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

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

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

Partie 1: Origine du radon et de ses descendants à vie courte, et méthodes de mesure associées

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Foreword

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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 11665-1 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 (see Annex A for further information). Solid elements, also radioactive, followed by stable lead are produced by radon disintegration[1].

Radon is considered a noble gas in the periodic table of elements, along with helium, argon, neon, krypton and xenon.

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 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. The UNSCEAR (2006) report[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 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.

The values usually found in the continental environment are normally between a few becquerels per cubic metre and several thousand becquerels per cubic metre. Activity concentrations of less than one becquerel per cubic metre may be observed in the oceanic environment. Radon activity concentrations vary inside houses from several tens of becquerels per cubic metre to several hundreds of becquerels per cubic metre[7]. Activity concentration can reach several thousands of becquerels per cubic metre in very confined spaces. Variations of a few nanojoules per cubic metre to several thousand nanojoules per cubic metre are observed for the potential alpha energy concentration of short-lived radon decay products.

ISO 11665 consists of 10 parts (see Figure 1) dealing with:

— measurement methods for radon-222 and its short-lived decay products (see ISO 11665-2, ISO 11665-3, ISO 11665-4, ISO 11665-5 and ISO 11665-6);

NOTE 1 There are many methods for measuring the radon-222 activity concentration and the potential alpha energy concentration of its short-lived decay products. The choice of measurement method will depend on the expected level of concentration and on the intended use of the data, such as scientific research and health-related assessments[8][9].

— measurement methods for the radon-222 exhalation rate (see ISO 11665-7 and ISO 11665-9);

NOTE 2 ISO 11665-7 refers back to ISO 11665-5 and ISO 11665-6.

— measurement methods for the radon-222 diffusion coefficient (see ISO 11665-10);

— methodologies for radon-222 measurements in buildings (see ISO 11665-8).

NOTE 3 ISO 11665-8 refers back to ISO 11665-4 for radon measurements for initial investigation purposes in a building and to ISO 11665-5, ISO 11665-6 and ISO 11665-7 for measurements for any additional investigation.

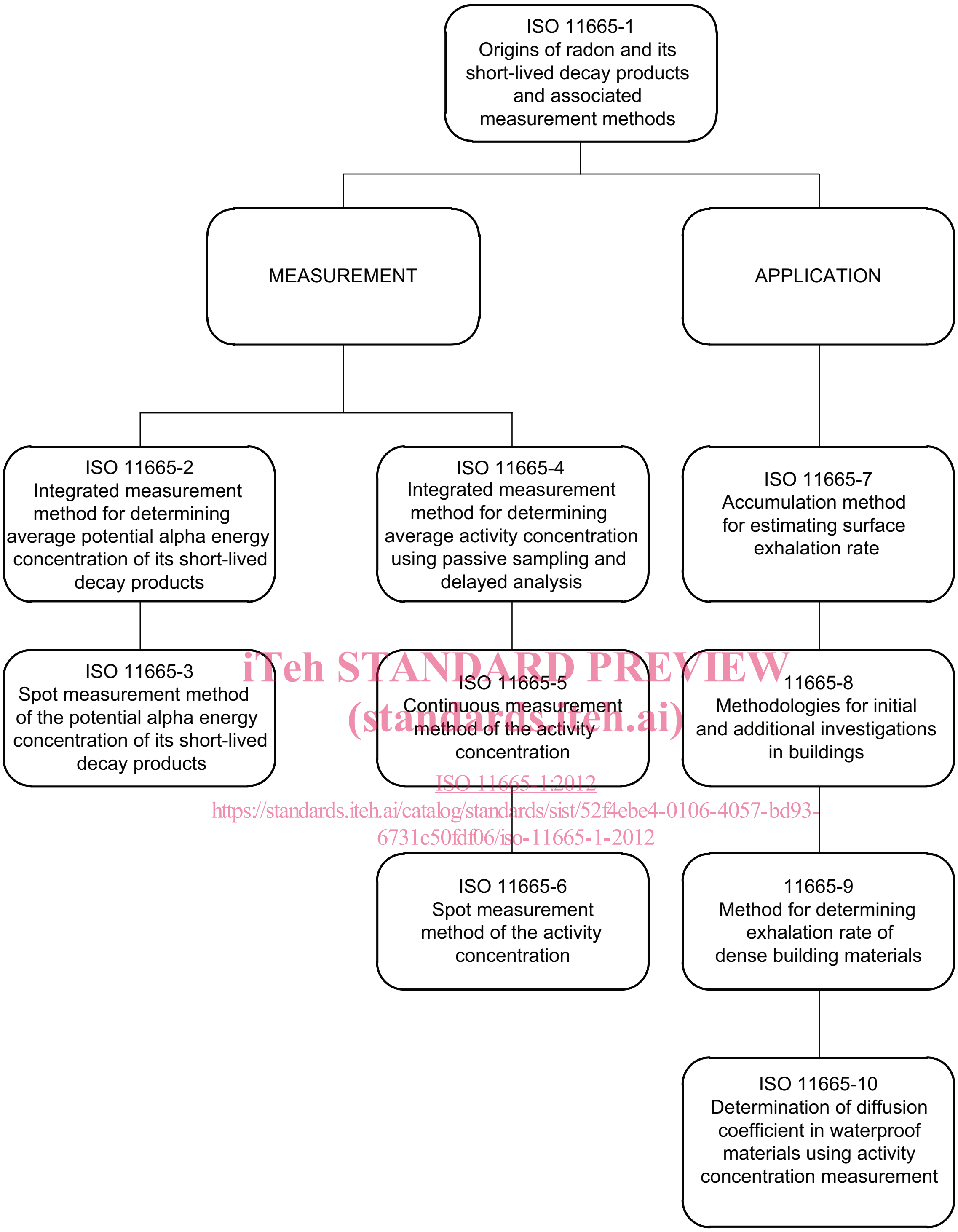

Figure 1 — Structure of the ISO 11665 series

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

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

1 Scope

This part of ISO 11665 outlines guidance for measuring radon-222 activity concentration and the potential alpha energy concentration of its short-lived decay products in the air.

The measurement methods fall into three categories:

a) spot measurement methods;

b) continuous measurement methods;

c) integrated measurement methods.

This part of ISO 11665 provides several methods commonly used for measuring radon-222 and its short-lived decay products in air.

This part of ISO 11665 also provides guidance on the determination of the inherent uncertainty linked to the measurement methods described in its different parts.

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/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*

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 following terms and definitions apply.

3.1.1
active sampling
sampling using active devices like pumps for sampling the atmosphere

[IEC 61577-1:2006]

3.1.2
activity
disintegration rate
number of spontaneous nuclear disintegrations occurring in a given quantity of material during a suitably small interval of time divided by that interval of time

[ISO 921:1997, term 23]

NOTE 1 Activity, A, is expressed by the relationship given in Formula (1):

$$A = \lambda \cdot N \quad (1)$$

where

λ is the decay constant per second;

N is the number of atoms.

NOTE 2 The decay constant is linked to the radioactive half-life by the relationship:

$$\lambda = \frac{\ln 2}{T_{1/2}} \quad (2)$$

where

$T_{1/2}$ is the radioactive half-life, in seconds.

3.1.3
activity concentration
activity per unit volume

[IEC 61577-1:2006]

3.1.4
attached fraction
fraction of the potential alpha energy concentration of short-lived decay products that is attached to the ambient aerosol

[IEC 61577-1:2006]

NOTE The sizes of the carrier aerosol to which most of the short-lived decay products are attached are generally in the 0,1 µm to 0,3 µm range of median values.

3.1.5
average activity concentration
exposure to activity concentration divided by the sampling duration

3.1.6
average potential alpha energy concentration
exposure to potential alpha energy concentration divided by the sampling duration

3.1.7
background noise
signals caused by something other than the radiation to be detected

NOTE A distinction can be made between signals caused by radiation from sources inside or outside the detector other than those targeted for the measurements and signals caused by defects in the detection system electronic circuits and their electrical power supply.

3.1.8
continuous measurement
measurement obtained by taking a sample continuously (or at integration intervals typically in range of 1 min to 120 min) with simultaneous or slightly delayed analysis

NOTE 1 The sampling duration shall be adapted to the dynamics of the phenomenon studied to monitor the evolution of radon activity concentration over time.

NOTE 2 See Annex B for further information.

3.1.9
diffusion length
distance crossed by an atom due to diffusion forces before decaying

NOTE Diffusion length, l, is expressed by the relationship given in Formula (3):

$$l = \left(\frac{D}{\lambda} \right)^{1/2} \quad (3)$$

where

D is the diffusion coefficient, in square metres per second;

λ is the decay constant per second.

3.1.10
equilibrium factor

ratio of the potential alpha energy concentration of short-lived radon decay products in a given volume of air to the potential alpha energy concentration of these decay products if these are in radioactive equilibrium with radon in the same volume of air

NOTE 1 The short-lived ^{222}Rn decay products present in an atmosphere are very rarely in radioactive equilibrium with their parent (through being trapped on the walls or eliminated by an air renewal system, for example) and the equilibrium factor is used to qualify this state of “non-equilibrium”.

NOTE 2 The equilibrium factor is between 0 and 1. The equilibrium factor in buildings typically varies between 0,1 and 0,9, with an average value equal to 0,4[4][6].

NOTE 3 The equilibrium factor, F_{eq}, is expressed by Formula (4):

$$F_{\text{eq}} = \frac{E_{\text{PAEC},{}^{222}\text{Rn}}}{5{,}57 \cdot 10^{-9} \times C_{{}^{222}\text{Rn}}} \quad (4)$$

where

$E_{\text{PAEC},{}^{222}\text{Rn}}$ is the potential alpha energy concentration of ^{222}Rn, in joules per cubic metre;

$5{,}57 \times 10^{-9}$ is the potential alpha energy concentration of the short-lived ^{222}Rn decay products for 1 Bq of ^{222}Rn in equilibrium with its short-lived decay products, in joules per becquerel;

$C_{{}^{222}\text{Rn}}$ is the activity concentration of ^{222}Rn, in becquerels per cubic metre.

3.1.11
grab sampling
collection of a sample (i.e of air containing radon or aerosol particles) during a period considered short compared with the fluctuations of the quantity under study (i.e volume activity of air)

[IEC 61577-1:2006]

3.1.12
guideline value
value which corresponds to scientific, legal or other requirements and which is intended to be assessed by the measurement procedure

NOTE 1 The guideline value can be given, for example, as an activity, a specific activity or an activity concentration, a surface activity, or a dose rate.

NOTE 2 The comparison of the detection limit with a guideline value allows a decision on whether or not the measurement procedure satisfies the requirements set forth by the guideline value and is therefore suitable for the intended measurement purpose. The measurement procedure satisfies the requirement if the detection limit is smaller than the guideline value.

[ISO 11929:2010, term 3.10]

3.1.13
integrated measurement
measurement performed by continuous sampling of a volume of air which, over time, is accumulating physical quantities (number of nuclear tracks, number of electric charges, etc.) linked to the disintegration of radon and/or its decay products, followed by analysis at the end of the accumulation period

NOTE See Annex B for further information.

3.1.14
long-term measurement
measurement based on an air sample collected within a period greater than one month

3.1.15
measurand
quantity intended to be measured

[ISO/IEC Guide 99:2007, term 2.3]

3.1.16
measuring system
set of one or more measuring instruments and often other devices, including any reagent and supply, assembled and adapted to give information used to generate measured quantity values within specified intervals for quantities of specified kinds

[ISO/IEC Guide 99:2007, term 3.2]

3.1.17
passive sampling
sampling using no active devices such as pumps for sampling the atmosphere, whereby in most instruments sampling is performed mainly by diffusion

NOTE Adapted from IEC 61577-1:2006.

3.1.18
potential alpha energy of short-lived radon decay products
total alpha energy emitted during the decay of atoms of short-lived radon decay products along the decay chain through to ^{210}Pb for the decay chains of the ^{222}Rn

NOTE 1 The potential alpha energy of short-lived ^{222}Rn decay products, $E_{\mathrm{PAE},^{222}\mathrm{Rn}}$, is expressed by Formula (5):

$$E_{\mathrm{PAE},^{222}\mathrm{Rn}} = \begin{bmatrix} \left(E_{\mathrm{AE},^{218}\mathrm{Po}} + E_{\mathrm{AE},^{214}\mathrm{Po}}\right)\cdot\left(N_{^{218}\mathrm{Po}}\right) \\ + E_{\mathrm{AE},^{214}\mathrm{Po}}\cdot\left(N_{^{214}\mathrm{Pb}} + N_{^{214}\mathrm{Bi}}\right) + E_{\mathrm{AE},^{214}\mathrm{Po}}\cdot\left(N_{^{214}\mathrm{Po}}\right) \end{bmatrix} \quad (5)$$

where

$E_{\text{AE},218\,\text{Po}}$ is the alpha particle energy produced by the disintegration of ^{218}Po, in joules;

$E_{\text{AE},214\,\text{Po}}$ is the alpha particle energy produced by the disintegration of ^{214}Po, in joules;

$N_{218\text{Po}}$ is the number of atoms of ^{218}Po;

$N_{214\text{Pb}}$ is the number of atoms of ^{214}Pb;

$N_{214\text{Bi}}$ is the number of atoms of ^{214}Bi;

$N_{214\text{Po}}$ is the number of atoms of ^{214}Po.

NOTE 2 The total alpha energy emitted during the decay of atoms of short-lived radon decay products along the decay chain through to ^{208}Pb for the decay chains of the ^{220}Rn is expressed by Formula (6):

$$E_{\text{PAE},220\,\text{Rn}} = \left[\begin{array}{l} \left(E_{\text{AE},216_{\text{Po}}} + 0{,}36 \cdot E_{\text{AE},212_{\text{Bi}}} + 0{,}64 \cdot E_{\text{AE},212_{\text{Po}}}\right) \cdot \left(N_{216_{\text{Po}}}\right) \\ + \left(0{,}36 \cdot E_{\text{AE},212_{\text{Bi}}} + 0{,}64 \cdot E_{\text{AE},212_{\text{Po}}}\right) \cdot \left(N_{212_{\text{Pb}}} + N_{212_{\text{Bi}}}\right) + E_{\text{AE},212_{\text{Po}}} \cdot \left(N_{212_{\text{Po}}}\right) \end{array} \right] \quad (6)$$

where

$E_{\text{PAE},220\text{Rn}}$ is the potential alpha energy of ^{220}Rn, in joules;

$E_{\text{AE},216\,\text{Po}}$ is the alpha particle energy produced by the disintegration of ^{216}Po, in joules;

$E_{\text{AE},212\,\text{Bi}}$ is the alpha particle energy produced by the disintegration of ^{212}Bi, in joules;

$E_{\text{AE},212\,\text{Po}}$ is the alpha particle energy produced by the disintegration of ^{212}Po, in joules;

$N_{212\text{Pb}}$ is the number of atoms of ^{212}Pb;

$N_{212\text{Bi}}$ is the number of atoms of ^{212}Bi;

$N_{212\text{Po}}$ is the number of atoms of ^{212}Po.

3.1.19

potential alpha energy concentration of short-lived radon decay products

concentration of any mixture of short-lived radon decay products in air in terms of the alpha energy released during complete decay through ^{210}Pb and/or ^{208}Pb respectively

[IEC 61577-1:2006]

NOTE The potential alpha energy concentration of the nuclide i, $E_{\text{PAEC},i}$, is expressed by Formula (7):

$$E_{\text{PAEC},i} = \frac{E_{\text{PAE},i}}{V} \quad (7)$$

where

$E_{\text{PAE},i}$ is the potential alpha energy of the nuclide i, in joules;

V is the sampled volume, in cubic metres.

3.1.20
potential alpha energy concentration exposure
integral with respect to time of potential alpha energy concentration accumulated during the exposure time

NOTE Exposure to potential alpha energy concentration, X_{PAEC}, is expressed by Formula (8):

$$X_{PAEC} = \int_0^t E_{PAEC} \cdot dt \qquad (8)$$

where

E_{PAEC} is the potential alpha energy concentration, in joules per cubic metre;

t is the sampling duration, in seconds.

3.1.21
primary standard
standard designed with, or widely acknowledged as having, the highest metrological qualities and whose value is accepted without reference to other standards of the same quantity

[IEC 61577-1:2006]

NOTE The concept of a primary standard is equally valid for base quantities and derived quantities.

3.1.22
radioactive equilibrium of radon-222 with its short-lived decay products
state of radon and its short-lived decay products whereby the activity of each radionuclide is equal

NOTE In radioactive equilibrium, the activity of each short-lived decay product decreases over time like the radon activity.

3.1.23
radon emanation
mechanism whereby a radon atom leaves the individual particle of solid material in which it has been formed and reaches the free space of pores

3.1.24
radon exhalation
mechanism whereby a radon atom produced by emanation and transported (by diffusion or convection) towards the material surface is released from the material into the surrounding medium (air)

3.1.25
radon exhalation rate
value of the activity concentration of radon atoms that leave a material per unit time

NOTE 1 The radon exhalation rate under conditions whereby the radon activity concentration at the surface of the material equals zero is called free radon exhalation rate.

NOTE 2 The free radon exhalation rate is approximated from the radon exhalation rate if the radon activity at the surface of the material has a sufficiently low value.

3.1.26
radon surface exhalation rate
value of the activity concentration of radon atoms that leave a material per unit surface of the material per unit time

3.1.27
radon mass exhalation rate
value of the activity concentration of radon atoms that leave a material per unit mass of the material per unit time

