INTERNATIONAL STANDARD

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

## Part 6:
## Spot measurement method of the activity concentration

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

*Partie 6: Méthode de mesure ponctuelle de l’activité volumique*

Reference number
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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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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 11665-6 was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiological protection*.

ISO 11665 consists of the following parts, under the general title *Measurement of radioactivity in the environment — Air: radon-222*:

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

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

— *Part 3: Spot measurement method of the potential alpha energy concentration of its short-lived decay products*

— *Part 4: Integrated measurement method for determining average activity concentration using passive sampling and delayed analysis*

— *Part 5: Continuous measurement method of the activity concentration*

— *Part 6: Spot measurement method of the activity concentration*

— *Part 7: Accumulation method for estimating surface exhalation rate*

— *Part 8: Methodologies for initial and additional investigations in buildings*

The following parts are under preparation:

— *Part 9: Method for determining exhalation rate of dense building materials*

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

# Introduction

Radon isotopes 222, 220 and 219 are radioactive gases produced by the disintegration of radium isotopes 226, 224 and 223, which are decay products of uranium-238, thorium-232 and uranium-235 respectively, and are all found in the earth's crust. Solid elements, also radioactive, followed by stable lead are produced by radon disintegration[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 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 commonly found in the continental environment are usually between a few becquerels per cubic metre and several thousand becquerels per cubic metre. Activity concentrations of one becquerel per cubic metre or less can be observed in the oceanic environment. Radon activity concentrations inside houses may vary from several tens of becquerels per cubic metre to several hundreds of becquerels per cubic metre[3]. Activity concentrations can reach several thousands of becquerels per cubic metre in very confined spaces.

The activity concentration of radon-222 in the atmosphere can be measured by spot, continuous and integrated measurement methods with active or passive air sampling (see ISO 11665-1). This part of ISO 11665 deals with radon-222 spot measurement methods.

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 6:
## Spot measurement method of the activity concentration

## 1 Scope

This part of ISO 11665 describes radon-222 spot measurement methods. It gives indications for carrying out spot measurements, at the scale of a few minutes at a given place, of the radon activity concentration in open and confined atmospheres.

This measurement method is intended for rapid assessment of the radon activity concentration in the air. The result cannot be extrapolated to an annual estimate of the radon activity concentration. This type of measurement is therefore not applicable for assessment of the annual exposure.

The measurement method described is applicable to air samples with radon activity concentration greater than 50 Bq/m$^3$.

NOTE For example, using an appropriate device, the radon activity concentration can be spot measured in the soil and at the interface of a material with the atmosphere (see also ISO 11665-7).

## 2 Normative references

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

ISO 11665-1, *Measurement of radioactivity in the environment — Air: radon-222 — Part 1: Origins of radon and its short-lived decay products and associated measurement methods*

ISO 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/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*

## 3 Terms, definitions and symbols

### 3.1 Terms and definitions

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

## 3.2 Symbols

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

| | |
|---|---|
| $C$ | activity concentration, in becquerels per cubic metre |
| $C^*$ | decision threshold of the activity concentration, in becquerels per cubic metre |
| $C^\#$ | detection limit of the activity concentration, in becquerels per cubic metre |
| $C^\triangleleft$ | lower limit of the confidence interval of the activity concentration, in becquerels per cubic metre |
| $C^\triangleright$ | upper limit of the confidence interval of the activity concentration, in becquerels per cubic metre |
| $U$ | expanded uncertainty calculated by $U = k \cdot u(\;)$ with $k = 2$ |
| $u(\;)$ | standard uncertainty associated with the measurement result |
| $u_{\mathrm{rel}}(\;)$ | relative standard uncertainty |
| $\mu$ | quantity to be measured |
| $\mu_0$ | background level |
| $\omega$ | correction factor linked to the calibration factor |

# 4 Principle

Spot measurement of the radon activity concentration is based on the following elements:

a) active grab sampling of a volume of air previously filtered and representative of the atmosphere under investigation at time $t$; this pre-filtered sample is introduced into the detection chamber;

b) measurement of the physical variable (photons, pulse counts and amplitude, etc.) linked to the radiation that is emitted by the radon and/or its decay products present in the detection chamber after sampling.

Several measurement methods meet the requirements of this part of ISO 11665. They are basically distinguished by the type of physical quantity and how it is measured. The physical quantity and its related measurement may be as follows, for example:

— photons emitted by a scintillating medium, such as ZnS(Ag), when excited by an alpha particle (see Annex A);

— gamma emission rates of the decay products $^{214}$Pb and $^{214}$Bi produced by the radon that is present in the sampled air volume.

The measurement results can be available immediately or after a certain period of time. Due to the great variability of the radon activity concentration in time and space, the measurement result is representative of the radon activity concentration at the sampling time and the sampling place only.

# 5 Equipment

The apparatus shall include the following:

a) a sampling device, including a filtering medium, for taking the air sample in the detection chamber; the role of the filtering medium is to stop the aerosols present in the air at the time of sampling, especially the solid radon decay products;

b) a device to pump the air for sampling if active sampling is required;

c) the detection chamber;

d) a measuring system adapted to the physical quantity.

The necessary equipment for a specific measurement method is specified in Annex A.

# 6 Sampling

## 6.1 Sampling objective

The sampling objective is to introduce an ambient air sample into the detection chamber of the device during a short period of time of less than 1 h.

## 6.2 Sampling characteristics

Sampling is active and may be carried out via pumping or suction in a detection chamber under vacuum.

Grab sampling is representative of the radon activity concentration at a given moment and a given place. An air sample adapted to the detection chamber of the measuring device used is taken directly in the atmosphere by pumping and filtering.

The filtering medium shall stop the aerosol particles present in the air at the time of sampling, especially the radon decay products.

The sampling device shall not include components that trap radon (desiccants, etc.).

## 6.3 Sampling conditions

### 6.3.1 General

Sampling shall be carried out as specified in ISO 11665-1. The sampling location and time (date and hour) shall be recorded.

### 6.3.2 Location of sampling place

Grab sampling may be carried out in the atmosphere, inside a building, in the ground or at the interface between a material and the atmosphere, etc.

The choice of each sampling location depends on the objectives sought (for example, verification of the homogeneity of the activity concentrations in an environment or a search for anomalies, etc.).

### 6.3.3 Sampling duration

Sampling is carried out over a short period of time. The sampling duration shall be less than one hour.

### 6.3.4 Volume of air sampled

The volume of air sampled shall be determined accurately with a flow-meter corrected for the temperature and pressure variation (expressed in cubic metres at a standard pressure and temperature of 1,013 hPa and 0 °C respectively) or by deducing it from a pressure measurement when sampling is carried out via suction (see Annex A).

# 7 Detection

Detection shall be carried out using silver-activated zinc sulphide ZnS(Ag) scintillation or gamma-ray spectrometry, as described in ISO 11665-1.

# 8 Measurement

## 8.1 Procedure

Measurement shall be carried out as follows.

a) Determine the background of the detection chamber.

b) Select and locate the measuring place.

c) Using grab sampling, collect an air sample representative of the atmosphere under investigation.

d) Record the location and time (date and hour) of sampling.

e) Wait until short-lived decay products are in equilibrium with radon in the detection chamber (3 h).

f) Measure the physical quantity emitted in the detection chamber with a suitable measuring chain.

g) Record the time (date and hour) of measurement.

h) Determine the activity concentration by calculation.

The measurement procedure for the scintillation method is detailed in Annex A.

## 8.2 Influence quantities

Various quantities can lead to measurement bias that could induce non-representative results. Depending on the measurement method and the control of usual influence quantities specified in IEC 61577-1 and ISO 11665-1, the following quantities shall be considered in particular:

a) the instrumental background noise;

b) the presence of other gaseous radionuclide alpha-emitters or gamma-emitters in the detection chamber, including other radon isotopes and their decay products.

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

## 8.3 Calibration

The entire measuring instrument (sampling system, detector and related electronics) shall be calibrated as specified in ISO 11665-1.

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 the reference atmosphere 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.

# 9 Expression of results

## 9.1 Radon activity concentration

The radon activity concentration shall be calculated as given in Formula (1):

$$C = \left(\mu - \mu_0\right) \cdot \omega \qquad (1)$$

### 9.2 Standard uncertainty

In accordance with ISO/IEC Guide 98-3, the standard uncertainty of $C$ shall be calculated as given in Formula (2):

$$u(C) = \sqrt{\omega^2 \cdot \left[u^2(\mu) + u^2(\mu_0)\right] + C^2 \cdot u_{\mathrm{rel}}^2(\omega)} \tag{2}$$

### 9.3 Decision threshold and detection limit

The characteristic limits associated with the measurand shall be calculated in accordance with ISO 11929. An example of the calculations of uncertainties and characteristic limits is detailed in Annex A for a specific measurement method.

### 9.4 Limits of the confidence interval

The lower, $C^{\triangleleft}$, and upper, $C^{\triangleright}$, limits of the confidence interval are calculated using Formulae (3) and (4) (see ISO 11929):

$$C^{\triangleleft} = C - k_p \cdot u(C); \quad p = \omega \cdot (1 - \gamma/2) \tag{3}$$

$$C^{\triangleright} = C + k_q \cdot u(C); \quad q = 1 - \omega \cdot \gamma/2 \tag{4}$$

where

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

$\omega = 1$ may be set if $C \geq 4 \cdot u(C)$, in which case:

$$C^{\triangleleft\triangleright} = C \pm k_{1-\gamma/2} \cdot u(C) \tag{5}$$

$\gamma = 0{,}005$ with $k_{1-\gamma/2} = 1{,}96$ are often chosen by default.

## 10 Test report

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

a) reference to this part of ISO 11665, i.e. ISO 11665-6:2012;

b) measurement method (spot);

c) identification of the sample;

d) sampling characteristic (active);

e) sampling time (date and hour);

f) duration of sampling;

g) sampling location;

h) units in which the results are expressed;

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

**10.2** Complementary information can be provided such as the following:

a) purpose of the measurement;

b) probabilities $\alpha$, $\beta$ and (1-$\gamma$);

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

   1) when the radon-222 activity concentration is compared with the decision threshold (see ISO 11929), the result of the measurement shall be expressed as $\leq C^*$ if the result is below the decision threshold;

   2) when the radon-222 activity concentration is compared with the detection limit, the result of the measurement shall be expressed as $\leq C^\#$ if the result is below the detection limit or, if the detection limit exceeds the guideline value, it shall be documented that the method is not suitable for the measurement purpose;

d) any relevant information likely to affect the results:

   1) weather conditions at the time of sampling;

   2) ventilation conditions for indoor measurement (mechanical ventilation system, doors and windows open or shut, etc.) prior to sampling (over a period of a few hours) and at the time of sampling.

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

# Annex A
(informative)

# Measurement method using scintillation cells

## A.1 General

This annex deals with the scintillation cell method, which is one of several methods that meet the requirements of this part of ISO 11665.

For the purpose of this annex, the symbols given in Clause 3 and following apply.

| | |
|---|---|
| $F_\mathrm{c}$ | calibration factor per alpha for counting carried out with a radioactive equilibrium between the radon and its short-lived decay products, in pulses per second per becquerel |
| $f_\mathrm{d}$ | correction factor for the decay of radon in the detection volume, dimensionless |
| $f_\mathrm{p}$ | correction factor for atmospheric pressure, dimensionless |
| $N_\mathrm{s}$ | number of gross counts |
| $N_0$ | number of background counts |
| $\bar{N}_\mathrm{s}$ | average number of gross counts |
| $\bar{N}_0$ | average number of background counts |
| $n$ | number of countings of each sample |
| $n_\alpha(t)$ | number of alpha emitters present in the cell per becquerel of radon after a waiting time between filling and counting the cell ($n_\alpha$ is approximately equal to 3 at a waiting time of 3 h for 1 Bq of radon) |
| $p_\mathrm{v}$ | pressure measured in the cell once under vacuum, in hectopascals |
| $p_\mathrm{r}$ | pressure measured in the cell after sampling, in hectopascals |
| $t_\mathrm{c}$ | counting duration (common to $N_\mathrm{s}$, $N_0$), in seconds |
| $V_\mathrm{sc}$ | cell volume, in cubic metres |
| $\lambda$ | decay constant of radon-222, per second |
| $\Delta t$ | elapsed time between the end of the sampling ($t = 0$) and the cell counting, in seconds |

## A.2 Principle of the measurement method

Measurement of the radon activity concentration using scintillation cells is based on the following elements:

a) active air sampling by filling a scintillation cell in which a vacuum is created prior to use; sampling is carried out via suction in the cell through a filter placed in a filter holder;

b) waiting until a radioactive equilibrium between the $^{222}$Rn and its short-lived decay products ($^{214}$Po, $^{218}$Po) is achieved in the scintillation cell (the alpha particles produced by the disintegration of the radon and its short-lived decay products transfer their energy as they travel to the scintillation medium; by returning to their ground state, the electrons energized in the scintillation medium emit photons);

c) detecting the photons emitted in the scintillation cells using a photomultiplier, converting them into electric pulses that are counted by a counting chain;

d) determining the radon activity concentration from the number of gross counts, the number of background counts, the sample volume, the counting duration and the calibration factor.

## A.3 Equipment

The apparatus shall include the following:

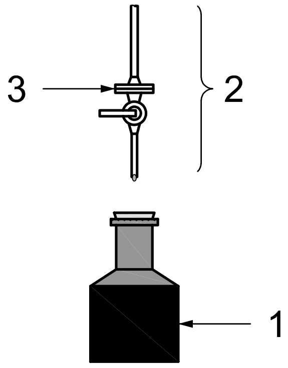
a) a device with a filtering medium placed in a filter holder for taking the air sample in the detection chamber (see Figure A.1);

b) a detection chamber made up of a scintillation cell used to take an air sample representative of the atmosphere under investigation; a scintillation cell is a hermetically-sealed glass flask with defined geometry and volume in which the internal surface, apart from the bottom, is covered in silver-activated zinc sulphide [ZnS(Ag)];

c) a device to create the vacuum in the cell;

d) a device to measure the pressure in the cell;

e) a counting chain equipped with a photomultiplier.



**Key**

1 scintillation cell

2 sampling device

3 filter

Figure A.1 — Example of a spot measuring system

## A.4 Sampling

### A.4.1 Sampling characteristics

A vacuum shall be created in the scintillation cell prior to use.

For optimal filling of the cell, the residual pressure in the cell before sampling shall be controlled and shall be lower than 40 hPa. Once sampling is terminated, the pressure inside the cell shall be controlled and shall be equal to the atmospheric pressure.

Sampling shall be carried out via suction in the cell through a filter placed in a filter holder.

### A.4.2 Sampling conditions

The sampling duration, equal to the time required for the scintillation cell to be filled when it reaches the atmospheric pressure, shall be less than 1 h.

The volume of air sampled shall be determined by measuring the pressure in the cell after the vacuum is created and after the sampling is terminated.

In order to improve the accuracy of the measurement, two scintillation cells with identical characteristics may be used for sampling the air at the same place.

## A.5 Measurement procedure

Measurement shall be carried out as follows.

a) Before using the cells, determine the background of each scintillation cell by counting the photons emitted before sampling for a suitable duration using a pre-calibrated photomultiplier placed in a lightproof enclosure.

b) Create a vacuum in the scintillation cells.

c) Measure the residual pressure in the cells and ensure the pressure stays below 40 hPa.

d) Select and locate the measuring place.

e) Take one or more air samples per sampling site using the scintillation cells.

f) Measure the pressure after filling the cells and ensure the pressure is equal to the atmospheric pressure.

g) Record the location and time (date and hour) of sampling.

h) Wait until a radioactive equilibrium between the $^{222}$Rn and its short-lived decay products ($^{214}$Po, $^{218}$Po) is achieved in the cell. For optimal counting, 3 h shall elapse after sampling in order to achieve radioactive equilibrium.

i) Count the number of photons emitted by the scintillation medium when excited by the alpha particles that are produced by the disintegration of the radon and its short-lived decay products present in the cells. A pre-calibrated photomultiplier placed in a lightproof enclosure shall be used for counting.

j) Determine the radon activity concentration by calculation.

It is assumed that the sample counting duration and the background counting duration are the same.

It is assumed that these counting durations are short compared with the radon half-life.

The accuracy sought shall dictate the counting duration and the number of countings for the sample.

## A.6 Expression of results

### A.6.1 Radon activity concentration

The spot radon activity concentration, $C$, is obtained from Formula (1). This yields Formula (A.1):

$$C = \frac{\left(\bar{N}_\mathrm{s} - \bar{N}_0\right) \cdot f_\mathrm{p}}{t_\mathrm{c} \cdot F_\mathrm{c} \cdot n_\alpha(t) \cdot V_\mathrm{sc} \cdot f_\mathrm{d}} = \left(\bar{N}_\mathrm{s} - \bar{N}_0\right) \cdot \omega \tag{A.1}$$

where

$$\bar{N}_\mathrm{s} = \frac{\sum_{j=1}^{n} N_{\mathrm{s}\,j}}{n} \quad \text{and} \quad \bar{N}_0 = \frac{\sum_{j=1}^{n} N_{0\,j}}{n}$$

$$\omega = \frac{f_\mathrm{p}}{t_\mathrm{c} \cdot F_\mathrm{c} \cdot n_\alpha(t) \cdot V_\mathrm{sc} \cdot f_\mathrm{d}} \tag{A.2}$$

where

$$f_\mathrm{p} = \frac{p_\mathrm{r}}{p_\mathrm{r} - p_\mathrm{v}} \tag{A.3}$$

$$f_\mathrm{d} = \exp(-\lambda \cdot \Delta t) \tag{A.4}$$

In practice, $f_\mathrm{p}$ is close to 1 and, for an optimum count, the cell counting should be performed 3 h after sampling, at which time the radioactive equilibrium between radon and its decay products is achieved. Therefore, $n_\alpha(t) \cong 3$ and Formula (A.1) may be simplified.

### A.6.2 Standard uncertainty

The standard uncertainty of $C$ is obtained from Formula (2). This yields Formula (A.5):

$$u(C) = \sqrt{\left(\bar{N}_\mathrm{s} + \bar{N}_0\right) \cdot \frac{\omega^2}{n} + C^2 \cdot u_\mathrm{rel}^2(\omega)} \tag{A.5}$$

The relative standard uncertainty of $\omega$ is calculated using Formula (A.6):

$$u_\mathrm{rel}^2(\omega) = u_\mathrm{rel}^2(F_c) + u_\mathrm{rel}^2(V_\mathrm{sc}) \tag{A.6}$$

where the uncertainties of the counting duration, the decay constant, the number of alpha emitters and the pressure are considered negligible.

Calculation of the characteristic limits (see ISO 11929) requires calculation of $\tilde{u}(\tilde{C})$, i.e. the standard uncertainty of $C$ as a function of its true value, calculated as given in Formula (A.7):

$$\tilde{u}(\tilde{C}) = \sqrt{\left(\frac{\tilde{C}}{\omega} + 2 \cdot \bar{N}_0\right) \cdot \frac{\omega^2}{n} + \tilde{C}^{\,2} \cdot u_\mathrm{rel}^2(\omega)} \tag{A.7}$$

### A.6.3 Decision threshold

The decision threshold, $C^*$, is obtained from Formula (A.7) for $\tilde{C} = 0$ (see ISO 11929).

This yields Formula (A.8):

$$C^* = k_{1-\alpha} \cdot \tilde{u}(0) = k_{1-\alpha} \cdot \omega \cdot \sqrt{\frac{2 \cdot N_0}{n}} \tag{A.8}$$

$\alpha = 0{,}05$ with $k_{1-\alpha} = 1{,}65$ is often chosen by default.

### A.6.4 Detection limit

The detection limit, $C^\#$, is calculated as given in Formula (A.9) (see ISO 11929):

$$C^\# = C^* + k_{1-\beta} \cdot \tilde{u}\left(C^\#\right) = C^* + k_{1-\beta} \cdot \sqrt{\left(\frac{C^\#}{\omega} + 2 \cdot \bar{N}_0\right) \cdot \frac{\omega^2}{n} + C^{\#2} \cdot u_\mathrm{rel}^2(\omega)} \tag{A.9}$$

$\beta = 0{,}05$ with $k_{1-\beta} = 1{,}65$ is often chosen by default.

The detection limit can be calculated by solving Formula (A.9) for $C^{\#}$ or, more simply, by iteration with a starting approximation $C^{\#} = 2 \cdot C^{*}$ in terms of the right side of Formula (A.9).

One obtains $C^{\#}$ with $k_{1-\alpha} = k_{1-\beta} = k$ :

$$C^{\#} = \frac{2 \cdot C^{*} + k^{2} \cdot \left(\omega / n\right)}{1 - k^{2} \cdot u_{\text{rel}}^{2}\left(\omega\right)} \tag{A.10}$$

Values $\alpha = \beta = 0{,}05$ and therefore $k_{1-\alpha} = k_{1-\beta} = 1{,}65$ are often chosen by default.

### A.6.5 Example

Measurement of the radon activity concentration in a cellar is achieved by sampling air with two scintillation cells at the same time.

Counting of the cells is carried out 3 h after sampling over a period of 3 min. The results are given below.

For the first cell with an average number of background counts $\bar{N}_0 = 3$ pulses:

$$\bar{N}_{\text{s1}} = \frac{280 + 268}{2} = 274 \text{ pulses}$$

For the second cell with an average number of background counts $\bar{N}_0 = 3$ pulses:

$$\bar{N}_{\text{s2}} = \frac{282 + 278}{2} = 280 \text{ pulses}$$

$$f_{\text{p}} = \frac{1\,030}{1\,030 - 35} = 1{,}035$$

$F_{\text{c}}$ = (0,6 ± 0,06) pulse/s/Bq per alpha

$V_{\text{sc}}$ = (125,0 ± 2,2) $\text{cm}^3$

$t_{\text{c}}$ = 180 s (the uncertainty of this variable is considered negligible)

$n_{\alpha} \approx 3$ for a waiting time = 3h (the uncertainty of this variable is considered negligible)

$\lambda = 2{,}1 \times 10^{-6}\ \text{s}^{-1}$ (the uncertainty of this variable is considered negligible)

NOTE 1 Uncertainties of the calibration factor and volume of the scintillation cells were estimated by the manufacturer from measurements carried out from a sample of one hundred cells.

For the first cell, the radon activity concentration at the time of counting is:

$$C = \frac{(274 - 3) \cdot 1{,}035}{180 \cdot 0{,}6 \cdot 3 \cdot 125 \cdot 10^{-6}} = 6\,925\ \text{Bq/m}^3$$

NOTE 2 The radon decay between sampling and counting is considered negligible.

The standard uncertainty of $C$ is calculated using Formula (A.5):

$$u(C) = 764\ \text{Bq/m}^3$$

Lastly, the result is expressed as follows:

$$C = (6\,925 \pm 764)\ \text{Bq/m}^3$$

The decision threshold, $C^*$, is obtained from Formula (A.8):

$$C^* = k_{1-\alpha} \cdot \tilde{u}(0) = 73\ \text{Bq/m}^3$$

The detection limit, $C^\#$, is calculated from Formula (A.10):

$$C^\# = 186\ \text{Bq/m}^3$$

For the second cell, the radon activity concentration at the time of counting is:

$$C = \frac{(280 - 3) \cdot 1{,}035}{180 \cdot 0{,}6 \cdot 3 \cdot 125 \cdot 10^{-6}} = 7\,079\ \text{Bq/m}^3$$

The standard uncertainty of $C$ is calculated using Formula (A.5):

$$u(C) = 780\ \text{Bq/m}^3$$

Lastly, the result is expressed as follows:

$$C = (7\,079 \pm 780)\ \text{Bq/m}^3$$

The decision threshold, $C^*$, is obtained from Formula (A.8):

$$C^* = k_{1-\alpha} \cdot \tilde{u}(0) = 73\ \text{Bq/m}^3$$

The detection limit, $C^\#$, is calculated from Formula (A.10):

$$C^\# = 186\ \text{Bq/m}^3$$

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