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Standard Guide for
Use of Modeling for Passive Gamma Measurements[1]

This standard is issued under the fixed designation C1726/C1726M; 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 guide addresses the use of models with passive gamma-ray measurement systems. Mathematical models based on physical principles can be used to assist in calibration of gamma-ray measurement systems and in analysis of measurement data. Some nondestructive assay (NDA) measurement programs involve the assay of a wide variety of item geometries and matrix combinations for which the development of physical standards are not practical. In these situations, modeling may provide a cost-effective means of meeting user's data quality objectives.

1.2 A scientific knowledge of radiation sources and detectors, calibration procedures, geometry and error analysis is needed for users of this standard. This guide assumes that the user has, at a minimum, a basic understanding of these principles and good NDA practices (see Guide C1592), as defined for an NDA professional in Guide C1490. The user of this standard must have at least a basic understanding of the software used for modeling. Instructions or further training on the use of such software is beyond the scope of this standard.

1.3 The focus of this guide is the use of response models for high-purity germanium (HPGe) detector systems for the passive gamma-ray assay of items. Many of the models described in this guide may also be applied to the use of detectors with different resolutions, such as sodium iodide or lanthanum halide. In such cases, an NDA professional should determine the applicability of sections of this guide to the specific application.

1.4 Techniques discussed in this guide are applicable to modeling a variety of radioactive material including contaminated fields, walls, containers and process equipment.

1.5 This guide does not purport to discuss modeling for "infinite plane" in situ measurements. This discussion is best covered in ANSI N42.28.

1.6 This guide does not purport to address the physical concerns of how to make or set up equipment for in situ measurements but only how to select the model for which the in situ measurement data is analyzed.

1.7 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.8 *The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C1490 Guide for the Selection, Training and Qualification of Nondestructive Assay (NDA) Personnel
C1592 Guide for Nondestructive Assay Measurements
C1673 Terminology of C26.10 Nondestructive Assay Methods

2.2 *Other Standard:*[3]

ANSI N42.28 Performance Standard for the Calibration of Germanium Detectors for In Situ Gamma-Ray Measurements

3. Terminology

3.1 See Terminology C1673.

4. Summary of Guide

4.1 Passive gamma-ray measurements are applied in conjunction with modeling to nondestructively quantify radioactivity.

4.1.1 Modeling may be used to *(1)* design and plan the measurements, *(2)* establish instrument calibration, *(3)* interpret the data acquired, *(4)* quantify contributions to the measurement uncertainty, *(5)* simulate spectra, and *(6)* evaluate the effectiveness of shielding.

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[1] This practice is under the jurisdiction of ASTM Committee C26 on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee C26.10 on Non Destructive Assay.

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[2] 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.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

4.1.2 Various models commonly use analytical, numerical integration and radiation transport approaches. This guide provides a brief review of several approaches to help the user select a suitable method and apply that method appropriately.

4.1.3 Modeling makes use of knowledge of the measurement configuration including the shape, dimensions and materials of the detector, collimator, and measurement item content.

4.1.4 The exact geometry may be approximated in the model. The degree of approximation acceptable is assessed on a case by case basis.

4.1.5 Process knowledge may be required to provide information about inner containers, intervening absorbers, matrix materials or which radionuclides are present.

4.1.6 The models make use of basic physical interaction coefficients. Libraries and data sets must be available.

4.1.7 Models are typically used to: *(1)* account for field of view and geometry effects, *(2)* account for matrix attenuation, *(3)* account for container wall and other absorbers, *(4)* model detectors, *(5)* transfer calibrations from one configuration to another, *(6)* bound the range of assay values due to variations in modeling representation parameters, *(7)* iteratively refine assessments and decision making based on comparisons with observations.

4.1.8 Scans may be performed using low-resolution, portable gamma-ray detectors (for example, NaI) to identify the location of activity and assist with the modeling.

4.1.9 Measurement uncertainties are estimated based on uncertainties of the assumptions of the model.

5. Significance and Use

5.1 The following methods assist in demonstrating regulatory compliance in such areas as safeguards (Special Nuclear Material), inventory control, criticality control, decontamination and decommissioning, waste disposal, holdup and shipping.

5.2 This guide can apply to the assay of radionuclides in containers, whose gamma-ray absorption properties can be measured or estimated, for which representative certified standards are not available. It can be applied to in situ measurements, measurement stations, or to laboratory measurements.

5.3 Some of the modeling techniques described in the guide are suitable for the measurement of fall-out or natural radioactivity homogenously distributed in soil.

5.4 Source-based efficiency calibrations for laboratory geometries may suffer from inaccuracies due to gamma rays being detected in true coincidence. Modeling can be an advantage since it is unaffected by true coincidence summing effects.

6. Procedure

6.1 Modeling may lead to a bias if any of the measurement parameters do not match the physical characteristics of the item. Uncertainties in the item parameters of the following may lead to a bias:

6.1.1 Matrix distribution is homogenous throughout the container,

6.1.2 Hidden containers,

6.1.3 Matrix identification,

6.1.4 Container fill heights,

6.1.5 Mass attenuation coefficients,

6.1.6 Matrix density,

6.1.7 Detector parameters, and

6.1.8 Physical distribution of radioactivity.

6.2 If the quantity of nuclear material is "infinitely thick" to the emitted gamma rays, measurement results will be biased. This hazard is common when measuring items containing large quantities of heavy elements (for example, thorium, uranium, or plutonium) or items with highly attenuating matrices. Alternate NDA assay methods are recommended if this condition exists.

6.3 Self attenuation, commonly present in lumps of actinide material, will bias results low unless lump corrections are computed.

6.4 The Generalized Geometry Holdup Method must be calibrated with the collimator attached to the detector. If the detector recess changes from the calibration position, the results will be biased.

6.5 Absorber foils that are used to reduce count rate must be included in the model.

6.6 Attenuation corrections for very thick items may be somewhat compromised by coherent scattering, which may not be accurately modeled by attenuation calculations.

7. Method Descriptions

Five commonly used methods are described. These include: *(1)* Generalized Geometry Holdup, *(2)* Far-field Approximation, *(3)* Voxel Intrinsic Efficiency, *(4)* Radiation Transport Code, and *(5)* Hybrid Monte Carlo.

7.1 *Generalized Geometry Holdup*—The method represents items as a point, line, or area (**1**).[4] Three method calibrations are obtained from one set of calibration measurements. Point sources of the same material as that to be measured are often used for the calibration. Measurements and calibrations are made with a collimator attached. Additional attenuation correction factors are needed for a complete analysis. The detector calibrations remain the same for all measurements, but attenuation correction factors will vary with the specific measurement. Results are typically reported in units of mass.

7.1.1 *Advantages of this method are:*

7.1.1.1 The detector efficiency is easily determined; three different types of geometry calibrations are performed concurrently.

7.1.1.2 Any cylindrical collimator could be used.

7.1.1.3 Typically, only point sources are used.

7.1.1.4 Additional geometry corrections do not require use of half-life or gamma ray yields.

7.1.2 *Disadvantages of this method are:*

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

7.1.2.1 Some holdup items being measured may not have geometries that simulate points, lines, or areas.[5] However, the errors introduced by these assumptions are often small compared to other errors.

7.1.2.2 The model assumes uniform concentration and distribution of radioactive material. The uncertainties due to these assumptions can be mitigated by taking multiple overlapping measurements (subject to time constraints) and judicial measurement placement.

7.1.2.3 The calibration applies only to the exact detector-collimator configuration used during the calibration.

7.1.2.4 Special nuclear material licenses may be required for the calibration sources.

7.1.3 Typical applications include uranium and plutonium holdup.

7.1.4 *Calibration*—Point sources, representative of the material, m_o, being measured, are positioned in off-axis positions and the peak count rate is determined at each location. The activity of each location can be used to represent the activity/unit area of the area within the concentric ring, a_i. See Fig. 1. This information is integrated to obtain calibration constants for point, line, and area configurations.

7.2 *Far-field Approximation*—This method is used for the calculation of activity in well-defined geometries (**2**). The method assumes that the matrix attenuation correction for the item being measured can be estimated using a far-field matrix correction approximation. Additional correction factors are needed for other types of attenuation and geometry. Templates may be prepared that match parameters of the items being measured and the positioning of the detector during the measurement. Geometry and attenuation correction factors are computed from the information supplied by the templates. This model can be used for many shapes. Usually measurements are made with a collimator to provide detector shielding and directional response. The detector calibration remains the same for all measurements, but attenuation and geometry correction factors will vary with the specific measurement. Results are reported in activity, concentration, or mass units.

7.2.1 *Advantages of this method are:*

7.2.1.1 The detector efficiency is easily determined.

7.2.1.2 The calibration can be applied to any gamma-emitting radionuclide within the energy range of the calibration source and the validity of the correction factors.

7.2.1.3 Models can be constructed for cylinders, boxes, point sources, and disc geometries.

7.2.1.4 Detector collimation is incorporated in the model and does not affect the detector calibration.

7.2.2 *Disadvantages of this method are:*

7.2.2.1 The model does not apply to the analysis of activity in a non-uniform condition (for example, activity in soil in an exponential distribution).

7.2.2.2 The calibration does not apply to close-up geometries, where the far-field approximation for matrix attenuation does not apply, or very large items (for example, infinite planes).

7.2.2.3 Correction factors assume incoming gamma rays are parallel to the detector axis and, therefore, have reduced accuracy for the off-axis portion of activity.

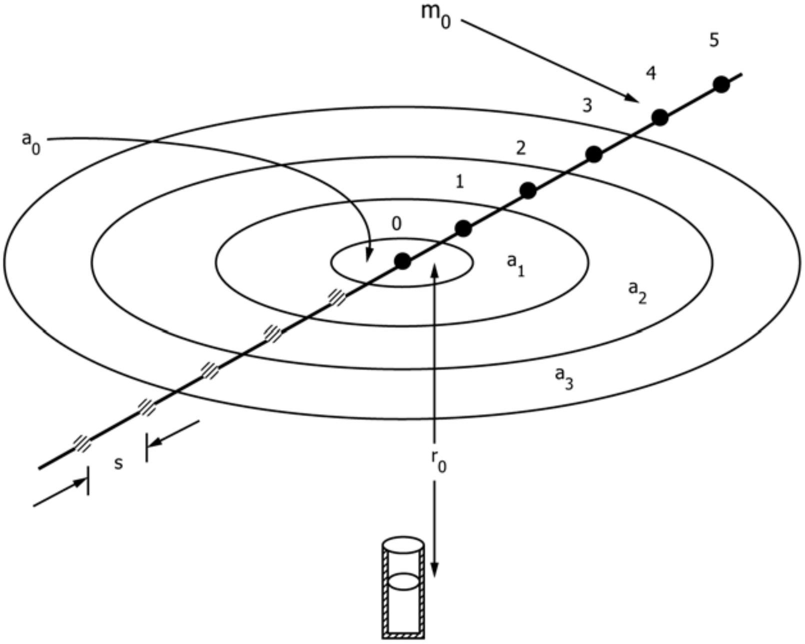

FIG. 1 Detector Position for Calibration

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[5] In a gaseous diffusion plant there are many items that contain holdup and cannot be measured as points, lines or areas. Two examples are converters and pipes in pipe galleys. In order to have a large enough standoff for pipes to meet the criteria for lines, several pipes in the galley are usually within the field-of-view. Converters are typically measured from outside cell housings, which places the detector several feet away. Because the converters have a large diameter (from 1.2 m to 2.7 m for the sizes that can be reliably measured by gamma), pulling back far enough to make them line sources would place several converters into the field-of-view, and then they would not be long enough to meet the line source definition. In addition, the internal structure of converters is too complex to model them as point, line, or area.