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**Water quality — Gross beta activity —  
Test method using thick source**

*Qualité de l'eau — Activité bêta globale — Méthode d'essai par  
source épaisse*

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Published in Switzerland

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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](http://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](http://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](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 147, *Water quality*, Subcommittee SC 3, *Radioactivity measurements*.

This fourth edition cancels and replaces the third edition (ISO 9697:2015), of which it constitutes a minor revision. The changes compared to the previous edition are as follows:

- the title has been changed from “Gross beta activity in non-saline water” to “Gross beta activity”;
- the Introduction has been reworded;
- [Formulae \(10\)](#) and [\(11\)](#) have been corrected to replace  $\pm$  by  $\alpha$  in the index of  $r$ ;
- the units have been corrected so that  $\text{mm}^2$  and  $\text{mol/l}$  are used throughout.

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](http://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  $^{40}\text{K}$ ,  $^3\text{H}$ ,  $^{14}\text{C}$ , and those originating from the thorium and uranium decay series, in particular  $^{226}\text{Ra}$ ,  $^{228}\text{Ra}$ ,  $^{234}\text{U}$ ,  $^{238}\text{U}$ ,  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  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),  $^3\text{H}$ ,  $^{14}\text{C}$ ,  $^{90}\text{Sr}$  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<sup>[1]</sup>. Drinking-water may thus contain radionuclides at activity concentrations which could present a risk to human health.

The radionuclides present in liquid effluents are usually controlled before being discharged into the environment<sup>[2]</sup> and water bodies. Drinking waters are monitored for their radioactivity as recommended by the World Health Organization (WHO)<sup>[3]</sup> 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 and ISO 5667-20<sup>[4]</sup>.

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 guidelines for guidance level in drinking water is 0,5 Bq/l for gross alpha activity and 1 Bq/l for gross beta activity.

**NOTE** The guidance level is the activity concentration with an intake of 2 l/d of drinking water for one year that results in an effective dose of 0,1 mSv/a 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<sup>[3]</sup>.

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<sup>[5]</sup><sup>[6]</sup><sup>[7]</sup>.

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 will 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 may be used during planned, existing and emergency exposure situations as well as for wastewaters and liquid effluents with specific modifications that could increase the overall uncertainty, detection limit, and threshold.

## ISO 9697:2018(E)

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

An International Standard on a test method of gross alpha and gross beta activity concentrations in water samples is justified for test laboratories carrying out these measurements, required sometimes by national authorities, as laboratories may have to obtain a specific accreditation for radionuclide measurement in drinking water samples.

This document is one of a set 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 — Gross beta activity — Test method using thick source

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

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

## 1 Scope

This document specifies a test method for the determination of gross beta activity concentration in non-saline waters. The method covers non-volatile radionuclides with maximum beta energies of approximately 0,3 MeV or higher. Measurement of low energy beta emitters (e.g.  $^3\text{H}$ ,  $^{228}\text{Ra}$ ,  $^{210}\text{Pb}$ ,  $^{14}\text{C}$ ,  $^{35}\text{S}$  and  $^{241}\text{Pu}$ ) and some gaseous or volatile radionuclides (e.g. radon and radioiodine) might not be included in the gross beta quantification using the test method described in this document.

This test method is applicable to the analysis of raw and drinking waters. The range of application depends on the amount of total soluble salts in the water and on the performance characteristics (background count rate and counting efficiency) of the counter used.

It is the laboratory's responsibility to ensure the suitability of this method for the water samples tested.

## 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 3696:1987, *Water for analytical laboratory use — Specification and test methods*

ISO 5667-1, *Water quality — Sampling — Part 1: Guidance on the design of sampling programmes and sampling techniques*

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

ISO 5667-14, *Water quality — Sampling — Part 14: Guidance on quality assurance and quality control of environmental water sampling and handling*

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

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

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

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

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

### 3 Terms, definitions, symbols and units

No terms and definitions are listed in this document.

For the purposes of this document, the symbols and designations given in ISO 80000-10, ISO 11929, ISO/IEC Guide 98-3, ISO/IEC Guide 99 and the following apply.

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

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

$A$	beta activity, in becquerels, of the calibration source
$c_A$	beta activity concentration, in becquerels per litre
$c_A^*$	decision threshold, in becquerels per litre
$c_A^\#$	detection limit, in becquerels per litre
$c_A^<, c_A^>$	lower and upper limits of the confidence interval, in becquerels per litre
$m$	mass, in milligrams, of ignited residue from volume, $V$
$m_r$	mass, in milligrams, of the sample residue deposited on the planchet
$r_0$	background count rate, per second
$r_{0\alpha}$	background count rate, per second, from the alpha window
$r_g$	sample gross count rate, per second
$r_{g\alpha}$	sample gross count rate, per second, from the alpha window
$r_s$	calibration count rate of the beta source, per second
$r_{s\alpha}$	calibration count rate of the alpha source, per second, from the alpha window
$S$	surface area, in square millimetres, of the planchet
$t_0$	background counting time, in seconds
$t_g$	sample counting time, in seconds
$t_s$	calibration count time of the beta source, in seconds
$t_{s\alpha}$	calibration count time of the alpha source, in seconds
$u(c_A)$	standard uncertainty, in becquerels per litre, associated with the measurement result
$U$	expanded uncertainty, in becquerels per litre, calculated from $U = ku(c_A)$ , with $k = 1, 2 \dots$
$V$	volume, in litres, of test sample equivalent to the mass of solid on the planchet
$V_t$	volume, in litres, of the water sample

$\varepsilon$	counting efficiency for the specified radioactive standard
$\rho_s$	source thickness, in milligrams per square millimetre, of the sample residue deposited on the planchet
$\chi$	alpha-beta cross-talk, percentage of alpha count going into the beta window from the alpha calibration source

## 4 Principle

Gross beta measurement is not intended to give an absolute determination of the activity concentration of all beta-emitting radionuclides in a test sample, but rather a screening analysis to ensure particular reference levels of specific beta emitters have not been exceeded. This type of determination is also known as gross beta index. Gross beta analysis is not expected to be as accurate nor as precise as specific radionuclide analysis after radiochemical separations.

The sample, taken, handled and preserved as specified in ISO 5667-1, ISO 5667-3 and ISO 5667-14, is evaporated to almost dryness, converted to the sulfate form, and ignited at 350 °C. A portion of the residue is transferred onto a planchet and the beta activity measured by counting in an appropriate counting assembly, which is calibrated against a suitable beta calibration source, such as potassium-40 ( $^{40}\text{K}$ ) or strontium-90/yttrium-90 ( $^{90}\text{Sr} + ^{90}\text{Y}$ ) in equilibrium.

If simultaneous gross alpha and beta measurements are required on the same water sample, the procedure specified in this document is common to that of ISO 9696[8]. However, to simultaneously measure gross alpha activity, the counting source thickness should be below 0,1 mg/ mm<sup>2</sup>[9][10].

A performance criteria example is given in [Annex A](#).

## 5 Reagents and equipment

### 5.1 Reagents

All reagents shall be of recognized analytical grade and shall not contain any detectable beta activity.

NOTE A method for preparing reagent blanks to check for the absence of any endemic beta radioactivity or contamination is given in [Clause 7](#).

**5.1.1 Water**, conforming to ISO 3696:1987, grade 3.

**5.1.2 Calibration source**, the choice of beta calibration source depends on the knowledge of the type of radioactive contaminant likely to be present in the waters being tested. Among calibration source of beta-emitting radionuclides,  $^{90}\text{Sr}$  and  $^{40}\text{K}$  are commonly used.

NOTE The beta activity of  $^{40}\text{K}$  in natural potassium is 27,9 Bq g<sup>-1</sup>, i.e. 14,5 Bq g<sup>-1</sup> in potassium chloride[3].

**5.1.3 Nitric acid**,  $c(\text{HNO}_3) = 8 \text{ mol/l}$ .

**5.1.4 Sulfuric acid**,  $c(\text{H}_2\text{SO}_4) = 18 \text{ mol/l}$ ,  $\rho = 1,84 \text{ g/ml}$ , mass fraction  $w(\text{H}_2\text{SO}_4) = 95 \%$ .

**5.1.5 Volatile organic solvents**, methanol or acetone.

**5.1.6 Calcium sulfate**,  $\text{CaSO}_4$ .

**5.1.7 Vinyl acetate**,  $[(\text{C}_4\text{H}_6\text{O}_2)_n]$ .

**CAUTION** — As calcium salts can contain trace amounts of  $^{226}\text{Ra}$  and/or  $^{210}\text{Pb}$ , checks for the presence of these radionuclides shall be made.

## 5.2 Equipment

Usual laboratory equipment and, in particular, the following.

**5.2.1 Beta counter**, preferably of the gas-flow proportional type, incorporating a plastic scintillation detector or a silicon-charged particle detector.

When using a gas-flow proportional counter, it is advisable to choose the electronic beta window with minimal beta-alpha cross-talk and correct for the alpha-beta cross-talk using a  $^{239}\text{Pu}$  alpha source. If equipment other than gas-flow proportional counters is used, then cross-talk can be insignificant and ignored.

If a windowless gas-flow proportional counter is used, carry out regular checks for possible contamination of the counting system by counting blank samples.

**NOTE** The particulate nature of the source to be counted can give rise to contamination if operated in a vacuum (as in the case of silicon-charged particle detector) or gas-flow systems (as used in a proportional counter).

**5.2.2 Planchet with counting tray**, of surface density at least  $2,5 \text{ mg/mm}^2$  ( $250 \text{ mg/cm}^2$ ), having a lipped edge and made of stainless steel.

The diameter of the planchet to be used is determined by the counter requirements, i.e. the detector diameter and source holder dimensions.

**NOTE** An evenly spread source is required and some analysts find it easier to produce this on a polished metal surface, whereas others prefer to use an etched or roughened planchet (sand blasting and chemical etching has been applied for this purpose).

**5.2.3 Muffle furnace**, capable of being maintained at  $(350 \pm 10) \text{ }^\circ\text{C}$ .

## 6 Procedure

### 6.1 Sampling

Collection, handling, and storage of water samples shall be performed as specified in ISO 5667-1, ISO 5667-3 and ISO 5667-14.

If the measurement of the activity in the filtered water sample is required, carry out filtration immediately on collection and before acidification.

**NOTE** Acidification of the water sample minimises the loss of radioactive material from solution by adsorption. If carried out before filtration, acidification desorbs radioactive material initially adsorbed on the particulate material.

### 6.2 Pre-treatment

The determination of the total solids content of the water can be performed to estimate the smallest volume of water needed for the measurement. Making due allowance for changes in composition due to

ignition at 350 °C and sulfation of the residue, calculate the volume of sample required to produce a mass per unit area of solid residue slightly in excess of  $\rho_s$  (mg/mm<sup>2</sup>) given by [Formula \(1\)](#):

$$\rho_s = \frac{m_r}{S} \geq 0,1 \quad (1)$$

Use this as a guide to determine the volume of sample required for the concentration stage below.

### 6.3 Concentration stage

Transfer to a beaker a measured volume,  $V$ , in litres, of the sample chosen such that after ignition the value for  $\rho_s$  is at least 0,1 mg/mm<sup>2</sup>.

With very soft waters, it is possible that the volume required to produce  $\rho_s \geq 0,1$  mg/mm<sup>2</sup> is impractically large. In these circumstances, the largest practicable volume should be used or calcium salts ([5.1.6](#)) should be added.

Evaporate the sample carefully on a hotplate until the volume is reduced to about 50 ml.

After cooling, transfer the concentrated solution to a weighed-silica or glazed porcelain dish that has been previously ignited at 350 °C. Rinse the beaker carefully with a minimum quantity of water ([5.1.1](#)) and transfer the rinses to the dish.

NOTE If the beaker is large, it might be more convenient to transfer the rinses to a smaller beaker. The rinses can then be evaporated to a lower volume to facilitate sample transfer to the silica dish.

### 6.4 Sulfation stage

After drying and ignition, some water residue can be hygroscopic or difficult to disperse, and thus, unsuitable for the activity measurement. A sulfation process is then a suitable treatment for such water samples.

Ensure that the rinses in the dish are cool and add  $(1 \pm 0,2)$  ml of sulfuric acid ([5.1.4](#)).

The volume of sulfuric acid chosen is sufficient for sulfating about 1,8 g of calcium carbonate. To ensure an excess of acid, the initial volume of sample should be chosen such that the total solids content does not exceed 1 g (experience with some waters can show this step to be unnecessary).

Carefully evaporate the contents of the dish to dryness.

To avoid spitting, heat the dish from above using an infrared lamp until fumes of sulfuric acid are evolved. Then, transfer the dishes to a hotplate until no further fumes are evolved.

### 6.5 Ignition stage

Transfer the dish and contents to the muffle furnace ([5.2.3](#)), ignite for 1 h at a temperature of  $(350 \pm 10)$  °C and allow to cool to room temperature in a desiccator.

Weigh the dish and the residue and obtain by difference,  $m$ , in milligrams, the mass of the ignited residue.

### 6.6 Source preparation

If the residue is coarse, grind it in a pestle and mortar. Transfer the required mass of the residue onto a planchet ([5.2.2](#)). Let this mass be  $m_r$ .

If the volume of the sample used ( $V$ , in [6.3](#)) has led to a value of  $\rho_s$  less than 0,1 mg/mm<sup>2</sup>, transfer as much as possible of the residue to the planchet.

Disperse the residue evenly over the planchet by slurring with a few drops of a volatile organic solvent (5.1.5, methanol or acetone) and allow it to dry to a constant mass. It is also recommended that, to produce evenly spread counting sources, vinyl acetate (5.1.7) can be added to the solvent to aid in binding the source. Make a note of the time and date of source preparation, and check that no residue has been lost.

Although beta-particle counting efficiency is not seriously affected by the source thickness up to 0,2 mg/mm<sup>2</sup> (see References [10] and [11]), it is recommended that, for the calibration of the detection system, either use standard sources of the same mass loading ( $m_r$ ) or repeat the procedure with the addition of calcium salts to the water sample to achieve the same mass loading as the calibration standard.

## 6.7 Measurement

Set up the counter (5.2.1) according to the manufacturer's instructions.

Immediately after drying the source, measure the activity on the planchet by counting for an appropriate duration. Note the time, date, and counting duration.

The counting time depends on the sample and background count rates, and also on the detection limit and decision threshold required.

NOTE Re-counting over a period of one month can reveal in-growth of daughter radionuclides from naturally occurring radioactive isotopes. The interpretation of the counting data can then be complicated. However, at normal environmental levels, it is rare for these phenomena to be apparent, particularly with a long counting time.

## 6.8 Determination of counting background

Measure the background activity using a clean planchet. Let the measured counting rate be  $r_0$ . Repeated counts confirm the stability of the counting background.

## 6.9 Preparation of calibration sources

Accurately weigh approximately 2,5 g of calcium sulfate into a 150 ml beaker. Carefully add ( $10 \pm 0,1$ ) ml of hot 8 mol l<sup>-1</sup> nitric acid (5.1.3), stir and add up to 100 ml of hot water (5.1.1).

Add an exactly known amount (in the range of 5 Bq to 10 Bq) of the appropriate standard (5.1.2).

Transfer the solution to 200 ml silica or glazed porcelain dish (that was previously ignited at 350 °C), weighed to  $\pm 0,001$  g, and evaporate the solution to dryness using an infrared lamp.

Ignite the dry residue in the muffle furnace (5.2.3) at  $(350 \pm 10)$  °C for 1 h.

Calculate the activity per unit of mass of the CaSO<sub>4</sub> (5.1.6) in becquerels per gram, by dividing the added activity of the chosen standard over the mass of the ignited residue.

Crush (and grind with a pestle and mortar, if necessary) the residue to produce a fine powder in a manner similar to that used for the preparation of the sample.

Prepare planchet calibration sources in the manner as specified for samples.

Measure these calibration sources in the beta counter.

If a gas-flow proportional counter is used, then an alpha calibration source (<sup>239</sup>Pu) shall be prepared in the same way as for the beta calibration source with a known amount (in the range of 5 Bq to 10 Bq) of the appropriate standard.

If potassium chloride is used as a calibration source, dry the KCl powder to constant mass at 105 °C. The beta activity of the KCl calibration source is given in 5.1.2.

**WARNING — In order to determine the alpha rejection rate in the beta window, this procedure requires the preparation of a dry powder spiked with beta- and alpha-emitting radionuclides.**

**Accidental intake of radioactive particulates shall be avoided and the use of a closed cabinet glove box for the sample is recommended for the preparation of the spiked sources. Alternatively, a laboratory fume cupboard can be used, provided that the extract draught is not excessive and liable to create disturbance or cause the suspension of fine powder particles in the air.**

## 6.10 Sensitivity and bias

These are dependent on the amount of inorganic material in the water, the characteristics of the detector and the radionuclides present.

As the result of the measurement is expressed as an equivalent concentration to the selected calibration standard, the standard shall be carefully chosen in order to minimize the bias.

## 6.11 Optimization of the determination

When using constant source thickness, it is necessary to make the sample and standard source as nearly alike as possible, i.e. in terms of density of material and distribution of radioactivity.

## 7 Source control

### 7.1 Contamination check

Check the contamination of reagents by evaporating the volumes of the reagents used in the procedure onto separate planchets. Check the contamination of the whole measurement system by processing (1 000 ± 10) ml of water (5.1.1) acidified with 20 ml of 8 mol l<sup>-1</sup> nitric acid (5.1.3), to which (0,1 ρ<sub>s</sub> S ± 1) mg of chromatographic reagent grade silica gel has been added, and measure the activity. This can be compared with the activity of a direct slurry of 0,1 ρ<sub>s</sub> S mg of the silica gel on a planchet. Ensure that the activity is not significantly different from that of the processed silica gel sample.

If the activity is significantly different, select reagents with lower activity, or include a blank determination and correction in the main procedure following the steps required for the sample preparation.

### 7.2 Potential disequilibrium of radionuclides

Some radionuclides are lost by volatilisation when this method is used. In the uranium decay series, <sup>222</sup>Rn is substantially lost during sample processing. When <sup>226</sup>Ra is present, <sup>222</sup>Rn and its alpha- and beta-emitting daughters subsequently grow in the source. Re-counting over a period of 3 weeks can reveal in-growth of the progenies of <sup>226</sup>Ra. Some short-lived radionuclides (e.g. <sup>224</sup>Ra), if unsupported by the parent <sup>228</sup>Th, could also be missed due to the time delay between the sampling and counting.

## 8 Expression of results

### 8.1 Calculation of activity concentration

When a gas-flow proportional counter is used, the sample gross beta activity concentration,  $c_A$ , in becquerels per litre, of the water sample is given by [Formula \(2\)](#):

$$c_A = \frac{r_g - r_0 - \chi(r_{g\alpha} - r_{0\alpha})}{V\varepsilon} = [r_g - r_0 - \chi(r_{g\alpha} - r_{0\alpha})]w \quad (2)$$

where

$V$  is the volume, in litres, of test sample equivalent to the mass of solid on the planchet, given by

$$V = \frac{V_t}{m} m_r$$

$$w = 1/(V \varepsilon)$$

The counting efficiency,  $\varepsilon$ , is given by [Formula \(3\)](#) equivalent to the specific beta calibration source used. Note that different calibration source used for beta efficiency determination will lead to different test results.

$$\varepsilon = \frac{r_s - r_0}{A} \quad (3)$$

If needed, the alpha-beta cross-talk correction factor,  $\chi$ , can be calculated using [Formula \(4\)](#):

$$\chi = \frac{r_{s\alpha \rightarrow \beta}}{r_{s\alpha}} \quad (4)$$

where

$r_{s\alpha \rightarrow \beta}$  is the count rate in the beta window when the alpha calibration source is measured.

If equipment other than a gas-flow proportional counter is used and the alpha-beta cross-talk can be neglected, then  $\chi = 0$ .

## 8.2 Standard uncertainty

As specified in ISO/IEC Guide 98-3 (see also ISO 11929), the standard uncertainty of  $c_A$  is calculated from [Formula \(2\)](#) by [Formula \(5\)](#):

$$u(c_A) = \sqrt{w^2 \left[ \left( \frac{r_g}{t_g} + \frac{r_0}{t_0} \right) + T(\chi) \right] + c_A^2 u_{\text{rel}}^2(w)} \quad (5)$$

with [Formula \(6\)](#):

$$T(\chi) = (r_{g\alpha} - r_{0\alpha})^2 u^2(\chi) + \chi^2 \left( \frac{r_{g\alpha}}{t_g} + \frac{r_{0\alpha}}{t_0} \right) \quad (6)$$

where the uncertainty of the counting time is neglected and the relative standard uncertainty of  $w$  is calculated using [Formula \(7\)](#):

$$u_{\text{rel}}^2(w) = u_{\text{rel}}^2(\varepsilon) + u_{\text{rel}}^2(V) \quad (7)$$

The relative standard uncertainty of  $\varepsilon$  is calculated using [Formula \(8\)](#):

$$u_{\text{rel}}^2(\varepsilon) = u_{\text{rel}}^2(r_s - r_0) + u_{\text{rel}}^2(A) = \frac{(r_s/t_s + r_0/t_0)}{(r_s - r_0)^2} + u_{\text{rel}}^2(A) \quad (8)$$

and the relative standard uncertainty of  $\chi$  is calculated using [Formula \(9\)](#):

$$u(\chi) = \sqrt{\frac{\chi(\chi+1)}{(r_{s\alpha} t_{s\alpha})}} \quad (9)$$

For the calculation of the characteristic limits in accordance with ISO 11929, one needs  $\tilde{u}(\tilde{c}_A)$  i.e. the standard uncertainty of  $c_A$  as a function of its true value, calculated using [Formula \(10\)](#):

$$\tilde{u}(\tilde{c}_A) = \sqrt{w^2 \left\{ \frac{\left[ \left( \tilde{c}_A / w \right) + \chi (r_{g\alpha} - r_{0\alpha}) + r_0 \right]}{t_g} + \frac{r_0}{t_0} + T(\chi) \right\} + \tilde{c}_A^2 u_{\text{rel}}^2(w)} \quad (10)$$

If equipment other than a gas-flow proportional counter is used and the alpha-beta cross-talk can be neglected, then  $\chi = 0$ .

### 8.3 Decision threshold

The decision threshold,  $c_A^*$ , is obtained from [Formula \(10\)](#) for  $\tilde{c}_A = 0$  (see also ISO 11929) giving [Formula \(11\)](#):

$$c_A^* = k_{1-\alpha} \tilde{u}(0) = k_{1-\alpha} w \sqrt{\frac{\left[ \chi (r_{g\alpha} - r_{0\alpha}) + r_0 \right]}{t_g} + \frac{r_0}{t_0} + T(\chi)} \quad (11)$$

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

If equipment other than a gas-flow proportional counter is used and the alpha-beta cross-talk can be neglected, then  $\chi = 0$ .

### 8.4 Detection limit

The detection limit,  $c_A^\#$ , is calculated using [Formula \(12\)](#) (see ISO 11929):

$$c_A^\# = c_A^* + k_{1-\beta} \tilde{u}(c_A^\#) = c_A^* + k_{1-\beta} w \sqrt{\frac{\left[ \left( c_A^\# / w \right) + \chi (r_{g\alpha} - r_{0\alpha}) + r_0 \right]}{t_g} + \frac{r_0}{t_0} + T(\chi)} + c_A^{\#2} u_{\text{rel}}^2(w) \quad (12)$$

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

The detection limit can be calculated by solving [Formula \(12\)](#) for  $c_A^\#$  or, more simply, by iteration with a starting approximation  $c_A^\# = 2c_A^*$ .

When taking  $\alpha = \beta$ , then  $k_{1-\alpha} = k_{1-\beta}$  and the solution of [Formula \(12\)](#) is given by [Formula \(13\)](#):

$$c_A^\# = \frac{2c_A^* + (k^2 w) / t_g}{1 - k^2 u_{\text{rel}}^2(w)} \quad (13)$$

### 8.5 Confidence limits

The lower,  $c_A^<$ , and upper,  $c_A^>$ , confidence limits are calculated using [Formulae \(14\)](#) and [\(15\)](#) (see ISO 11929):

$$c_A^< = c_A - k_p u_c(c_A) \quad p = \omega \frac{(1-\gamma)}{2} \quad (14)$$

$$c_A^> = c_A + k_q \cdot u_c(c_A) \quad (15)$$

$$q = 1 - \frac{\omega\gamma}{2}$$

where  $\omega$  is given by

$$\omega = \Phi \left[ \frac{y}{u(y)} \right]$$

where

$\Phi$  is the distribution function of the standardised normal distribution;

$1 - \gamma$  is the probability for the confidence interval of the measurand.

If  $c_A \geq 4 u_c(c_A)$ ,  $\omega$  can be set to unity. In this case, [Formula \(16\)](#):

$$c_A^<, c_A^> = c_A \pm k_{(1-\gamma)/2} u_c(c_A) \quad (16)$$

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

## 9 Test report

The test report shall conform to ISO/IEC 17025 requirements. It shall contain at least the following information:

- a) the test method used, together with a reference to this document, i.e. ISO 9697;
- b) an identification of the sample;
- c) the dates of sample preparation and measurement;
- d) the units in which the results are expressed;
- e) the test result,  $c_A \pm u(c_A)$  or  $c_A \pm U$ , with the associated  $k$  value;
- f) the radionuclide reference used for beta efficiency calibration. In case of a gas proportional counter, specify the alpha reference used for the alpha-to-beta crosstalk correction factor.

Complementary information can be provided, such as:

- g) the probabilities  $\alpha$ ,  $\beta$ , and  $(1 - \gamma)$ ;
- h) decision threshold and detection limit;
- i) dependent on customer requirements, there are different ways to present the result:
  - 1) when the activity concentration,  $c_A$ , is compared with the decision threshold (see ISO 11929), the result of the measurement should be expressed as  $\leq c_A^*$  when the result is below the decision threshold;
  - 2) when the activity concentration,  $c_A$ , is compared with the detection limit, the result of the measurement can be expressed as  $\leq c_A^\#$  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;
- j) details of any operating procedures not specified in this document, or regarded as optional, together with details of any incidents likely to have affected the results.