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Measurement of radioactivity in the environment — Soil —

Part 7:
In situ measurement of gamma-emitting radionuclides

Mesurage de la radioactivité dans l'environnement — Sol —

Partie 7: Mesurage in situ des radionucléides émetteurs gamma

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Foreword

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The committee responsible for this document is ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiological protection*.

ISO 18589 consists of the following parts, under the general title *Measurement of the radioactivity in the environment — Soil*:

— *Part 1: General guidelines and definitions*

— *Part 2: Guidance for the selection of the sampling strategy, sampling and pre-treatment of samples*

— *Part 3: Measurements of gamma-emitting radionuclides*

— *Part 4: Measurement of plutonium isotopes (plutonium 238 and plutonium 239 + 240) by alpha spectrometry*

— *Part 5: Measurement of strontium 90*

— *Part 6: Measurement of gross alpha and gross beta activities*

— *Part 7: In situ measurement of gamma-emitting radionuclides*

Introduction

In situ gamma spectrometry is a rapid and accurate technique to assess the activity concentration of gamma-emitting radionuclides present in the top soil layer or deposited onto the soil surface. This method is also used to assess the dose rates of individual radionuclides.

In situ gamma spectrometry is a direct physical measurement of radioactivity that does not need any soil samples, thus reducing the time and cost of laboratory analysis of large number of soil samples.

The quantitative analysis of the recorded line spectra requires a suitable area for the measurement. Furthermore, it is required to know the physicochemical properties of the soil and the vertical distribution in the soil to assess the activity of the radionuclides.

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Measurement of radioactivity in the environment — Soil —

Part 7: In situ measurement of gamma-emitting radionuclides

1 Scope

This part of 18589 specifies the identification of radionuclides and the measurement of their activity in soil using *in situ* gamma spectrometry with portable systems equipped with germanium or scintillation detectors.

This part of ISO 18589 is suitable to rapidly assess the activity of artificial and natural radionuclides deposited on or present in soil layers of large areas of a site under investigation.

This part of ISO 18589 can be used in connection with radionuclide measurements of soil samples in the laboratory (ISO 18589-3) in the following cases:

— routine surveillance of the impact of radioactivity released from nuclear installations or of the evolution of radioactivity in the region;

— investigations of accident and incident situations;

— planning and surveillance of remedial action;

— decommissioning of installations or the clearance of materials.

It can also be used for the identification of airborne artificial radionuclides, when assessing the exposure levels inside buildings or during waste disposal operations.

Following a nuclear accident, *in situ* gamma spectrometry is a powerful method for rapid evaluation of the gamma activity deposited onto the soil surface as well as the surficial contamination of flat objects.

NOTE   The method described in this part of ISO 18589 is not suitable when the spatial distribution of the radionuclides in the environment is not precisely known (influence quantities, unknown distribution in soil) or in situations with very high photon flux. However, the use of small volume detectors with suitable electronics allows measurements to be performed under high photon flux.

2 Normative references

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

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

IEC 61275, *Radiation protection instrumentation — Measurement of discrete radionuclides in the environment — In situ photon spectrometry system using a germanium detector*

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*

3 Terms, definitions, symbols, and units

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
intrinsic efficiency
η_0
cross section of a detector for photons from the direction of the crystal symmetry axis

Note 1 to entry: The intrinsic efficiency depends on the energy of the photon.

3.1.2
detector efficiency
$\eta_0(E)$
detector efficiency in the direction of the crystal symmetry axis as a function of the photon energy E

3.1.3
detector height
d
distance between the geometrical centre of the crystal and the soil surface

3.1.4
efficiency per unit of surface area or unit of mass
ε
ratio between the net count rate of an absorption line with energy E and the photon emission rate per unit area or mass

3.1.5
relative detection efficiency
ratio, expressed in percentage, of the count rate in the ^{60}Co 1 333 keV total absorption peak to the one obtained with a 3 x 3 inch NaI(Tl) scintillator for normal incidence and at 0,25 m from the source

3.1.6
geometry factor
G
ratio between the flux density without scattered photons measured at the detector location and the photon emission rate per unit area or mass

3.1.7
aperture angle of collimator
ϑ_{col}
characteristic angle for an *in situ* gamma spectrometer with collimator

3.1.8
relaxation mass per unit area[7]
β
mathematical parameter describing radionuclide distribution as a function of soil depth

Note 1 to entry: It indicates the soil mass per unit of surface area at which gamma activity decreases to 1/e (37 %).

3.1.9
field-of-view of a detector
soil surface area, from which 90 % of the unscattered detected photons originate

3.1.10
distribution model
V
entity of all physical and geometrical parameters to describe the distribution of the radionuclide in the environment as well as the interaction of an emitted photon with soil and air

3.1.11
angular coefficient
k_m
factor taking into account the angular response of the detector and the angular distribution of the incident flux

3.1.12
measurement area
area in the soil and/or on the soil surface having radionuclide activity per unit of surface area or unit of mass

3.1.13
mass per unit area (collimator)[7]
ζ_{col}
product of material density and wall thickness of a collimator

Note 1 to entry: The mass per unit area is reported for a polar angle, ϑ, of 90° in relation to the crystal centre.

3.1.14
cross section of the detector
ratio of the net rate of the total absorption line at energy E and the flux density of unscattered photons of the energy E in the detector

3.1.15
calibration factor per unit of surface area or unit of mass
w
ratio of the activity of surface area or unit of mass of the radionuclide to the net count rate of the total absorption line

3.2 Symbols and units

For the purposes of this part of ISO 18589, the symbols and units defined in ISO 11929 and given in Table 1 apply.

Table 1 — Symbols

Symbols	Designation	Unit
a	Activity of a given radionuclide at the time of measurement	
	a) per unit of surface area	$Bq \cdot m^{-2}$
	b) per unit of mass	$Bq \cdot kg^{-1}$
$\hat{a}$	Best estimate of the measurand of the activity of the radionuclide in question	
	a) per unit of surface area	$Bq \cdot m^{-2}$
	b) per unit of mass	$Bq \cdot kg^{-1}$
a_K	Activity of the calibration standard at the time of measurement	Bq
a_0	Activity of the radionuclide in question at the soil surface	$Bq \cdot m^{-2}$
$a(\zeta)$	Projected surface activity as a function of mass per unit at the surface of the soil	$Bq \cdot m^{-2}$
a^*	Decision threshold of the measurand of the radionuclide in question at the time of measurement	
	a) per unit of surface area	$Bq \cdot m^{-2}$
	b) per unit of mass	$Bq \cdot kg^{-1}$
$a^{\#}$	Detection limit of the measurand of the radionuclide in question at the time of measurement	
	a) per unit of surface area	$Bq \cdot m^{-2}$

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Table 1 *(continued)*

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Symbols	Designation	Unit
	b) per unit of mass	$Bq \cdot kg^{-1}$
$a^{\triangleright}$, $a^{\triangleleft}$	Upper and lower limit of the confidence interval, respectively, of the measurand of the radionuclide in question at the time of measurement	
	a) per unit of surface area	$Bq \cdot m^{-2}$
	b) per unit of mass	$Bq \cdot kg^{-1}$
c_0, c_1, c_2	Quantities to determine the decision threshold and limit of detection	-
d	Distance between the calibration source and the geometrical centre of the crystal	m
$\dot{D}$	Ambient dose rate as air kerma rate	$Gy \cdot h^{-1}$
E	Photon energy	keV
E_1	1. order exponential integral function $E_1(\alpha) = \int_1^{\infty} \frac{e^{-\alpha x}}{x} dx$	-
E_2	2. order exponential integral function $E_2(\alpha) = \int_1^{\infty} \frac{e^{-\alpha x}}{x^2} dx$	-
f_d	Decay factor	-
f_D	Factor for converting the activity of a radionuclide to ambient dose rate as air kerma rate	
	a) per unit of surface area	$Gy \cdot m^2 \cdot h^{-1} \cdot Bq^{-1}$
	b) per unit of mass	$Gy \cdot kg \cdot h^{-1} \cdot Bq^{-1}$
$f_{\dot{H}^*(10)}$	Factor for converting the activity of a radionuclide to ambient dose equivalent rate	
	a) per unit of surface area	$Sv \cdot m^2 \cdot h^{-1} \cdot Bq^{-1}$
	b) per unit of mass	$Sv \cdot kg \cdot h^{-1} \cdot Bq^{-1}$
G	Geometry factor	
	a) per unit of surface area	-
	b) per unit of mass	$kg \cdot m^{-2}$
$G(E, V)$	Geometry function of photon energy, E, and distribution, V	
	a) per unit of surface area	-
	b) per unit of mass	$kg \cdot m^{-2}$
$\dot{H}^*(10)$	The dose equivalent rate at a point in a radiation field that would be produced by the corresponding expanded and aligned field in the ICRU sphere at a depth, d (here 10 mm), on the radius opposing the direction of the aligned field	$Sv \cdot h^{-1}$
$k, k_{1-\alpha}, k_{1-\beta}, k_{1-\gamma/2}$	Quantiles of the standardized normal distribution	-
k_m	Angular coefficient for photon irradiation from the polar angular segment, m	-
M	Number of polar angular segments	-
m	Index for polar angular segment	-
n_g	Total counts of the total absorption line	-

Table 1 *(continued)*

Symbols	Designation	Unit
n_b	Background counts (under the region of the total absorption line)	-
n_n	Net counts in the total absorption line	-
p	Emission probability per decay for the considered photon energy, E	-
R	Radius of the distribution model	m
R_S	Radius of field of view	m
$u(x_i)$	Standard uncertainty of the input quantity x_i	The unit results from the input quantity.
$u_{rel}^2(x_i)$	Relative variance of the input quantity x_i	The unit results from the input quantity.
t	Measuring time	s
V	Distribution model	-
W	Angular correction factor	-
w	Calibration factor to calculate the activity per unit of surface area or mass of the radionuclide in question	m^{-2} or kg^{-1}
w_h	Calibration factor to calculate the radionuclide specific ambient dose equivalent rate	-
ζ	Mass per unit area	kg · m^{-2}
z	Soil depth	m
z'	Variable of integration of the soil depth	-
ϑ	Polar angle	Degree
ε	Detector efficiency	
	a) per unit of surface area	m^2
	b) per unit of mass	kg
η_m	Cross section of the detector for photons from the polar segment, m	m^2
η_0	Intrinsic efficiency	m^2
ϑ_{ext}	External polar angle of the angular segment of interest	Degree
ϑ_{lim}	Limit angle of the distribution model	Degree
ϑ_{int}	Internal polar angle of the angular segment of interest	Degree
ϑ_{col}	Aperture angle of the collimated spectrometer	Degree
μ_{Air}	Linear attenuation coefficient of air	m^{-1}
μ_S/ρ_S	Mass attenuation coefficient of soil	m^2 · kg^{-1}
$\rho_S(z)$	Soil density as function of soil depth, z	kg · m^{-3}
Φ	Density of flux of unscattered photons of energy E for distribution model V at the detector location	s^{-1} · m^{-2}
$\left(\dfrac{\Delta\Phi_m}{\Phi}\right)_{E,V}$	Portion of flux density of unscattered photons of energy E resulting from polar angle segment m for distribution model V at the detector location	-
β	Relaxation mass per unit area	kg · m^{-2}

4 Principles

4.1 Measurement method

In situ gamma spectrometry is a direct, physical method for fast determination of activity per unit of surface area or per mass unit of gamma-emitting radionuclides present in or deposited on the soil surface.

In situ gamma spectrometry can be considered as a screening method that can supplement soil sampling with a subsequent gamma spectrometry in the laboratory, with the following advantages:

— no time-consuming sampling and no test sample preparation necessary for laboratory;

— short measuring time;

— immediate availability of results in the field;

— representativeness of the results for a fairly large area corresponding to the field-of-view of the detector.

During the measurement, the detector is positioned preferably with the end cap down on an assembly jig.

For quantitative analysis of the pulse height spectra, assumptions are made concerning the distribution of radionuclides in soil, as well as the specific physical properties of the soil and the air.

Generally, the distribution of the radionuclides in soil is not known. The following ideal models are used:

— homogeneous distribution for natural radionuclides;

— surface deposition on the soil top layer for fresh, dry deposition of fallout;

— exponential decreasing activity concentration with increasing depth in soil following a fallout surface deposition of activity and subsequent migration down into deeper soil layers.

NOTE   For the description of the activity distribution in the soil, simple exponential models are mostly used.

According to the assumed distribution model, for homogeneously distributed radionuclides, the activity is given in activity per unit of mass, whereas for artificial radionuclides, which are deposited on the surface and afterwards have migrated into the soil, the results are reported in activity per unit area.

4.2 Uncertainties of the measurement method

Uncertainties of the measurement method are principally due to

— uncertainty of the distribution of the radionuclides on and in the soil,

— contribution from other sources (e.g. activity in the surrounding air, see Annex A).

The main influence quantities are listed in Annex B, with the numerical values given in reference.[14]

5 Equipment

5.1 Portable *in situ* spectrometry system

An *in situ* gamma spectrometer consists of five main components, as listed below:

— high purity germanium detector or scintillation detector;

— pulse processing electronics;

— data recording and evaluation system;

— fixture for mounting the detector (e.g. tripod);

— cooling and, if required, shielding.

A portable *in situ* spectrometry system is recommended. It consists of a portable cooling device and electronics [the latter being a compact multichannel analyser system (MCA) with integrated high voltage power supply and pulse processing unit. Today, pulse processing is preferably performed as digital pulse processing]. Data transfer can be performed through telecommunication, e.g. by cable, radio, or satellite. The spectral data are transferred via cable, WLAN, or radio communication to a PC and stored on a hard disk or digital storage media (e.g. memory sticks, memory cards).

Since, in general, there is no power supply during the measurements in the field, it is useful that the measurement equipment is equipped with internal batteries for a self-contained operation.

5.2 Detector System

5.2.1 General

The high purity germanium system (HPGe System) is described in ISO 18589-3 and IEC 61275. Depending on the measurement objectives, two different types of germanium crystals (n type, p type) can be used. They can be built with different shapes, crystal mountings, end cap, and end cap window materials. The detector characteristics also define the measurement range, both in terms of gamma energy and count rate. A summary of the specifications is given in Annex C.

However, it shall be stressed that detectors capable of measuring at very low energies (like n-type detectors or detectors with special end cap materials) are not very useful for *in situ* measurements. This is due to the fragility of the detector and the large uncertainties of the measured activities caused by the high absorption of gamma radiation in the air and in the ground.

NOTE 1   Although quantitative measurements of radionuclides at low photon energies are not possible with p-type HPGe detectors for in situ measurements, the use of n-type detectors or detectors with special end cap materials provides the ability to identify radionuclides whose energies are below 60 keV.

For general applications, such as the determination of the activity concentration of naturally occurring radioactive material (NORM) in ground or soil contamination by artificial radionuclides, it is recommended to use germanium detectors with a relative detection efficiency of 20 % to 50 % and an energy range above 50 keV.

NOTE 2   In case of emergency measurements with high dose rates above 20 μSv/h (high photon fluxes) smaller germanium detectors with relative detector efficiency less than 20% are preferable.

It is recommended to use detectors which have an isotropic response function, i.e. detectors, which have no or nearly no dependency on the direction of the incident photons. This is the case if the surface area of the detector (i.e. its cross section perpendicular to the direction of the incident photon) is independent of the incidence angle, i.e. if the diameter of the crystal is approximately the same as its length.

NOTE 3   For detectors with a strong directional dependency, it is preferable to use mathematical methods to simulate detector efficiency since this dependency is inherently taken into account. On the other hand, these detectors are advantageous in cases where a limited field-of-view is required.

Under certain conditions, scintillation detectors [NaI(Tl), LaBr$_3$] can be used especially if high precision is not required. In this case, no cooling is required but the nuclide threshold decision and detection limit are higher due to lower energy resolution.

5.2.2 Field-of-view

The field-of-view of the detector is the soil surface area, from which 90 % of the unscattered detected photons originate. This area depends on the characteristics of the detector, the measurement height, the gamma energy, and the distribution of the radionuclide of interest in soil. The field-of-view is always calculated for an infinite measurement area.

5.2.3 Special requirements

The detector system shall comply with the special requirements for *in situ* measurements according to IEC 61275. Specifically, the following topics shall be considered.

a) The system shall be humidity-proof and waterproof (splashing). This is especially true for all mechanical and electrical connections between the preamplifier and multichannel analyser.

b) The crystal shall be mounted in the detector end cap in such a way that the mechanical stress of detector transport does not result in any detector damage. This may mean that special transport containers shall be used.

c) The operating temperature for the detector shall be in the range of −20 °C to +50 °C. (Higher temperatures at the detector end cap may result in worse vacuum in the cap).

d) The capacity of the cooling system shall be sufficient for a complete operation time. In case of loss of cooling (e.g. if the Dewar vessel for liquid nitrogen runs empty), the detector recycling time as specified by the supplier shall be taken into account.

NOTE 1   If the detector is cooled by liquid nitrogen, transport activities result in higher nitrogen consumption.

NOTE 2   For standard applications, high-purity materials for detector mounting, end cap, and end cap window are not required.

5.3   Pulse processing electronics

5.3.1   Components

The pulse processing system consists of the following components:

— detector high voltage power supply;

— spectroscopy amplifier;

— analog-to-digital converter (ADC);

— multichannel analyser (MCA).

Latest versions of commercial electronic units use digital electronics to process the pulses. In this case, the spectroscopy amplifier and the ADC are substituted by a digital signal processor.

It is highly recommended to use integrated pulse processing units. In this case, all the individual electronic components are integrated into one box, which in turn is connected to the detector preamplifier and a personal computer (PC).

The connection to the PC can be done by a serial connection (cable), by USB (cable), by WLAN (wireless), or by other types of radio communication (wireless). The PC should be battery operated.

5.3.2   Special requirements

The pulse processing electronics shall fulfil the following special requirements for *in situ* measurements; if no digital signal processing is used, the system should be temperature stabilized. This can be done by a digital spectrum stabilizer. Digital signal processors normally are not temperature sensitive; hence, stabilization is not required.

NOTE   Stabilization can be done using the gamma line of ^{40}K at 1 461 keV.

It is preferable to use battery-operated electronics. The minimum operation time of the batteries should be 4 hours. Switching between battery and mains operation should be possible.