



Designation: E3376 – 23

Standard Practice for Calibration and Usage of Germanium Detectors in Radiation Metrology for Reactor Dosimetry¹

This standard is issued under the fixed designation E3376; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This standard establishes techniques for calibration, usage, and performance testing of germanium detectors for the measurement of gamma-ray emission rates of radionuclides in radiation metrology for reactor dosimetry. The practice is applicable only to samples of small size, approximating to point sources. It covers the energy and full-energy peak efficiency calibration as well as the determination of gamma-ray energies in the 0.06 MeV to 2 MeV energy region and is designed to yield gamma-ray emission rates with an uncertainty of $\pm 3\%$ (see [Note 1](#)). This technique applies to measurements that do not involve overlapping peaks, and in which peak-to-continuum considerations are not important.

NOTE 1—Uncertainty U is given at the 68 % confidence level; that is, $U = \sqrt{\Sigma \sigma_i^2 + 1/3 \Sigma \delta_i^2}$ where δ_i are the estimated maximum systematic uncertainties, and σ_i are the random uncertainties at the 68 % confidence level. Other techniques of error analysis are in use ([1](#), [2](#)).²

1.2 Additional information on the setup, calibration, and quality control for radiometric detectors and measurements is given in IEEE/ANSI N42.14 and in Guide [C1402](#) and Practice [D7282](#).

1.3 The values stated in SI units are generally to be regarded as standard. The rad is an exception.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 ASTM Standards:³

[C1402](#) Guide for High-Resolution Gamma-Ray Spectrometry of Soil Samples

[D7282](#) Practice for Setup, Calibration, and Quality Control of Instruments Used for Radioactivity Measurements

[E170](#) Terminology Relating to Radiation Measurements and Dosimetry

2.2 IEEE/ANSI Standard:⁴

[N42.14](#) Calibration and Usage of Germanium Detectors Spectrometers for Measurement of Gamma-Ray Emission Rates of Radionuclides

3. Terminology

3.1 Definitions:

3.1.1 *certified radioactivity standard source*—a calibrated radioactive source, with stated uncertainties, whose calibration is certified by the source supplier as traceable to an international or national standards laboratory.

3.1.2 *check source*—a radioactivity source, not necessarily calibrated, that is used to confirm the continuing satisfactory operation of an instrument.

3.1.3 *correlated photon summing*—the simultaneous detection of two or more photons originating from a single nuclear disintegration.

3.1.4 *dead time*—the time after a triggering pulse during which the system is unable to retrigger.

3.1.5 *FWHM*—(full width at half maximum) the full width of a gamma-ray peak distribution measured at half the maximum ordinate above the continuum.

3.1.6 *FWTM*—(full width at tenth maximum) the full width of a gamma-ray peak distribution measured at one tenth of the maximum ordinate above the continuum.

¹ This practice is under the jurisdiction of ASTM Committee [E10](#) on Nuclear Technology and Applications and is the direct responsibility of Subcommittee [E10.05](#) on Nuclear Radiation Metrology.

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² The boldface numbers in parentheses refer to a list of references at the end of this standard.

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

⁴ Available from Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., Piscataway, NJ 08854-4141, <http://www.ieee.org>.

3.1.7 *national radioactivity standard source*—a calibrated radioactive source prepared and distributed as a standard reference material by an international or national standards laboratory.

3.1.7.1 *Discussion*—In the United States, the national standards laboratory is the U.S. National Institute of Standards and Technology (NIST).

3.1.8 *resolution, gamma ray*—the measured FWHM, after background subtraction, of a gamma-ray peak distribution, expressed in units of energy.

3.2 Acronyms:

3.2.1 *GUM*—the GUM, Guide to the Expression of Uncertainty in Measurement (2).

3.2.2 *ROI*—region of interest.

3.3 For other relevant terms, see Terminology E170.

NOTE 2—The terms “standard source” and “radioactivity standard” are general terms used to refer to the sources and standards of National Radioactivity Standard Source and Certified Radioactivity Standard Source.

4. Summary of Practice

4.1 This practice describes the calibration and usage of germanium detectors for measurement of gamma-ray emission rates of radionuclides in radiation metrology for nuclear reactors. The practice is intended for use by knowledgeable persons who are responsible for the development of correct procedures for the calibration and usage of germanium detectors.

4.2 A source emission rate for a gamma ray of a selected energy is determined from the counting rate in a full-energy peak of a spectrum, together with the measured efficiency of the spectrometry system for that energy and source location. It is usually not possible to measure the efficiency directly with emission rate standards at all desired energies. Therefore, a curve or function is constructed to permit interpolation between available calibration points.

5. Significance and Use

5.1 High-purity germanium detectors are used for precise gamma-ray spectroscopy for the purpose of determining radioactivity in materials. Typical applications include monitoring, mapping, and characterization of neutron energy spectra in nuclear reactors or isotopic fission sources.

6. Apparatus

6.1 A typical gamma-ray spectrometry system used in reactor dosimetry consists of a germanium crystal, cooling system (cryogenic or electronic), power supply, and either digital or analog signal processing. When gamma rays interact with the detector, they produce pulses which must be analyzed and counted. Digital processing is often integrated into the detector system with fast analog-to-digital converter, mathematical shaping, signal, and amplification followed by the binning of the pulses. In analog systems, signal processing takes place in individual modules. In both cases, the resultant channelized data are collected and stored electronically for further analysis.

7. Preparation of Apparatus

7.1 Follow the manufacturer’s instructions for setting up and preliminary testing of the equipment. Observe all of the manufacturer’s limitations and cautions. All tests described in Section 12 should be performed before starting the calibrations, and all corrections made when required. A check source may be used to check the stability of the system at least before and after the calibration. In cases where electronic settings are adjustable by the user, it is essential that all the settings be the same for calibration and subsequent use.

8. Calibration Procedure

8.1 *Energy Calibration*—Determine the energy calibration (channel number versus gamma-ray energy) of the detector system at a fixed gain by determining the channel numbers corresponding to full-energy peak centroids from gamma rays emitted over the full-energy range of interest from multi peaked or multinuclide radioactivity sources, or both. Determine nonlinearity correction factors as necessary (3).

8.1.1 Using suitable gamma-ray compilations (4, 5), plot or fit to an appropriate mathematical function the values for peak centroid (in channels) versus gamma energy.

8.2 Efficiency Calibration:

8.2.1 Accumulate an energy spectrum using calibrated radioactivity standards at a desired and reproducible source-to-detector distance. Set the ROI for each peak of interest to include at least all channels within the FWTM of the peak. At least 20 000 net counts should be accumulated in each full-energy gamma-ray peak of interest using National or Certified Radioactivity Standard Sources, or both (see 12.1, 12.5, and 12.6).

8.2.2 For each standard source, obtain the net count rate (total count rate of region of interest minus the Compton continuum count rate and, if applicable, the ambient background count rate within the same region) in the full-energy gamma-ray peak, or peaks, using a method that provides consistent results (see 12.2, 12.3, and 12.4).

8.2.3 Correct the standard source emission rate for decay to the date and time of the count in 8.2.2.

8.2.4 Calculate the full-energy peak efficiency, E_f , as follows:

$$E_f = \frac{N_p}{N_\gamma} \quad (1)$$

where:

E_f = full-energy peak efficiency (counts per gamma ray emitted),

N_p = net gamma-ray count in the full-energy peak (counts per second live time) (Note 3) (see 8.2.2), and

N_γ = gamma-ray emission rate (gamma rays per second).

NOTE 3—Any other unit of time is acceptable provided it is used consistently throughout.

8.2.5 There are many ways of calculating the net gamma-ray count. This practice specifies a valid, common technique, applicable when there are no interferences from photo peaks within an energy range at least equal to the FWTM adjacent to the peak of interest.

8.2.5.1 Other net peak area calculation techniques used for single peaks when there is interference from adjacent peaks are not considered in this practice. Other techniques are acceptable, if they are used in a consistent manner and have been verified to provide accurate results.

8.2.5.2 Using a simple model, the net peak area for a single peak can be calculated as follows:

$$N_A = G_s - B - I \quad (2)$$

where:

G_s = gross count in the peak region of interest (ROI) in the sample spectrum,

B = continuum, and

I = number of background counts in the region of interest (if there is no background peak, or if a background subtraction is not performed, $I = 0$).

8.2.5.3 The net gamma-ray count, N_p , is related to the net peak area as follows:

$$N_p = N_A / T_s \quad (3)$$

where:

T_s = spectrum live time.

8.2.5.4 The continuum, B , is calculated from the sample spectrum using the following equation (see Fig. 1):

$$B = \frac{N}{2n}(B_{1s} + B_{2s}) \quad (4)$$

where:

N = number of channels in the peak ROI,

n = number of continuum channels on each side,⁵

B_{1s} = sum of counts in the low-energy continuum region in the sample spectrum, and

B_{2s} = sum of counts in the high-energy continuum region in the sample spectrum.

NOTE 4—These equations assume that the channels that are used to calculate the continuum do not overlap with the peak ROI, and are

⁵ For simplicity of these calculations, n is assumed to be the same on both sides of the peak. If the continuum is calculated using a different number of channels on the left of the peak than on the right of the peak, different equations must be used.

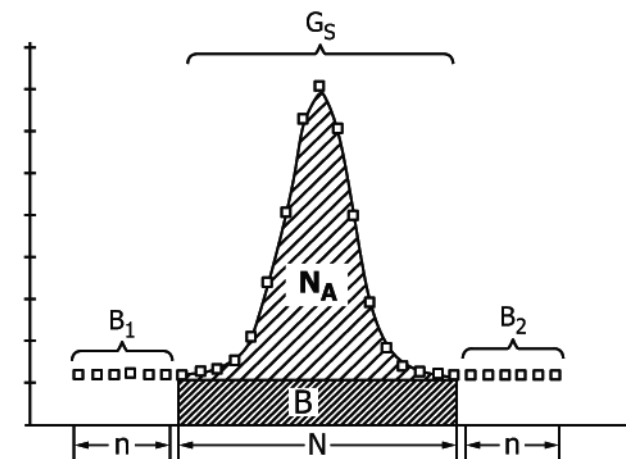


FIG. 1 Typical Spectral Peak with Parameters Used in the Peak Area Determination Indicated

adjacent to it or have the same size gap between the two regions on both sides. A different equation must be used if the gaps are of a different size.

8.2.5.5 The peak background, I , is calculated from a separate background measurement using the following equation:

$$I = \frac{T_s}{T_b} I_b \quad (5)$$

where:

T_s = live time of the sample spectrum,

T_b = live time of the background spectrum, and

I_b = net background peak area in the background spectrum.

8.2.5.6 If a separate background measurement exists, the net background peak area is calculated from the following equation:

$$I_b = G_b - B_b \quad (6)$$

where:

G_b = sum of gross counts in the background peak region (of the background spectrum), and

B_b = continuum counts in the background peak region (of the background spectrum).

8.2.5.7 The continuum counts in the background spectrum are calculated from the following equation:

$$B_b = \frac{N}{2n}(B_{1b} + B_{2b}) \quad (7)$$

where:

N = number of channels in the background peak ROI,

n = number of continuum channels on each side (assumed to be the same on both sides),

B_{1b} = sum of counts in the low-energy continuum region in the background spectrum, and

B_{2b} = sum of counts in the high-energy continuum region in the background spectrum.

8.2.5.8 If the standard source is calibrated in units of Becquerels, the gamma-ray emission rate is given by:

$$N_\gamma = AP_\gamma \quad (8)$$

where:

A = number of nuclear decays per second, and

P_γ = probability per nuclear decay for the gamma ray (4, 5).

8.2.6 In cases where a calibrated standard source is available for a particular isotope that is also used in an unknown sample, the measured efficiency for that isotope is used directly for the unknown.

8.2.7 Plot, or fit to an appropriate mathematical function, the values for full-energy peak efficiency (determined in 8.2.4) versus gamma-ray energy (see 12.5) (6-14).

9. Measurement of Gamma-Ray Emission Rate of the Sample

9.1 Place the sample to be measured at the source-to-detector distance used for efficiency calibration (see 12.6).

9.1.1 Accumulate the gamma-ray spectrum, recording the count duration.

9.1.2 Determine the energy of the gamma rays present by use of the energy calibration obtained under and at the same gain as 8.1.