ANSI N42.13-1986
(Revision of ANSI N42.13-1978)

American National Standard

Calibration and Usage of "Dose Calibrator" Ionization Chambers for the Assay of Radionuclides

National Committee on Radiation Instrumentation, N42
accredited by the American National Standards Institute

Secretariat

Institute of Electrical and Electronics Engineers, Inc

Approved April 30, 1985
American National Standards Institute

Published by
The Institute of Electrical and Electronics Engineers, Inc
345 East 47th Street, New York, NY 10017

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Foreword

(This Foreword is not a part of ANSI N42.13-1986, American National Standard Calibration and Usage of "Dose Calibrator" Ionization Chambers for the Assay of Radionuclides.)

This revised standard is the responsibility of Accredited Standards Committee N42 on Radiation Instrumentation. Committee N42 delegated the development of the standard to its Subcommittee N42.2. Drafts were reviewed by the members of Committee N42, Subcommittee N42.2, and by other interested parties. The comments received were utilized in producing the standard as finally approved and issued. The revised standard was approved by Committee N42 letter ballot of December 30, 1984, with minor modifications as submitted to the Committee N42 membership on August 29, 1984.

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

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The membership of Subcommittee N42.2 was as follows:

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The following persons were on the balloting committee that approved this document for submission to the Accredited Standards Committee N42:

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Calibration and Usage of "Dose Calibrator" IonizationChambers for the Assay of Radionuclides

1. Introduction

The wide range of *calibrator*-type instruments currently being used primarily for radionuclide assay in nuclear medicine indicates the need for a standard for uniformity in measurement and test techniques. Such devices are composite systems consisting of an ionization chamber integrally coupled to appropriate electronic circuitry that converts the ionization current to a readout in units of activity. The principles of operation of the ionization chamber are well summarized in the NCRP Report No 58 [1][1] and will not be repeated here. Wide activity range and stability are useful characteristics of ionization chambers in this application. The advantages of this type of system for radionuclide assay include ease of use and interpretation.

2. Scope

2.1

This standard covers the technique for the quantification of the activity of identified radionuclides using any of a variety of ionization chambers currently available for this purpose. Application of the standard is limited to instruments that incorporate well-type ionization chambers as detectors.

2.2

This standard provides a method for obtaining measurements that are accurate to within ± 10% and reproducible to within ± 5% [usually for sources of more than 100 μCi (3.7×10^6 Bq)]. The standard is also intended to assure continuing performance of the apparatus within these specifications. For purposes of this standard, accuracy and reproducibility are described in 4.6.

[1]The numbers in brackets correspond to the references in 3.2.

3. Definitions and References

3.1 Definitions

accuracy: Accuracy, usually described in terms of overall uncertainty, is the estimate of the overall possible deviation from the stated value. As used in this standard, the overall uncertainty is a total of the estimated error itemized in Section 5. plus the random uncertainty of the measurement.

calibration: The process of determining the numerical relationship, within an overall stated uncertainty, between the observed output of a measurement system and the value, based on standard sources, of the physical quantity being measured.

shall: Indicates a recommendation that is necessary or essential to meet requirements of this standard.

should: Indicates an advisory recommendation that is to be applied when practicable.

simulated sources: Simulated sources usually contain long-lived radionuclides, alone or in combination, that are chosen to simulate, in terms of photon or particle emission, a short-lived radionuclide of interest.

standard sources: A general term used to refer to the standard sources listed below:

1) *national radioactivity standard source.* A calibrated radioactive source prepared and distributed as a standard reference material by the US National Bureau of Standards.
2) *certified radioactivity standard source.* A calibrated radioactive source, with stated accuracy, whose calibration is certified by the source supplier as traceable to the National Radioactivity Measurements System [2].

3.2 References

[1] National Council on Radiation Protection and Measurements. *A Handbook of Radioactivity Measurements Procedures.* NCRP Report no 58, 2nd ed, Washington, DC, 1985.

[2] CAVALLO, L. M., COURSEY, B. M., GARFINKEL, S. B., HUTCHINSON, J. M. R., and MANN, W. B. Need for Radioactivity Standards and Measurements in Different Fields. *Nuclear Instruments and Methods*, vol 112, 1973, pp 5–18.

4. Procedure

4.1 General

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

4.2 Initial Calibrations

Instruments shall be calibrated with identified radionuclide sources of known activity and established purity. As described in 4.4, calibrations should be performed with standard sources of each radionuclide of interest, if at all feasible.

4.2.1 Geometry

The dependence of the assay on the geometrical configuration and composition of the source container shall be taken into consideration in the calibration procedure. Most manufacturers have adopted a calibration geometry using a nominal 30 mL multidose vial with 20 mL of contents, and standard sources of this description are generally available (usually in plastic containers).

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Positioning of such vials in the detector well must be reproducible for such systems. Correction factors or new calibrations shall be obtained for assaying radionuclides in containers of different sizes or shapes. Such correction factors may be determined by measurement of the same quantity of a given radionuclide in containers of different geometry, with any necessary adjustment to the volume using the appropriate carrier solution. Correction factors supplied by the manufacturer should also be checked as described above.

4.2.2 Activity Ranges

Calibration of the equipment should cover as completely as practicable the activity ranges for which it will be used, particularly those ranges of activity of radionuclides to be administered to patients. Whenever measurements in the low microcurie range are attempted, background corrections are imperative.

4.2.3 Energy Range

Calibration shall be performed over the photon energy range of proposed application.

4.2.4 Accuracy and Reproducibility

The calibration procedures should be such that the accuracy and reproducibility of measurements made with the calibrated instrument will be within the limits stated in 4.6.

4.3 Standard Sources

Suitable standard sources characterized as to radionuclide purity and activity shall be used for routine calibration of the equipment. Correction for decay of a standard source since the time of standardization should be applied if more than 2% of a half life has expired.

4.3.1 Geometry

Ideally, to avoid the necessity for corrections, the geometry of the standard source should be identical to the geometry of the source to be assayed. Source manufacturers now offer standard sources that conform to the calibration geometry described in 4.2.1.

4.3.2 Activity Range

A suitable range of activities should be available for use. The selection of standard sources should take into consideration the accuracy required over the ranges of activity of radionuclides to be administered to patients.

4.3.3 Energy Range

A suitable range of photon emission energies should be covered in the selection of standard sources. ^{125}I (0.03 MeV) (0.05×10^{-13} J), ^{57}Co (0.12 MeV) (0.19×10^{-13} J), ^{133}Ba (0.36 Mev) (0.58×10^{-13}J), and ^{137}Cs (0.66 MeV) ($1.06 \cdot 10^{-13}$ J) are representative of radionuclide sources of photons in the energy range typically used in nuclear medicine.

4.4 Assay

Radionuclides shall be assayed in a properly calibrated instrument using an appropriate precalibrated radionuclide setting or plug-in module. The activity of a radionuclide for which no setting or module is available may also be accurately measured relative to a standard source of the same radionuclide using any setting or module that yields a high enough reading to give reproducible results.

4.5 Performance Testing

Regular testing of the instrument performance is required to assure the accuracy of assays.

4.5.1 Reference Source Checks

Calibration checks using a long-lived reference source shall be performed and logged on each work shift during which the instrument is used. This check shall be repeated whenever sample readings are not within 10% of their anticipated assay. It is required that at least two such reference sources be available [for example, 100–200 μCi ($3.70–7.40 \times 10^6$ Bq) of ^{137}Cs, and 1–5 mCi ($40–180 \times 10^6$ Bq) of ^{57}Co with appropriate correction for decay]. These sources could be alternated each day of use to test the instrument's performance over a range of photon energies and source activities.

4.5.2 Linearity Check

A convenient high-activity-range linearity check is outlined in 6.2. This check shall be performed and logged at intervals not to exceed 3 months.

4.5.3 Background Checks

Background checks shall be performed and logged daily, at least at the radionuclide settings to be used that day. These checks will serve to detect either contamination or faulty operation.

4.5.4 Response Check at Various Settings

Measurements of a long-lived reference source at settings for several radionuclides of interest will yield readings that should be reproducible over a period of time. Such readings serve as suitable checks on the stability of the instrument for measurements of radionuclides for which calibrations have been established, but for which standard sources are not always available for use. This check shall be performed and logged daily utilizing such sources as those listed in 4.5.1 to check the response of the instrument for the calibration of radionuclides that the user anticipates assaying on that day.

4.5.5 Frequency of Calibration

Annually, following repair, and following extended periods of nonutilization, calibrations using standard sources of at least two radionuclides covering the energy and activity ranges of interest shall be performed and logged.

4.5.6 Supplementary Calibrations

As standard sources of additional radionuclides of interest become available, the instrument should be calibrated against such standard sources, particularly if such radionuclides are intended for human administration.

4.6 Accuracy and Reproducibility

Minimum requirements, in terms of accuracy and reproducibility for such instruments, are as follows.

4.6.1 Accuracy

The accuracy of the instruments, when used with the source geometry recommended by the manufacturer at activity levels above 100 μCi (3.7×10^6 Bq) shall be such that the measured activity of a standard source as defined in 3.1, standard sources (1) or (2), shall be within ± 10% of the stated activity of that source. Accuracy of measurements of activity levels below 100 μCi (3.7×10^6 Bq) may not fall within the ± 10% limits and should be determined for each instrument on which such assays will be performed.

4.6.2 Reproducibility

The reproducibility (or random error of the measurement) shall be such that all of the results in a series of ten consecutive measurements on a source of greater than 100 μCi (3.7×10^6 Bq) in the same geometry shall be within ± 5% of the average measured activity for that source, assuming no decay corrections over the measurement period are required.

4.6.3 Corrective Action

If the accuracy or reproducibility requirements are not met, the instrument shall be recalibrated, or repaired and recalibrated. If the instrument exhibits erratic performance, it shall be repaired and recalibrated.

5. Sources of Error

Common sources of error in the assay of radionuclides with ionization chambers are as follows:

1) Errors in calibration of the standard source
2) Variations in geometries of the sample to be assayed (see 4.2.1)
3) Variations in radiation background (particularly for low-activity measurements)
4) The presence of radionuclide impurities (see 6.3)
5) Changes in attenuation due to variations in container wall thickness or material (see 6.4 and 6.5)
6) Nonuniformity of radioactivity distribution (see 6.6 and 6.7)

6. Precautions

Some of the major areas in which discrepancies have been experienced with equipment of this type are as follows.

6.1 Assay of a Radionuclide for Which No Standard or Calibration Setting Is Available

The user shall consider all gamma-ray and other photon emissions (including bremsstrahlung) and all beta-particle contributions to radiation emitted from the container when assaying a radionuclide for which no precalibrated radionuclide setting or plug-in module is provided, or for which no standard source is available. An understanding of the energy response of the ionization chamber is also necessary, particularly where energies of less than 150 keV (0.240×10^{-13} J) are present in the decay scheme. In general, the manufacturer should be consulted for advice on such measurements. (See [1] for further assistance in this regard.)

6.2 Nonlinearity Effect

A nonlinearity effect at high activity levels is characteristic of equipment of this type. To guard against errors in this regard, instruments should be checked against activities at the upper range of proposed administration to patients for a given radionuclide. If it is not practical to obtain a standard source of such high activity, measure the highest activity likely to be administered to patients, divide, and measure both parts (compensating for volume changes by adding carrier or a suitable diluent as necessary). Compare the total of parts with the original reading. Nonlinearity deviation should be no greater than ± 5%. Repeat division as necessary until extent of nonlinearity is established. (Appropriate radiation safety precautions to minimize exposure and contamination shall be observed in handling such quantities of radioactive material). Such nonlinearity problems have usually been noted above 100 mCi (3.7×10^9 Bq). If nonlinearity greater than ± 5% is detected above a given level of activity, measurements at or above this level may not be depended upon and the instrument shall be so labeled. If accurate measurements above such levels are necessary and the condition is not repairable, correction factors for each radionuclide and geometry shall be developed.

6.2.1 Nonlinearity Checks—Other Methods

Alternately, instrument linearity may be checked by assaying the maximum activity likely to be administered to patients (correcting for background, as necessary), then following the decay of that vial until the measured activity is in the activity range where the instrument is properly calibrated. Assuming that the final measurement is correct, apply decay correction to earlier measurements and determine the deviation of the decay-corrected measurements from the final measurements. Nonlinearity effects in excess of ± 5% must be dealt with as in 6.2 above.

Another linearity check method in common use involves the application of a series of shielding sleeves to the vial containing the first elution from a new generator, observing the measurement reduction obtained with the addition of each sleeve. Since this is not a true measure of linearity under identical geometrical conditions, it is recommended that this technique be limited to that of a supplementary consistency check on the linearity checks described previously, after first establishing the results of the sleeve-shield technique during the performance of a true linearity check. A satisfactory combination of techniques involves the annual performance of a true linearity check by either the subdivision or decay techniques described above, followed by quarterly checks with the shield-sleeve technique, the expected results for which have been established annually during the true linearity checks.

6.3 Radionuclidic Impurities

The presence of radionuclidic impurities may result in large assay errors, particularly during measurement of short-lived radionuclides several half lives after initial preparation. Determination of the photon energy spectrum with a photon-spectrometry system may be necessary if accurate assays are to be performed whenever the presence of radionuclidic impurities may be a problem.

6.4 Beta-Particle Emitters

When measuring beta-particle-emitting radionuclides in an instrument of this type, the container becomes extremely important. Measurements on sources of the same radionuclide and activity will vary greatly with container composition (for example, glass versus plastic) and wall thickness. Such measurements depend on a measure of bremsstrahlung produced by deceleration of the beta particles in the container material. Reproducible measurements depend upon consistent container selection and consistency in the manner in which the instrument is used.

6.5 Low-Energy-Photon Emitters

Low-energy-photon sources (for example, ^{125}I) may be assayed incorrectly unless care is taken in the selection of the source container. The wall thickness of the container plus the thickness of the interior wall of the chamber may represent a significant attenuation factor for low-energy photons. Wide variations in solution volume or container composition may also lead to erroneous results due to variations in absorption of such low-energy photons in the solution or the container.

6.6 Dissolved Gaseous Radionuclides

The user must be alert to a possible source of error in the measurement of radioactive solutions that tend to be unstable to the extent that part of the radionuclide may be present in a gaseous phase (for example, ^{133}Xe in saline). Readout results will be strongly dependent on the partitioning of the radionuclide between the gaseous and solution phases that occur in such a situation. Questionable readings in this regard may be checked by removing the liquid from the vial through the rubber septum with a syringe. Measurement of the vial after liquid removal will provide an estimate of the quantity of gaseous activity present.

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6.7 Plate-Out of Radionuclides

Care shall be taken in the measurement of radionuclides that show a tendency to plate-out of solution onto the walls or the cap of the container. This phenomenon may affect the measurement due to both change in geometry and change in internal absorption factors. Repeating the measurement on the vial after the liquid has been removed will yield data that may be used to determine the net activity removed or to estimate the fraction plated out.

6.8 Simulated Sources

Although they may be useful as a check source, simulated sources in general are not recommended for activity-calibration purposes. Such sources, which are usually a mixture of long-lived radionuclides chosen to yield an approximation of the photon spectrum of the radionuclide they simulate, may not yield accurate calibration data in terms of ionization current. Also, their component parts may decay at different rates.