

N42.28

American National Standard for Calibration of Germanium Detectors for In-Situ Gamma-Ray Measurements

Accredited by the American National Standards Institute

Sponsored by the
National Committee on Radiation Instrumentation, N42



Published by
The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

26 February 2004

Print: SH95154
PDF: SS95154

American National Standard for Calibration of Germanium Detectors for In-Situ Gamma-Ray Measurements

Sponsor

National Committee on Radiation Instrumentation, N42

Accredited by the

American National Standards Institute

Secretariat

The Institute of Electrical and Electronics Engineers, Inc.

Approved 6 September 2002

American National Standards Institute

Abstract: The need for accurately measuring radioactivity in-situ for a variety of detector characterization techniques requires that performance criteria for efficiency calibration be developed, and such a calibration technique is described in this standard.

Keywords: calibration, gamma-ray, germanium detectors, in-situ

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2003 by the Institute of Electrical and Electronic Engineers, Inc.
All rights reserved. Published 26 February 2004. Printed in the United States of America.

Print: ISBN 0-7381-3763-4 SH95154

PDF: ISBN 0-7381-3764-2 SS95154

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission from the publisher.

American National Standard

An American National Standard implies a consensus of those substantially concerned with its scope and provisions. An American National Standard is intended as a guide to aid the manufacturer, the consumer, and the general public. The existence of an American National Standard does not in any respect preclude anyone, whether he has approved the standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the standard. American National Standards are subject to periodic reviews and users are cautioned to obtain the latest editions.

CAUTION NOTICE: This American National Standard may be revised or withdrawn at any time. The procedures of the American National Standards Institute require that action be taken to affirm, revise, or withdraw this standard no later than five years from the date of publication. Purchasers of American National Standards may receive current information on all standards by calling or writing the American National Standards Institute.

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1-978-750-8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Introduction

(This introduction is not part of ANSI N42.28-2002, American National Standard for Calibration of Germanium Detectors for In-Situ Gamma-Ray Measurements.)

This standard is the responsibility of the Accredited American Standards Committee on Radiation Instrumentation, N42. Committee N42 delegated the development of this standard to Subcommittee N42.RM. Drafts were reviewed by Committee N42, Subcommittee N42.RM, and other interested parties; and the comments were utilized in producing the standard as finally approved. This standard was approved on N42 letter ballot of 25 September 2002.

Participants

At the time Committee N42 approved this standard, it had the following members:

Louis Costrell, *Chair*
Michael P. Unterweger, *Vice Chair*
Sue Vogel, *Administrative Secretary*

<i>Organization Represented</i>	<i>Name of Representative</i>
American Conference of Governmental Industrial Hygienists.....	Jesse Lieberman
Battelle Pacific Northwest Laboratories	Joseph C. McDonald
Consultant	Morgan Cox
Eberline Instruments	Mitchell Truitt
Entergy-ANO.....	Ron Schwartz
Health Physics Society.....	Joseph R. Stencil
Institute of Electrical and Electronics Engineers, Inc.....	Louis Costrell
	Julian Forster (<i>Alt.</i>)
	Anthony J. Spurgin (<i>Alt.</i>)
Lawrence Berkeley Laboratory	Edward J. Lampo
Lawrence Livermore Laboratory	Gary Johnson
Massachusetts Institute of Technology, Bates Linear Accelerator Center, RPO	Frank X. Masse
Oak Ridge National Laboratory.....	Charles L. Britton
	Peter J. Chiaro, Jr. (<i>Alt.</i>)
ORTEC.....	Ronald M. Keyser
Overhoff Technology Corporation.....	Mario W. Overhoff
Saint-Gobain	Richard P. Oxford
Swinth Associates	Kenneth L. Swinth
Thermo Gamma-Metrics.....	Ernesto A. Corte
U.S. National Institute of Standards & Technology	Louis Costrell
	Michael P. Unterweger (<i>Alt.</i>)
Wisconsin Public Service Group	Timothy Martinson
Members-at-Large.....	Joseph G. Bellian
	Paul L. Phelps
	Jack M. Selby
	Carl R. Siebentritt
	Al N. Tschaech
	Lee J. Wagner

At the time this standard was approved, Subcommittee N42.RM had the following members:

Frank X. Masse, *Chair*
J. M. R. Hutchinson, *Secretary*

Robert Ayres
Joseph G. Bellian
John D. Buchanan
R. F. Coley
Bert M. Coursey

Michael Devine
Roger Ferris
Robert J. Gehrke
Y. Kobyashi
Markku Koskelo
J. L. Lazewatsky

David McCurdy
D. M. Montgomery
Carl W. Seidel
John Sonewald
Michael P. Unterweger

The balloting committee that approved this standard consisted of all persons listed herein as members of Accredited Standards Committee on Radiation Instrumentation, N42.

At the time this standard was approved, the Working Group had the following members:

P. Shebell, *Co-Chair and Co-Project Leader*
R. J. Gehrke, *Co-Chair and Co-Project Leader*

Frasier Bronson
Scott Faller

David Keefer

Ronald Reiman
Michael P. Unterweger

Contents

1. Overview	1
1.1 Scope and purpose	1
2. References.....	2
3. Definitions	2
4. General requirements	6
4.1 Documents and records supplied by the service provider	6
4.2 Reporting of uncertainty	6
4.3 Detection limits	6
4.4 Quality assurance	7
5. General test procedures.....	7
5.1 General.....	7
5.2 Test conditions.....	7
5.3 Test procedure.....	7
5.4 Sources.....	8
6. Test configurations, test ranges, and test values	8
6.1 Partial compliance and limitations on test results.....	9
7. Characterizing the performance	9
7.1 Performance specification.....	9
7.2 Performance analysis	10
7.3 Performance criteria.....	10
8. Uncertainties and uncertainty propagation	11
8.1 Evaluation of the standard uncertainty of the source distribution	12
8.2 Evaluation of the standard uncertainty in the source matrix and attenuating layers	12
Annex A (normative) Test methods using point sources.....	13
Annex B (normative) Test methods using gamma emitters in surface soils	23
Annex C (normative) Test methods using simulations.....	28
Annex D (normative) Characterized large area sources	31
Annex E (normative) Calculation and approximation of solid angles.....	35
Annex F (informative) Bibliography	36

List of figures

A.1—Drawing of an experimental arrangement	13
A.2—The coordinate system as seen by looking down from at the cryostat face	15
A.3—Example of one potential detector misalignment	16
A.4—Geometry of the experiment with labeling of distances and angles	17
A.5—Extrapolation of average counting rate per segment as a function of horizontal position, x_{ic} , for a line source and for a disk source	19
A.6—Geometry of the experiment showing an absorber of thickness t covering the point source	22
B.1—Square sampling pattern (the dot marks the in-situ measurement location).....	26
B.2—Triangular sampling pattern (the dot marks the in-situ measurement location)	26
B.3—Radial sampling pattern (the dot marks the in-situ measurement location)	26
E.1—Solid angle, Ω , subtended by a disk of radius r at a standoff distance d	35

List of tables

1—Test values for the test configurations	8
2—Performance criteria for the specified test configurations	10
B.1—Energy ranges, nuclides, and gamma-ray energies for tests	24
D.1—Assigned parameters for the Walker Field pads (30 ft by 40 ft)	31
D.2—Assigned parameters for Grand Junction H pads (48 in. diameter by 20 in. height)	32
D.3—Assigned parameters for Grand Junction P pads (60 in. diameter by 24 in. height)	32
D.4—Assigned parameters for Grand Junction E pads (42 in. diameter by 18 in. height)	32
D.5—Assigned parameters for Casper E pads (42 in. diameter by 18 in. height)	33
D.6—Assigned parameters for Grants P pads (42 in. diameter by 24 in. height)	33
D.7—Assigned parameters for Grants E pads (42 in. diameter by 24 in. height)	33
D.8—Assigned Parameters for George West E pads (42 in. diameter by 18 in. height)	34

American National Standard for Calibration of Germanium Detectors for In-Situ Gamma-Ray Measurements

1. Overview

In-situ gamma-ray spectrometry using portable high-purity germanium (HPGe) detectors, collimated or uncollimated, is a technique for measuring the gamma-ray fluence rate from a gamma-emitting source for the purpose of obtaining or estimating a specific activity or activity concentration. The most common and well-established application of in-situ spectrometry has been the measurements of gamma-emitting radionuclides in surface soils. Recently, the technique is being applied to large extended objects such as walls, pipes, and containers of radioactive material. The impracticality of constructing standards for these geometries precludes the use of traditional approaches to detector calibration. Therefore, those wishing to use the technique have developed alternative approaches that use a combination of measurements and calculations. The growing need for quality assurance for in-situ measurements of radioactivity, along with the variety of calibration techniques, requires that performance tests be developed for assessing the calibration of HPGe detectors for the sources currently being measured.

1.1 Scope and purpose

The purpose of this standard is to specify performance tests for the calibrations of in-situ gamma-ray measurement systems for a range of test configurations. This standard applies to service providers and their customers performing or requiring radioassay of sources using in-situ gamma-ray spectrometry with HPGe detectors (hereafter referred to as “detectors”). It is generally assumed, but not required, that the sources are large (with respect to the detector). It is also assumed that the calibration is performed without the benefit of certified reference materials that are identical, in terms of the radionuclide mix and geometry, to the objects being measured. This standard applies to the calibration of detectors, uncollimated or collimated, for the measurement of the following objects:

- Uniformly contaminated surface soils
- Surficial contamination of flat objects
- Volumetric contamination of cylindrical and rectangular objects
- Containerized homogeneous sources (cylindrical and rectangular containers)
- Attenuated sources

The energy of the gamma-rays addressed in this standard is 60 keV to 3000 keV.

This standard does not treat the specialized cases of aerial gamma-ray spectrometry, in-situ spectrometry in boreholes. Moreover, this standard does not address in-situ gamma-ray spectrometry measurements for detectors operated in a gross counting mode. Discussions of procedures as they pertain to peak-finding algorithms, peak-position, peak-area measurements, and energy calibration, as well as discussions of performance tests of spectrometry systems and analysis software are beyond the scope of this standard; refer to ANSI N42.14-1999 and IEC 61275-1997-09 for such methods.

CAUTION—While guidance on the application of in-situ gamma-ray spectrometry and the use of in-situ measurement data is beyond the scope of this standard, some general remarks concerning the technique are warranted. As with any measurement technique, one must be aware of assumptions that give rise to limitations on the range of potential applications. In-situ measurements carry specific assumption regarding many measurement parameters. The most notable parameter is the distribution of activity in the source. A detector measures only the gamma-ray fluence from which one can infer an activity concentration. The extent to which the measurement assumptions reflect the actual or true measurement conditions is the extent to which the measurements results will satisfy their intended purpose. For example, a detector that is calibrated to measure sources with uniformly distributed activity will produce inconsistent and misleading results if the source is highly heterogeneous. However, there could be an acceptable degree of heterogeneity that would still allow for useful data. Service providers and their customers should consider using data quality objectives as a guide or a means to evaluate a measurement program that uses or intends to use this technique.

2. References

This standard shall be used in conjunction with the following publications. When the following specifications are superseded by an approved revision, the revision shall apply.

ANSI/ASQC E4-1994, American National Standard Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs.¹

ANSI N42.23-1996, American National Standard Measurement and Associated Instrumentation Quality Assurance for Radioassay Laboratories.

ANSI N42.14-1999, American National Standard for Calibration and Use of Germanium Spectrometers for the Measurement of Gamma-Ray Emission Rates of Radionuclides.

HPS N13.30-1996, Performance Criteria for Radiobioassay.²

IEC 61275-1997-09, Radiation protection instrumentation—Measurement of discrete radionuclides in the environment—In-situ photon spectrometry system using a germanium detector.³

3. Definitions

The word “shall” denotes a requirement, the word “should” denotes a recommendation, and the word “may” denotes permission. To conform to this standard, in-situ gamma-ray spectrometry measurements (hereafter referred to as in-situ measurements) shall be evaluated according to the requirements of this standard, but not necessarily with its recommendations; however, justification should be documented for deviations from a recommendation.

¹ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

²HPS standards are available from HPS, 1313 Dolley Madison Blvd., Suite 402, MacLean, VA 22101, USA, Fax 703-790-2672 (<http://hps.org/documents/>).

³IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA.

For the purposes of this standard, the following terms and definitions apply:

3.1 absorber: Any material that absorbs or diminishes the gamma-ray fluence from the source.

3.2 activity concentration: The expected number of spontaneous nuclear decays (transformations) per gram, per surface or volume of material in a unit time from a specified energy state (excluding prompt decays from a lower nuclear level) for a given amount of a radionuclide. Its standard unit (SI) is the becquerel (Bq) per mass, volume or surface area, where one Bq equals one decay per second. Activity concentration has often been expressed in curies (Ci), where 3.7×10^{10} Bq equals 1 Ci, exactly.

NOTE—The activity concentration is generally abbreviated to concentration and is sometimes called the *specific activity*.

3.3 attenuated source: A source is attenuated when at least 25% of the gamma rays emitted from the source and in the direction of the detector arrive at the detector having undergone some energy reduction as a result of interactions with absorbers between the source and the detector's encap.

NOTE—The absorbers are generally part of the source, such as a container.

3.4 calibration: The determination of a value that converts a measured number into a desired physical quantity (e.g., pulse height into photon energy, or counts per second into an activity concentration).

NOTE—The calibration refers to a process, procedure, and/or methodology by which one determines an efficiency value.

3.5 coefficient of variation (CV): The standard deviation divided by the average value.

3.6 collimated: Refers to the use of absorbers with transmission holes between the source and the detector to reduce or restrict the detector's field of view.

3.7 combined standard uncertainty (u_c): The uncertainty resulting from combining category A and category B uncertainties, as defined by the Bureau International des Poids et Mesures (BIPM), using standard statistical methods. Category A uncertainties are evaluated by applying statistical methods to a series of repeated measurements and are characterized by the estimated standard deviation, σ_A ; category B uncertainties are assigned to quantities whose variation is not explicitly observed. Category B uncertainties are determined by estimating from other information an approximation to a corresponding "standard deviation," σ_B , whose existence is assumed. They are combined as if they are all standard deviations.

3.8 containerized source: A radioactive source that is encased or sealed in a specific, regularly shaped container.

3.9 conventional true value: The value attributed to a particular quantity and accepted, sometimes by convention, as having an uncertainty appropriate for a given purpose. *Syn:* **reference value.**

3.10 counting rate: The rate at which detector pulses are being registered in a selected voltage interval. The units are s^{-1} .

3.11 customer: The recipient and user of the in-situ measurement data.

3.12 efficiency: The ratio between the detector response, e.g., the number of selected pulses recorded per unit time to the number of gamma rays emitted by the source per unit time.

NOTE—The efficiency as it is defined above corresponds to what usually is referred to as the *absolute efficiency*.

3.13 field conditions: Environmental and operating conditions under which an in-situ measurement is performed.

3.14 field of view (FOV): The portion of the source that is bounded by the solid angle subtended by the detector (with respect to the source) in which 90% of photons that are recorded in the full energy photopeak or photopeaks of the spectrum for the energy or energies of interest.

NOTE—The FOV varies with gamma-ray energy, source thickness, composition and density of the source, external attenuation, as well as properties of the detector. The FOV can be expressed in terms of the solid angle or in terms of the linear dimensions of the source.

3.15 full-energy peak: A peak in the spectrum resulting from the complete (total) absorption of gamma rays of a given energy in the active volume of the detector and the collection of all of the resulting charge. *Syn:* **photopeak.**

3.16 high energy: High energy refers to a range of gamma-ray energies. If E is the gamma-ray energy, then a photon is high energy if $100 < E \leq 3000$ keV.

3.17 infinite half-space: A source that subtends a solid angle of 2π steradians and has an infinite thickness.

3.18 in-situ measurement: A measurement that is performed on a source or object in its natural or native condition.

3.19 large source: A source that subtends a solid angle greater than $\pi/2$ but less than 2π steradians.

3.20 linear attenuation coefficient (μ): The linear attenuation coefficient of a material for uncharged ionizing particles is given by the relation

$$\mu = \frac{1}{N} \frac{dN}{dl}$$

where dN/N is the fraction of particles that experience an interaction while traversing a distance dl in a material. The units are cm^{-1} .

3.21 low energy: Refers to a range of gamma-ray energies. If E is the gamma-ray energy, then a photon is low energy if $60 < E \leq 100$ keV.

3.22 mass attenuation coefficient (μ/ρ): The mass attenuation coefficient is the linear attenuation per unit density. The units are $\text{cm}^2 \text{g}^{-1}$.

3.23 mass thickness: The mass thickness is mass per unit area (density $\times$ thickness). The units are $\text{cm}^{-2} \text{g}$.

3.24 mean free path (MFP): The average length a photon will travel before having an interaction. It can be estimated by the reciprocal of the linear attenuation coefficient. The units are cm.

$$\text{MFP} \equiv 1/\mu$$

3.25 measurements assurance program (MAP): A program that allows manufacturers to verify the accuracy of their measurements through exchange of samples with the National Institute of Standards and Technology (NIST). This involves the analysis of blind samples sent to suppliers by NIST, and NIST measurement of sources certified and provided by the supplier.

3.26 NIST: National Institute of Standards and Technology (formerly U.S. National Bureau of Standards, NBS).

3.27 NSLR: A country's national standardizing laboratory for radioactivity measurements.

3.28 point source: A source material confined to a volume whose dimensions are small compared with the distance between the source and detector and small compared to the mean free path of the material for its own radiation.

3.29 relative bias (B): The difference between the measurement value and the reference value divided by the reference value.

3.30 relative standard uncertainty [$u_{c,r}(y)$]: The relative standard uncertainty of the measurement result y is the combined standard uncertainty $u_c(y)$ divided by $|y|$.

$$u_{c,r}(y) \equiv \frac{u_c(y)}{|y|} \quad |y| \neq 0$$

3.31 service provider: The provider of in-situ measurements data.

3.32 small source: A source that subtends a solid angle less than $\pi/2$ steradians.

3.33 soil moisture: The water content in soil expressed as a percentage of mass per unit volume.

3.34 solid angle (Ω): The angular spread at the vertex of a cone measured by the area intercepted by the cone on a unit sphere whose center is at the vertex of the cone. The units are steradians.

3.35 source: An object, typically in solid, that emits gamma rays.

3.36 standard uncertainty (u): A component of the uncertainty that contributes to the uncertainty of a measurement result by an estimated standard deviation. It is equal to the positive square root of the estimated variance.

3.37 standoff distance (d): The distance along the detector's azimuthal axis from the face of the window of the detector housing to the point at which the axis of the detector intersects the plane of the source or its container.

3.38 source thickness (t): The distance between the two boundary surfaces of the source that are aligned along the axis of the detector.

3.39 test conditions: Environmental and operating conditions under which a performance test is executed.

3.40 test value: A value corresponding to a given test configuration that shall be used to demonstrate compliance with this standard.

3.41 thick source: A source is thick if the source thickness is greater than or equal to 1.5 times the mean free path of the gamma ray.

3.42 thin source: A source is thin if the source thickness is less than 1.5 times the mean free path of the gamma ray.

3.43 weighted average ($\bar{y}$): The sum of the products of each value and its weight, divided by the sum of the weights. The weights used in this standard are the measurement uncertainties, σ .

NOTE—If a series of n measurements are performed measuring values y_i and uncertainties σ_i , then the weighted average is given by

$$\bar{y} = \frac{\sum_{i=1}^n (\sigma_i^{-2} y_i)}{\sum_{i=1}^n \sigma_i^{-2}}$$

4. General requirements

4.1 Documents and records supplied by the service provider

The service provider shall provide data in the form of documents and records that demonstrate their ability to accurately calibrate a detector for the full range of source-detector geometries set forth in this standard, or to an appropriate subset of geometries that has been agreed to by the customer. The data may apply to a specific detector or to the calibration, in which case the data may apply to a range or class of detectors. In this case, the service provider shall include documentation that demonstrates the calibration to be detector independent; that is, the documentation shall show that those features and/or properties of the range or class of detectors that affect its efficiency for the measurement conditions have been adequately measured and/or modeled.

NOTES

1—A range or class of detectors refers to a collection of detectors that have similar physical properties and are constructed with similar materials. For example, a service provider may have several detectors from a single manufacturer that differ only with respect to the shape and size of the germanium crystal. Such a collection would constitute a range or class of detectors.

2—The features and/or properties of the detector that affect its efficiency include, but are not limited to, its active volume, the shape of the crystal, and materials surrounding the active volume. A service provider wishing to demonstrate that the calibration is detector-independent would have to show that differences or variations in the active volume, crystal shape, and materials surrounding the active volume have been addressed in the calibration.

4.2 Reporting of uncertainty

The service provider shall provide the uncertainty associated with an in-situ measurement. When reporting uncertainty, the service provider shall follow the approach given in Section 7 of NIST Technical Note 1297 [B20]. Specific recommendations on the evaluation of the standard uncertainty and the combined standard uncertainty of an in-situ measurement are given in Clause 8 of this standard, ANSI N42.28-2002.

4.3 Detection limits

The service provider shall furnish estimates of the detection limit for the radionuclides of interest for the techniques used in the measurement. The service provider shall follow the recommendations and practices regarding the use and reporting of detection limits found in A.7 of ANSI N42.23-1996.⁴

⁴Information on references can be found in Clause 2.

4.4 Quality assurance

The service provider shall have a quality assurance process associated with in-situ measurements. This quality assurance process should be part of an overall quality assurance program. The program should be in compliance with national consensus standards that provide guidance on quality assurance practices such as ANSI N42.23-1996, ANSI/ASQC E4-1994, and ASME NQA-1-1994 [B5].⁵ At a minimum, the quality assurance program should address the quality of the following elements:

- Procedures and instruction
- Document control
- Records
- Personnel qualifications
- Quality control of instruments

For guidance on good practices for performing in-situ measurements, as well as calibration methods, this standard recommends ICRU Report 53 [B9].

RECOMMENDATION—An intercomparison between service providers is instrumental for evaluating undetected biases. This standard recommends that, whenever possible, the service provider participate in intercomparison programs for in-situ spectrometric measurements. A description and the results of a previous intercomparison may be found in Miller et al. [B14].

5. General test procedures

5.1 General

The performance tests developed in this standard, ANSI N42.28-2002, are designed to demonstrate the ability of the service provider to calibrate a detector with the accuracy and precision required by this standard for a range of source-detector geometries. The performance shall apply to a specific detector or to the calibration process. In the latter case, the performance can be applied to a range or class of detectors if it can be shown and documented that those features and/or properties of the range or class of detectors that affect its efficiency for the measurement conditions have been adequately measured and/or modeled.

5.2 Test conditions

The test conditions should reasonably simulate the in-situ conditions. If it can be shown that environmental conditions such as temperature, relative humidity, wind, and atmospheric pressure do not influence the result of an in-situ measurement, then they do not need to be simulated in the test.

5.3 Test procedure

The test procedure shall be performed in a manner consistent with the procedures for in-situ measurements. As set forth in 4.4 of this standard, the procedures shall be part of a quality assurance program. It is recommended that any ancillary equipment used in the in-situ measurement that might affect the efficiency, such as analyzer, cables, detector support mechanism, and computer software, also be used in the test.

⁵The numbers in brackets correspond to those of the bibliography in Annex F.