
**Measurement of radioactivity —
Gamma emitting radionuclides —
Reference measurement standard
specifications for the calibration of
gamma-ray spectrometers**

*Mesurage de la radioactivité — Radionucléides émetteurs gamma —
Caractéristiques des étalons de mesure de référence pour l'étalonnage
de spectromètres gamma*

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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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 on 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 the following URL: www.iso.org/iso/foreword.html.

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

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

Everyone is exposed to natural radiation. The natural sources of radiation are cosmic rays and naturally occurring radioactive substances existing in the Earth itself and inside the human body. Human activities involving the use of radiation and radioactive substances cause radiation exposure in addition to the natural exposure. Some individual activities, such as the mining, use of ores containing naturally radioactive substances and the production of energy by burning coal that contains such substances, can simply enhance the exposure from natural radiation sources. Nuclear installations use radioactive materials and produce radioactive effluent and waste during operations. The use of radioactive materials in industry, medicine, agriculture and research is expanding around the globe.

All these human activities generally also give rise to radiation exposures that are only a small fraction of the global average level of natural exposure. The medical use of radiation is the largest and a growing man-made source of radiation exposure in developed countries. It includes diagnostic radiology, radiotherapy, nuclear medicine and interventional radiology.

Radiation exposure also occurs as a result of occupational activities. It is incurred by workers in industry, medicine and research using radiation or radioactive substances, as well as by passengers and crew during air travel and space travel. The average level of occupational exposures is generally similar to the global average level of natural radiation exposure^[10].

As the uses of radiation increase, the potential health risk and the public's concerns may increase. Thus, ionizing radiation exposures are regularly assessed in order to improve the understanding of regional levels and temporal trends of public and worker exposure, to evaluate the components of exposure to provide a measure of their relative importance, and to identify emerging issues that may warrant more attention and scrutiny. While doses to workers are usually directly measured, doses to the public are usually assessed by indirect methods using radioactivity measurements results performed on various sources, including waste, liquid or air effluent, and environmental samples. Environmental samples may include ambient air, soil, surface water, ground water, treated water, vegetation, livestock and game or other biota.

Surveillance programs require financial and technical resources. The program should be designed to acquire data to adequately monitor potential risks. To ensure that the data obtained from radioactivity monitoring programs support their intended use, it is essential in the dose assessment process that stakeholders (the operators, the regulatory bodies, the local information committee and associations, etc.) agree on appropriate data quality objectives, methods and procedures for

- the acquisition, handling, transport, storage and preparation of test samples;
- the test analytical method, and
- for calculating measurement uncertainty.

As reliable, comparable and 'fit for purpose' data are an essential requirement for any public health decision based on radioactivity measurements, international standards of tested and validated radionuclide test methods are an important tool for the production of such measurement results. The application of standards serves also to guarantee comparability over time of the test results and between different testing laboratories. Laboratories apply them to demonstrate their technical qualifications with successful completion of proficiency tests during laboratory intercomparison, two prerequisites to obtain national accreditation. Today, over a hundred international standards, prepared by Technical Committees of the International Organization for Standardization, including those produced by ISO/TC 85, and the International Electrotechnical Commission, are available for application by testing laboratories to measure the main radionuclides.

A reliable determination of the activity concentration of gamma-emitting radionuclides in various matrices is necessary for the assessment of any potential human exposure (public and workers) to the radioactivity of these sources.

Gamma-ray spectrometry is commonly used to determine the activity of gamma-emitting radionuclides. ISO 20042 describes the generic requirements and instrumentation to quantify the

activity concentration of gamma-emitting radionuclides in samples after proper sampling, sample handling and test sample preparation in a testing laboratory or directly on site. ISO 20042 also helps testing laboratories to manage the measurement process by setting out the general requirements and methods to calibrate and validate techniques. It forms the basis for measurement tasks using gamma-ray spectrometry, such as those set out in ISO 18589-3, ISO 18589-7, ISO 10703, ISO 13164-2 and ISO 13165-3.

According to ISO 20042 and the above-mentioned ISO standards, reference measurement standards that are traceable to International Standards or national standards are required to calibrate gamma-ray spectrometry systems. The necessity for developing this document originated from the need for standardized specifications for radioactive reference measurement standards used to calibrate gamma-ray spectrometers, as mentioned in those International Standards. Accordingly, traceability of measurement standards to International Standards or national standards is established by use of sources of reference measurement standards that comply with this document.

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Measurement of radioactivity — Gamma emitting radionuclides — Reference measurement standard specifications for the calibration of gamma-ray spectrometers

1 Scope

This document specifies the characteristics of solid, liquid or gas sources of gamma emitting radionuclides used as reference measurement standards for the calibration of gamma-ray spectrometers. These reference measurement standards are traceable to national measurement standards.

This document does not describe the procedures involved in the use of these reference measurement standards for the calibration of gamma-ray spectrometers. Such procedures are specified in ISO 20042 and other documents.

This document specifies recommended reference radiations for the calibration of gamma-ray spectrometers. This document covers, but is not restricted to, gamma emitters which emit photons in the energy range of 60 keV to 1 836 keV. These reference radiations are realized in the form of point sources or adequately extended sources specified in terms of activity which are traceable to national standards.

Liquid standards that are intended to be used for preparing extended standards by the laboratories are also within the scope of this document. Reference materials (RMs) produced in accordance with ISO 17034 are out of scope of this document.

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 2919, *Radiological protection — Sealed radioactive sources — General requirements and classification*

ISO 9978, *Radiation protection — Sealed sources — Leakage test methods*

ISO 12749-2, *Nuclear energy, nuclear technologies, and radiological protection — Vocabulary — Part 2: Radiological protection*

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

IEC 60050-395, *International Electrotechnical Vocabulary — Part 395: Nuclear instrumentation: Physical phenomena, basic concepts, instruments, systems, equipment and detectors*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12749-2, IEC 60050-395, ISO/IEC Guide 99 and the following 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/>

**3.1
activity**

<of a source> quantitative indication of the radioactivity of an amount of each radionuclide in a source of reference measurement standard, at reference date

Note 1 to entry: It is expressed as $A = -dN/dt$ where dN is the mean change in the number of nuclei in that energy state due to spontaneous nuclear transformations in the time interval dt .

Note 2 to entry: The special name for the unit of activity is becquerel (Bq), where $1 \text{ Bq} = 1 \text{ s}^{-1}$ and $1 \text{ Ci} = 3,7 \times 10^{10} \text{ Bq}$.

**3.2
reference measurement standard
RMS**

<of activity> measurement standard designated for the calibration of other measurement standards for quantities of a given kind in a given organization or at a given location

Note 1 to entry: Reference measurement standard (RMS) for activity of a quantity of radionuclide(s) is provided as radioactive material sealed in a container or associated with a material to which it is closely bonded, this capsule or bonding material being strong enough to maintain leak-tightness of the sealed source under the conditions of use and wear for which it was designed.

**3.3
working measurement standard
WMS**

<of activity> measurement standard used routinely to calibrate or verify measuring instruments or measuring systems

Note 1 to entry: A working measurement standard (WMS) is usually calibrated with respect to a reference measurement standard.

Note 2 to entry: In relation to verification, the terms “check standard” or “control standard” are also sometimes used.

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**3.4
transfer measurement device**
device used as an intermediary to compare measurement standards

**3.5
cascade summing**
simultaneous detection of two or more photons originating from a single nuclear disintegration that results in only one observed (summed) pulse

**3.6
detection efficiency**
ratio of the count rate of detected photons to the photon emission rate of the same energy E from a RMS (3.2) at actual measurement geometry

**3.7
self-absorption**
<of a source> absorption of radiation which occurs within the material of the source itself

**3.8
uncertainty**
standard uncertainty ($k = 1$) unless otherwise stated

Note 1 to entry: The treatment of uncertainties is in accordance with ISO/IEC Guide 98-3.

**3.9
homogeneity**
<of a volume in respect of a given property> indication of the lack variation of that property over the radioactive region in a volume standard

3.10**instrument check source**

single or mixed radionuclide source which have been developed to check the correct functioning of radiation measurement equipment involving gamma-ray spectrometers

Note 1 to entry: Instrument check sources are not used for the calibration of gamma-ray spectrometers.

3.11**metrological traceability**

property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement *uncertainty* (3.8)

3.12**bulk density**

value in g cm^{-3} obtained by the mass of radioactive matrix material filling a container divided by the volume of the container

4 Metrological traceability of reference measurement standards (RMSs)

National metrology institutes (NMIs) or calibration laboratories should, at their discretion, provide the means whereby reference measurement standards of a specified range of radionuclides may be certified by them. In other words, the NMIs or calibration laboratory should be able to provide traceability documentation for RMSs that they create, use, or measure. NMIs and calibration laboratories that provide measurement standards should be accredited in accordance with ISO/IEC 17025 requirements for calibration of measurement standards.

For those countries signatory to the Mutual Recognition Arrangement (MRA), a certificate of calibration from another participating institute in a second country is recognized as valid in the first country for the quantities, ranges, and measurement uncertainties specified in Annex C of Reference [11].

The RMS provided as a solid sealed source should be fabricated using liquid standards of radionuclides. The activity concentration of such a solution named “standardized solution” is determined by absolute activity measurement (e.g. $4\pi\beta - \gamma$ coincidence counting technique) by NMIs.

Pressurized ionization chambers or germanium semiconductor detectors, which were previously calibrated by use of standardized solutions of several kinds of nuclides are also commonly used to determine the activity concentration of the liquid standard by secondary calibration laboratories.

For a point source RMS [see 5.1 a)], the well-mixed liquid standard shall be gravimetrically deposited onto an infinitesimal small substrate (e.g. ion-exchange resin) and the radioactive material is sealed in the source capsule in accordance with ISO 2919.

The well-mixed liquid standard can also be gravimetrically deposited into the capsule and after the drying process, it is covered to avoid leakage of radioactive material.

The activity of the point source can be determined from the activity concentration of the solution source and deposited mass of the liquid standard expressed in grams. Such sources are also used as the RMS to determine the activity of other point sources of the same nuclide by the comparative measure in the secondary calibration laboratory.

In case of the RMS of wide area sources [see 5.1 b)], the well-mixed liquid standard shall be gravimetrically deposited uniformly onto filter paper and after the drying process, sealed in the source capsule [12]. The activity of the wide area RMS can be determined from the activity concentration of the liquid standard and the deposited mass of liquid standard in grams.

For solid source RMS [see 5.1 c)], the well-mixed liquid standard shall be gravimetrically added to a sorbent (e.g. resin, agar, various adsorbents). After a homogenizing process, the radioactive matter shall be gravimetrically deposited in a container and sealed to prevent leakage. The resulting activity can be determined from the mass of radioactive matter in grams, dilution factor (mass of liquid standard per total volume of liquid standard plus sorbent) and the activity concentration of the master solution.

The uncertainty of the calibrated activity should be estimated taking into consideration the uncertainty caused by the loss of activity during the source fabrication process and the homogeneity of the activity distribution across the radioactive matter.

Organizations that type test or require calibrated instruments to measure radioactivity (e.g. testing laboratory of environmental radioactivity measurements) need to have access to suitable RMSs.

The purpose of a working measurement standard is for in-house routine calibration or confirmation of the detection efficiencies of gamma-ray spectrometers. It shall not be confused with instrument check sources which are only intended to verify that a monitor is operating.

Organizations with a requirement to provide WMSs for the routine calibration or confirmation of the detection efficiencies of gamma-ray spectrometers require access to a transfer measurement device with which to calibrate such sources in terms of activity against a RMS. Where only a few monitors need calibration or a high degree of accuracy is required, RMSs may be used as WMSs.

5 Specification of measurement standards

5.1 General

RMSs are of the following kinds:

- a) point source RMSs consisting of an infinitesimal substrate of a known small size (e.g. <1 mm in diameter) comprising the radioactivity homogeneously inside of it. The size of the radioactive part is generally less than 10 mm in diameter,
 - b) wide area source RMSs consisting of a planar radioactive area source (e.g. a filter standard), wherein the activity is uniformly distributed in the radioactive area,
 - c) solid source RMSs filled with a sealed solid substrate with a known density wherein the activity is homogeneously distributed,
- or
- d) liquid source RMSs sealed in glass ampoules which contain a liquid, wherein the activity is homogeneously distributed.

Point sources RMSs are used to infer efficiencies for a counting geometry different from measured efficiency obtained by a point source geometry. When calculations are used to determine efficiencies in the use of gamma-ray spectrometry systems based on numerical models, point sources might be also used to characterize individual detectors of users.

Wide area source RMSs and volume sources RMSs are used to determine full-energy peak efficiency as a function of energy, or detection efficiency of a specific gamma-ray or radionuclide at a certain detector-sample geometry that are employed by the user.

Liquid source RMSs sealed in glass ampoules for calibration of instruments are commonly referred to as reference solutions. The reference solutions are used to prepare reference material or measurement standards by the users themselves after opening ampoules. Prepared reference materials or measurement standards are used to determine full-energy peak efficiency as a function of energy, or detection efficiency of a specific gamma-ray or radionuclide at a certain detector-sample geometry that are employed by the user.

RMSs shall be fit for purpose and it shall be the responsibility of the manufacturer to determine and report the radioactive impurities to the extent necessary to ensure that the use of the source is not compromised by emissions from any impurity.

At a minimum, all radioactive impurities in a measurement standard with an activity of at least 1 % of the total source activity, shall be determined and reported. For those sources which might contain

radioactive impurities, users should take due account that the relative level of the impurity changes with time and could produce a significant effect on the efficiency calibration.

5.2 Reference measurement standard

5.2.1 General requirements

The general method used to calibrate a spectrometer is to establish the detection efficiency as a function of energy for a defined geometry and energy range. One or more RMSs containing single or multiple radionuclides are used for this purpose. The activity or the activity concentration of the radionuclide(s) in the RMS(s) shall be traceable to national or international standards (see ISO 20042).

In order to comply with the requirements specified in this document, volume source RMSs should match, as closely as possible, the geometry, density and matrix of the samples to be measured in testing laboratories.

RMSs shall be accompanied by a calibration certificate involving a product specification giving the following information:

- a) unique RMS identification number;
- b) manufacturer and year of manufacture;
- c) mass or volume (in grams or litres respectively) of the radioactive solution or matrix in the container or the ampoule (for liquid source RMS or solid source RMS);
- d) nature of radioactive matrix (elemental composition) (for liquid source RMS or solid source RMS);
- e) bulk density of radioactive matrix (for solid volume source RMS);
- f) homogeneity (for solid volume source RMS);
- g) Results of the leak test according to ISO 9978;
- h) Then, radionuclide;

NOTE Half-life values and other current nuclear data values are provided by Reference [13].

- 1) activity or activity concentration and its expanded uncertainty ($k = 2$);
- 2) impurities of an activity of at least 1 % of the total radionuclide activity;
- 3) reference date [shall be identical for 1) and 2)];

Manufacturers may decide to give further useful information. Additionally, markings on the RMS itself shall indicate the radionuclide and the RMS identification number.

In order to maintain history and owner inventory information, the following optional descriptive information can be appended to the certificate by the owner, including:

- physical description of source;
- owner inventory identification number;
- date of purchase;
- purchased from.