ANSI N42.12-1994(R2004)
(Revision of ANSI N42.12-1980)

American National Standard Calibration and Usage of Thallium Activated Sodium Iodide Detector Systems for Assay of Radionuclides

Sponsor
National Committee on Radiation Instrumentation, N42

Accredited by the

American National Standards Instititute

Secretariat
The Institute of Electrical and Electrical Engineers, Inc.

Reaffirmed Decmber 2, 2004
Approved December 8, 1994

American National Standards Institute

Abstract: Methods for performance testing, calibration, and usage of Nal(TI) detector systems for the measurement of gamma ray emission rates of radionuclides; the assay for radioactivity; and the determination of gamma ray energies and intensities are established. Both energy calibration and efficiency calibration are covered
Keywords: calibration, efficiency calibration, energy calibration, gamma-ray energy, radioactivity, radionuclides

---

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

Copyright © 1995 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published1995. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by the Institute of Electrical and Electronics Engineers, Incorporated.

ISBN 0-5593-7491-8

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

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS

Not for Resale

IEEE Standards documents are developed within the Technical Committees of the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE that have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason IEEE and the members of its technical committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

IEEE Standards documents may involve the use of patented technology. Their approval by the Institute of Electrical and Electronics Engineers does not mean that using such technology for the purpose of conforming to such standards is authorized by the patent owner. It is the obligation of the user of such technology to obtain all necessary permissions.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

Introduction

(This introduction is not a part of ANSI N42.12-1994, American National Standard Calibration and Usage of Thallium-Activated Sodium Iodide Detector Systems for Assay of Radionuclides.)

This standard, a revision of ANSI N42.12-1980, is the responsibility of the Accredited Standards Committee N42 on Radiation Instrumentation. Committee N42 delegated the development of this standard to its Subcommittee N42.2. Drafts were reviewed by Committee N42, Subcommittee N42.RM on Radioactivity Measurements, and other interested parties, and the comments received were utilized in producing the standard as finally approved. The standard was approved by N42 letter ballot of 11 April 1994.

At the time it approved this standard, the Accredited Standards Committee on Radiation Instrumentation, N42, had the following members:

Louis Costrell, *Chair* **Luigi Napoli,** *Administrative Secretary*

Organization Represented	*Name of Representative*
American Conference of Governmental Industrial Hygienists	Jesse Lieberman
Health Physics Society	George Campbell
	Joseph R. Stencel (*Alt.*)
Institute of Electrical and Electronics Engineers	Louis Costrell
	Julian Forster (*Alt.*)
	Anthony J. Spurgin (*Alt.*)
Lawrence Berkeley Laboratory	Edward J. Lampo
Lawrence Livermore National Laboratory	Paul L. Phelps
National Institute of Standards and Technology	Louis Costrell
	Michael P. Unterweger (*Alt.*)
Oak Ridge National Laboratory	Hugh R. Brashear
Pacific Northwest Laboratories	Kenneth L. Swinth
US Army Center for EW/RSTA	Edward Groeber
US Department of Energy	Gerald Goldstein
US Federal Emergency Management Agency	Carl R. Siebentritt
US Nuclear Regulatory Commission	Edward C. Wenzinger, Sr.
Members-at-Large	Joseph C. Bellian
	Ernesto A. Corte
	Morgan Cox
	John M. Gallagher
	Jack M. Selby
	Al N. Tschaeche
	Edward J. Vallario
	Lee J. Wagner
	Sanford 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	Bert M. Coursey	Y. Kobyashi
Joseph G. Bellian	Michael Devine	David McCurdy
John D. Buchanan	Roger Ferris	D. M. Montgomery
R. F. Coley	Robert J. Gehrke	Carl W. Seidel

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

The working group for this standard had the following members:

Joseph G. Bellian, *Project Leader*

Rod Dayton	Tom Jenkins	Robert Kinzer
J. M. R. Hutchinson	Peter Paul	Ernesto A. Corte
Melvyn Halbert	Don W. Miller	Frank X. Massey

The following persons were on the balloting committee:

Joseph G. Bellian	Gerald Goldstein	Anthony J. Spurgin
Hugh R. Brashear	Edward Groeber	Joseph R. Stencil
George Campbell	Edward J. Lampo	Kenneth L. Swinth
Ernesto A. Corte	Jesse Lieberman	Al N. Tschaeche
Louis Costrell	Paul L. Phelps	Michael Unterweger
Morgan Cox	Jack M. Selby	Edward J. Vallario
Julian Forster	Carl L. Siebentritt	Sanford Wagner
John M. Gallagher		Edward C. Wenzinger, Sr.

Mary Lynne Nielsen
IEEE Standards Project Editor

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

Contents

CLAUSE PAGE

1. Overview 1

1.1 Scope 1
1.2 Purpose 1

2. References 2

3. Definitions 2

4. Procedure 3

4.1 Total spectrum counting systems 3
4.2 SCA counting systems 5
4.3 MCA counting systems 6

5. Sources of systematic error 8

6. Precautions 9

6.1 Assay for a radionuclide for which no radioactivity standard is readily available 9
6.2 Assay of mixtures of radionuclides 9
6.3 Thin-Window detectors 9
6.4 Count rates 9
6.5 Geometric correction factors 9
6.6 Counting statistics 9
6.7 Dead-Time corrections 9
6.8 Correction for decay during the counting period 10
6.9 Counting geometry 11
6.10 Spectral features 11
6.11 Full-Energy-Peak efficiency versus energy function or curve 11
6.12 Net count rate 12
6.13 Temperature effects 12
6.14 Linearity 12

7. Bibliography 12

--`,,`,,,,-`-`,,`,,`,`,,`---

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS Not for Resale

American National Standard Calibration and Usage of Thallium-Activated Sodium Iodide Detector Systems for Assay of Radionuclides

1. Overview

1.1 Scope

This standard establishes methods for performance testing, calibration, and usage of thallium-activated sodium iodide [NaI(Tl)] detector systems for the measurement of gamma ray emission rates of radionuclides; the assay for radioactivity; and the determination of gamma ray energies and intensities. It covers both energy calibration and efficiency calibration. The following three techniques are considered:

a) Total spectrum counting (see 4.1) employs a system that counts all pulses above a low-energy threshold (see 6.1, 6.2, and 6.3).
b) Single-channel analyzer (SCA) counting (see 4.2) employs a system with a counting "window," which establishes upper and lower energy boundaries (see 6.1, 6.2, and 6.3).
c) Multichannel analyzer (MCA) counting (see 4.3) employs a system in which multiple counting windows are utilized. This technique allows measurements for which the continuum under the full-energy peak may be subtracted without introducing unacceptable error.

In case of overlapping peaks in the spectrum, it is realized that an MCA with access to a spectrum-stripping program is necessary. Such cases are not covered by this standard.

1.2 Purpose

The purpose of this document is to provide a standardized basis for the calibration and usage of sodium iodide detector systems for the measurement of gamma ray emission rates of radionuclides. Typical applications include radionuclide identification and assay in various industrial, environmental, and medical applications. An NaI(Tl) detector system consists of three major components: a scintillating medium that produces a flash of light when ionizing radiation interacts with it; one or more photomultipliers, optically coupled to the scintillator, which converts the light flash to an amplified electrical impulse; and associated electronic instrumentation that powers the photomultiplier and processes the output signal. (See IEEE Std 398-1972.[1])

[1]Information on the reference can be found in clause 2.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

The theory of operation of NaI(Tl) detectors is presented in numerous publications, including [B3], [B5], and [B9] in clause 7.

2. References

This standard shall be used in conjunction with the following publication:

IEEE Std 398-1972 (Reaff 1990), IEEE Standard Test Procedures for Photomultipliers for Scintillation Counting and Glossary for Scintillation Counting Field (ANSI).[2]

3. Definitions

3.1 accuracy: The degree of agreement of the measured value with the true value of the quantity being measured.

3.2 assay: The determination of the activity of a radionuclide in a sample.

3.3 ambient background: Those counts that can be observed, and thereby allowed for, by measuring a sample that is identical to the unknown sample in all respects except for the absence of radioactivity. These counts are attributable to environmental radioactivity in the detector itself, the detector shielding material, and the sample container; cosmic rays; electronic noise pulses; etc.

3.4 check source: A radioactive source, not necessarily calibrated, that is used to confirm the continuing satisfactory operation of an instrument.

3.5 correlated gamma ray summing: The simultaneous detection of two or more gamma rays originating from a single atom disintegration.

3.6 dead time (t_d): The time after a triggering pulse during which the system is unable to retrigger.

3.7 efficiency: The net number of counts registered by the detector system per unit of time, divided by the number of photons of interest originating in the radioactive source during the same unit of time.

3.8 energy calibration: The relationship between the height of the amplifier output pulse and the energy of the photons originating in the radioactive source.

3.9 full-energy peak: The peak in a pulse height spectrum that corresponds to total absorption of a gamma photon in the NaI(Tl) detector.

3.10 full width at half maximum (FWHM): The full width of a gamma photon peak distribution measured at an ordinate halfway between the maximum ordinate of the peak and the background.

3.11 live time: The total time of the measurement minus the total dead time.

3.12 precision: The degree of agreement of repeated measurements of the same property, expressed quantitatively as the standard deviation computed from the results of the series of measurements.

3.13 pulse height radiation: See 3.16.

[2]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS Not for Resale

3.14 radioactivity standard source: A radioactivity standard, as used in this document, shall be either a radioactivity standard that has been certified as to absolute radioactivity by a laboratory recognized as the National Standardizing Laboratory of a country for radioactivity measurements or a radioactivity standard that has been obtained from a supplier who participates in measurement assurance activities with the National Standardizing Laboratory when such standards are available. In such measurement assurance activities, the radioactivity calibration value of the suppliers should agree with the National Standardizing Laboratory value within the overall uncertainty stated by the supplier in its certification of the same batch of sources or in its certification of similar sources.

3.15 random photon summing: The simultaneous detection of two or more photons originating from the disintegrations of more than one atom.

3.16 resolution, pulse height: The measured FWHM, after ambient background subtraction, of a gamma-ray peak distribution, expressed as a percentage of the pulse height corresponding to the centroid of the distribution.

3.17 sensitivity response: The net number of counts registered by the detector system per unit of time, divided by the activity of the radionuclide.

3.18 shall: A verb indicating an action required by this standard.

3.19 should: A verb indicating an action that is to be included when practical.

3.20 simulated source: A radioactive source consisting of one or more long-lived radionuclides that are chosen to simulate the radiations from a short-lived or unavailable radionuclide of interest.

3.21 window width: The difference between the upper-level and lower-level discriminator settings.

4. Procedure

4.1 Total spectrum counting systems

4.1.1 General

All instruments shall be installed and operated in accordance with the instructions of the manufacturer (see clause 6). The activity of a radionuclide can only be determined if the instrument has been calibrated with a standard source (or simulated standard source) of the radionuclide being assayed and in the absence of other radionuclides.

4.1.2 Sensitivity response calibration

a) Set the low-level discriminator to a value such that the following conditions are satisfied:
   1) The gamma rays of interest are being counted.
   2) The system response is as insensitive as possible to small changes in discriminator setting.
   3) Any electronic noise is below the counting threshold.
b) For each radionuclide of interest, accumulate counts using a radioactivity standard source in a desired and reproducible counting geometry (see 6.5). At least 10 000 net counts should be accumulated (see 6.4 and 6.6).
c) Correct for dead time, as described in 6.7.
d) Obtain the net count rate by subtracting the ambient background count rate from the total count rate. The same instrument settings shall be used for both counts.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

e) Correct for decay of the radioactivity standard source activity from the time of standardization to the time at which the count rate is measured (see 6.8).

f) Calculate the sensitivity response (R) as follows:

$$R = C/A \quad (1)$$

where

C is the net count rate [from item d)]

A is the activity of the radioactivity standard [from item e)]

4.1.3 Activity determination (see 6.1 and 6.2)

a) Using the instrument settings of 4.1.2, place the sample to be measured in the same counting geometry that was used for the activity response calibration (see 6.5 and 6.9).

b) Accumulate enough counts to obtain the desired statistical level of accuracy (see 6.4 and 6.6).

c) Correct the count rate for dead time, as described in 6.7.

d) Obtain the net count rate for the sample by subtracting the ambient background count rate from the total count rate (see 6.8).

e) Calculate the activity (A) of the sample as follows:

$$A = C/R \quad (2)$$

where

C is the net count rate [from item d)]

R is the sensitivity response [from item f) of 4.1.2]

4.1.4 Performance testing

4.1.4.1 System count rate reproducibility

The system count rate reproducibility shall be checked and recorded on each day of use using at least one long-lived radioactive source with energies that span the region of interest. Correction for radioactive decay of the source since its original measurement shall be applied. Refer to the record to be sure that system count rate is reproducible.

4.1.4.2 Ambient background

The ambient background of the system shall be checked as often as is practical. For accurate assays of radioactive materials whose activities are only slightly above background, the system background will be determined using a sufficient number of background readings and using counting times of sufficient length so as to minimize the error associated with the count rate.

4.1.4.3 Results

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.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS Not for Resale

4.2 SCA counting systems

4.2.1 General

All instruments shall be installed and operated in accordance with the instructions of the manufacturer (see clause 6).

4.2.2 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 upper-level and lower-level discriminators. Measure the count rate as a function of the lower-level discriminator setting at gamma ray energy increments of not more than 2% of the energy range of interest. The window width should be held constant and approximately equal to the increments of the lower-level discriminator setting. The center of the window position corresponding to the highest count rate may be assumed to be the center of the full-energy peak. The energy calibration shall be determined for each amplifier gain or 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 (see 6.14).

4.2.3 Full-Energy-Peak efficiency calibration

a) The lower-level discriminator and the window width shall be set to include the full-energy peak(s) of interest and to minimize variations in counting rate due to gain change.

b) For each radionuclide of interest, accumulate counts using a radioactivity standard source in a desired and reproducible counting geometry (see 6.5). At least 10 000 net counts should be accumulated (see 6.4 and 6.6).

c) Correct for dead time, as described in 6.7.

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

e) Correct the radioactivity standard source gamma ray emission rate for decay from the time of standardization to the time at which the count rate is measured (see 6.8).

f) Calculate the full-energy-peak efficiency (E) for each gamma ray energy as follows:

$$E = C/G \tag{3}$$

where

C is the net count rate [from item d)]

G is the gamma ray emission rate of the radioactivity standard [from item e)]

If the radioactivity standard source is calibrated as to activity, the gamma ray emission rate is given by

$$G = AP \tag{4}$$

where

A is the activity

P is the probability of emission (of the gamma ray of interest) per disintegration

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

4.2.4 Activity determination (see 6.1 and 6.2)

a) Using the instrument settings of 4.2.3, place the sample to be measured in the same counting geometry that was used for the efficiency calibration (see 6.5 and 6.9).
b) Accumulate enough counts to obtain the desired statistical level of accuracy (see 6.4 and 6.6).
c) Correct the count rate for dead time, as described in 6.7.
d) Obtain the net count rate for the sample by subtracting the ambient background count rate from the total count rate (see 6.8 and 6.10).
e) Calculate the gamma ray emission rate of the sample by

$$G = C/E \quad (5)$$

where

C is the net count rate [from item d)]
E is the efficiency [from item f) of 4.2.3]

When calculating an activity, the number of gamma rays emitted per disintegration is required, so that

$$A = G/P \quad (6)$$

where

A is the activity
P is the probability of emission (of the gamma ray of interest) per disintegration [B7]

4.2.5 Performance testing

a) The system energy calibration and measurement of resolution shall be repeated at least once in each month of use with one or more check sources in the energy range of interest.
b) The efficiency calibration shall be checked at least once in each day of use by using radioactivity standard sources of radionuclides with energies that span the energy range of interest.
c) The ambient background shall be measured at the beginning and ending of each day's counting and should be measured before and after each batch of samples.
d) 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 the predetermined limits.

4.3 MCA counting systems

4.3.1 General

All instruments shall be installed and operated in accordance with the instructions of the manufacturer (see 6.3).

4.3.2 Energy calibration

Establish the energy calibration of the system over the desired energy region at a fixed gain. Using sources of a known energy, record a spectrum containing full-energy peaks that span the gamma ray energy region of interest. Determine the channel numbers that correspond to two gamma ray energies that are near the extremes of the energy region of interest. From these data, determine the slope and the intercept of the energy calibration curve. For most applications, such a linear energy calibration curve will be adequate. The

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS Not for Resale

energy calibration shall be determined for each amplifier gain or photomultiplier high-voltage setting used. (See 6.14.)

4.3.3 Full-Energy-Peak efficiency calibration (see 6.11)

a) Accumulate gamma-ray spectra using radioactivity standard sources in a desired and reproducible counting geometry (see 6.5). At least 10 000 net counts should be accumulated in each full-energy gamma ray peak of interest (see 6.4 and 6.6).
b) Record the live time counting interval (see 6.5 and 6.8).
c) For each radioactivity standard source, determine the net counts in the full-energy gamma ray peaks of interest (see 6.12).
d) Correct the radioactivity standard source gamma ray emission rate for decay from the time of standardization to the time at which the count rate is measured (see 6.8).
e) Calculate the full-energy-peak efficiency (E) for each gamma ray energy as follows:

$$E = C/G \tag{7}$$

where

C is the net count rate in the full-energy peak [from item b) and item c)]
G is the gamma ray emission rate of the radioactivity standard [from item d)]

If the radioactivity standard source is calibrated as to activity, the gamma ray emission rate is given by

$$G = AP \tag{8}$$

where

A is the activity
P is the probability of emission (of the gamma ray of interest) per disintegration [B7]

f) To obtain full-energy-peak efficiency calibration data at energies for which radioactivity standards are not available, plot, or fit an appropriate mathematical function to, the values for the full-energy-peak efficiency [from item e)] versus gamma ray energy ([B3], [B5], and [B9]) (see 6.10 and 6.13).

4.3.4 Assay

a) Using the instrument settings of 4.3.3, place the sample to be measured in the same counting geometry that was used for the efficiency calibration (see 6.5 and 6.9).
b) Accumulate enough counts in the gamma ray spectrum to obtain the desired statistical level of accuracy (see 6.4 and 6.6).
c) Record the live time counting intervals (see 6.4 and 6.7).
d) Determine the energy of the gamma rays present by the use of the energy calibration data obtained according to 4.3.2.
e) Obtain the net count rate in each full-energy gamma ray peak of interest (see 6.8, 6.10, and 6.12) by dividing the net counts by the live time.
f) Calculate the gamma ray emission rate (G) for each full-energy peak of interest as follows:

$$G = C/E \tag{9}$$

where

C is the net count rate in the full-energy peak [from item e)]
E is the efficiency [from item e) of 4.3.3]

--`,,`,,,-`-`,,`,,`,`,,`---

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

From the identified gamma ray energies, decide what radionuclides are present in the sample. When calculating the activities of specific radionuclides, the number of gamma rays emitted per disintegration is required so that

$$A = G/P \quad (10)$$

where

A is the activity
P is the probability of emission (of the gamma ray of interest) per disintegration [B7]

4.3.5 Performance testing

a) The system energy calibration shall be repeated on each day of use with one or more check sources in the energy region of interest.
b) The system count rate precision for at least one long-lived radionuclide check source shall be checked on each day of use. Correction for radioactive decay of the source since the original measurement shall be applied.
c) The efficiency calibration shall be checked at least semiannually by using radioactivity standard sources of radionuclides with energies that span the energy region of interest.
d) The ambient background shall be checked at the beginning and ending of each day's counting and should be measured before and after each batch of samples.
e) The pulse height resolution of the system shall be determined at the time of initial installation and shall be checked at least once on each day of use.
f) 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 the predetermined limits.

5. Sources of systematic error

Possible sources of systematic error in NaI(Tl) measurements are given in the following list. See also clause 6.

a) Uncertainties in the calibration of the standard sources.
b) Deviations in the sample geometry from the standard geometry. This may include nearby material that can scatter gamma rays into the detector.
c) Variations in ambient radiation background (particularly for low-activity measurements).
d) The presence of radionuclide impurities.
e) Differences in attenuation due to differences in container wall thickness or material.
f) Nonuniformity of the radioactivity distribution in the sample.
g) Compton continuum subtractions.
h) Timing, including errors in dead time corrections. (See 6.8.)
i) Equipment malfunctions.
j) The counting of beta particles, conversion electrons, and bremsstrahlung that are energetic enough to enter the NaI(Tl) crystal and add, in an unpredictable way, to the gamma ray pulse-height spectrum.
k) Random photon summing at high count rates (see 6.4).
l) Photomultiplier tube gain drift as a function of time or count rate.
m) Gain shift caused by a changing magnetic field or a change in the orientation of the detector in a fixed magnetic field.
n) Gain shift caused by ambient temperature change.
o) The effect of detector activation by neutrons and charged particles.
p) Saturation or ringing of amplifiers or other system components.

--`,,`,,,-`-`,,`,,`,`,,`---
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS Not for Resale

6. Precautions

6.1 Assay for a radionuclide for which no radioactivity standard is readily available

A total-spectrum counting system or an SCA counting system shall not be used for quantitative determinations of radionuclides for which radioactivity standards are not readily available. Multichannel counting systems shall be used in such cases.

6.2 Assay of mixtures of radionuclides

A total-spectrum counting system or an SCA counting system shall not be used for attempted quantification of the radionuclides contained within a mixture. In certain special cases, SCA counting systems and multiple window devices can be successfully used for the measurement of mixtures containing two radionuclides. Such cases require careful procedures to ensure accurate results.

6.3 Thin-Window detectors

When working with a thin-window detector, one has to be cautious about radionuclides emitting conversion electrons that have energies close to that of the gamma ray of interest. To avoid counting the conversion electrons in such detectors, insert a sufficient amount of absorbing material between the source and the detector, then calibrate the detector.

6.4 Count rates

Three NaI(Tl) detector systems are described; these are a total spectrum counting system, an SCA counting system, and an MCA counting system. The performance of each system over a wide range of count rates is unique. In general, the simplest system provides the highest rate capability and requires the fewest corrections. System gain stability and spectral shape may be count-rate dependent.

6.5 Geometric correction factors

The dependence of the measurement on the geometric configuration and composition of the sample container and other absorbers shall be taken into consideration in the calibration procedure. Positioning of the sample containers within detector wells usually provides good positional reproducibility. Positioning of sample containers on or above the surface of detectors requires a method for reproducing the position. Correction factors and new calibrations shall be obtained to assay for radionuclides in containers of different sizes or shapes.

6.6 Counting statistics

The recommendation of 10 000 net counts is made for measurements of activities that are not near the Lower Limit of Detectability (LLD). For measurements of activities near LLD, see [B1] and [B2].

6.7 Dead-Time corrections

For a number of systems, there is internal dead-time compensation. However, for those systems that have no such compensation, the dead-time-corrected count rate, N_o, is given by:

--`,,`,,,,-`-`,,`,,`,`,,`---

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

$$N_O = \frac{N}{1 - Nt_d} \tag{11}$$

where

N is the observed count rate
t_d is the dead time

The dead time can be experimentally determined, as described in the following text, using the so-called "two-source method." The measurement should be considered invalid if N_o exceeds N by more than 20%. Equation 11 gives, for example, a correction of 1% for a dead time of 10 μs and a count rate of 1000/s. In this method, three counting rates are measured using sources from the same radioisotope: the first from source 1, the second from source 2, the third from sources 1 and 2, and the fourth with no source present. From these measurements, the respective count rates N_1, N_2, N_{12}, and N_b are obtained. The dead time, t_d, is determined using the following equations:

$$t_d = \frac{x[1 - \sqrt{(1 - z)}]}{y} \tag{12}$$

where

$$x = N_1N_2 - N_bN_{12} \tag{13}$$

$$y = N_1N_2\,(N_{12} + N_b) - N_bN_{12}(N_1 + N_2) \tag{14}$$

$$z = \frac{y(N_1 + N_2 - N_{12} - N_b)}{x^2} \tag{15}$$

When making the measurements, it is important not to disturb source 1 when introducing source 2 and, similarly, when removing source 1, not to disturb source 2. For MCA systems, the "live-time" feature is designed to compensate for counting time lost during pulse processing, and a further correction for dead-time losses is usually not required.

When either source 1 or source 2 is not in use, it may be advisable in some cases to replace the source that is not in use by an equivalent blank so that the scattering geometry is unchanged.

6.8 Correction for decay during the counting period

6.8.1 Measurement at the beginning of the counting period

If the value of a net count rate is determined by a measurement that spans a significant fraction of a half life, and the value is assigned to the beginning of the counting period, a multiplicative correction factor, F_b, has to be applied:

$$F_b = \frac{\lambda t}{(1 - e^{-\lambda t})} \tag{16}$$

where

F_b is the decay-during-count correction (count rate referenced to the beginning of the counting period)
t is the elapsed counting time

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS Not for Resale

λ is the radionuclide decay constant (Ln $2/T_{1/2}$)

$T_{1/2}$ is the radionuclide half life

NOTE—t and $T_{1/2}$ have to be expressed in the same units of time.

The correction for F_b is 1.01 for a ratio of $t/T_{1/2}$ equal to 0.03.

6.8.2 Measurement at the midpoint of the counting period

If, under the same conditions, the counting rate is assigned to the midpoint of the counting period, the multiplicative correction (F_m) will be essentially 1 for $t/T_{1/2}$ of 0.03 and 0.995 for $t/T_{1/2}$ of 0.5. If it need be applied, the correction factor to be used is

$$F_m = \left[\frac{\lambda t}{(1 - e^{-\lambda t})}\right] e^{\frac{-\lambda t}{2}} \tag{17}$$

6.9 Counting geometry

The source to be measured shall duplicate, as closely as possible, the calibration standards in all aspects (such as shape, physical and chemical characteristics, homogeneity, etc.). The source-to-detector relationship shall be the same for the source and the standard. Care shall be taken to avoid deposition of the source material on the surfaces of the sample container. For multiphase samples, such as radon in radium solution and krypton in saline solution, care shall be taken to control carefully the partitioning of the radioactivity between the gaseous and liquid phases (for example, by shaking just prior to counting).

6.10 Spectral features

The following effects that will occur are important:

a) Scattering from the surroundings, including induced X-ray emissions from lead shielding and the source housing.
b) Summing of coincident Compton events to give spurious pulses in the region of a full-energy peak of interest.
c) Iodine K X-ray escape for low-energy photon sources ([B3], [B5]).
d) Summing of coincident Compton and full-energy events to give spurious pulses above the region of a full-energy peak of interest.

6.11 Full-Energy-Peak efficiency versus energy function or curve

The expression or curve showing the variation of the full-energy-peak efficiency with energy shall be determined for a particular detector and shall be checked for changes with time and temperature as specified in this standard [see 4.3.5, item c)]. There should be a minimum of three calibration points, approximately evenly spaced, spanning the energy region of interest below 0.300 MeV. Above 0.300 MeV, calibration points should be obtained approximately every 0.250 MeV, spanning the energy region of interest. Full-energy-peak efficiency calibrations below 0.100 MeV should be determined using a radioactivity standard of the radionuclide to be measured. A full-energy-peak efficiency calibration using the same radionuclides that are to be measured should be made and may provide the only reliable full-energy-peak efficiency calibration when a radionuclide with cascade gamma rays is measured.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

6.12 Net count rate

When using MCA systems, the appropriate continuum in the region of interest shall be subtracted from the ambient background spectrum and from the sample spectrum. The difference of those two results is the net sample count in the full-energy peak.

6.13 Temperature effects

Under certain conditions, corrections for temperature may be required.

6.14 Linearity

Over a wide energy range, a two-point energy calibration may not be sufficient. In these instances, a polynomial fit may be required for precise energy calibration.

7. Bibliography

[B1] *EML Procedures Manual*, 27th ed., HASL-300, February 1992.[3]

[B2] ICRU Report 22-1972, *Measurement of Low-Level Radioactivity.*[4]

[B3] Adams, F. and Dams, R., *Applied Gamma-Ray Spectrometry*, 2d ed. New York: Pergamon Press, 1970.

[B4] Brinkman, G. A., et al., "Absolute Standardization with NaI(Tl) Crystal-1," *International Journal of Applied Radiation and Isotopes*, vol. 14, p. 153, 1963.

[B5] Heath, R. L., IDO-16880, *Scintillation Spectrometry Gamma-Ray Spectrum Catalogue*, 2d ed., 1964. US Department of Energy, Idaho Falls, ID.[5]

[B6] Knoll, G. F., *Radiation Detection and Measurement*. New York: John Wiley and Sons, 1989.

[B7] Kocher, D. C., ed., ORNL/NUREG/TM-102-1977, *Nuclear Decay Data for Radionuclides Occurring in Routine Releases from Nuclear Fuel Cycle Facilities.*[6]

[B8] Kokta, L., "Determination of Peak Area," *Nuclear Instruments and Methods*, vol. 112, p. 242, 1973.

[B9] Mann, W. B., ed., NCRP Report 58-1985, *A Handbook of Radioactivity Measurement Procedures.*[7]

[3]This document is available from National Technical Information Service, US Department of Commerce, Springfield, VA 22161, USA.

[4]ICRU publications are available from the National Council on Radiation Protection and Measurements, 7910 Woodmont Avenue, Suite 800, Bethesda, MD 20814, USA.

[5]This document is available from the Idaho National Engineering Laboratory, P. O. Box 1625, Idaho Falls, ID 83415, USA.

[6]This document is available from National Technical Information Service, US Department of Commerce, Springfield, VA 22161, USA.

[7]NCRP publications are available from the National Council on Radiation Protection and Measurements, 7910 Woodmont Avenue, Suite 800, Bethesda, MD 20814, USA.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale