TECHNICAL SPECIFICATION

ISO/TS 11665-13

First edition
2017-10

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

Part 13:
Determination of the diffusion coefficient in waterproof materials: membrane two-side activity concentration test method

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

Partie 13: Détermination du coefficient de diffusion des matériaux imperméables : méthode de mesurage de l'activité volumique des deux côtés de la membrane

Reference number
ISO/TS 11665-13:2017(E)

Contents

Page

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.

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).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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*.

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

Introduction

Radon isotopes 222, 219 and 220 are radioactive gases produced by the disintegration of radium isotopes 226, 223 and 224, which are decay products of uranium-238, uranium-235 and thorium-232, respectively, and are all found in the earth's crust. Solid elements, also radioactive, followed by stable lead are produced by radon disintegration[5].

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. UNSCEAR[7] 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 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, 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[2].

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

To limit the risk to individuals, a national reference level of 100 $Bq \cdot m^{-3}$ is recommended by the World Health Organization[8]. Wherever this is not possible, this reference level should not exceed 300 $Bq \cdot m^{-3}$. This recommendation was endorsed by the European Community Member States that shall establish national reference levels for indoor radon activity concentrations. The reference levels for the annual average activity concentration in air shall not be higher than 300 $Bq \cdot m^{-3}$[9].

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.

When a building requires protection against radon from the soil, radon-proof insulation (based on membranes, coatings or paints) placed between the soil and the indoors may be used as a stand-alone radon prevention/remediation strategy or in combination with other techniques such as passive or active soil depressurization. Radon-proof insulation functions at the same time as the waterproof insulation.

Radon diffusion coefficient is a parameter that determines the barrier properties of waterproof materials against the diffusive transport of radon. Applicability of the radon diffusion coefficient for radon-proof insulation can be prescribed by national building standards and codes. Requirements for radon-proof insulation as regards the durability, mechanical and physical properties and the maximum design value of the radon diffusion coefficient can also be prescribed by national building standards and codes.

As no reference standards and reference materials are currently available for these types of materials and related values of radon diffusion coefficient, the metrological requirement regarding the determination of the performance of the different methods described in ISO/TS 11665-12 and this document, as required by ISO/IEC 17025[3], cannot be directly met.

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

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

Part 13:
Determination of the diffusion coefficient in waterproof materials: membrane two-side activity concentration test method

1 Scope

This document specifies the different methods intended for assessing the radon diffusion coefficient in waterproofing materials such as bitumen or polymeric membranes, coatings or paints, as well as assumptions and boundary conditions that shall be met during the test.

This document is not applicable for porous materials, where radon diffusion depends on porosity and moisture content.

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 11665-5, *Measurement of radioactivity in the environment — Air: radon-222 — Part 5: Continuous measurement method of the activity concentration*

ISO 11665-6, *Measurement of radioactivity in the environment — Air: radon-222 — Part 6: Spot measurement method of the activity concentration*

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 80000-10, *Quantities and units — Part 10: Atomic and nuclear physics*

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

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 and ISO 80000-10 and the following apply.

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

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

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

3.1.1
material
product according to a certain technical specifications which is the object of the test

3.1.2
sample (of material)
certain amount of material chosen from the production batch for determination of the radon diffusion coefficient

3.1.3
radon diffusion coefficient
D
radon activity permeating due to molecular diffusion through unit area of a monolayer material of unit thickness per unit time at unit radon activity concentration gradient on the boundaries of this material

3.1.4
equivalent radon diffusion coefficient
D_{eqv}
radon diffusion coefficient of the multilayer material that numerically equals to the radon diffusion coefficient of a homogeneous material of the same thickness as the layered material through which radon penetrates in the same amount as through the layered material

3.1.5
radon diffusion length
l
distance crossed by radon due to diffusion in which activity is reduced by "e" times because of decay

Note 1 to entry: Numeric "e" is the natural logarithm, equal to about 2,72.

Note 2 to entry: Radon diffusion length is expressed by the relationship given in the following formula:

$$l = (D/\lambda)^{1/2} \tag{1}$$

where

l is the radon diffusion length, in metres;

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

λ is the radon decay constant, in per second.

3.1.6
diffusive radon surface exhalation rate
E
value of the activity concentration of radon atoms that leave a material per unit surface per unit time

Note 1 to entry: For the purpose of this document, only the diffusion transport through the sample is taken into account. The diffusive radon exhalation rate is given by the following formula (Fick's law):

$$E(x) = -D\frac{\partial C(x)}{\partial x} \tag{2}$$

where

$E(x)$ is the distribution function along the axis "x" of the radon exhalation rate in the sample, in Becquerel per square metre per second;

$C(x)$ is the distribution function along the axis "x" of the radon activity concentration in the sample, in Becquerel per cubic metre;

D is the radon diffusion coefficient of the sample, in square metre per second;

x is the coordinate on axis "x" (the axis is directed along radon transport and perpendicular to the sample surface), in metre.

3.1.7
non-stationary radon diffusion
time-dependent radon diffusion through the sample when the radon activity concentration within the sample is changing (in dependence on time, distance from the surface exposed to radon and the radon activity concentration in the source container) and the radon surface exhalation rate from the sample into the receiver container is also changing

Note 1 to entry: One-dimensional non-stationary radon diffusion is described by the partial differential equation:

$$D \cdot \frac{\partial^2 C(x,t)}{\partial x^2} - \lambda \cdot C(x,t) = \frac{\partial C(x,t)}{\partial t} \quad (3)$$

where

D is the radon diffusion coefficient of the sample, in square metre per second;

$C(x,t)$ is the function changing in time along the axis "x" of radon activity concentration in the sample, in Becquerel per cubic metre;

x is the coordinate on axis "x" (the axis is directed along radon transport and perpendicular to the sample surface), in metre;

λ is the radon decay constant, in per second.

Note 2 to entry: Non-stationary radon diffusion occurs during the time when radon activity concentration in the source container is not steady and in the time interval that immediately follows the moment when the steady concentration in the source container is established.

3.1.8
stationary radon diffusion
time-independent radon diffusion through the sample; stationary radon diffusion is characterized by a stable (time-independent) radon distribution within the sample and consequently by a stable radon surface exhalation rate from the sample into the receiver container (long term test methods)

Note 1 to entry: One-dimensional stationary radon diffusion is described by the differential equation:

$$D \cdot \frac{\partial^2 C(x)}{\partial x^2} - \lambda \cdot C(x) = 0 \quad (4)$$

where

D is the radon diffusion coefficient of the sample, in square metre per second;

$C(x)$ is the distribution function along the axis "x" of the radon activity concentration in the sample, in Becquerel per cubic metre;

x is the coordinate on axis "x" (the axis is directed along radon transport and perpendicular to the sample surface), in metre;

λ is the radon decay constant, in per second.

3.1.9
decisive measurement of radon activity concentrations
measurement of the time courses of radon activity concentrations in the source and receiver containers used for calculating the radon diffusion coefficient

Note 1 to entry: The duration of the decisive measurement can be shorter or the same as the duration of the test.

3.1.10
decisive volume of the container
V
volume of the container used to calculate the radon diffusion coefficient

3.1.11
decisive sample area
S_s
material sample area used to calculate the radon diffusion coefficient

3.1.12
minimum duration of the decisive measurement for non-stationary radon diffusion
period of time in the frame of the decisive measurement of radon activity concentrations in the source and receiver containers taken during the phase of non-stationary diffusion ensuring the uncertainty of the radon diffusion coefficient assessment lower than ±20 %

3.1.13
minimum duration of the decisive measurement for stationary radon diffusion
period of time in the frame of the decisive measurement of radon activity concentrations in the source and receiver containers taken during the phase of stationary diffusion ensuring the uncertainty of the radon diffusion coefficient assessment lower than ±20 %

3.1.14
minimum radon activity concentration in the source container
concentration of radon in the source container which for the particular sample characterized by the d/l ratio ensures values of radon activity concentration in the receiver container measurable with uncertainty lower than 10 %

3.1.15
radon transfer coefficient
radon transport in thin boundary layer of air near the surface of the sample

Note 1 to entry: In this boundary, layer radon activity concentration on the surface of the sample equalizes with radon activity concentration in the surrounding air.

Note 2 to entry: For waterproof materials, the default value of the radon transfer coefficient is 0,1 $m \cdot s^{-1}$

3.1.16
standard uncertainty of a variable
X
standard deviation of a variable *X*

3.1.17
relative uncertainty of a variable *X*
$u(X) = k \cdot s(X)/EX$

where

EX is the expected value of a variable X;

k is the shrinkage factor (k = 1,96 by default for 95 % confidence interval).

3.2 Symbols

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

λ radon decay constant, in per second

λ_V radon leakage rate characterizing the ventilation of the receiver container, in per second

C radon activity concentration in the sample, in Becquerel per cubic metre

C_a radon activity concentration in a particular container of the measuring device, in Becquerel per cubic metre

C_s radon activity concentration on the surface of the sample, in Becquerel per cubic metre

C_{rc} radon activity concentration in the receiver container, in Becquerel per cubic metre

C_{sc} radon activity concentration in the source container, in Becquerel per cubic metre

D radon diffusion coefficient of the monolayer sample, in square metre per second

D_{eqv} equivalent radon diffusion coefficient of the multilayer sample, in square metre per second

d thickness of the sample, in metre

E diffusive radon surface exhalation rate, in Becquerel per square metre per second

E_{rc} diffusive radon surface exhalation rate from the sample to the receiver container, in Becquerel per square metre per second

h radon transfer coefficient, in metre per second

l radon diffusion length, in metre

S_s decisive area of the sample, in square metre

t time, in second

Δt duration of the considered time step between time t_{i-1} and t_i, in second

V decisive volume of the receiver container, in cubic metre

x distance within the tested sample measured from the surface of the sample exposed to radon, in metre

$u(X)$ relative uncertainty of a variable X, in relative units

$s(X)$ standard uncertainty of a variable X, in same units as variable X

4 Principle of the test method

The sample of the tested material is placed between the air-tight source and the receiver containers, and the joint is carefully sealed.

Radon activity concentration in both containers shall be measured using continuous or spot measurement methods as specified in ISO 11665-5 and ISO 11665-6.

By means of the radon source with stable radon production rate, the radon activity concentration in the source container is kept on a high level (usually within the range 1 MBq·m^{-3} to 100 MBq·m^{-3}). The radon that diffuses through the sample is monitored using calibrated radon monitor in the receiver container.

Using an appropriate mathematical process (either analytical or numerical), the radon diffusion coefficient is afterwards calculated from the time-dependent courses of the radon activity concentrations measured in the source and receiver containers, and the area and thickness of the tested sample. In case of multilayer samples, the above described principle results in determination of the equivalent radon diffusion coefficient D_{eqv}.

5 Measuring system

5.1 Components of the measuring system

The measuring system for determining the radon diffusion coefficient in the waterproof materials shall comprise the following components:

a) at least two air-tight containers (source and receiver), each with a minimum air volume of 0,5 × 10^{-3} m^3 or when the spot measurement method for radon activity concentration is going to be used, the minimum air volume should be at least 10 times larger than the total volume of spot samples taken from each of the containers during the test performance, and made from metal materials (for example, aluminium, stainless steel, etc.) of a thickness at least 5 × 10^{-4} m that effectively eliminates radon transport between the air inside and outside the containers; each container shall be equipped with a test area of at least 5 × 10^{-3} m^2 surrounded by flanges for fixing the tested material; the minimum width of the flanges shall be 0,01 m and their arrangement shall eliminate the transport of radon from the source container to the receiver container; each container shall be further equipped with an appropriate number of valves intended for ventilating the containers, for measuring the pressure differences between the containers, for extracting air samples for control measurements of radon activity concentration and for connecting to the radon source;

b) a measuring instrument capable of determining the thickness of the tested sample with accuracy ±0,01 mm (maximum standard relative uncertainty of measurement 5 %);

c) a source of radon with stable radon production rate capable of creating a radon activity concentration in the source container within the range 1 MBq·m^{-3} to 100 MBq·m^{-3};

d) an air-tight flow pump with the range of air flow rates 6 × 10^{-3} m^3/h to 30 × 10^{-3} m^3/h that is used in some measurement methods in a closed circuit with a radon source and a source container;

e) a calibrated measuring device for monitoring the radon activity concentration in the receiver container with standard relative uncertainty 10 % and a dynamic measuring range from 500 Bq·m^{-3} to 1,0 MBq·m^{-3};

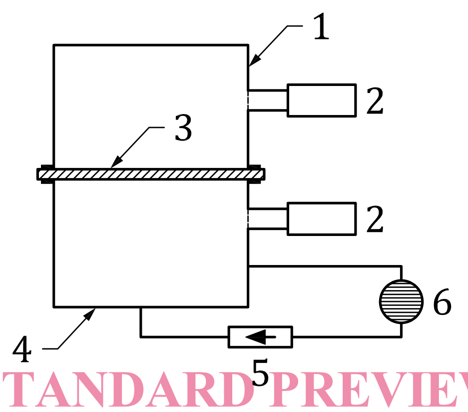
f) a calibrated measuring device for monitoring the radon activity concentration in the source container with standard relative uncertainty 10 % and a dynamic measuring range from 10 kBq·m^{-3} to 100,0 MBq·m^{-3};

g) a measuring instrument for determining the relative pressure difference between the air volume in the source container and the air volume in the receiver container with standard relative uncertainty of 10 % and a dynamic measuring range from 1 Pa to 150 Pa;

h) suitable sensors and a data storage system capable of continuously monitoring the temperature and relative humidity of air, atmospheric pressure and radon activity concentration in the place where the measuring device is positioned.

5.2 Configuration of the measuring system

In the simplest case, the measuring system can comprise one source container, one receiver container and a radon source connected to the source container (see Figure 1). If more than one sample is to be measured under equal conditions, it is convenient to use a measuring system comprising more than one receiver container assembled on one source container (see Figure 2), or a set of pair containers (source + receiver) connected to the radon source in a parallel circuit (see Figure 3) or connected to each other and to the radon source through the source containers in a serial circuit.



Key

1 receiver container

2 radon detector

3 tested sample

4 source container

5 pump

6 radon source

Figure 1 — Measuring system comprising one receiver container and one source container