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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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ISO 11665-11 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*

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

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

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

Introduction

Radon isotopes 222, 220 and 219 are radioactive gases produced by the disintegration of radium isotopes 226, 224 and 223, which are decay products of uranium-238, thorium-232 and uranium-235 respectively, and are all found in the earth's crust. Solid elements, also radioactive, followed by stable lead are produced by radon disintegration [1].

When disintegrating, radon emits alpha particles and generates solid decay products, which are also radioactive (polonium, bismuth, lead, etc.). The potential effects on human health of radon lie in its solid decay products rather than the gas itself. Whether or not they are attached to atmospheric aerosols, radon decay products can be inhaled and deposited in the bronchopulmonary tree to varying depths according to their size.

Radon is today considered to be the main source of human exposure to natural radiation. The UNSCEAR (2006) report [2] suggests that, at the worldwide level, radon accounts for around 52% of global average exposure to natural radiation. The radiological impact of isotope 222 (48%) is far more significant than isotope 220 (4%), while isotope 219 is considered negligible. For this reason, references to radon in this part of 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 this standard (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, characterisation of radon potential of building sites, characterisation 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, 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 many 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 measurements results of radon in the soils to ensure that they can be compared in time and space.

Depending of the depth, the values usually found in the soil gas are normally between a few hundreds 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/m3.

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

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 the 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 the radioactivity in the environment* — Air: Radon-222 — *Part 5: Continuous measurement method of the activity concentration.*

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

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

ISO 11929, *Determination of the characteristic limits (decision threshold, detection limit and limits of the confidence interval) for ionizing-radiation measurements — Fundamentals and application.*

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

IEC 61577-1, *Radiation protection instrumentation — Radon and radon decay product measuring instruments — Part 1: General principles.*

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

3 Terms, definitions and symbols

3.1 Terms and definitions

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

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

3.1.2
soil porosity
ratio of the volume of soil pores and the volume of soil

3.1.3
effective soil porosity
ratio of the volume of soil pores filled with air 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

[ISO 10381-7:2005]

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

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

[ISO 10381-7:2005]

3.2 Symbols

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

C	Activity concentration, in becquerel per cubic metre
μ	Quantity to be measured
μ_0	Background level
ω	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, in percent

n Soil porosity, in percent

n_{eff} Effective soil porosity, in percent

$u(\ )$ Standard uncertainty associated with the measurement result

$u_{rel}(\ )$ 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:

— 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:

— 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 standard. They are basically distinguished by the type of the sampling and measurement of the physical quantity.