
Water quality — Radium-226 —
Part 2:
Test method using emanometry

Qualité de l'eau — Radium-226 —

Partie 2: Méthode d'essai par émanométrie

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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 of 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 www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 147, *Water quality*, Subcommittee SC 3, *Radioactivity measurements*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 230, *Water analysis*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 13165-2:2014), which has been technically revised.

The main changes compared to the previous edition are as follows:

- a common introduction has been added;
- the shortest coverage interval in accordance with the new ISO 11929 series has been introduced;
- the test report has been modified.

A list of all parts in the ISO 13165 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Radioactivity from several naturally-occurring and anthropogenic sources is present throughout the environment. Thus, water bodies (e.g. surface waters, ground waters, sea waters) can contain radionuclides of natural, human-made, or both, origins.

- Natural radionuclides, including ^{40}K , ^3H , ^{14}C , and those originating from the thorium and uranium decay series, in particular ^{226}Ra , ^{228}Ra , ^{234}U , ^{238}U and ^{210}Pb , can be found in water for natural reasons (e.g. desorption from the soil and washoff by rain water) or can be released from technological processes involving naturally occurring radioactive materials (e.g. the mining and processing of mineral sands or phosphate fertilizers production and use).
- Human-made radionuclides such as transuranium elements (americium, plutonium, neptunium, curium), ^3H , ^{14}C , ^{90}Sr and gamma emitting radionuclides can also be found in natural waters. Small quantities of these radionuclides are discharged from nuclear fuel cycle facilities into the environment as a result of authorized routine releases. Some of these radionuclides used for medical and industrial applications are also released into the environment after use. Anthropogenic radionuclides are also found in waters as a result of past fallout contaminations resulting from the explosion in the atmosphere of nuclear devices and accidents such as those that occurred in Chernobyl and Fukushima.

Radionuclide activity concentration in water bodies can vary according to local geological characteristics and climatic conditions and can be locally and temporally enhanced by releases from nuclear installation during planned, existing and emergency exposure situations^[1]. Drinking water can thus contain radionuclides at activity concentrations which can present a risk to human health.

The radionuclides present in liquid effluents are usually controlled before being discharged into the environment^[2] and water bodies. Drinking waters are monitored for their radioactivity as recommended by the World Health Organization (WHO)^[3] so that proper actions can be taken to ensure that there is no adverse health effect to the public. Following these international recommendations, national regulations usually specify radionuclide authorized concentration limits for liquid effluent discharged to the environment and radionuclide guidance levels for waterbodies and drinking waters for planned, existing, and emergency exposure situations. Compliance with these limits can be assessed using measurement results with their associated uncertainties as specified by ISO/IEC Guide 98-3^[13] and ISO 5667-20^[4].

Depending on the exposure situation, there are different limits and guidance levels that would result in an action to reduce health risk. As an example, during a planned or existing situation, the WHO guideline for guidance level in drinking water is $1 \text{ Bq}\cdot\text{l}^{-1}$ for ^{226}Ra activity concentration.

NOTE 1 The guidance level (GL) is the activity concentration with an intake of 2 l per day of drinking water for one year that results in an effective dose of $0,1 \text{ mSv}\cdot\text{a}^{-1}$ for members of the public. This is an effective dose that represents a very low level of risk and which is not expected to give rise to any detectable adverse health effects^[3].

In the event of a nuclear emergency, the WHO Codex Guideline Levels^[5] mentioned that the activity concentrations can be greater.

NOTE 2 The Codex GLs apply to radionuclides contained in food destined for human consumption and traded internationally, which have been contaminated following a nuclear or radiological emergency. These GLs apply to food after reconstitution or as prepared for consumption, i.e. not to dried or concentrated foods, and are based on an intervention exemption level of 1 mSv in a year for members of the public (infant and adult)^[5].

Thus, the test method can be adapted so that the characteristic limits, decision threshold, detection limit and uncertainties ensure that the radionuclide activity concentrations test results can be verified to be below the guidance levels required by a national authority for either planned/existing situations or for an emergency situation^{[6][7]}.

Usually, the test methods can be adjusted to measure the activity concentration of the radionuclide(s) in either wastewaters before storage or in liquid effluents before being discharged to the environment. The

test results enable the plant/installation operator to verify that, before their discharge, wastewaters/ liquid effluent radioactive activity concentrations do not exceed authorized limits.

The test method(s) described in this document can be used during planned, existing and emergency exposure situations as well as for wastewaters and liquid effluents with specific modifications that can increase the overall uncertainty, detection limit, and threshold.

The test method(s) can be used for water samples after proper sampling, sample handling and test sample preparation (see the relevant part of the ISO 5667 series).

This document has been developed to support the need of test laboratories carrying out these measurements, that are sometimes required by national authorities, as they can be required to obtain a specific accreditation for radionuclide measurement in drinking water samples.

This document is one of a series of International Standards on test methods dealing with the measurement of the activity concentration of radionuclides in water samples.

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Water quality — Radium-226 —

Part 2: Test method using emanometry

WARNING — Persons using this document should be familiar with normal laboratory practice. This document does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and to determine the applicability of any other restrictions.

IMPORTANT — It is essential that tests conducted in accordance with this document be carried out by suitably qualified staff.

1 Scope

This document specifies a test method to determine radium-226 (^{226}Ra) activity concentration in all types of water by emanometry.

The test method specified is suitable for the determination of the soluble, suspended and total ^{226}Ra activity concentration in all types of water with soluble ^{226}Ra activity concentrations greater than $0,02 \text{ Bq l}^{-1}$.

The decay chains of ^{238}U and ^{232}Th are given in Annex A. Figure A.1 shows the ^{238}U and its decay chain.

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 5667-3, *Water quality — Sampling — Part 3: Preservation and handling of water samples*

ISO 11929-1, *Determination of the characteristic limits (decision threshold, detection limit and limits of the coverage interval) for measurements of ionizing radiation — Fundamentals and application — Part 1: Elementary applications*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

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

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 80000-10 apply.

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.2 Symbols

For the purposes of this document, the symbols given in ISO 80000-10 and [Table 1](#) apply.

Table 1 — Symbols

Symbol	Description	Unit
c	Concentration	Bq·l ⁻¹
c_A	²²⁶ Ra activity concentration in water	Bq·l ⁻¹
c_A^*	Decision threshold	Bq·l ⁻¹
$c_A^\#$	Detection limit	Bq·l ⁻¹
$c_A^<, c_A^>$	Lower and upper limits of the probabilistically symmetric coverage interval	Bq·l ⁻¹
$c_A^{<}, c_A^{>}$	Lower and upper limits of the shortest coverage interval	Bq·l ⁻¹
f_a	Correction factor for ingrowth of ²²² Rn in the bubbler	—
f_d	Correction factor for the decay of ²²² Rn in the detection volume	—
i	Different steps of the measurement procedure, $i = 0, 1$ and 2	—
$k_{1-\alpha}$	Quantile of the standardized normal distribution for the false positive decision	—
$k_{1-\beta}$	Quantile of the standardized normal distribution for the false negative decision	—
k_p	Quantile of the standardized normal distribution for the probability p (for instance, $p = 1 - \alpha, 1 - \beta$ or $1 - \gamma/2$)	—
k_q	Quantile of the standardized normal distribution for the probability q (for instance, $q = 1 - \alpha, 1 - \beta$ or $1 - \gamma/2$)	—
n	Number of counting cycle	—
$n_\alpha(t)$	Number of alpha-emitters present in the cell per becquerel of radon after a waiting time period between the filling time and the counting time of the cell (n_α is approximately 3 at a waiting time of 3 h for 1 Bq of radon)	—
N_0	Number of background counts	—
N	Number of gross counts	—
\bar{N}_0	Average of number of background counts	—
\bar{N}	Average of number of gross counts	—
p	Probability (for instance $p = 1 - \alpha, 1 - \beta$ or $1 - \gamma/2$)	—
q	Probability	—
t_c	Counting time (common to N, N_0)	s
t_i	Time of the different steps of the measurement procedure, $i = 0, 1$ and 2	s
U	Expanded uncertainty calculated by $U = ku(c_A)$ with $k = 2$	Bq·l ⁻¹
u_{rel}	Relative standard uncertainty	—
$u(c_A)$	Standard uncertainty associated with the measurement result	Bq·l ⁻¹
$u(c_A^\#)$	Standard uncertainty of the $c_A^\#$	—
$\tilde{u}(\tilde{c}_A)$	Standard uncertainty of c_A as a function of its true value	—
$\tilde{u}(\tilde{a})$	Standard uncertainty of a as a function of its true value	—
w	Estimate of the calibration factor	—
V	Volume of the test sample	l
y	Primary measurement result of measurand	—
α	Probability of a false positive decision	—
β	Probability of a false negative decision	—

Table 1 (continued)

Symbol	Description	Unit
ρ	Density	$\text{g}\cdot\text{l}^{-1}$
ε	Total efficiency including degassing efficiency and counting efficiency of the system for a count carried out with a radioactive equilibrium between ^{222}Rn and its short-lived decay products	pulses $\cdot\text{s}^{-1}\cdot\text{Bq}^{-1}$
Φ	Distribution function of the standardized normal distribution	—
λ	Decay constant of the ^{222}Rn	s^{-1}
ω	Auxiliary quantity	—

4 Principle

This test method is based on the emanation and scintillation counting of ^{222}Rn , a gaseous daughter product of ^{226}Ra , from a solution (see Reference [8]).

The measurement of ^{226}Ra activity concentration in water is carried out following two separate steps, the sample preparation followed by the measurement of the test sample.

The preparation consists of:

- dissolution when total or particulate radium shall be assayed;
- filtration when soluble radium shall to be measured.

It is followed by pre-concentration, if necessary, and an accumulation of decay products without an initial separation.

After filtration and acidification, the test sample is placed in a bubbler (see Figure B.1) and stored for ingrowth of ^{222}Rn .

After a suitable ingrowth period, the radon gas is removed from the solution by purging with the radon-free gas and transferring it to a scintillation cell, whose internal surface is coated with silver-activated zinc sulfide, $\text{ZnS}(\text{Ag})$ (see Figure C.1 and Reference [10]).

The alpha-particles produced by the decay of ^{222}Rn and its short-lived decay products (^{218}Po , ^{214}Po) transfer their energy as they pass through the scintillation medium. As they return to their ground state, the excited electrons in the scintillation medium emit photons from the $\text{ZnS}(\text{Ag})$ coating that can be detected by a photomultiplier (PMT). The photomultiplier converts the photons into electrical pulses that are then counted. The pulse count is directly proportional to the activity concentration of radon and its decay products present in the scintillation cell.

The soluble ^{226}Ra activity concentration is calculated, taking into account the known steady-state between ^{226}Ra and ^{222}Rn after transferring ^{222}Rn into a scintillation cell.

Given its high power of emanation, radon can also escape from particles suspended in water. In the case of the analysis of raw water, it is therefore advisable to dissolve the particulate fraction (see Reference [9]).

Other detection techniques such as semiconductor silicon detector can be applied to determine radon activity concentration in the gas phase^[17].

In water containing high activity concentrations of ^{228}Th , interference from ^{220}Rn decay products can lead to overestimation of measured levels (see Figure A.2).

5 Reagents and equipment

5.1 Reagents

Unless otherwise stated, use only reagents of recognized analytical grade and distilled or demineralized water or water of equivalent purity and no undesirable radioactivity.

5.1.1 Nitric acid, HNO₃, concentrated ($\rho = 1,39 \text{ g}\cdot\text{ml}^{-1}$), $c = 65 \%$.

5.1.2 Nitric acid, HNO₃, diluted (1,58 mol·l⁻¹), with no alpha-radioactivity.

5.1.3 Reference solution of ²²⁶Ra.

5.1.4 Cellulose ester filter, 0,45 μm porosity.

5.1.5 Hydrochloric acid, HCl, concentrated ($\rho = 1,19 \text{ g}\cdot\text{ml}^{-1}$), **if the particulate fraction of ²²⁶Ra requires dissolution.**

5.2 Equipment

Usual laboratory equipment and, in particular, the following.

5.2.1 Hotplates.

5.2.2 Needles, length of approximately 30 mm, diameter of approximately 1,5 mm.

5.2.3 Bubblers, minimum volume of 125 ml with two (poly)tetrafluoroethylene needle valves (see [Figure B.1](#)).

5.2.4 Specialized solid-state scintillation detection set, equipped with a photomultiplier.

5.2.5 Manometer, to measure pressure.

5.2.6 Flat-bottomed glass scintillation cell, volume of 250 ml to 500 ml.

The internal surface of the cell, apart from the bottom, is coated with silver-activated zinc sulfide, ZnS(Ag). The external surface is coated with a light-excluding material except on its flat bottom, which forms the measurement window (see [Figure C.1](#)).

5.2.7 Vacuum pump, to obtain a pressure reduction of about 300 Pa.

5.2.8 Constant alpha-emitting radioactive source, for example, ²³⁹Pu.

6 Sampling and storage

6.1 Sampling

The sampling conditions shall conform with ISO 5667-3.

It is important that the laboratory receive a sample that has not been damaged or modified during transport or storage.

6.2 Sample storage

If required, the water sample (from 0,5 l to 1,0 l) shall be stored in accordance with ISO 5667-3.

When pre-concentration is desired, acidify the sample to between pH 1 and pH 3 with HNO_3 (5.1.1). When necessary, carry out filtration immediately on collection and before acidification.

Acidification of the water sample minimizes the loss of radioactive material from the solution by adsorption. If filtration of the sample is required, perform the acidification afterwards; otherwise, radioactive material already adsorbed on to the particulate material can be desorbed.

7 Procedures

7.1 Sample preparation

When the soluble radium and particulate radium shall be measured separately, the water sample is filtrated using a 0,45 μm filter.

The initial sample volume is generally 0,5 l or 1,0 l.

For 0,5 l, add 5 ml of the concentrated nitric acid solution (5.1.1) to the sample (raw or filtrated). Concentrate the solution by evaporation, without boiling, down to a volume of about 25 ml. Alternative methods can be used to concentrate the sample, such as sulfate co-precipitation followed by dissolution using EDTA. In this case, if a complete recovery of ^{226}Ra is not guaranteed, the chemical yield should be determined and corrected for.

The particulate fraction of ^{226}Ra is dissolved by mineralization using hydrochloric acid (5.1.5) or nitric acid (5.1.1).

After cooling, pour the solution into a bubbler, rinse several times with the dilute nitric acid solution (5.1.2), rubbing the inner walls of the container. The rinsing solutions are transferred successively to the bubbler. The total volume shall not exceed 50 ml.

^{222}Rn initially dissolved in the water is eliminated by a first bubbling step:

- open the valves;
- sparge the radon-free gas through the water sample using a fine air bubble for at least 20 min;
- close the valves.

Note the date and time corresponding to t_0 .

Let ^{222}Rn accumulate in the bubbler for at least 5 d (at least 2 d if results are urgently needed and provided the activity concentration is at least $2 \text{ Bq}\cdot\text{l}^{-1}$).

The formation of precipitates in the bubbler during the ^{222}Rn ingrowth period demonstrates that ^{222}Rn recovery can be impaired and that the sample preparation procedure needs the addition of a filtration step.

7.2 Measurement conditions

Due to the degassing process, only gaseous alpha-emitting radionuclides, ^{219}Rn (actinon) and ^{220}Rn (thoron), can interfere. Interference from these radionuclides would be expected to be very rare in water not contaminated by such industrial wastes as uranium mill effluents. As the half-lives of these nuclides are short, less than 1 min, only their alpha-emitting decay products can interfere.

7.3 Counting procedure

In parallel, prepare the scintillation cell as follows:

- produce a vacuum of a few kPa with the pump (5.2.7) to remove the air of the scintillation cell;
- fill the cell with radon-free gas up to atmospheric pressure;
- measure the cell background by counting the electrical pulses from the PMT for a suitable duration equal to the sample counting time;
- produce a vacuum of a few kPa with the pump (5.2.7) to remove the air of the scintillation cell again.

Connect the bubbler (5.2.3) (valve 2) to the scintillation cell. To transfer the radon, open valve 1 and when no more bubbles are produced, open valve 2. The bubbling shall be very slow (fine bubbles). When the pressures are balanced, the transfer is completed (about 20 min).

Note the date and time corresponding to t_1 .

Close the valves. Set aside the flask.

For an optimum counting, allow radioactive equilibrium between the ^{222}Rn and its short-lived decay products (^{214}Po , ^{218}Po) to be reached in the scintillation cell. The radioactive equilibrium is reached 3 h after the radon gas is introduced into the scintillation cell.

Place the scintillation cell on the detector photocathode and count for at least 1 h, or perform repeated counts to ensure equilibrium is achieved. The time the counting starts is t_2 .

Finally, immediately after counting, flush the scintillation cell with a radon-free gas in order to avoid a further accumulation of $^{210}\text{Pb}/^{210}\text{Po}$ in the cell.

8 Quality assurance and quality control programme

8.1 General

Quality control operations shall meet the requirements of ISO/IEC 17025.

8.2 Influence parameters

Special precautions shall be taken to minimize the influence of parameters that can affect the measurement results: loss of ^{222}Rn from the bubbler (5.2.3) and the scintillation cell to be measured; a gas-tight system of bubbler and scintillation cell shall be used.

Wide temporal variations of the radon activity concentration can be observed in the atmosphere of the laboratory. The continuous monitoring of the ^{222}Rn activity concentration in the laboratory using a radon-measuring device is recommended since, even in well-ventilated rooms, considerable variations are possible in special weather conditions.

The continuous renewal of the air through an air-conditioning system is suggested to maintain a constant temperature and relative humidity.

The painting of the walls of the laboratory with a suitable material is suggested in order to limit the release of radon from the material within the walls (e.g. epoxy paints) (see Reference [12]).

8.3 Instrument verification and calibration

Major instrument parameters (PMT high voltage setting, counting yield, background count rate) should be periodically checked within a quality assurance programme established by the laboratory and following the manufacturer's instructions.

Make sure the whole data acquisition chain is correctly set. To do so, use the alpha-emitting constant radioactive source (5.2.8) (e.g. ^{239}Pu) to check that the data acquisition chain gives the expected value of the source.

As the decay of an atom of ^{222}Rn and its decay products ^{218}Po and ^{214}Po result in three alpha-emissions to arrive at ^{210}Pb , the term “yield” to be used is thus equal to the detection yield multiplied by three.

The total efficiency can vary over time and so it shall be determined at intervals by degassing ^{222}Rn from a standard solution of ^{226}Ra with known activity (5.1.3) (contained in a bubbler), with the procedure used for the assay.

8.4 Method verification

Periodical verifications of the accuracy of the method shall be run. These can be accomplished by

- participating in intercomparison exercises, and
- analysing reference materials.

8.5 Demonstration of analyst capability

If an analyst has not used this procedure before, a precision and bias test shall be performed by running a duplicate measurement of a reference or spiked material. Acceptance limits shall be defined by the laboratory.

A similar test should be performed by analysts routinely using this procedure with a periodicity defined by the laboratory. Acceptance limits shall be defined.

9 Expression of results

9.1 Activity concentration of water-soluble ^{226}Ra

The activity concentration of water-soluble ^{226}Ra , c_A , is obtained from [Formulae \(1\), \(2\), \(3\) and \(4\)](#):

$$c_A = \frac{(\bar{N} - \bar{N}_0)}{t_c \cdot \varepsilon \cdot n_\alpha(t) \cdot V \cdot f_a \cdot f_d} = (\bar{N} - \bar{N}_0) \omega \quad (1)$$

where

$$\bar{N} = \frac{\sum_{i=1}^n N_i}{n}$$

$$\bar{N}_0 = \frac{\sum_{i=1}^n N_{0i}}{n}$$

$$\omega = \frac{1}{t_c \cdot \varepsilon \cdot n_\alpha(t) \cdot V \cdot f_a \cdot f_d} \quad (2)$$

where

$$f_a = 1 - \exp[-\lambda(t_1 - t_0)] \quad (3)$$

$$f_d = \exp \left[-\lambda (t_2 - t_1) \right] \quad (4)$$

When the radioactive equilibrium between radon and its decay products is reached, $n_\alpha \cdot (t) \approx 3$ and [Formula \(1\)](#) can be simplified.

9.2 Standard uncertainty of activity concentration

9.2.1 General

The standard uncertainty of c_A is obtained as given in [Formula \(5\)](#):

$$u(c_A) = \sqrt{(\bar{N} + \bar{N}_0) \frac{\omega^2}{n} + c_A^2 \cdot u_{\text{rel}}^2(\omega)} \quad (5)$$

The relative standard uncertainty of ω is calculated using [Formula \(6\)](#):

$$u_{\text{rel}}^2(\omega) = u_{\text{rel}}^2(\varepsilon) + u_{\text{rel}}^2(V) \quad (6)$$

where the uncertainties of the counting time, the decay constant, and the number of alpha-emitters are neglected.

The calculation of the characteristic limits requires the calculation of $\tilde{u}(\tilde{c}_A)$, i.e. the standard uncertainty of c_A as a function of its true value, calculated as given in [Formula \(7\)](#):

$$\tilde{u}(\tilde{c}_A) = \sqrt{\left(\frac{\tilde{c}_A}{\omega} + 2\bar{N}_0 \right) \frac{\omega^2}{n} + \tilde{c}_A^2 \cdot u_{\text{rel}}^2(\omega)} \quad (7)$$

9.2.2 Decision threshold

The decision threshold, c_A^* , is obtained from [Formula \(7\)](#) for $\tilde{c}_A = 0$ according to ISO 11929-1. This yields to [Formula \(8\)](#):

$$c_A^* = k_{1-\alpha} \cdot \tilde{u}(0) = k_{1-\alpha} \cdot \omega \cdot \sqrt{\frac{2\bar{N}_0}{n}} \quad (8)$$

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

9.2.3 Detection limit

The detection limit, $c_A^\#$, is calculated as given in [Formula \(9\)](#) according to ISO 11929-1.

$$c_A^\# = c_A^* + k_{1-\beta} \cdot \tilde{u}(c_A^\#) = c_A^* + k_{1-\beta} \sqrt{\left(\frac{c_A^\#}{\omega} + 2\bar{N}_0 \right) \frac{\omega^2}{n} + c_A^{\#2} \cdot u_{\text{rel}}^2(\omega)} \quad (9)$$

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

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

With $k_{1-\alpha} = k_{1-\beta} = k$ as given in [Formula \(10\)](#):

$$c_A^\# = \frac{2c_A^* + k^2 (\omega/n)}{1 - k^2 u_{\text{rel}}^2 (\omega)} \quad (10)$$

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

9.3 Limits of the coverage intervals

9.3.1 Limits of the probabilistically symmetric coverage interval

The lower, c_A^\triangleleft , and upper, c_A^\triangleright , coverage limits shall be calculated using [Formulae \(11\)](#) and (12) according to ISO 11929-1:

$$c_A^\triangleleft = c_A - k_p \cdot u(c_A) ; p = \omega \cdot (1 - \gamma/2) \quad (11)$$

$$c_A^\triangleright = c_A + k_q \cdot u(c_A) ; q = 1 - \omega \cdot \gamma/2 \quad (12)$$

where

ω equals $\Phi [y/u(y)]$;

Φ is the distribution function of the standardized normal distribution;

$(1 - \gamma)$ is the probability for the coverage interval of the measurand;

$\omega = 1$ can be set if $c_A \geq 4 \cdot u(c_A)$; in this case:

$$c_A^\triangleleft, c_A^\triangleright = c_A \pm k_{1-\gamma/2} \cdot u(c_A) \quad (13)$$

$\gamma = 0,05$ and then, $k_{1-\gamma/2} = 1,96$ is often chosen by default.

9.3.2 Shortest coverage interval

As described in detail in ISO 11929-1, the lower limit of the shortest coverage interval, c_A^\triangleleft , and the upper limit of the shortest coverage interval, c_A^\triangleright , are calculated from a primary measurement result, c_A , of the measurand and the standard uncertainty, $u(c_A)$, associated with c_A , either by [Formula \(14\)](#):

$$c_A^\triangleleft, c_A^\triangleright = c_A \pm k_p \cdot u(c_A) ; p = (1 + \omega \cdot (1 - \gamma))/2 \quad (14)$$

or if $c_A^\triangleleft \leq 0$ were the result, by [Formula \(15\)](#):

$$c_A^\triangleleft = 0 ; c_A^\triangleright = c_A \pm k_q \cdot u(c_A) ; q = 1 - \omega \cdot \gamma \quad (15)$$

$\omega = \Phi [y/u(y)]$

where Φ is the distribution function of the standardized normal distribution.

The relations $0 \leq c_A^\triangleleft < c_A^\triangleright$ apply and the approximation of [Formula \(13\)](#) is valid.

9.4 Example

For an accumulation time of 5 d, 19 h and a decay time of 3 h and 30 min, the counting time is 1 h.

$f_a = 0,65$	$f_d = 0,974$	$V = 0,50 \text{ l} \pm 0,01 \text{ l}$	$\varepsilon = 0,60 \pm 0,03$
$N = 1\,849$ pulses	$N_0 = 262$ pulses	$t_c = 3\,600$ s	$n = 1$
$c_A = 0,77$ Bq l ⁻¹	$u(c_A) = 0,047$ Bq l ⁻¹	$c_A^* = 0,018$ Bq l ⁻¹	$c_A^\# = 0,038$ Bq l ⁻¹

10 Test report

The test report shall conform with the ISO/IEC 17025 requirements. The test report shall also contain the following information:

- a) a reference to this document, i.e. ISO 13165-2:2022;
- b) identification of the sample;
- c) units in which the results are expressed;
- d) the test result:
 - 1) when the activity concentration, c_A , is compared with the decision threshold (according to ISO 11929 series);
 - if the result is less than the decision threshold, the result of the measurement is expressed as $\leq c_A^*$,
 - if the result is greater than the decision threshold, the result of the measurement is expressed as $c_A \pm u(c_A)$ or $c_A \pm U$ with the associated k value,
 - 2) when the activity concentration, c_A , is compared with the detection limit;
 - if the result is less than the detection limit, the result of the measurement is expressed as $\leq c_A^\#$,
 - if the result is greater than the detection limit, the result of the measurement is expressed as $c_A \pm u(c_A)$ or $c_A \pm U$ with the associated k value;
- e) the method used (if the standard includes several);
- f) the result(s), including a reference to the clause which explains how the results were calculated;
- g) any deviations from the procedure;
- h) any unusual features observed;
- i) the date of the test.

Complementary information can be provided such as:

- e) the uncertainty can also be expressed as the limits of the probabilistically symmetric coverage interval $c_A^<, c_A^>$ and/or the limits of the shortest coverage interval $c_A^{<}, c_A^{>}$;
- f) probabilities α, β and $(1 - \gamma)$;
- g) decision threshold and the detection limit;
- h) if the detection limit exceeds the guideline value, it shall be documented that the method is not suitable for the measurement purpose;
- i) mention of any relevant information likely to affect the results.

NOTE Occasionally, it is requested by the customer or regulator to compare the primary measurement result, c_A , with the detection limit, $c_A^\#$, in order to decide whether the physical effect is recognized or not. Such stipulations are not in accordance with ISO 11929-1. They have the consequence that it is decided too frequently that the physical effect is absent when in fact it is not absent.

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Annex A (informative)

Decay chains of ^{238}U and ^{232}Th

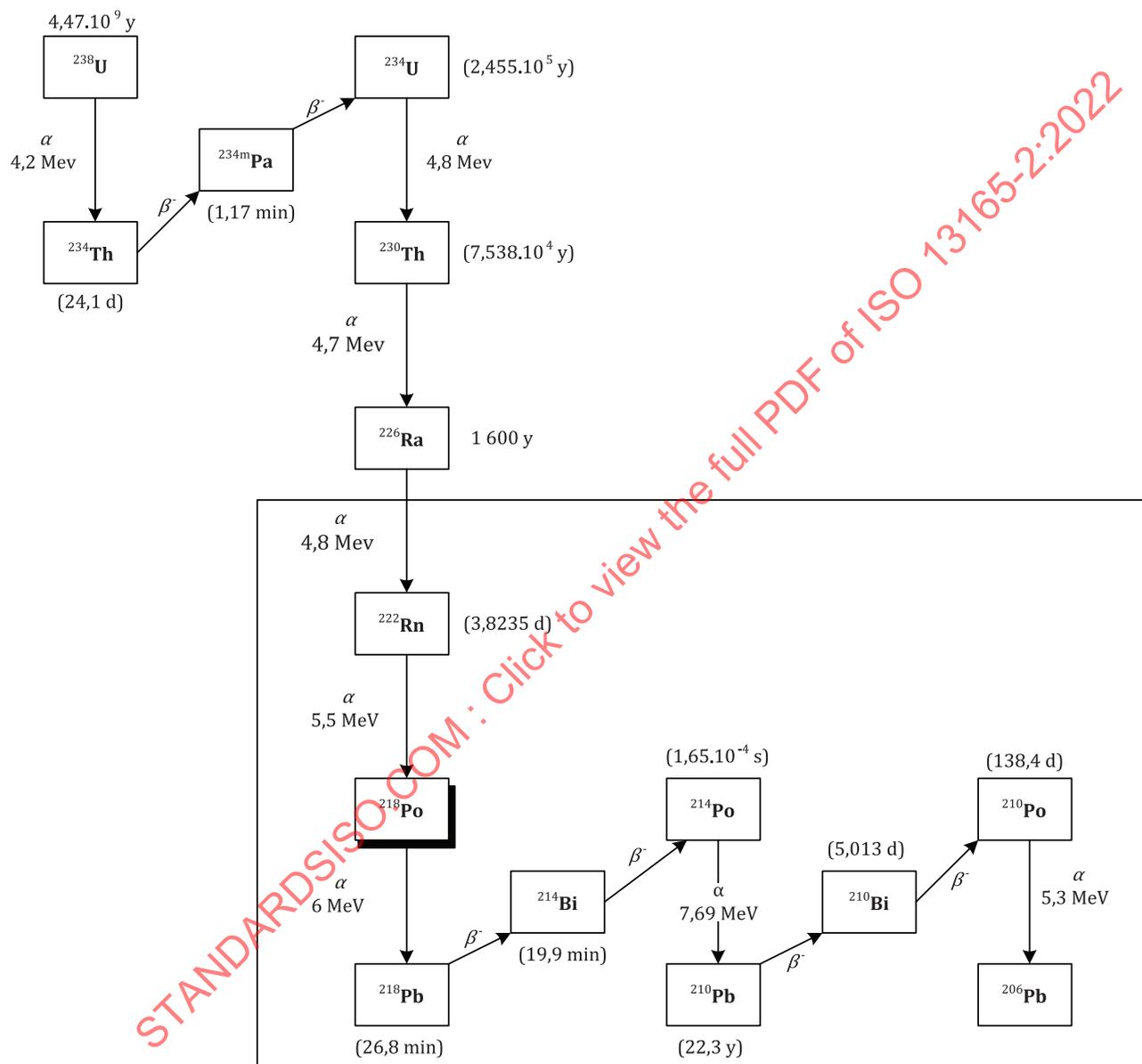


Figure A.1 — Uranium-238 and its decay chain^[11]

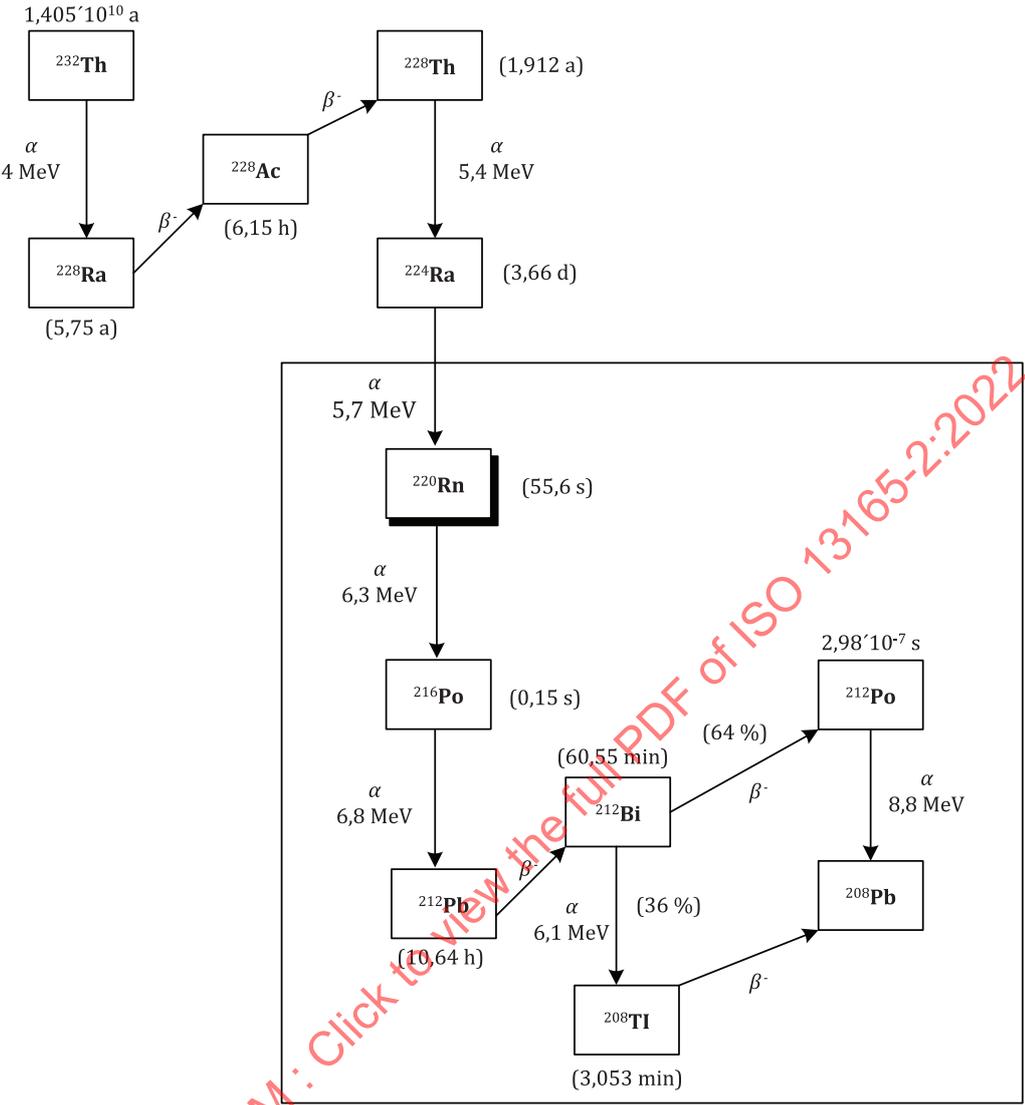


Figure A.2 — Thorium-232 and its decay chain^[11]

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