INTERNATIONAL STANDARD

ISO 19581

First edition
2017-10

Measurement of radioactivity — Gamma emitting radionuclides — Rapid screening method using scintillation detector gamma-ray spectrometry

Mesurage de la radioactivité — Radionucléides émetteurs gamma — Méthode d'essai de dépistage par spectrométrie gamma utilisant des détecteurs par scintillation

Reference number
ISO 19581:2017(E)

ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

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Foreword

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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).

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For an explanation on 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.*

Introduction

Everyone is exposed to natural radiation. The natural sources of radiation are cosmic rays and naturally occurring radioactive substances which exist in the earth and within the human body. Human activities involving the use of radiation and radioactive substances add to the radiation exposure from this natural exposure. Some of those activities, such as the mining and use of ores containing naturally-occurring radioactive materials (NORM) and the production of energy by burning coal that contains such substances, simply enhance the exposure from natural radiation sources. Nuclear power plants and other nuclear installations use radioactive materials and produce radioactive effluent and waste during operation and on their decommissioning. The use of radioactive materials in industry, agriculture and research is expanding around the globe.

All these human activities 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 for astronauts. The average level of occupational exposures is generally below the global average level of natural radiation exposure[11].

As uses of radiation increase, so do the potential health risk and the public's concerns. Thus, all these exposures are regularly assessed in order to

a) improve the understanding of global levels and temporal trends of public and worker exposure

b) to evaluate the components of exposure so as to provide a measure of their relative importance, and

c) to identify emerging issues that may warrant more attention and study.

While doses to workers are mostly directly measured, doses to the public are usually assessed by indirect methods using radioactivity measurements results performed on various sources: waste, effluent and/or environmental samples.

To ensure that the data obtained from radioactivity monitoring programs support their intended use, it is essential that the stakeholders (for example, nuclear site operators, regulatory and local authorities) agree on appropriate methods and procedures for obtaining representative samples and then handling, storing, preparing and measuring the test samples. A assessment of the overall measurement uncertainty needs also to be carried out systematically. 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 and to successfully complete proficiency tests during interlaboratory comparison, two prerequisites for obtaining national accreditation. Today, over a hundred international standards, prepared by Technical Committees of the International Standardization Organization, including those produced by ISO/TC85, and the International Electrotechnical Commission (IEC), are available for application by testing laboratories to measure the main radionuclides.

Generic standards help testing laboratories to manage the measurement process by setting out the general requirements and methods to calibrate and validate techniques. These standards underpin specific standards which describe the test methods to be performed by staff, for example, for different types of sample. The specific standards cover test methods for:

— Naturally-occurring radionuclides (including ^{40}K, ^{3}H, ^{14}C and those originating from the thorium and uranium decay series, in particular ^{226}Ra, ^{228}Ra, ^{234}U, ^{238}U, ^{210}Pb) which can be found in materials from natural sources or can be released from technological processes involving naturally

occurring radioactive materials (e.g. the mining and processing of mineral sands or phosphate fertilizer production and use);

— Human-made radionuclides, such as transuranium elements (americium, plutonium, neptunium, and curium), ^{3}H, ^{14}C, ^{90}Sr and gamma emitting radionuclides found in waste, liquid and gaseous effluent, in environmental matrices (water, air, soil, biota) and food and feed as a result of authorized releases into the environment and of fallout resulting from the explosion in the atmosphere of nuclear devices and accidents, such as those that occurred in Chernobyl and Fukushima.

Environmental materials, including foodstuffs, thus may contain radionuclides at activity concentrations which could present a risk to human health. In order to assess the potential human exposure to radioactivity and to provide guidance on reducing health risks by taking measures to decrease radionuclide activity concentrations, the environment and foodstuffs are routinely monitored for radioactivity content as recommended by the World Health Organization (WHO). Gamma-emitting radionuclides are usually quantified in environmental and food samples by gamma-ray spectrometry using High Purity Germanium (HPGe) gamma-ray spectrometry. Following a nuclear accident, a screening approach based on rapid test methods is recommended to help the decision makers to decide whether activity concentrations in environmental samples, feed and food samples are above or below operational intervention levels (OILs)[12] that are specifically set up to manage nuclear and radiological emergency. During nuclear emergency response, these default radionuclide specific OILs for food, milk and water concentrations from laboratory analysis would be used to measure the effectiveness of protective actions and contribute to determining any further actions required[12][13].

In 1989, following the Chernobyl accident, the first version of the Codex Guideline Levels (GLs) for Radionuclides in Foods Contaminated Following a Nuclear or Radiological Emergency (in the following referred to as "Codex GLs") was adopted. The Codex GLs were reviewed in 2006 and are included in the General Standard for Contaminants and Toxins in Food and Feeds[14][15]. During a nuclear emergency situation, the Codex GLs for gamma-emitting radionuclides such as ^{106}Ru/^{106}Rh and ^{131}I is 100 Bq·kg^{-1}; the GL for ^{60}Co, ^{103}Ru, ^{137}Cs and ^{134}Cs, ^{144}Ce is higher at 1000 Bq·kg^{-1} but a lower limit of 100 Bq·kg^{-1} still applies for foods for infants. Default radionuclide specific OILs for food, milk and water concentrations from laboratory analysis set up by FAO, IAEA, ILO, OECD/NEA, PAHO, OCHA, WHO were recently revised[16].

NOTE The Codex GLs are the activity concentration in foods that would result in an effective dose of 1 mSv/year for members of the Public (infant and adult) in accordance with the most recent recommendations of the International Commission on Radiological Protection (ICRP) considering that 550 kg of food is consumed per year by an adult and 200 kg of food and milk is consumed per year by an infant, with 10 % of the diet is of imported food, all of which is contaminated giving an import to production factor of 0,1. For convenience the GL values were rounded, and radionuclides with ingestion dose coefficients of similar magnitudes grouped and given similar GLs values. However, separate GLs were derived for infants and adults due to differences in radionuclide absorption, metabolism and sensitivity to radiation.

Emergency preparedness should include planning for the implementation of optimized test methods that can provide rapid estimates of activity concentration to be checked against OILs. Thus, an international standard on a screening method using Gamma-Ray Spectrometry is justified for use by testing laboratories carrying out measurements of gamma-emitting radionuclides during an emergency situation. Such laboratories are intended to obtain a specific accreditation for radionuclide measurement in environmental and/or food samples.

This document describes, after proper sampling, sample handling and preparation, a screening method to quantify rapidly the activity concentration of iodine and caesium in environmental, feedstuffs and foodstuffs samples using scintillation spectrometer during an emergency situation.

This document is one of a set of generic international standards on measurement of radioactivity.

Measurement of radioactivity — Gamma emitting radionuclides — Rapid screening method using scintillation detector gamma-ray spectrometry

WARNING — Persons using this document should be familiar with normal testing laboratory practice. This standard 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 ensure compliance with any national regulatory conditions.

IMPORTANT — It is absolutely essential that tests conducted according to this document be carried out by suitably trained staff.

1 Scope

This document specifies a screening test method to quantify rapidly the activity concentration of gamma-emitting radionuclides, such as ^{131}I, ^{132}Te, ^{134}Cs and ^{137}Cs, in solid or liquid test samples using gamma-ray spectrometry with lower resolution scintillation detectors as compared with the HPGe detectors (see IEC 61563).

This test method can be used for the measurement of any potentially contaminated environmental matrices (including soil), food and feed samples as well as industrial materials or products that have been properly conditioned. Sample preparation techniques used in the screening method are not specified in this document, since special sample preparation techniques other than simple machining (cutting, grinding, etc.) should not be required. Although the sampling procedure is of utmost importance in the case of the measurement of radioactivity in samples, it is out of scope of this document; other international standards for sampling procedures that can be used in combination with this document are available (see References [1],[2],[3],[4],[5],[6]).

The test method applies to the measurement of gamma-emitting radionuclides such as ^{131}I, ^{134}Cs and ^{137}Cs. Using sample sizes of 0,5 l to 1,0 l in a Marinelli beaker and a counting time of 5 min to 20 min, decision threshold of 10 Bq·kg^{-1} can be achievable using a commercially available scintillation spectrometer [e.g. thallium activated sodium iodine (NaI(Tl)) spectrometer 2" ϕ × 2" detector size, 7 % resolution (FWHM) at 662 keV, 30 mm lead shield thickness].

This test method also can be performed in a "makeshift" laboratory or even outside a testing laboratory on samples directly measured in the field where they were collected.

During a nuclear or radiological emergency, this test method enables a rapid measurement of the sample activity concentration of potentially contaminated samples to check against operational intervention levels (OILs) set up by decision makers that would trigger a predetermined emergency response to reduce existing radiation risks[12].

Due to the uncertainty associated with the results obtained with this test method, test samples requiring more accurate test results can be measured using high-purity germanium (HPGe) detectors gamma-ray spectrometry in a testing laboratory, following appropriate preparation of the test samples[7][8].

This document does not contain criteria to establish the activity concentration of OILs.

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 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*

IEC 61453, *Nuclear instrumentation — Scintillation gamma ray detector systems for the assay of radionuclides – Calibration and routine tests*

3 Terms and definitions

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

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

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
blank sample
sample, liquid or solid, with very low to no activity for radiation of the same type and region of interest, with a mass and a composition as close as possible to those of the test sample

3.2
emergency
non-routine *situation* that necessitates prompt action, primarily to mitigate a hazard or adverse consequences *for human life and health*, property and the environment

[SOURCE: IAEA safety glossary 2016 Rev.]

Note 1 to entry: This includes nuclear and radiological emergencies and conventional emergencies such as fires, release of hazardous chemicals, storms or earthquakes. It includes situations for which prompt action is warranted to mitigate the effects of a perceived hazard[12].

3.3
operational intervention level
OIL
set level of a measurable quantity that corresponds to a generic criterion

[SOURCE: IAEA safety glossary 2016 Rev. Mod]

Note 1 to entry: OILs are calculated levels, measured by instruments or determined by laboratory analysis, that corresponds to an intervention level or action level. These are typically expressed in terms of dose rates or of activity of radioactive material released, time integrated air activity concentrations, ground or surface concentrations, or activity concentrations of radionuclides in environmental, food or water samples. OILs are used immediately and directly (without further assessment) to determine the appropriate protective actions on the basis of an environmental measurement[12].

3.4
reference level
<emergency exposure situation or existing exposure situation> level of dose, risk or activity concentration above which it is not appropriate to plan exposures to occur and below which optimization of protection and safety would continue to be implemented

[SOURCE: IAEA safety glossary 2016 Rev.]

Note 1 to entry: The chosen value for a reference level depends upon the prevailing circumstances of the exposure under consideration[13]. Above the reference level, it is judged that the risks from exposure are not justified and therefore is not allowed to occur. Below the reference level, optimization of personnel protection needs to be implemented to keep exposures as low as reasonably achievable (ALARA).

3.5
screening level
SL
values that are set up by the laboratory taking into account the characteristics of the measuring equipment and the test method to guarantee that the test result and its uncertainty obtained are fit for purpose for comparison with the operational intervention levels (OILs)

Note 1 to entry: The screening level is less than the OIL. Therefore food is safe for consumption if the screening level is not exceeded. Actions to take, if the food is not safe for consumption, are given in Reference[16].

4 Symbols and units

A	Activity of each radionuclide in reference source, at the measurement time, in becquerels
c_A	Activity concentration of each radionuclide expressed in becquerels per kilogram
$c_{A,\mathrm{SL}}$	Activity concentration that corresponds to the screening level of each radionuclide expressed in becquerels per kilogram
$c_{A,\mathrm{RL}}$	Activity concentration that corresponds to the OIL of each radionuclide expressed in becquerels per kilogram
c_A^*	Decision threshold, without and with corrections, in becquerels per kilogram
$c_A^\#$	Detection limit, without and with corrections, in becquerels per kilogram
$c_A^\triangleright$	Upper limits of the confidence interval, in becquerels per kilogram
R_i	the ratio of the indicated value of a spectrometer to the conventional true value of specific radionuclide, i
ε_E	Counting efficiency of the detector at energy, E
$\varepsilon_{i,E}$	Radionuclide-specific counting efficiency of the detector at energy, E, of specific radionuclide, i
$n_{N,E}$, $n_{\mathrm{Ns},E}$, $n_{N,\mathrm{SL},E}$	Number of net counts in the gamma-ray energy region of interest, at energy E, in the sample spectrum, in the calibration spectrum and in the spectrum obtained from the measurement of reference sample having activity that corresponds to the screening level, respectively
$n_{\mathrm{g},E}$, $n_{\mathrm{gb},E}$, $n_{\mathrm{gs},E}$ $n_{\mathrm{g,SL},E}$	Number of gross counts in the gamma-ray energy region of interest, at energy E, in the sample spectrum, in the background spectrum, in the calibration spectrum and in the spectrum obtained from the measurement of reference sample having activity that corresponds to the screening level, respectively

P_E	Probability of the emission of a gamma ray with energy, E, of each radionuclide, per decay
R_i	Response of the detector/radiometer to the reference activity of radionuclide, i
t_g	Sample counting live time, in seconds
T_b	Background counting live time, in seconds
t_s	Reference source counting live time, in seconds
t_{SL}	Counting live time, in seconds, of a reference sample with an activity corresponding to a screening level
$t_{k\text{-}1,\alpha}$	The two sided t-distribution with k-1 degree of freedom and α two sides probability
$u(c_A)$	Standard uncertainty associated with the measurement result c_A, without and with corrections, in becquerels per kilogram
U	Expanded uncertainty calculated by $U = k \cdot u\ (c_A)$ with $k = 1, 2...$, in becquerels per kilogram
m	Mass of the sample for test, in kilograms
α, β	Probability of a false positive and false negative decision, respectively
$1-\gamma$	Probability for the coverage interval of the measurand

5 Principle

During a nuclear or radiological emergency, it is essential to measure rapidly the activity concentration in samples from the environment and potentially contaminated foodstuffs and feed to protect workers and the public, in accordance with international standards, by keeping doses below the dose reference levels[13]. It is recognized among organizations responsible for emergency management that good preparedness can substantially improve the emergency situation response. Thus default OILs for food are set up by national authorities, and measurement procedures using commonly available contamination screening equipment are implemented to meet the OILs criteria. This should be carried out as part of the emergency preparedness process. The process of assessing radionuclide concentrations in food, milk and water is shown in Figure 1. During the process of assessing radionuclide concentrations in food, milk and water the potentially contaminated food should be screened over a wide area and analysed to determine promptly the activity concentration of gross and/or individual radionuclides. If the OIL are not exceeded, the food, milk and water are safe for consumption during the emergency phase. If an OIL is exceeded, the radionuclide specific concentrations in the food, milk or water should be determined. Finally, as soon as possible the guidance in Reference[17] should be used to determine whether the food, milk or water is suitable for international trade, and national criteria or WHO guidance[18] should be used to determine whether the food, milk or water is suitable for long term consumption after the emergency phase[16].

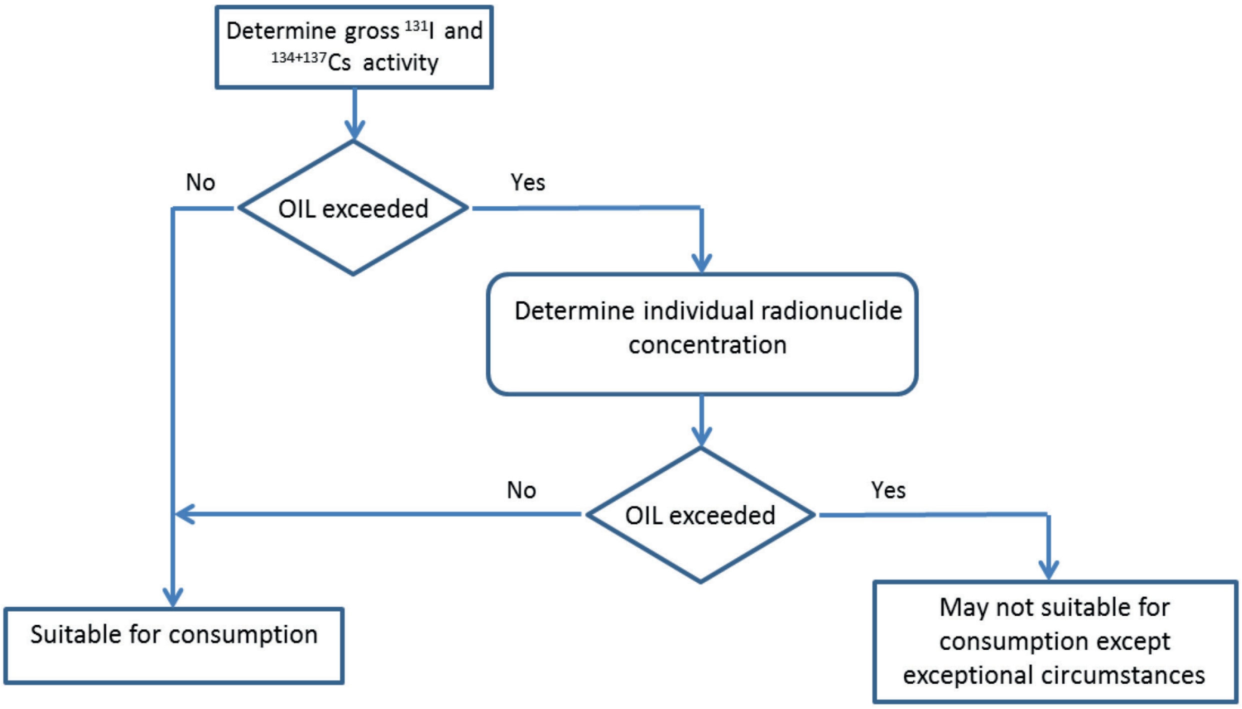

Figure 1 — Example of process of assessing radionuclide concentrations in food
(see explanations in the text and modified from Reference[16])

Laboratories shall make the necessary arrangements to be able to perform appropriate and reliable analyses of environmental and food/feed samples for the purposes of an emergency response. Thus, a screening approach is required, using a fast test method that rapidly provides test results to the decision maker in order to determine whether food and/or feed is suitable for human and/or animal consumption during the post-accident monitoring period and for international trade.

The main radioactive materials released into the atmosphere during a power plant nuclear accident are volatile elements including iodine isotopes (^{131}I, ^{132}I, ^{133}I), caesium isotopes (^{134}Cs, ^{136}Cs, ^{137}Cs) and tellurium (^{132}Te). Samples taken from the environment, the foodstuffs and feed may initially contain high activity concentrations of ^{131}I relative to the caesium isotopes[19]. Although often activity released is also dominated by noble gases, these cannot end up in food.

Therefore the accident monitoring that shall be implemented immediately following a nuclear accident requires a test method designed for the screening of ^{131}I activity concentration of environmental and food samples. When using a test method with a scintillation detector system incorporating a spectrometer (hereinafter referred to as scintillation spectrometer) or a portable gamma-ray detector (e.g. survey meter) with no radionuclide discrimination function, ^{131}I is not determined separately from other iodine isotopes and caesium isotopes. When using a test method with a scintillation spectrometer ^{131}I, ^{134}Cs and ^{137}Cs can be discriminated and potentially quantified with a test method using a scintillation spectrometer. However, using a multichannel analyzer (MCA) with a peak deconvolution program does not avoid the contributions in the energy region of interest of other radionuclides, including short-lived iodine isotopes, caesiums and naturally occurring radionuclides. The ^{131}I activity concentration is therefore overestimated but this is considered as acceptable during the immediate phase following a nuclear accident to rapidly assess the contamination.

A few months after the accident, the short-lived radionuclides, including iodine isotopes, have decayed. Longer-lived radionuclides including ^{134}Cs and ^{137}Cs become predominant in environmental and food samples. During this later period, when using a test method with a portable gamma-ray detector (e.g. survey meter) with no radionuclide discrimination function, ^{134}Cs and ^{137}Cs activity concentration cannot be quantified separately and the test result is considered as the gross activity of both ^{134}Cs and ^{137}Cs. With a scintillation spectrometer individual nuclide activity concentrations can be determined.

