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

Part 11:
Test method for soil gas with sampling at depth

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

Partie 11: Méthode d'essai pour le gaz du sol avec un prélèvement en profondeur

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information.

The committee responsible for this document is 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*

— *Part 9: Test methods for exhalation rate of building materials*

— *Part 11: Test method for soil gas with sampling at depth*

The following part is under preparation:

— *Part 10: Determination of the 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. Reference [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 ISO 11665 refer only to radon-222.

Radon activity concentration can vary from 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.

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 (building materials) and ISO 13164 (water).

Measurements of radon in the soil gas are performed for several applications dealing with radon risk management (drawing up of radon potential maps, defining radon-prone areas, characterization of radon potential of building sites, characterization of soil contaminated with radium-226, defining mitigation techniques to be applied in a building, verification of applied mitigation techniques, etc.), and phenomenological observation (understanding radon transport mechanisms in the soil and from the soil into the building, identification and analysis of radon entry parameters, gas activity measurement for survey of CO_2, volcanic eruption prediction, earthquake prediction, etc.).

The radon activity concentrations in the soil gas not only vary substantially at the season scale but also from day to day and even from hour to hour. It also varies in space in the horizontal, as well as the vertical dimension, depending on the following parameters characterizing the soil properties[3][4][5][19]:

- geochemical parameters of soils (mainly distribution of uranium and radium in soils and rocks and their localization influencing the radon emanation);
- physical parameters of all present layers of soils (grain size, permeability, porosity and effective porosity, soil moisture and water saturation, density);
- geological situation (thickness of Quaternary cover, weathering character of the bedrock, stratification, modification of layers by various antropogeneous activities);
- soil structure (deformation, presence of cracks);
- hydrological and geodynamic processes (transport of gaseous and liquid substances in porous and fractured environment, radium and radon in underground/fissure water);
- geomorphological situation (location of the area in a valley, on the slopes, or on the top of a hill);
- exogenous/meteorological factors (temperature, pressure, precipitation).

Because of these fluctuations, standardized measurement protocols are needed in order to ensure accurate and consistent measurement results of radon in the soils to ensure that they can be compared in time and space.

Depending on the depth, the values usually found in the soil gas are normally between a few hundred becquerels per cubic metre and several hundred of thousand becquerels per cubic metre. Activity concentrations can reach several billions of becquerels per cubic metre in radium-rich soils.

Theoretically, the radon activity concentration in the soil gas can be defined for any variable depth below the ground surface and it generally increases with depth below the surface in an ideal homogeneous soil[6]. But there is a minimal depth below the ground surface, at which the parameter can be really measured. The minimal depth depends on the soil properties at a given place and on the measurement method used. In particular, it depends on the volume of the soil gas sample. When the depth below the ground surface is lower than the above mentioned minimal depth, the soil gas sample is diluted with atmospheric air and the real value of radon activity concentration in the soil gas is underestimated (see Annex A).

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 11:
Test method for soil gas with sampling at depth

1 Scope

This part of ISO 11665 describes radon-222 test methods for soil gas using passive and active in-situ sampling at depth comprised between surface and 2 m.

This part of ISO 11665 gives general requirements for the sampling techniques, either passive or active and grab or continuous, for in-situ radon-222 activity concentrations measurement in soil gas.

The radon-222 activity concentration in the soil can be measured by spot or continuous measurement methods (see ISO 11665-1). In case of spot measurement methods (ISO 11665-6), the soil gas sampling is active only. On the other hand, the continuous methods (ISO 11665-5) are typically associated with passive soil gas sampling.

The measurement methods are applicable to all types of soil and are determined according to the end use of the measurement results (phenomenological observation, definition or verification of mitigation techniques, etc.) taking into account the expected level of the radon-222 activity concentration.

These measurement methods are applicable to soil gas samples with radon activity concentrations greater than 100 Bq/m^3.

NOTE This part of ISO 11665 is complementary with ISO 11665-7 for characterization of the radon soil potential.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10381-7, *Soil quality — Sampling — Part 7: Guidance on sampling of soil gas*

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 ionizing radiation measurements — Fundamentals and application*

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 the following apply.

3.1.1
water saturation of soil
part of soil pores filled with water

3.1.2
effective soil porosity
ratio of the volume of soil pores, which is available for transport, and the volume of soil

3.1.3
effective air porosity
ratio of the volume of soil pores filled with air, which is available for transport, and the volume of soil

3.1.4
activity concentration in soil air
activity per unit volume of soil air

3.1.5
active soil-gas sampling
sampling by extracting a certain volume of soil-gas

[SOURCE: ISO 10381-7:2005]

3.1.6
passive soil-gas sampling
sampling performed without employing negative pressure or suction

3.1.7
dead volume
volume which is present between suction opening of the soil-gas probe and the sampling vial or the detection chamber

3.1.8
soil-gas sampling probe
probe, generally a tube, which is installed directly in soil (one-stage soil-gas sampling), to take soil-gas samples

3.1.9
one-stage soil-gas sampling
sampling of soil-gas directly from a soil-gas probe placed in soil, without pre-drilling

[SOURCE: ISO 10381-7:2005]

3.2 Symbols

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

C	Activity concentration, in becquerel per cubic metre
μ	Quantity to be measured
μ_0	Background level
ε	Correction factor linked to the calibration factor
V_s	Volume of the soil gas extracted from the soil during the soil gas sampling, in cubic metre
V_{soil}	Volume of a sphere of an homogeneous soil, which contains the volume, V_s, of soil gas available for extraction, in cubic metre

r	Radius of the sphere of an homogeneous soil, in metre
s	Water saturation of soil
n_{eff}	Effective soil porosity
n_{a}	Effective air porosity
$u(\,)$	Standard uncertainty associated with the measurement result
$u_{\mathrm{rel}}(\,)$	Relative uncertainty associated with the measurement result
U	Expanded uncertainty calculated by $U = k \cdot u(\,)$ with $k = 2$
C^{*}	Decision threshold of the activity concentration, in becquerel per cubic metre
$C^{\#}$	Detection limit of the activity concentration, in becquerel per cubic metre
$C^{\triangleleft}, C^{\triangleright}$	Lower and upper limit of the confidence interval, respectively, of the activity concentration, in becquerel per cubic metre

4 Principle

When the active soil gas sampling is used, the measurement of the radon activity concentration in the soil gas is based on the following:

— sampling of a volume of soil gas representative of the soil under investigation at time, t, or during time interval Δt;

— transfer of the soil gas sample into the detection chamber;

— measurement of the physical variable (photons, pulse counts and amplitude, etc.) linked to the radiation emitted by radon and/or its decay products present in the detection chamber after the transfer of the soil gas sample.

When the passive soil gas sampling is used, the measurement of the radon activity concentration in the soil gas is based on the following:

— placing of the detection chamber to the place below the ground surface representative of the soil under investigation during time interval Δt;

— passive transfer of the soil gas sample into the detection chamber by diffusion;

— measurement of the physical variable linked to the radiation emitted by radon and/or its decay products present in the detection chamber after the transfer of the soil gas sample.

Several measurement methods meet the requirements of this part of ISO 11665. They are basically distinguished by the type of the sampling and measurement of the physical quantity.

5 Equipment

The apparatus includes the following:

a) soil-gas sampling probe installed directly in soil if an active sampling is performed;

b) device for placing the detection chamber to the chosen place below the ground surface if a passive sampling is used;

c) detection chamber;

d) measuring system adapted to the physical quantity.

The necessary equipment for specific measurement methods is specified in Annex B and Annex C.

6 Sampling

6.1 Sampling objective

The sampling objective is to obtain an air sample representative of the soil without creating a perturbation of the soil.

6.2 Sampling characteristics

The sampling is passive or active. The sampling is grab or continuous.

The sampling is representative of the radon activity concentration at a given place and at a given depth (or at a given depth interval) below the ground surface.

Grab sampling is representative of the radon activity concentration in the soil at a given moment.

Continuous sampling is representative of the radon activity concentration in the soil at a given time interval.

Active sampling is based on the extraction of the soil-gas sample by applying a negative pressure on the gas-soil sampling probe (using a syringe, pump, etc.).

Passive sampling is based on the transport of the soil gas from the soil into the detection chamber by diffusion.

6.3 Sampling conditions

6.3.1 General

Sampling shall be carried out as specified in ISO 11665-1 and ISO 10381-7. The sampling location, the sampling depth (or depth interval) and the sampling time (or time interval) shall be recorded.

The sampling method shall enable that the sampling depth (or depth interval) is well-defined and cannot be influenced by changes of other parameters (soil permeability, soil moisture, meteorological conditions, and others).

Circumstances in cold conditions make soil-gas sampling difficult in many ways. Ground frost greatly limits the mobility of gas in soil and should be considered in planning and carrying out sampling, as well as interpreting the measurement results. Similarly, water saturated ground can limit mobility (see ISO 10381-7).

When sampling soil gas close to the surface, the effect of ambient air penetration needs to be considered. It is considered unlikely that useful samples can be collected at depth less than 0,5 m. To avoid dilution of the soil-gas sample,

- a minimum depth of 1 m is recommended,
- the sampling method, especially the volume of the soil gas sample, shall correspond to the soil properties at a given place and to the chosen sampling depth if an active sampling is used,
- all parts of the soil-gas sampling probe shall be perfectly sealed if an active sampling is used,
- a penetration of the ambient air through leakages along the soil-gas sampling probe shall be avoided if an active sampling is used, and
- a penetration of the ambient air into the chamber of a passive sampling device shall be avoided.

If a passive sampling is used, the preparatory works before placing the detection chamber to the chosen place below the ground surface shall be performed in order to limit perturbation of the soil. It should be considered that any invasive activity can affect migration patterns and acts as a pathway for the gas. A hand-held auger may be used to bore into the ground.

If a measuring system is used in the field, check that the variations of meteorological conditions which can be met in the field are in the range of operation conditions.

In case of some active sampling and measurement methods, the soil-gas sample shall be filtered before the transfer of the sample into the detection chamber. The filtering medium shall stop the aerosol particles present in the soil gas at the time of sampling, especially the radon decay products and the soil moisture. When the delay between the soil-gas sampling and the beginning of measurement is longer than three hours, the filtering of the radon decay products are not needed.

The soil-gas sampling probe shall not include components that trap the radon (desiccants, etc.).

Detailed requirements related to sampling conditions are specified in Annex B and Annex C.

6.3.2 Location of sampling place

Sampling may be carried out in any kind of soil.

The location and number of the sampling points should be planned in advance in accordance with the aims of the site investigations (for example, verification of the homogeneity of the activity concentrations in an environment or search for anomalies, etc.).

The spacing of the sampling points is dependent on the nature of the strata (see ISO 10381-7).

6.3.3 Sampling duration

Sampling duration depends on the objectives sought and on the sampling method used (spot, continuous, or integrated).

6.3.4 Volume of air sampled

The volume of soil-gas sample can be determined accurately for example,

- with a part of the soil-gas sampling probe that enables to determine the volume of the soil-gas sample directly (syringe),
- with a flow-meter corrected for the temperature and pressure variation (expressed in m^3 at standard pressure and temperature, 1,013 hPa and 0°C), and
- by deducing it from a pressure measurement when sampling is carried out by applying a negative pressure via suction.

The extraction of soil gas during sampling reduces pressure in the pore space and hence influences phase and solution equilibria. To limit these influences, especially when taking point samples, volume of <1 l and flow rates up to a maximum of 2 l/min are recommended. For soils exhibiting low gas permeability and a small gas pore volume, even lower flow rates should be used (see ISO 10381-7).

6.3.5 Minimal depth of sampling

The radon activity concentration in the soil gas can be theoretically defined for any variable depth below the ground surface. But there is a minimal depth below the ground surface at which the parameter can be really measured. The minimal depth depends on the soil properties at a given place and on the measurement method used. In particular, it depends on the volume of the soil gas sample. When the depth below the ground surface is lower than the above mentioned minimal depth, the soil gas sample is diluted with atmospheric air and the real value of radon activity concentration in the soil gas is underestimated.

If a homogeneous soil environment is assumed, the minimal sampling depth can be derived using a spherical model.

The radius, *r*, is calculated by Formula (1):

$$r = \left[\frac{\left(3 \cdot V_\mathrm{s}\right)}{4 \cdot \pi \cdot n_\mathrm{a}} \right] \tag{1}$$

with

$$n_\mathrm{a} = n_\mathrm{eff} \cdot \left(1 - s\right)$$

In the homogeneous soil environment, the minimal sampling depth should be larger than the radius, *r*.

As the real soil environment is almost never homogeneous, the minimal sampling depth should be at least twice larger than the radius, *r*, under normal field conditions.

Informative values of radius, *r*, calculated for different values of V_s (0,2; 1; 5; 25 l), for a typical range of water saturation, *s*, (from 45 % to 90 %) and for a typical range of soil porosity, n_eff, (from 25 % to 40 %) are presented in Annex A.

7 Detection

Different detection methods may be used to measure the radon activity concentration of the sampled air.

For grab sampling, the detection methods are described in ISO 11665-6.

For continuous sampling, the detection methods are described in ISO 11665-5.

8 Measurement

8.1 Procedure

The examples of available measurement procedures for different sampling and measurement methods are detailed in Annex B and Annex C.

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 quoted in IEC 61577-1 and ISO 11665-1, the following quantities shall be, particularly, considered:

- uncertainty associated with the determination of the real sampling depth (depth interval) below the ground surface;
- the soil characteristics (permeability, soil humidity, soil temperature, and others);
- the instrumental background noise;
- influence of changes of soil characteristics (moisture, temperature, CO_2 level, CH_4 level, etc.) on the response of the measuring system. In this case, both parameters shall be measured and results of the radon activity concentration in the soil gas shall be corrected. The measuring system shall be used under conditions specified by the manufacturer;
- influence of any meteorological parameter on the response of the measuring system. In this case, such parameter shall be measured and results of the radon activity concentration in the soil gas shall be corrected;

- the presence of thoron (radon-220) and its decay products. In order to avoid thoron interference, sufficient delay between the soil-gas sampling and the detection chamber shall be used.

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

Passive detection of radon isotopes depends on diffusion of radon atoms from the sites of their generation to the location of the detecting or collecting device. Because some radon decays en route to a passive detector in soil, the radon activity concentration measured by the detector shall be less than the concentrations in those soil pores where it is undiminished by diffusion to the detector cavity. The "true" radon activity concentration may be significantly underestimated especially in moist soils or when large detector cavities are used. As the soil moisture usually changes during a one-year cycle, a degree of underestimating may also change with time[16].

8.3 Calibration

No calibration facility for a calibration of the entire system (sampling system and measurement device) is available. The only way how to compare different methods consists of the following two steps:

- calibration of measurement devices for the measurement of radon-222 activity concentration in air (in soil gas);
- field intercomparison measurements (exercises) that enable to compare different sampling methods[20][21].

The relationship between the physical quantity measured by the detection device (count rate, etc.) and the activity concentration of the radon in the air sample shall be established based on the measurement of a radon-222 reference atmosphere. The radon-222 activity concentration in these reference atmospheres 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.

NOTE Field intercomparison measurements are not intended to be used as an intercalibration of methods and instruments. Measured values are not reported against a standard or reference measurement. Participant's results are compared to each other, in order to obtain an indication of the precision and deviations of various measurements.

9 Expression of results

9.1 Radon activity concentration

The radon activity concentration is calculated as given in Formula (2):

$$C = \left(\mu - \mu_0\right) \cdot \varepsilon \qquad (2)$$

9.2 Standard uncertainty

According to ISO/IEC Guide 98, the standard uncertainty of, C, is calculated as given in Formula (3):

$$u\left(C\right) = \sqrt{\varepsilon^2 \cdot \left(u^2\left(\mu\right) + u^2\left(\mu_0\right)\right) + C^2 \cdot u_{\mathrm{rel}}^2\left(\varepsilon\right)} \qquad (3)$$

9.3 Decision threshold and detection limit

The characteristics limits associated with the measurand are calculated according to ISO 11929.

9.4 Limits of the confidence interval

The lower limits, $C^{\triangleleft}$, and upper limits, $C^{\triangleright}$, of the confidence interval are calculated using Formula (4) and Formula (5) (see ISO 11929):

$$C^{\triangleleft} = C - k_{\mathrm{p}} \cdot u\left(C\right); p = \omega \cdot \left(1 - \gamma/2\right) \tag{4}$$

$$C^{\triangleright} = C + k_{\mathrm{q}} \cdot u\left(C\right); q = 1 - \omega \cdot \gamma/2 \tag{5}$$

where

$\omega = \Phi\left(y/u\left(y\right)\right)$ where Φ is the distribution function of the standardized normal distribution.

ω =1 may be set if $C \geq 4 \cdot u\left(C\right)$.

In this case, use Formula (6):

$$C^{\triangleleft\triangleright} = C \pm k_{1-\gamma/2} \cdot u\left(C\right) \tag{6}$$

γ = 0,05 with $k_{1\text{-}\gamma/2}$ = 1,96 are often chosen by default.

10 Test report

The test report shall be in accordance with the ISO/IEC 17025 requirements and shall contain the following information:

a) a reference to this part of ISO 11665, i.e. ISO 11665–11;

b) the measurement method including measuring device and measuring parameters;

c) an identification of the sample;

d) the sampling characteristic (active or passive);

e) the sampling time [date (day, month, year) and hour];

f) the duration of sampling;

g) the sampling location;

h) the volume of the soil-gas sample;

i) the sampling depth;

j) the units in which the results are expressed;

k) the test result, $C \pm u\left(C\right)$ or $C \pm U$, with the associated k value.

Complementary information can be provided such as the following:

l) the purpose of the measurement;

m) the probabilities α, β and (1-γ);

n) the decision threshold and the detection limit; depending on the customer request, there are different ways to present the result:

   - when the radon-222 activity concentration is compared with the decision threshold (see ISO 11929), the result of the measurement shall be expressed as $\leq C^{*}$ when the result is below the decision threshold;
   - when the radon-222 activity concentration is compared with the detection limit, the result of the measurement can be expressed as $\leq C^{\#}$ when the result is below the detection limit. If the detection limit exceeds the guideline value, it shall be documented that the method is not suitable for the measurement purpose;

o) the mention of any relevant information likely to affect the results:

   - weather conditions at the time of sampling;
   - water saturation of the soil at the time of sampling.

Annex A
(informative)

Values of soil-gas volumes available for extraction

Informative values of radius, *r*, calculated for different values of V_S (0,2; 1; 5; 25 l), for a typical range of water saturation, *s*, (from 45 % to 90 %) and for a typical range of soil porosity, n_{eff}, (from 25 % to 40 %) are presented in Table A.1.

Table A.1 — Radius *r* of a sphere of a homogeneous soil, which contains the volume, V_S, of soil gas available for extraction

V_S		n_{eff}	s	$1 - s$	n_a	r
m^3	l					m
0,0002	**0,2**	0,25	0,45	0,55	0,1375	**0,07**
		0,25	0,9	0,1	0,025	**0,124**
		0,4	0,45	0,55	0,22	**0,06**
		0,4	0,9	0,1	0,04	**0,106**
0,001	**1**	0,25	0,45	0,55	0,1375	**0,120**
		0,25	0,9	0,1	0,025	**0,212**
		0,4	0,45	0,55	0,22	**0,103**
		0,4	0,9	0,1	0,04	**0,181**
0,005	**5**	0,25	0,45	0,55	0,1375	**0,206**
		0,25	0,9	0,1	0,025	**0,363**
		0,4	0,45	0,55	0,22	**0,176**
		0,4	0,9	0,1	0,04	**0,31**
0,025	**25**	0,25	0,45	0,55	0,1375	**0,351**
		0,25	0,9	0,1	0,025	**0,62**
		0,4	0,45	0,55	0,22	**0,3**
		0,4	0,9	0,1	0,04	**0,53**

NOTE It is almost impossible to take large-volume soil gas samples in low permeable soils.

Annex B
(normative)

Measurement method using an active sampling

B.1 General

This Annex deals only with measurement method using active sampling from among the various methods able to meet the requirements of this part of ISO 11665.

This method is suitable for spot measurement.

B.2 Principle of the measurement method

The measurement of the radon activity concentration in soil gas using active sampling is based on the following:

- pounding a soil-gas sampling probe into the soil at the desired depth;
- sucking the soil gas with large volume syringe to introduce the soil-gas into the probe (to evacuate the air present in the probe);
- sampling soil gas by sucking with large volume syringe;
- introducing the soil gas sample into the detection volume;
- determining the radon-222 activity concentration.

B.3 Apparatus

The apparatus includes the following:

a) small-diameter hollow steel probe with a free, sharpened lower tip;

b) hammer;

c) rod wire;

d) rubber tube;

e) large volume syringes

f) detection chamber;

g) measuring system adapted to the physical quantity.

B.4 Sampling

The sampling system consists of a small-diameter hollow steel probe with a free, sharpened lower tip (“lost tip”, which remains in the soil after sampling)[5][9][10]. The probe is pounded into the ground to a desired depth below the ground surface using a hammer. A punch wire is then inserted into the probe and the tip is moved a few centimetres lower using a hammer again. This action creates a cavity at the lower end of the probe. A rubber tube is placed on the upper end of the probe. The soil gas is sucked and samples of a controlled volume are collected using a large volume syringe (see Table B.1).

Table B.1 — Sampling procedure

	Inserting the free, sharpened lower tip into the lower end of the sampling probe
	
	The probe with the tip is prepared at the sampling place
	Preparing the drive in head

Table B.1 *(continued)*

	The probe is pounded to a chosen depth using the special hammer and the drive in head
	Inserting of the punch wire into the probe
	The sharp tip is moved a few centimetres lower, which makes a cavity at the lower end of the probe

Table B.1 *(continued)*

	Preparation for sampling
	The soil-gas is first sucking to introduce the soil-gas into the probe
	The rubber tube is kept closed between the first and the second sampling
	The soil-gas sampling for measurement

The entire system shall be perfectly sealed. The use of a sampling system that is not perfectly sealed or that does not reach a sufficient level of under pressure to collect gas samples in soils of low permeability, may result in an underestimated radon activity concentration in the soil gas. Values of radon activity concentration lower than 1 kBq/m^3 are usually excluded from the evaluation because of possible sampling error.

The internal volume of the cavity, which is created at the lower end of the probe, shall be large enough to enable the sample collection. The soil gas samples are typically collected from a depth of about 1,0 m below the ground surface.

If the soil gas samples cannot be collected due to extremely low soil permeability, high groundwater saturation, or presence of shallow, solid rock layers, some modifications can be used. For example, if the soil permeability is very low, the cavity at the lower end of the sampling probe can be enlarged by retracting the probe about (0,10 to 0,15) m toward the surface.

NOTE Examples of other sampling devices are given in Annex D.

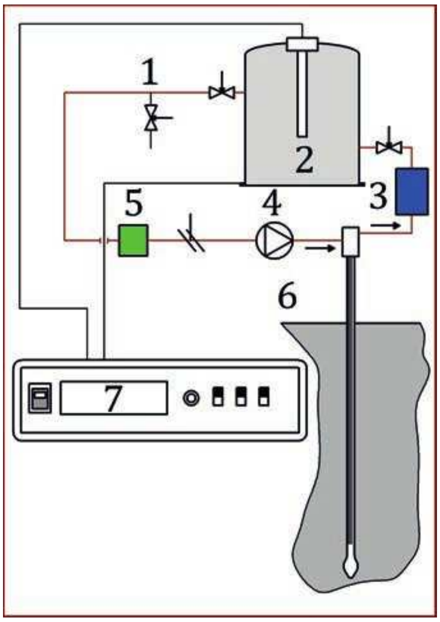
B.5 Detection

Spot measurement shall be performed following requirements of ISO 11665-6.

The samples are introduced into previously evacuated scintillation cells (Lucas cells, for example) or into ionization chambers (see Figure B.1).

Figure B.1 — Introduction of soil-gas sample into previously evacuated ionization chamber

The sampling system according to Figure B.2 can be used also for continuous sampling.



Key

1	control valves
2	detector IC
3	thoron
4	pump
5	flow meter
6	sampling probe
7	electrometer

Figure B.2 — System for continuous sampling and measurement of radon activity concentration in the soil gas[18]

B.6 Interference quantities

B.6.1 Temporal variability

Observed temporal variations of radon activity concentration in the soil gas do not reflect real variations of the measured parameter very often. They can be caused by the following:

- the fact that soil gas samples are partly diluted by the atmospheric air and the intensity of this negative influence changes with time;
- the fact that soil gas samples are sampled from different depths during the whole measurement period, the sampling depth is not well-defined (the soil is never homogeneous; properties of different soil layers change with time depending on changing meteorological conditions; the soil gas coming to an active sampling system “uses the easiest way”, i.e. at a given time, it comes preferably from layers with a higher permeability);
- the fact that the response of field measurement instruments may be influenced by changing meteorological conditions (especially very low air temperature may be critical).

All the above mentioned confusing effects should be eliminated especially in case when observation of the temporal variability itself represents the goal of the measurement.

B.6.2 Inappropriate sampling methods

Some available sampling methods are not suitable for taking soil-gas samples; for example, small-diameter probes inserted into previously drilled holes with a larger diameter. When the sampling system is sealed only on the top (close to the ground surface), the sampling depth is not well-defined.

Measured soil gas radon activity concentration cannot be then related to any sampling depth. The probability that soil gas sample is diluted with atmospheric air is very high.

B.6.3 Elimination of radon-220

For a continuous sampling, the influence of radon-220 is usually eliminated by inserting a delay line before the detection chamber and the beginning of measurement (counting).

When continuous active sampling system is used, a radon-220 suppression unit can be used for this purpose. The radon-220 additional signal is eliminated by the radioactive decay of radon-220 in a retarding piping system inserted in the close circuit (see Figure B.3).

Figure B.3 — Example of radon-220 suppression unit

Annex C
(normative)

Measurement method using a passive sampling

C.1 General

This Annex deals only with measurement method using passive sampling from among the various methods able to meet the requirements of this part of ISO 11665.

For long-term monitoring of soil-gas radon, different setups are used depending on the soil configuration (horizons), soil composition (sand, argillaceous sand, gravels, etc.) and local meteorology effect soil water contents. This Annex describes the most used configuration[17][11].

This method is suitable for continuous measurement.

C.2 Principle of the measurement method

The measurement of the radon activity concentration in soil gas using passive sampling is based on the following:

- drilling a hole in the soil at the desired depth with a hand-held auger;
- inserting a plastic tube in the hole;
- placing an autonomous detection device in the plastic tube;
- sealing the tube to avoid dilution with ambient air;
- performing the measurement during a long time;
- reading the detection device to determine the Rn activity concentration.

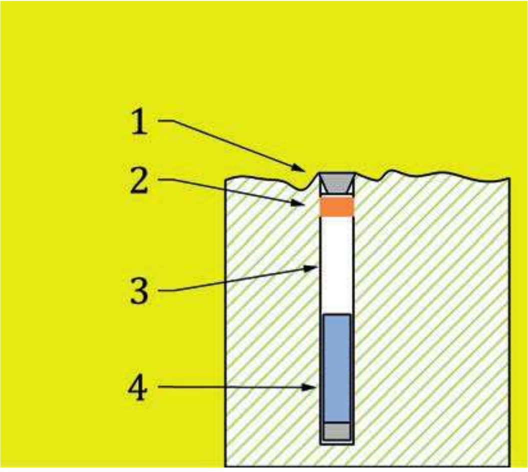
C.3 Sampling

Equipment shall follow requirements of ISO 10381-7 for volatile organic compounds.

A PVC pipe (1 m length and diameter adapted to the probe) is inserted vertically into the soil, open at the bottom and airtight closed at the top by a plastic[11][12][13][14][15].

The pipe shall be installed air-tight. Additional sealing with polyurethane foam may be necessary (see Figure C.1).

The installation of the PVC tubes may be very labour-intensive. But, this preparatory works before placing the detection chamber to the chosen place below the ground surface shall be performed in order to minimize perturbation of the soil.



Key

1 plug

2 foam

3 sampling probe

4 Rn measuring device

Figure C.1 — Example of sampling configuration

C.4 Detection methods

Continuous measurement shall be performed following requirements of ISO 11665-5. Compact and autonomous electronic probes based on silicon detector or alpha analyser with tubular geometry may be used. Probes shall contain dead volume at the entrance of the probe to overcome the isotope 220 of radon. Probes shall be designed to measure Rn activity concentrations ranging from a few hundred of Bq.m^{-3} to 10^9 Bq.m^{-3} with an autonomy of several months.

C.5 Interference parameters

Various quantities can lead to measurement bias when using any passive sampling systems for measurement of the radon activity concentration in the soil gas that could make the result non-representative of the situation under investigation. Depending on the measurement method and the control of usual influence quantities quoted in IEC 61577-1 and ISO 11665-1, the following ones shall be, particularly, considered:

— determination of the real sampling depth can be complicated (or almost impossible);

— sealing of the measuring system in the soil can be complicated, it can be difficult to avoid a dilution of the soil gas sample with the atmospheric air;

— elimination of the radon-220 influence can be also complicated;

— the fact that the detector response may be strongly influenced by changing soil properties (especially by changes of soil temperature and of soil moisture).

Observed temporal variations do not reflect real variations of the measured parameter very often. They can be caused by the following:

a) the fact that soil gas samples are partly diluted by the atmospheric air and the intensity of this negative influence changes with time;

b) the fact that soil gas samples are sampled from different depths during the whole measurement period; the sampling depth is not well-defined (the soil is never homogeneous; properties of different soil layers change with time depending on changing meteorological conditions; the soil gas coming to a passive detection chamber “uses the easiest way”, i.e. it comes preferably from layers with a higher diffusion coefficient).

Annex D
(informative)

Examples of soil-gas sampling probes for active sampling

D.1 General

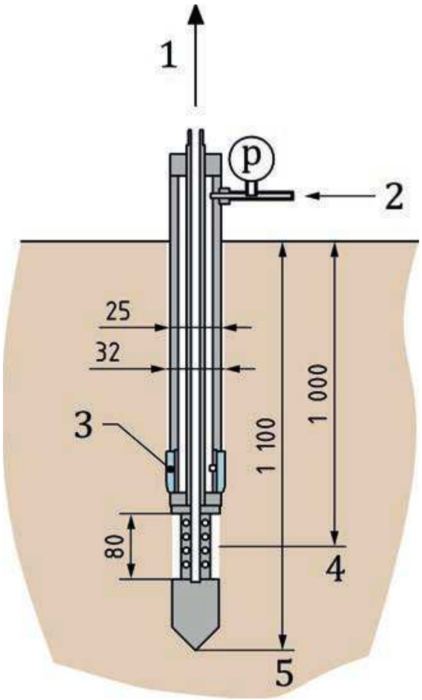
The soil-gas sampling probe represents a substantial part of instrumentation. Different sampling devices have been proposed, described and tested in the field[7][8][9][10].

D.2 Packer probes

A so-called “packer probes” has been proposed, tested and used in Germany[3][10]. It is a modification of the system originally described in Reference [7]. To measure the radon activity concentration in soil gas, an active spot measuring system with gas samples taken from a depth of 1 m is used. After sampling, several different detection methods can be used for measuring the radon activity concentration (e.g. electrostatic precipitation on semiconductor detectors followed by alpha spectrometry, ionization chamber, scintillation counters with Lucas cells).

In the first step, a bore hole with a depth of 1 m is drilled. In the second step, the probe is inserted into the hole. Afterwards, the packer is inflated by the valve on the upper end to tighten the lower end of the probe. The tightness can be controlled by a manometer. After pumping 10 l to 15 l soil gas from the borehole to avoid contamination by atmospheric air, an amount of 100 ml to 2 l (depending on the size of the sampling container) is sampled for radon measurement (see Figure D.1 and Figure D.2).

Dust, moisture and radon decay products can be filtered out of the soil gas by appropriate equipment, if desired or if necessary.



Key

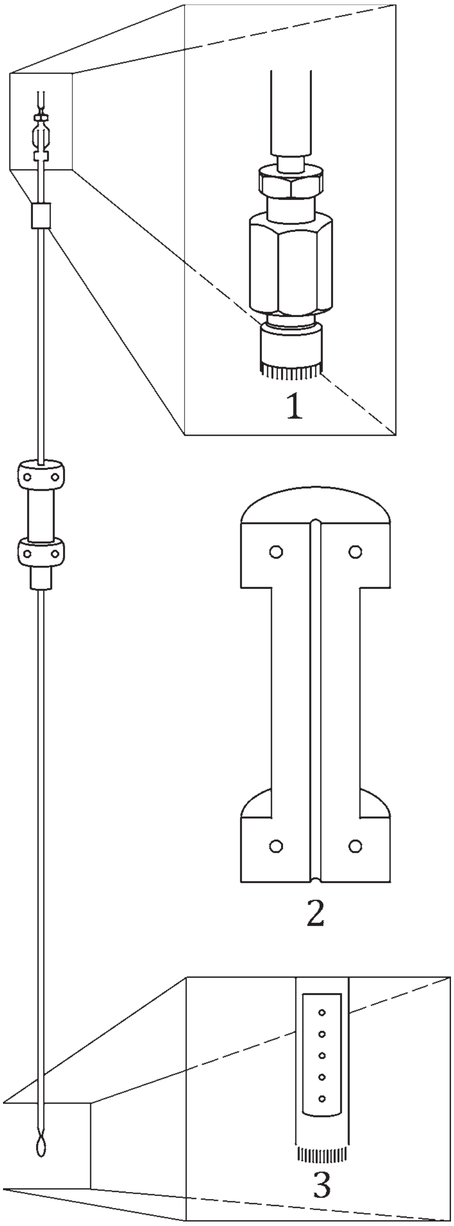
1	radon
2	air into packer
3	packer
4	sampling depth
5	depth of probe

Figure D.1 — Packer probe

Figure D.2 — Examples of packer probe

D.3 Other sampling devices

Other sampling systems have been described. One example is presented in Figure D.3[8]. It should be noted that the applicability of complicated sampling systems in the field is usually limited. Too complicated sampling systems tend to be damaged or destroyed during field work.



Key

1 needle guide CAP

2 sp;it hammer

3 probe TIP

Figure D.3 — Soil-gas sampling probe showing the tip, hammer and needle guide components as proposed in Reference [8]

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