes Messverfahren für  
die Bestimmung des Durchschnittswertes der  
potenziellen Alpha-Energiekonzentration der  
kurzlebigen Radon-Folgeprodukte (ISO 11665-2:2012)

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

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

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**CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels**

## European foreword

The text of ISO 11665-2:2012 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 11665-2:2015 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

### Endorsement notice

The text of ISO 11665-2:2012 has been approved by CEN as EN ISO 11665-2:2015 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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 11665-2 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<sup>[1]</sup>.

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<sup>[2]</sup> 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 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 areas where individuals are exposed.

Variations of a few nanojoules per cubic metre to several thousand nanojoules per cubic metre are observed in the potential alpha energy concentration of short-lived radon decay products.

The potential alpha energy concentration of short-lived radon-222 decay products in the atmosphere can be measured by spot and integrated measurement methods (see ISO 11665-1). This part of ISO 11665 deals with integrated measurement methods. Integrated measuring methods are applicable in assessing human exposure to radiation<sup>[3]</sup>.

**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 2:

# Integrated measurement method for determining average potential alpha energy concentration of its short-lived decay products

## 1 Scope

This part of ISO 11665 describes integrated measurement methods for short-lived radon-222 decay products<sup>[4]</sup>. It gives indications for measuring the average potential alpha energy concentration of short-lived radon-222 decay products in the air and the conditions of use for the measuring devices.

This part of ISO 11665 covers samples taken over periods varying from a few weeks to one year. This part of ISO 11665 is not applicable to systems with a maximum sampling duration of less than one week.

The measurement method described is applicable to air samples with potential alpha energy concentration of short-lived radon-222 decay products greater than 10 nJ/m<sup>3</sup> and lower than 1 000 nJ/m<sup>3</sup>.

NOTE For informative purposes only, this document also addresses the case of radon-220 decay products, given the similarity in behaviour of the radon isotopes 222 and 220.

## 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/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 61577-3, *Radiation protection instrumentation — Radon and radon decay product measuring instruments — Part 3: Specific requirements for radon decay product 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.

$a$	attenuation coefficient relating to the $^{222}\text{Rn}$ found in the collimators corresponding to the range $P_1$ (established theoretically and provided by the manufacturer)
$b$	attenuation coefficient relating to the $^{222}\text{Rn}$ found in the collimators corresponding to the range $P_2$ (established theoretically and provided by the manufacturer)
$E_{\text{AE},i}$	alpha particle energy produced by the disintegration of the nuclide $i$ , in joules
$\bar{E}_{\text{PAEC},i}$	average potential alpha energy concentration of the nuclide $i$ , in joules per cubic metre
$\bar{E}_{\text{PAEC},i}^*$	decision threshold of the average potential alpha energy concentration of the nuclide $i$ , in joules per cubic metre
$\bar{E}_{\text{PAEC},i}^\#$	detection limit of the average potential alpha energy concentration of the nuclide $i$ , in joules per cubic metre
$\bar{E}_{\text{PAEC},i}^{\triangleleft}$	lower limit of the confidence interval of the average potential alpha energy concentration of the nuclide $i$ , in joules per cubic metre
$\bar{E}_{\text{PAEC},i}^{\triangleright}$	upper limit of the confidence interval of the average potential alpha energy concentration of the nuclide $i$ , in joules per cubic metre
$n$	counting number of each range $P_i$
$P_i$	range recording alpha particles for $i = 1, 2, 3, 4$
$R_{P_i,j}$	$j^{\text{th}}$ number of net count of range $P_i$ with deduced background for $i = 1, 2, 3, 4$
$\bar{R}_{P_i}$	mean number of net count of range $P_i$ with deduced background for $i = 1, 2, 3, 4$
$\bar{R}_0$	mean number of count due to background
$r$	ratio between the number of alpha particles emitted by $^{212}\text{Bi}$ ( $\alpha$ emitter at 36 %) and the number of alpha particles emitted by $^{212}\text{Po}$ (produced by $\beta$ disintegration at 64 % of $^{212}\text{Bi}$ ); 0,56
$U$	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
$V$	sampled volume, in cubic metres
$\varepsilon_{\text{gd}}$	geometric detection efficiency (established theoretically), i.e. the ratio between the number of tracks counted and the number of alpha particles emitted by the deposit collected on the filter
$\varepsilon_{\text{hc}}$	collection efficiency (established experimentally), i.e. the ratio between the number of atoms of short-lived decay products collected per unit of sampled volume of air and the number of atoms per unit of volume of air present in the detection system environment

## 4 Principle of the measurement method

Integrated measurement of potential alpha energy concentration of short-lived radon decay products is based on the following elements:

- a) continuous sampling of short-lived radon decay products contained in an air volume representative of the atmosphere under investigation, using a high-efficiency filtering membrane;
- b) counting, and discriminating over four energy ranges, the alpha particles emitted by the collected short-lived radon-222 decay products (alpha particles with an energy  $E_{AE,218Po}$  and  $E_{AE,214Po}$  produced by the disintegration of  $^{218}Po$  and  $^{214}Po$ , and the disintegration of  $^{214}Pb$  and  $^{214}Bi$  potential emitters of alpha particles of this type), using a solid-state nuclear track detector;
- c) calculation of the potential alpha energy concentration of the short-lived radon-222 decay products.

NOTE For the radon-220 decay products, this involves distinguishing between, and counting, the alpha particles, with an energy  $E_{AE,212Bi}$  and  $E_{AE,212Po}$ , released through disintegration of  $^{216}Po$  and  $^{212}Po$ , and disintegration of  $^{212}Pb$  and  $^{212}Bi$  potential emitters of alpha particles of this type.

## 5 Equipment

### 5.1 General

The apparatus shall include a measuring device, composed of a sampling system and a detection system (see Figure 1), and a counting system. The measuring device shall be in accordance with IEC 61577-1 and IEC 61577-3.

### 5.2 Measuring device

#### 5.2.1 Sampling system

The sampling system shall include the following components:

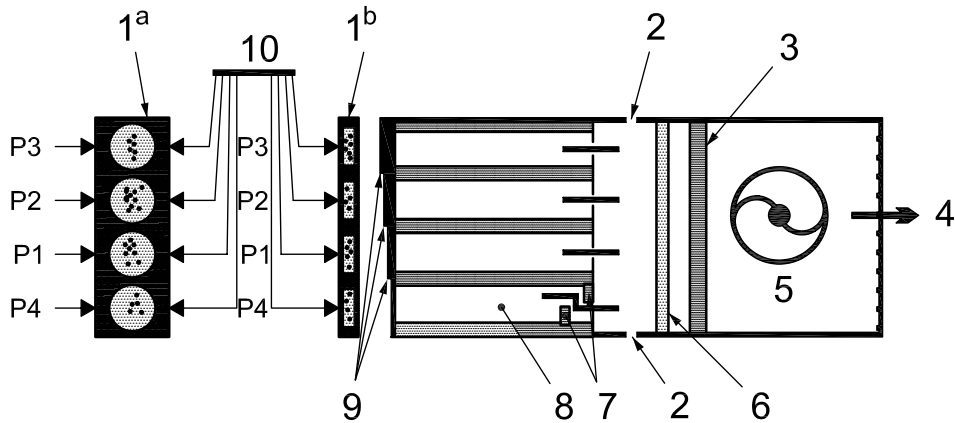
- a) a high-efficiency filtering membrane in cellulose acetate to collect the radon decay products;
- b) a sampling pump which provides a volume rate compatible with the air and metrological characteristics of the detection system;
- c) a mass flow-meter which measures the flow-rate of air sampled throughout the sampling duration.

The sampling system is located downstream of the detection system.

#### 5.2.2 Detection system

The detection system shall include the following components:

- a) three boPET screens of different thickness placed at one end of the collimators are used to discriminate between the particles over three energy ranges. This geometry is used to mitigate the initial energy of each alpha particle emitted by the collected radionuclides in an energy range compatible with the characteristics of the sensor (SSNTD) used;
- b) a solid-state nuclear track detector (SSNTD).



**Key**

- 1 solid state nuclear track detector (SSNTD)
- 2 air inlet
- 3 mass flow-meter
- 4 air outlet
- 5 vacuum pump
- 6 high-efficiency filter
- 7 baffles (diffusion barrier)
- 8 collimator
- 9 boPET (biaxially oriented polyethylene terephthalate) screen
- 10 scanning range

- a Front view.
- b Side view.

**Figure 1 — Example set-up of a measuring device for determination over four energy ranges of average potential alpha energy concentration of short-lived radon-222 decay products**

**5.3 Counting system**

The counting system shall include the following components:

- a) equipment and suitable chemical reagents for etching the detector (SSNTD);
- b) an optical microscope and associated equipment for scanning and counting the etched tracks.

**6 Sampling**

**6.1 Sampling objective**

The sampling objective is to collect, without interruption, all the aerosols carrying short-lived radon decay products, regardless of size (unattached and attached fractions), that are contained in the ambient air during a given sampling duration (at least one week).

**6.2 Sampling characteristics**

Sampling shall be carried out under the conditions specified in ISO 11665-1.

The short-lived radon decay products shall be sampled continuously and directly in the atmosphere under investigation by pumping and filtering a known volume of air through a high-efficiency collection membrane. The air sample shall be omni-directional.

The filtering membrane shall be as close as possible to the sampler inlet section, so as to collect the ambient decay products with the maximum efficiency.

In order to count the emitted alpha particles correctly, the sampling system shall conduct to the surface deposit of the radionuclides on the filter and shall prevent the aerosols from being buried.

The sampling system shall be used in conditions that preclude clogging of the filtering membrane, which would cause self-absorption of the alpha emissions of particles collected on the filter or a reduction in the sampling flow-rate over time.

The sampling flow-rate shall be stable (no more than 10 % variation from the average value) in order for the sampling to remain representative throughout the sampling duration. This can be achieved by using a flow-rate controller (sonic throat, servo-controlled valve, etc.).

### **6.3 Sampling conditions**

#### **6.3.1 General**

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

#### **6.3.2 Installation of sampling system**

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

In the specific case of an indoor measurement, the sampling system shall be installed as follows:

- a) in an area not directly exposed to solar radiation;
- b) away from a heat source (radiator, picture windows, electrical equipment, etc.);
- c) away from traffic areas, doors and windows, walls and ventilation sources (it could, for example, be sited on an item of furniture like a shelf or sideboard).

#### **6.3.3 Sampling duration**

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

Time (date and hour) of installation and time of removal of the sampling system shall be recorded.

Sampling duration shall be determined according to the intended use of the measurement results and the phenomenon under investigation.

A sampling duration of at least one week is required in order to obtain a measurement result above the detection limit.

It is recommended that measurements be performed with a sampling duration of several months when assessing the annual human exposure.

Users should be aware of the saturation characteristics of the sensor (SSNTD) and should perform their sampling regime so as to ensure that saturation does not occur.

#### **6.3.4 Volume of air sampled**

The volume of air sampled shall be ascertained by measuring the flow-rate or volume during sampling with a calibrated system (for example, a sonic nozzle) (see IEC 61577-3).

The total volume of air sampled throughout the sampling duration shall be recorded.

## 7 Detection method

Detection shall be carried out using solid-state nuclear track detectors (SSNTD), as described in ISO 11665-1.

## 8 Measurement

### 8.1 Procedure

Measurement shall be carried out as follows.

- a) Select and locate the measuring point.
- b) Install the measuring device (sampling system with detection system).
- c) Record the location and the time (date and hour) of installation of the measuring device.
- d) Carry out sampling of the air under investigation.
- e) Remove the measuring device after the exposure period.
- f) Record the time (date and hour) of removal of the measuring device.
- g) Remove the detection system from the measuring device.
- h) Remove the detector (SSNTD) from the detection system.
- i) Develop the detector by etching with a suitable chemical treatment in the laboratory. The latent tracks caused by the alpha particles produced by the disintegration of the radon and its short-lived decay products are converted into "visible tracks".
- j) Scan the detector under an optical microscope. The scanning ranges on the detector are marked as shown in Figure 1:
  - 1) range  $P_1$  records alpha particles caused by  $^{218}\text{Po}$ ,  $^{212}\text{Bi}$  and  $^{222}\text{Rn}$ ;
  - 2) range  $P_2$  records alpha particles caused by  $^{214}\text{Po}$  and  $^{222}\text{Rn}$ ;
  - 3) range  $P_3$  records alpha particles caused by  $^{212}\text{Po}$ ;
  - 4) range  $P_4$  records alpha particles caused by  $^{222}\text{Rn}$ .
- k) Determine the background level of the detector: Place ten detectors from each batch installed in a detection system in a radon-free atmosphere for a period of time equal to the sampling duration. Repeat steps h) to j) to determine the background level.
- l) Determine the potential alpha energy concentration by calculation.

**NOTE** This method is used to determine the average potential alpha energy concentration of short-lived radon decay products, as well as decay products from isotope 220, by considering the number of alpha particles with an energy  $E_{\text{AE},212\text{Bi}}$  and  $E_{\text{AE},212\text{Po}}$  produced by the disintegration of  $^{216}\text{Po}$ ,  $^{212}\text{Pb}$ ,  $^{212}\text{Bi}$  and  $^{212}\text{Po}$ , potential emitters of alpha particles of this type.

### 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 presence of  $^{226}\text{Ra}$  or of any other alpha emitters collected on the filtering membrane: This can produce erroneous results if appropriate correction is not made. A gross alpha counting of the filtering membrane is

performed. When the count rate is high, alpha spectrometry may be used to identify and quantify the alpha emitter radionuclides present.

- b) The temperature (influencing the sampling process) and the humidity (influencing the capacity of the sampling device): The influence of these variables is limited by halting sampling if the recommended values are exceeded.

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

### 8.3 Calibration

The measuring device (sampling system and detection system) shall be calibrated as specified in ISO 11665-1.

Calibration of the sampling system flow-rate shall be performed using a reference flow-meter.

The relationship between the variable measured by the detection system and the average potential alpha energy concentration of the radon decay products in the air shall be established by using reference radioactive sources or another standard (a reference atmosphere, for example) recognized through international inter-comparison programmes.

To calibrate the detection system, an instrument taken from a batch is placed in a reference atmosphere with known concentration of radon and its decay products, using a  $^{226}\text{Ra}$  source in equilibrium with its decay products.

## 9 Expression of results

### 9.1 Average potential alpha energy concentration

The average potential alpha energy concentration of short-lived radon-222 decay products is calculated as given in Formula (1) (see also ISO 11665-1):

$$\bar{E}_{\text{PAEC},222\text{Rn}} = \frac{\left[ E_{\text{AE},218\text{Po}} \cdot N_{218\text{Po}} + E_{\text{AE},214\text{Po}} \cdot (N_{218\text{Po}} + N_{214\text{Bi}} + N_{214\text{Pb}} + N_{214\text{Po}}) \right]}{V} \quad (1)$$

Formula (2) is obtained by taking into account the different ranges in which the device records alpha particles, and the collection and detection efficiencies:

$$\bar{E}_{\text{PAEC},222\text{Rn}} = \frac{\left[ E_{\text{AE},218\text{Po}} \cdot (\bar{R}_{P_1} - r \cdot \bar{R}_{P_3} - a \cdot \bar{R}_{P_4}) + E_{\text{AE},214\text{Po}} \cdot (\bar{R}_{P_2} - b \cdot \bar{R}_{P_4}) \right]}{V \cdot \varepsilon_{\text{hc}} \cdot \varepsilon_{\text{gd}}} \quad (2)$$

where

$$\bar{R}_{P_i} = \frac{\sum_{j=1}^n R_{P_i,j}}{n} \quad \text{for } i = 1, 2, 3, 4 \quad (3)$$

NOTE This method is used to determine the average potential alpha energy concentration of short-lived radon decay products as well as those of the isotope 220 decay products due to the track counting of range  $P_3$ .

The average potential alpha energy concentration of the radon-220 decay products can be calculated as given in Formula (4):

$$\bar{E}_{\text{PAEC},220\text{Rn}} = \frac{\left( E_{\text{AE},212\text{Bi}} \cdot r \cdot \bar{R}_{P_3} + E_{\text{AE},212\text{Po}} \cdot \bar{R}_{P_3} \right)}{V \cdot \varepsilon_{\text{hc}} \cdot \varepsilon_{\text{gd}}} = \frac{\left( E_{\text{AE},212\text{Bi}} \cdot r + E_{\text{AE},212\text{Po}} \right) \cdot \bar{R}_{P_3}}{V \cdot \varepsilon_{\text{hc}} \cdot \varepsilon_{\text{gd}}} \quad (4)$$

## 9.2 Standard uncertainty

In accordance with ISO/IEC Guide 98-3, the standard uncertainty of  $\bar{E}_{\text{PAEC},222\text{Rn}}$  shall be calculated as given in Formula (5):

$$u(\bar{E}_{\text{PAEC},222\text{Rn}}) = \sqrt{\frac{E_{\text{AE},218\text{Po}}^2 \cdot (\bar{R}_{P1} + r^2 \cdot \bar{R}_{P3}) + E_{\text{AE},214\text{Po}}^2 \cdot \bar{R}_{P2} + (a \cdot E_{\text{AE},218\text{Po}} + b \cdot E_{\text{AE},214\text{Po}})^2 \cdot \bar{R}_{P4}}{(V \cdot \varepsilon_{\text{hc}} \cdot \varepsilon_{\text{gd}})^2 \cdot n} + (\bar{E}_{\text{PAEC},222\text{Rn}})^2 \cdot [u_{\text{rel}}^2(V) + u_{\text{rel}}^2(\varepsilon_{\text{hc}}) + u_{\text{rel}}^2(\varepsilon_{\text{gd}})]}$$
 (5)

where

$$u^2(\bar{R}_{P_i}) = \frac{\bar{R}_{P_i}}{n} \text{ for } i = 1, 2, 3, 4$$
 (6)

In addition, the following applies when using Formula (5):

- the standard uncertainties of  $E_{\text{AE},218\text{Po}}$  and  $E_{\text{AE},214\text{Po}}$  are considered negligible;
- the standard uncertainties of  $a$  and  $b$  are considered negligible;
- the standard uncertainty of the detection efficiency,  $\varepsilon_{\text{gd}}$ , is calculated using the MONTE-CARLO method and is usually provided by the manufacturer;
- the standard uncertainty of the collection efficiency,  $\varepsilon_{\text{hc}}$ , is obtained by measurement and is usually provided by the manufacturer.

NOTE 1 The standard uncertainty of the background count,  $u(\bar{R}_0)$ , obtained from a sample of 10 detectors installed in a detection system in a radon-free atmosphere for two months remains negligible compared with the variances caused by the production and counting of tracks.

NOTE 2 In accordance with ISO/IEC Guide 98-3, the standard uncertainty of the average potential alpha energy concentration of the radon-220 decay products,  $u(\bar{E}_{\text{PAEC},220\text{Rn}})$ , can be calculated as given in Formula (7):

$$u(\bar{E}_{\text{PAEC},220\text{Rn}}) = \bar{E}_{\text{PAEC},220\text{Rn}} \cdot \sqrt{\left( \frac{1}{n \cdot \bar{R}_{P3}} + u_{\text{rel}}^2(V) + u_{\text{rel}}^2(\varepsilon_{\text{hc}}) + u_{\text{rel}}^2(\varepsilon_{\text{gd}}) \right)}$$
 (7)

where

$$u^2(\bar{R}_{P3}) = \frac{\bar{R}_{P3}}{n}$$
 (8)

## 9.3 Decision threshold and detection limit

For practical measurements of the potential alpha energy concentration, a calculation of the decision threshold and the detection limit is not necessary, since both are far below any reasonable environmental potential alpha energy concentration. It is sufficient to give the standard uncertainty of the results and, if required, a coverage interval.

NOTE Blank results obtained from the evaluation of detection systems, stored for 6 months without any exposure to radon-222 and radon-220, yielded mean values of 3 nJ, with a standard uncertainty of 5 nJ, allowing calculation of a decision threshold for the determination of the net potential alpha energy of 12 nJ and a detection limit of the net potential alpha energy of about 24 nJ.



Assuming a sampled volume of 40 m<sup>3</sup> (typical value for an exposure time of 1 month), this yields a decision threshold of the net potential alpha energy concentration of 0,3 nJ/m<sup>3</sup> and a detection limit of the net potential alpha energy concentration of about 0,6 nJ/m<sup>3</sup>, which are far below any reasonable environmental potential alpha energy concentration.

#### 9.4 Limits of the confidence interval

The lower,  $\bar{E}_{\text{PAEC},222\text{Rn}}^{\triangleleft}$ , and upper,  $\bar{E}_{\text{PAEC},222\text{Rn}}^{\triangleright}$ , limits of the confidence interval shall be calculated using Formulae (9) and (10) (see ISO 11929):

$$\bar{E}_{\text{PAEC},222\text{Rn}}^{\triangleleft} = \bar{E}_{\text{PAEC},222\text{Rn}} - k_p \cdot u(\bar{E}_{\text{PAEC},222\text{Rn}}); \quad p = \omega \cdot (1 - \gamma/2) \quad (9)$$

$$\bar{E}_{\text{PAEC},222\text{Rn}}^{\triangleright} = \bar{E}_{\text{PAEC},222\text{Rn}} + k_q \cdot u(\bar{E}_{\text{PAEC},222\text{Rn}}); \quad q = 1 - \omega \cdot \gamma/2 \quad (10)$$

where

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

$\omega = 1$  may be set if  $\bar{E}_{\text{PAEC},222\text{Rn}} \geq 4 \cdot u(\bar{E}_{\text{PAEC},222\text{Rn}})$ , in which case:

$$\bar{E}_{\text{PAEC},222\text{Rn}}^{\triangleleft\triangleright} = \bar{E}_{\text{PAEC},222\text{Rn}} \pm k_{1-\gamma/2} \cdot u(\bar{E}_{\text{PAEC},222\text{Rn}}) \quad (11)$$

$\gamma = 0,05$  and  $k_{1-\gamma/2} = 1,96$  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 11665-2:2012;
- b) measurement method (integrated);
- c) identification of the sample;
- d) sampling characteristic (active);
- e) time (date and hour) of installation and removal of the measuring device;
- f) duration of sampling;
- g) sampling location;
- h) units in which the results are expressed;
- i) test result,  $\bar{E}_{\text{PAEC},222\text{Rn}} \pm u(\bar{E}_{\text{PAEC},222\text{Rn}})$  or  $\bar{E}_{\text{PAEC},222\text{Rn}} \pm U$ , with the associated  $k$  value.

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

- a) purpose of the measurement;
- b) probabilities  $\alpha$ ,  $\beta$  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 average potential alpha energy concentration of the short-lived radon-222 decay products is compared with the decision threshold (see ISO 11929), the result of the measurement shall be expressed as  $\leq \bar{E}_{\text{PAEC},222\text{Rn}}^*$  if the result is below the decision threshold;
  - 2) when the average potential alpha energy concentration of the short-lived radon-222 decay products is compared with the detection limit, the result of the measurement shall be expressed as  $\leq \bar{E}_{\text{PAEC},222\text{Rn}}^\#$  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.).

**10.3** The results can be expressed in a similar format to that shown in 11665-1:2012, Annex C.

## Annex A (informative)

### Example of a method meeting the requirements of this part of ISO 11665

#### A.1 Equipment

The measuring system includes a detection system and a sampling system (see Figure 1).

A high-efficiency filtering membrane in cellulose acetate (1,2 µm pore size) is used for collecting the radon decay products.

The detection system includes the following components:

- a) a mechanical energy discriminator marked by three boPET screens varying in thickness from 8 µm to 40 µm and linked to collimators (the geometry thus formed is used to mitigate the initial energy of each alpha particle emitted by the collected radionuclides in an energy range compatible with the characteristics of the detector used);
- b) a solid-state nuclear track detector comprising a polyethylene terephthalate base 100 µm thick, covered by a layer of cellulose nitrate coloured red, 11,5 µm to 12 µm thick and sensitive to the alpha particles.

The detector used shall not have been stored in temperatures higher than 50 °C.

#### A.2 Sampling

The nominal flow-rate of the sampling pump is 0,08 m<sup>3</sup>/h in normal operating conditions.

Sampling the air and recording the tracks on the detector are simultaneous.

The measuring device is left in place for one month (1 to 30 November 2000) in three French regions.

The air volume sampled is calculated recording the sampling duration and the measured flow-rate.

#### A.3 Measurement procedure

The measurement is performed as described in Clause 8.

The detector is etched in the laboratory after the exposure period to reveal the tracks caused by the passage of the alpha particles.

Step 8.1 i) is performed by developing the detector by etching with a suitable chemical treatment. The reagent is a solution of sodium hydroxide with a concentration of (2,50 ± 0,05) mol/l. The etching takes (90 ± 1) min with a bath temperature of (60,0 ± 0,5) °C.

#### A.4 Example

$\bar{E}_{\text{PAEC},222\text{Rn}}$  and  $\bar{E}_{\text{PAEC},220\text{Rn}}$  measurement results over a one-month accumulation period (1 to 30 November 2000) in three French regions are given in Table A.1.

**Table A.1 — Results of potential alpha energy concentration measurements**

Sampling location	$V$ m <sup>3</sup>	$\bar{R}_{P1}$	$\bar{R}_{P2}$	$\bar{R}_{P3}$	$\bar{R}_{P4}$	$\bar{E}_{\text{PAEC},222_{\text{Rn}}} \pm$ $u(\bar{E}_{\text{PAEC},222_{\text{Rn}}})$ nJ/m <sup>3</sup>	$\bar{E}_{\text{PAEC},220_{\text{Rn}}} \pm$ $u(\bar{E}_{\text{PAEC},220_{\text{Rn}}})$ nJ/m <sup>3</sup>
Parisian Basin	42,3	385	1 133	498	16	42 ± 5	28 ± 4
Massif Central	55,9	321	1 600	117	2	48 ± 6	5 ± 1
Vendée	45,7	263	1 270	217	16	44 ± 5	11 ± 2

The following applies for the results in Table A.1:

—  $E_{\text{AE},218_{\text{Po}}} = 9,615 \times 10^{-13}$  J

—  $E_{\text{AE},214_{\text{Po}}} = 1,23 \times 10^{-12}$  J

—  $E_{\text{AE},212_{\text{Bi}}} = 9,772 \times 10^{-13}$  J

—  $E_{\text{AE},212_{\text{Po}}} = 1,434 \times 10^{-12}$  J

—  $r = 0,56$

—  $a = 1,099$

—  $b = 0,045$

—  $n = 2$

—  $\varepsilon_{\text{hc}} = 0,8$

—  $\varepsilon_{\text{gd}} = 1,037 \times 10^{-3}$

—  $u_{\text{rel}}(\varepsilon_{\text{hc}}) = 0,025$

—  $u_{\text{rel}}(\varepsilon_{\text{gd}}) = 0,015$

—  $u_{\text{rel}}(V) = 0,05$

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