IEC 61453

Edition 2.0 2007-08

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Nuclear instrumentation – Scintillation gamma ray detector systems for the assay of radionuclides – Calibration and routine tests

Instrumentation nucléaire – Equipements avec détecteurs à scintillation de rayonnement gamma, pour le dosage de radionucléides – Etalonnage et essais individuels

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

PRICE CODE
CODE PRIX
R

ICS 27.120

ISBN 2-8318-9258-9

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NUCLEAR INSTRUMENTATION – SCINTILLATION GAMMA RAY DETECTOR SYSTEMS FOR THE ASSAY OF RADIONUCLIDES – CALIBRATION AND ROUTINE TESTS

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International Standard IEC 61453 has been prepared by IEC International Committee 45: Nuclear instrumentation.

This second edition cancels and replaces the first edition published in 1997. It constitutes a technical revision and an expansion of detector types considered.

The major change in comparison with the previous edition of IEC 61453 is an expansion of detector types considered. Along with sodium iodide detector systems, this new edition standardizes scintillation detector systems based on other inorganic scintillators for photon measurements. Furthermore, Clause 2 has been updated.

The revision of the standard is intended to accomplish the following:

- to extend detector systems base from sodium iodide to inorganic scintillators for photon measurements;
- to review the existing requirements and to update the terminology, definitions and normative references.

The text of this standard is based on the following documents:

FDIS	Report on voting
45/645/FDIS	45/646/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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NUCLEAR INSTRUMENTATION – SCINTILLATION GAMMA RAY DETECTOR SYSTEMS FOR THE ASSAY OF RADIONUCLIDES – CALIBRATION AND ROUTINE TESTS

1 Scope

This International Standard specifies methods of calibration and routine tests of scintillation detector systems for the measurement of gamma-ray energies and emission rates of radionuclides and the assay of radioactivity.

This International Standard is applicable to scintillation detector systems based on inorganic scintillators for photon measurements.

Typical applications include radionuclide identification and assay in various industrial, environmental, and medical applications. The detector system consists of three major components: a scintillating material that produces photons of light when ionizing radiation interacts with it; one or more photomultipliers or photodiodes, optically coupled to the scintillator, which convert the light photons to an amplified electrical pulse or pulses; and associated electronic instrumentation which powers the photomultiplier and processes the output signal.

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Both energy calibration and efficiency calibration are covered. The following three techniques are considered:

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a) total spectrum counting (see 3.1) which employs a system that counts all pulses above a low-energy threshold (see 5.1, 5.2 and 5.3);
b) single-channel analyzer (SCA) counting (see 3.2) which employs a system with a counting channel established through upper and lower energy boundaries (see 5.1, 5.2, and 5.3);
c) multichannel analyzer counting (see 3.3) which employs a system in which multiple counting windows are utilized. This technique allows measurements for which the continuum under the total absorption peak may be subtracted without introducing unacceptable error. In case of overlapping peaks in the spectrum, a multichannel analyzer (MCA) with access to a peak deconvolution program is necessary. This case is not covered by this standard.

2 Terms, definitions, symbols and abbreviations

2.1 Terms and definitions

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

2.1.1
accuracy of measurement
closeness of the agreement between the result of a measurement and the conventionally true value of the measurand

NOTE 1 "Accuracy" is a qualitative concept.

NOTE 2 The term precision should not be used for "accuracy".

[IEV 394-40-35]

2.1.2
activity
A
quantitative indication of the radioactivity of an amount of radionuclide in a particular energy state at a given time. Activity is determined as the quotient of dN by dt, where dN is the expectation value of the number of spontaneous nuclear transitions from that energy state in the time interval dt:

$$A = \frac{\mathrm{d}N}{\mathrm{d}t}$$

The unit of activity is the reciprocal second (s^{-1}). The special name of the unit of activity is the becquerel (Bq), 1 Bq being equal to one transition per second. The earlier unit of activity was the curie (Ci), 1 Ci being equal to $3{,}7 \times 10^{10}$ transitions per second

[IEC 60788:2004, rm-13-18]

2.1.3
assay of activity
determination of the activity of a radionuclide in a sample

2.1.4
assembly
a light protective chamber containing a housed scintillator, photomultiplier, photomultiplier voltage divider

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NOTE Assembly is used for testing of the housed scintillator.

[IEC 62372:2006, 3.1.4]

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2.1.5
background level (of a measuring assembly)
signals of origin other than the radiation to be detected.

NOTE It may refer to:

a) signals caused by radiations from sources inside or outside the detector other than those of interest in the measurement;

b) signals resulting from the short-comings of the electronic circuits of the detecting system and their power supplies.

[IEV 394-39-08]

2.1.6
check source
radioactive source used to confirm the normal operation of measuring instruments

NOTE A source placed at a given distance from the detector producing a stable and reproducible indication.

[IEV 394-40-18]

2.1.7
resolving time correction
dead time correction
correction to be applied to the observed number of pulses in order to take into account the number of pulses lost due to the resolving time or the dead time

[IEV 394-39-22]

2.1.8
detector efficiency
ratio of the number of detected photons or particles to the number of photons or particles of the same type which are incident on the detector in the same time interval

[IEV 394-38-17]

2.1.9
energy calibration
process of establishing a relation between the window setting of the pulse height analyzer and the energy of the photons

[IEC 61948-1:2001, 3.5]

2.1.10
energy resolution
term used to characterize the ability of radiation detector to distinguish between photons of different energies

NOTE The energy resolution can be expressed as the ratio of the peak full width at half maximum (*FWHM*) to peak energy expressed as a percentage.

[IEC 61948-1:2001, 3.6]

2.1.11
Full Width at Half Maximum
FWHM
in a distribution curve comprising a single peak, the distance between the abscissa of two points on the curve whose ordinates are half of the maximum ordinate of the peak

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NOTE If the curve considered comprises several peaks, a full width at half maximum exists for each peak.

[IEC 62372:2006, 3.1.11]

2.1.12
live time
duration during which a detection assembly is sensitive to the input signal

[IEV 394-39-31]

2.1.13
net count rate
observed count rate (number of counts per unit time) corrected for dead time minus background count rate

2.1.14
radiation detection assembly
assembly designed to produce a signal in response to incident ionizing radiation

NOTE 1 This signal carries information about physical properties of the radiation.

NOTE 2 One or more sub-assemblies may be included in the same unit.

[IEV 394-21-11]

2.1.15
reference source
radioactive secondary standard source for use in the calibration of the measuring instrument

[IEV 394-40-19]

2.1.16
response (of a radiation measuring assembly)
ratio, under specified conditions, given by the relation:

$$R = \frac{v}{v_c}$$

where

v is the value measured by the equipment or assembly under test;

v_c is the conventionally true value of this quantity

NOTE 1 The input signal to a measuring system may be called the stimulus; the output signal may be called the response (IVM).

NOTE 2 Response can have several definitions. As an example, the definition of the response of a radiation measuring assembly is given.

[IEV 394-40-21]

2.1.17
routine test
conformity test made on each individual item during or after manufacture

[IEV 394-40-03]

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2.1.18
total absorption peak
portion of the spectral response curve corresponding to the total absorption of photon energy in a radiation detector

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NOTE This peak represents the total absorption of photon energy from all interactive processes, namely:

a) photoelectric absorption,

b) Compton effects, and

c) pair production.

[IEV 394-38-57]

2.2 Symbols and abbreviations

A	the activity of a sample;
A_r	the activity of a reference source;
C_n	the net count rate of a sample;
C_{nr}	the net count rate of a reference source;
G	the gamma-ray emission rate of a sample;
G_E	the gamma-ray emission rate of the gamma-ray of interest of energy E of a sample;
G_r	the gamma-ray emission rate of a reference source;
F_b	multiplicative correction factor to correct for decay of the source during counting;
F_m	multiplicative correction factor considering decay during a measurement;
ε	the total absorption peak efficiency;
λ	the radionuclide decay constant;
C	the observed count rate;
C_o	dead time corrected count rate;

P	the absolute emission probability (of the gamma rays of interest) per decay;
R	the response;
$T_{1/2}$	the radionuclide half-life;
t	the counting time;
t_d	the dead time;
S_B	the standard deviation of a background;
v	the value of a quantity measured by the equipment or assembly under test;
v_C	the conventionally true value of this quantity;
dV	the number of spontaneous nuclear transitions from that energy state;
dt	the time interval;
FWHM	full width at half maximum;
SCA	single-channel analyzer;
MCA	multichannel analyzer.

3 Procedure

3.1 Total spectrum counting systems

3.1.1 General

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All instruments shall be installed and operated in accordance with the manufacturer's instructions. The activity of a radionuclide can only be determined if the instrument has been calibrated with a reference source (or simulated reference source) of the radionuclide being assayed and in the absence of other radionuclides.

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3.1.2 System response calibration

3.1.2.1 Set the lower-level discriminator to a value such that the following conditions are satisfied:

a) the gamma rays of interest are being counted;

b) the system response is insensitive to small changes in discriminator setting;

c) any significant electronic noise is below the counting threshold and the upper-limit discriminator is set to the highest possible setting.

3.1.2.2 For each radionuclide of interest, accumulate counts using a reference source in the reproducible counting geometry desired (see 5.5). At least 10 000 total counts should be accumulated (see 5.4; 5.6).

3.1.2.3 Correct for dead time as specified in 5.7.

3.1.2.4 Obtain the net count rate by subtracting the background level count rate from the total count rate. The same instrument settings shall be used for both counts.

3.1.2.5 Correct for decay of the reference source activity from the time of calibration to the time at which the count rate is measured (see 5.8).

3.1.2.6 Calculate the response R as follows:

$$R = \frac{C_{nr}}{A_r} \quad (1)$$

where

C_{nr} is the net count rate of the reference source (according to 3.1.2.4);

A_r is the activity of the reference source (according to 3.1.2.5).

3.1.3 Activity determination

3.1.3.1 Using the instrument settings according to 3.1.2, place the sample to be measured in the same counting geometry that was used for the system response calibration (see 5.5; 5.9).

3.1.3.2 Accumulate enough counts to obtain the desired statistical level of accuracy (see 5.4; 5.6).

3.1.3.3 Correct the count rate for dead time as specified in 5.7.

3.1.3.4 Obtain the net count rate for the sample by subtracting the background level count rate from the total count rate.

3.1.3.5 Calculate the activity A of the sample by

$$A = \frac{C_n}{R} \qquad (2)$$

where

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C_n is the net count rate of the sample (according to 3.1.3.4);

R is the response (according to 3.1.2.6).

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3.1.4 Routine test

3.1.4.1 Reproducibility tests shall be performed by checking the system response calibration at least once in every week of use with at least one long-lived radioactive checking source with energies that span the region of interest. Correction for radioactive decay of the source since its calibration shall be applied.

3.1.4.2 The response calibration of an idle system when returned to use shall be checked at least semi-annually by using reference sources of radionuclides that span the energy region of interest.

3.1.4.3 The background level of the system shall be measured immediately before and after each batch of samples. The background level shall also be measured periodically, at least once in every week of use.

For accurate assays of radioactive materials whose activities are only slightly above background, the system background should be determined using a sufficient number of background readings and using counting times of sufficient length so as to minimize the uncertainty associated with the background count rate.

3.1.4.4 The results of all performance checks shall be recorded in such a way that deviations from the norm will be readily observable. Appropriate action which could include confirmation, repair and recalibration as required shall be taken when the measured values fall outside of predetermined limits.

3.2 Single-channel analyzer counting systems

3.2.1 General

All instruments shall be installed and operated in accordance with the manufacturer's instructions.

3.2.2 Energy calibration

Establish the energy calibration of the system over the desired energy region at a fixed gain. Using sources of known energy, determine the relationship between the gamma-ray energies and the corresponding settings of the discriminator. Measure the count rate as a function of the lower level discriminator setting at increments of not more than 2 % of the energy range of interest. The window width should be constant and approximately equal to the increments of the lower level discriminator setting. The centre of the window position corresponding to the highest count rate may be assumed to be the centre of the total absorption peak. An improved position can be found through function fit to the count rates around the maximum. The energy calibration shall be determined for each amplifier gain and photomultiplier high-voltage setting used. Radionuclides for which assays will be performed should be used for the energy calibration. If that is not practical, radionuclides with gamma rays that span the energy region of interest shall be used. It is recommended to use single- or double-line emitting radionuclides for the energy calibration.

3.2.3 Total absorption peak efficiency calibration

3.2.3.1 The lower level discriminator and the window width shall be set to include the total absorption peak(s) of interest.

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3.2.3.2 For each radionuclide of interest, accumulate counts using a reference source in a desired and reproducible counting geometry (see 5.5). At least 10 000 total counts should be accumulated (see 5.4; 5.6).

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3.2.3.3 Correct for dead time as specified in 5.7.

3.2.3.4 Obtain the net count rate by subtracting the background level count rate from the total count rate. The same instrument settings shall be used for both counts.

3.2.3.5 Correct the reference source gamma-ray emission rate for decay from the time of calibration to the time at which the count rate is measured (see 5.8).

3.2.3.6 Calculate the total absorption peak efficiency (ε) for each gamma-ray energy as follows:

$$\varepsilon = \frac{C_{\mathrm{nr}}}{G_{\mathrm{r}}} \tag{3}$$

If the reference source is calibrated with regard to activity, the gamma-ray emission rate is given by

$$G_{\mathrm{r}} = A_{\mathrm{r}} \times P \tag{4}$$

3.2.4 Activity determination

3.2.4.1 Using the instrument settings of 3.2.3, place the sample to be measured in the same counting geometry that was used for the efficiency calibration (see 5.5; 5.9).