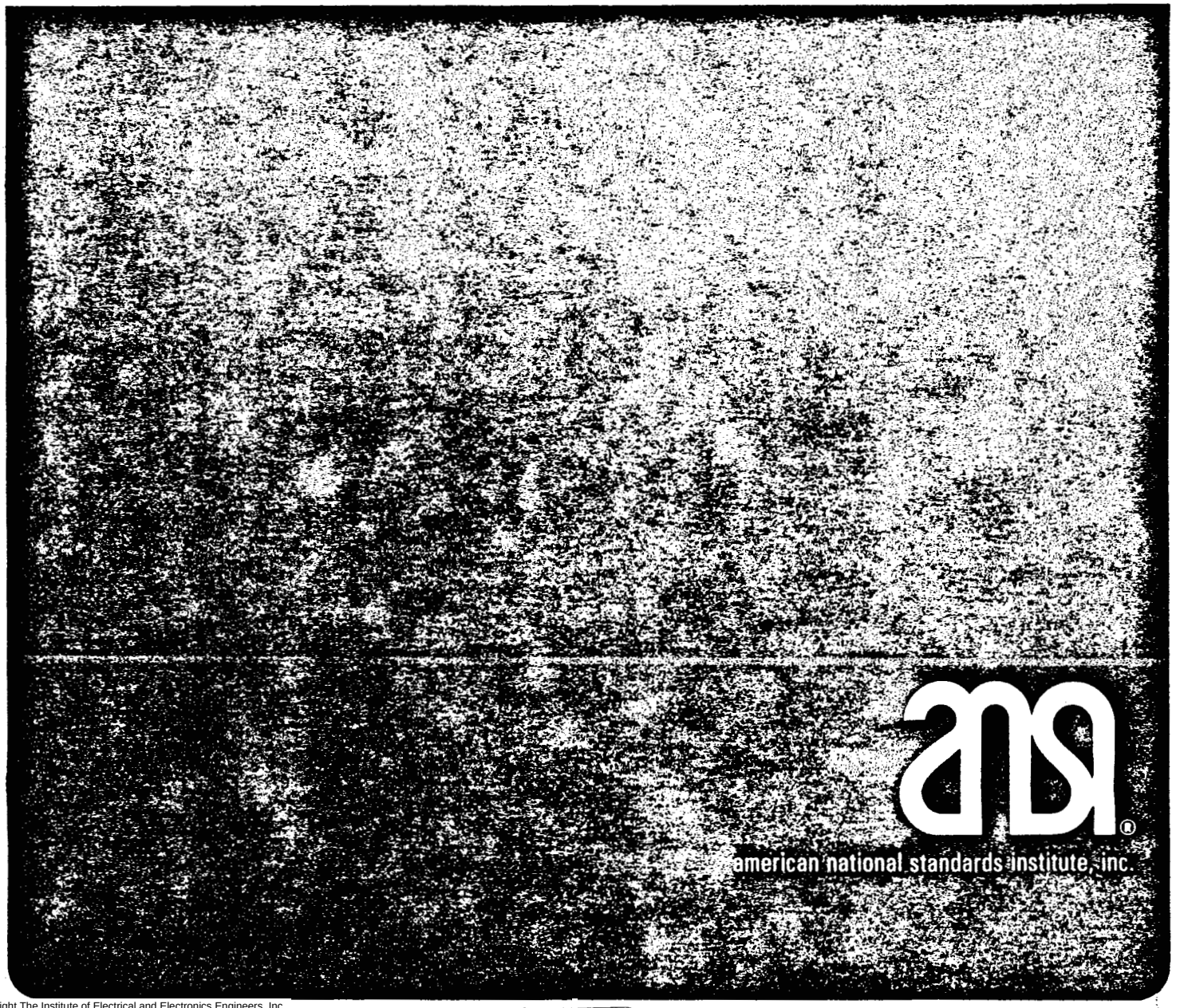
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American National Standard

radiation protection instrumentation test and calibration



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American National Standard Radiation Protection Instrumentation Test and Calibration

Secretariat for N13

Health Physics Society

Secretariat for N42

Institute of Electrical and Electronics Engineers, Inc

Approved September 13, 1977

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 American National Standard Radiation Protection Instrumentation Test and Calibration, ANSI N323-1978.)

The American National Standards Institute Joint Subcommittee N13/42 which was responsible for the development of this standard was established by authority of the Chairman of American National Standards Institute Committees N13 and N42 to represent the interests of the respective parent committees. The Joint Subcommittee comprises manufacturer and user membership in about equal numbers.

The ANSI Committee on Radiation Protection, N13, and Instrumentation, N42, which reviewed and approved this standard, had the following representatives at the time of approval:

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M. E. Wrenn, *Chairman* — **J. Sohngen,** *Secretary*

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American National Standards Committee N42

Louis Costrell, *Chairman* — **D. C. Cook,** *Secretary*

Organization Represented	*Name and Business Affiliation*
American Chemical Society	Vacant
American Conference of Governmental Industrial Hygienists	Jesse Lieberman Department of Public Health
American Industrial Hygiene Association	W. H. Ray† US Energy Research and Development Administration
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†Deceased

Organization Represented	*Name and Business Affiliation*
Health Physics Society	Dr. J. B. Horner Kuper Brookhaven National Laboratory
Alternate	Robert L. Butenhoff US Energy Research and Development Administration
Institute of Electrical and Electronics Engineers	Louis Costrell National Bureau of Standards
Alternate	J. Forster General Electric Company
Alternate	David C. Cook Naval Research Laboratory
Alternate	A. J. Spurgin General Atomic Company
Instrument Society of America	M. T. Slind Atlantic Richfield Hanford Company
Alternate	J. Kaveckis United Nuclear Industries, Inc
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Oak Ridge National Laboratory	Frank W. Manning Oak Ridge National Laboratory
Alternate	D. J. Knowles Oak Ridge National Laboratory
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US Defense Civil Preparedness Agency	Carl R. Siebentritt, Jr US Defense Civil Preparedness Agency
US Department of Commerce National Bureau of Standards	Louis Costrell National Bureau of Standards
US Energy Research and Development Administration Division of Biomedical and Environmental Research	Hodge R. Wasson US Development Research and Development Administration
US Naval Research Laboratory	D. C. Cook U.S. Naval Research Laboratory
Individual Members	J. C. Bellian Bircon Corporation
	O. W. Bilharz General Electric Company
	John M. Gallagher, Jr Westinghouse Electric Corporation
	S. H. Hanauer US Nuclear Regulatory Commission
	Walter C. Lipinski Argonne National Laboratory
	Voss A. Moore US Nuclear Regulatory Commission
	R. F. Shea Consultant
	E. J. Vallario US Energy Research and Development Administration

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This standard was prepared under the direction of the joint ANSI Subcommittee N13/N42, Radiation Protection Instrumentation, which had the following membership at the time of approval:

Edward J. Vallario, *Chairman*

E. Bemis
V. T. Chilson
A. Cohen
John Dempsey
E. E. Goodale
J. D. Henderson
R. L. Kathren
W. R. Klein
T. P. Loftus
H. W. Patterson
H. J. L. Rechen
C. R. Siebentritt, Jr
H. R. Wasson

The working group responsible for the preparation of this standard consisted of the following personnel:

J. M. Selby, *Chairman*

R. Beard
R. L. Kathren
H. V. Larson
T. P. Loftus
W. H. Ray†
A. R. Smith

†Deceased

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American National Standard Radiation Protection Instrumentation Test and Calibration

1. Scope

This standard establishes calibration methods for portable radiation protection instruments used for detection and measurement of levels of ionizing radiation fields or levels of radioactive surface contamination. For purposes of this standard, portable radiation protection instruments are those which are carried by hand to a specific facility or location for use. Although this standard is specific to portable radiation protection instrumentation, the basic calibration principles may be applicable to radiation detection instrumentation in general.

Included within the scope of this standard are conditions, equipment, and techniques for calibration as well as the degree of precision and accuracy required. Alpha, beta, photon, and neutron radiations are considered. Passive integrating dosimetric devices such as film, thermoluminescent, and chemical dosimeters are outside the scope of this standard, but the basic principles and intent may apply. In cases where integrating capability is included along with rate measurement or detection, this standard shall apply.

Throughout these criteria, four verbs have been used to indicate the degree of rigor intended by the specific criterion. "Shall" and "will" indicate a minimum criterion that must be met, while "should" and "would" indicate a criterion that is recommended as good practice and is to be applied when practical.

2. Definitions

Technical terminology used in this standard is generally consistent with the definitions in the American National Standard Glossary of Terms in Nuclear Sciences and Technology, N1.1-1976 [1],[1] and ICRU Report 20 [2]. The following terms are defined specifically for use within this standard.

accuracy. The degree of agreement of the observed value with the true or correct value of the quantity being measured.

calibrate. To determine (1) the response or reading of an instrument relative to a series of known radiation values over the range of the instrument or (2) the strength of a radiation source relative to a standard.

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

decade. Synonymous with power of ten.

detection limit. The extreme of detection or quantification for the radiation of interest by the instrument as a whole or an individual readout scale. The *lower detection limit* is the minimum quantifiable instrument response or reading. The *upper detection limit* is the maximum quantifiable instrument response or reading.

detector. A device or component which produces an electronically measurable quantity in response to ionizing radiation.

effective center. The point within a detector that produces, for a given set of irradiation conditions, an instrument response equivalent to that which would be produced if the entire detector were located at the point.

energy dependence. A change in instrument response with respect to radiation energy for a constant exposure or exposure rate.

[1]Numbers in brackets refer to those of the references in Section 7 of this standard.

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extracameral. Pertaining to that portion of the instrument exclusive of the detector.

geotropism. A change in instrument response with a change in instrument orientation as a result of gravitational effects.

instrument. A complete system designed to quanitify one or more particular ionizing radiation or radiations.

overload. Response of less than full scale (that is, maximum scale reading) when exposed to radiation intensities greater than the upper detection limit.

photon. A quantum of electromagnetic radiation irrespective of origin.

range. The set of values lying between the upper and lower detection limits.

readout. The device that conveys information regarding the measurement to the user.

reproducibility (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.

response. The instrument reading.

sensitivity. The ratio of a change in response to the corresponding change in the field being measured.

standard (instrument or source) (1) national standard. An instrument, source, or other system or device maintained and promulgated by the U.S. National Bureau of Standards as such.

(2) derived or secondary standard. A calibrated instrument, source, or other system or device directly relatable (that is, with no intervening steps) to one or more U.S. National Standards.

(3) laboratory standard. A calibrated instrument, source, or other system or device without direct one-step relatability to the U.S. National Bureau of Standards, maintained and used primarily for calibrated and standardization.

test. A procedure whereby the instrument, component, or circuit is evaluated for satisfactory operation.

transfer instrument. Instrument or dosimeter exhibiting high precision which has been standardized against a *national* or *derived standardized* source.

uncertainty. The estimated bounds of the deviation from the mean value, generally expressed as a percent of the mean value. Ordinarily taken as the sum of (1) the random errors at the 95 percent confidence level and (2) the estimated upper limit of the systematic error.

unwanted radiation. Any ionizing radiation other than that which the instrument is designed to measure.

3. General Discussion

The operational requirements of radiation protection instrumentation are set forth in the recommendations of various commissions and committees [2],[3]. Additionally, the user may establish the need for different or more restrictive requirements. The ability to meet these requirements will depend not only on the instrument capabilities but also on periodic recalibration, preventative maintenance, and testing of the instruments.

For the purpose of this standard, new instruments are assumed to have been evaluated by the manufacturer to assure that the instruments are working properly. This evaluation, which is described in more detail by Zuerner and Kathren [4] involves a measurement of the characteristics of the instrument under design conditions. The evaluation includes determination of some or all of the following characteristics.

Nonradiological Characteristics:

(1) Physical construction, that is, safety, utility, weight, and ease of decontamination

(2) Effect of shock, sound and vibration, electric transients, RF energy, magnetic fields, high humidity, or other environmental influences

(3) Extent of switching transients, capacitance effects, geotropism, and static charge effects

(4) Power supply, including stability and battery life

Radiological Characteristics:

(1) Range, sensitivity, linearity, detection limit, and response to overload conditions*

(2) Accuracy and reproducibility*

(3) Energy dependence*

(4) Angular dependence

(5) Response to ionizing radiations other

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than those intended to be measured

(6) Temperature and pressure dependence*

Certain tests from the above list (indicated by *) should be repeated routinely because aging of components, changes in available power (battery aging), and replacement of components may affect the calibration. Since the reproducibility of an instrument is critically important such a test should be performed regularly.

Periodic recalibration is distinct from a field test or simple evaluation with a check source. It includes a precalibration check followed by adjustment and calibration as described in Section 4 and perhaps a recheck of response, if any, to unwanted radiations. During the precalibration check, the instrument is tested to assure that certain operating requirements, specified by the manufacturer, are met. Thus, the instrument is determined to be in proper working order prior to calibration and adjustment.

If the instrument is to be adjusted or used for conditions other than those for which it was designed, such as use outside the designed energy range or under different environmental conditions, calibration for these conditions is necessary. Similarly, if the instrument is physically altered such that the previous calibration result could be invalidated, recalibration is required.

Components may change values with time or even fail. An instrument check must be made prior to use to ensure that (1) the instrument is operating properly, and (2) the response to a given check source is the same as it was immediately following calibration.

Radiation fields used for calibration must be thoroughly understood in terms of quality, quantity, and reproducability. Radiation sources and standard instruments that may be used in calibration are discussed in the appendix. A good review of calibration assemblies [5] should be consulted by those who calibrate instruments. Such problems as charged particle equilibrium, scattered or unwanted radiations from the source, and ambient background radiation must be taken into account quantitatively.

4. Inspection, Calibration, and Performance Test Requirements

4.1 Precalibration. The following conditions shall be established prior to exposing the instrument to a source for adjustment and calibration:

(1) The instrument should be free of significant radioactive contamination

(2) The meter shall be adjusted to zero or the point specified by the manufacturer using the adjustment or adjustments provided

(3) The batteries or power supply shall comply with the instrument manufacturer's specification

(4) The instrument shall be turned on and allowed to warm up for the time period specified by the manufacturer

(5) Electronic adjustments such as high voltage shall be set, as applicable, to the manufacturer's specifications

(6) Geotropism shall be known for orientation of the instrument in the three mutually perpendicular planes, and this effect shall be taken into account during calibration and performance testing

(7) The performance of any internal sampling time base in digital readout instruments should be verified as being within the manufacturer's specifications

4.2 Primary Calibration

4.2.1 General. The reproducibility (precision) of the instrument should be known prior to making calibration adjustments. This is particularly important if the instrument failed to pass the source check (see 4.6) or if repairs have been made. To check reproducibility, the instrument should be exposed to a radiation field three or more times under identical conditions. The readings obtained should normally not deviate from the mean value by more than ± 10 percent.

The response of an instrument may vary as a function of such parameters as energy, temperature, pressure, humidity, and source/detector geometry. The primary calibration should be accomplished with known values of these parameters. The calibration should be performed under the conditions specified by the manufacturer. Alternatively, any of these parameters may be fixed to the condition in which the instrument is to be used routinely, and notation made of these values. The steps that constitute the primary calibration when taken in conjunction with 4.1 are described in 4.2.2.

4.2.2 Readout Scale and Linearity Calibration and Adjustment

4.2.2.1 *Linear Readout Instruments.* Linear instruments usually have a scale selection

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switch. If controls are provided for each scale, adjustment of each shall be made according to the manufacturer's specifications or at the midpoint of each scale. If only one control is provided, adjustment shall be made either (1) at the point specified by the manufacturer, (2) near the midpoint of the middle scale, or (3) near the midpoint of a scale that is particularly important to the user's requirements.

After adjustment, calibration shall be checked near the ends of each scale (approximately 20 percent and 80 percent of full scale). After an adjustment or adjustments have been completed, instrument readings shall be within ± 10 percent of known radiation values at these two points. However, readings within ± 20 percent shall be acceptable if a calibration chart or graph shall be prepared and made available with the instrument.

4.2.2.2 *Logarithmic Readout Instruments.* Logarithmic readout instruments commonly have a single readout scale spanning several decades with two or more adjustments. The instrument should be adjusted for each scale according to the manufacturer's specifications or, alternatively, at points of particular importance to the user.

After adjustment, calibration shall be performed at a minimum of one point near the midpoint of each decade. After adjustments have been completed, instrument readings shall be within ± 10 percent of the known radiation values at these points. However, readings within ± 20 percent is acceptable if a calibration chart or graph is prepared and made available with the instrument.

4.2.2.3 *Digital Readout Instruments.* Digital instruments may have manual scale switching, automatic scale switching (auto ranging) or no scale switching. For instruments with either manual or automatic scale switching, the calibration shall be performed as in 4.2.2.1. For instruments without scale switching, the calibration shall be performed as in 4.2.2.2.

4.3 Calibration for Special Conditions

4.3.1 General. If the instrument is to be used under conditions (that is, radiation energy, temperature and pressure, or source/detector geometry) which vary significantly from those for which the instrument is designed, the instrument should be adjusted, calibrated, and used only for the special conditions. When an instrument is calibrated for special conditions, a special condition identification label shall be attached (in addition to any required calibration labels) to indicate its applicability *for this special use only.* However, if the instrument is also to be used within its design limits, the adjustments made during primary calibration (see 4.2) shall remain the same, and instrument readings for the special conditions shall be corrected using correction factors obtained from appropriate tables or graphs. Only one parameter should be varied at a time during calibration for the special conditions, but the interrelationships of the variables should be known.

4.3.2 Radiation Energy. Calibration shall be performed with a standard source or sources providing radiation fields similar to those in which the instrument will be used. Where instruments will be used in radiation fields of widely differing energies, the response of the instrument at several energies over the energy range shall be determined.

The response of the instrument to various energies of radiation shall be (1) plotted as a function of energy, or otherwise called out, (2) normalized to the response to a specific energy obtained during primary calibration, and (3) provided with the instrument. This type of graph is commonly called an energy dependence or spectral sensitivity curve.

4.3.3 Temperature, Pressure, and Humidity. Instruments to be used outside the manufacturer's recommended temperature range or at temperatures which differ by more than 30°C from the calibration temperature shall be calibrated over the temperature range at which they will be used. Care should be taken to ensure that instruments are not exposed to temperatures that will damage detector or electronic components.

If the manufacturer has not stated operating limits for humidity or atmospheric pressures, the instruments shall be calibrated at the approximate humidity or pressure expected to be encountered in use. Care should be taken to ensure that an instrument is not damaged by exceeding its pressure or humidity limits.

4.3.4 Detector Directional Dependence. If an instrument is to be used in a detector orientation relative to the source which is different from that used during primary calibration, correction factors should be developed.

4.4 Discrimination Against Unwanted Radiation. If adjustments or changes are made which

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might alter the instrument response to unwanted ionizing and nonionizing radiations, the discrimination against unwanted radiation should be determined for all unwanted radiations that may be encountered.

4.5 Calibration Records. A record shall be maintained of all calibration, maintenance, repair, and modification data for each instrument. The record shall be dated and shall identify the individual performing the work. The record shall be filed with previous records on the same instrument in accordance with American National Standard Practice for Occupational Radiation Exposure Records Systems, N13.6-1966(R1972) [6].

Each instrument shall be labeled with the following information:

(1) Date of most recent calibration

(2) Initials or other specific identifying mark of calibrator

(3) Energy correction factors, where required

(4) Graph or table of calibration factors, where necessary, for each type of radiation for which the instrument may be used; this should relate the scale reading to the units required if units are not provided on the scale

(5) Instrument response to an identified check source (to be provided either by calibrator or user)

(6) Unusual or special use conditions or limitations

(7) Date that primary calibration is again required

(8) Special condition identification label (if applicable); see 4.3.1

4.6 Periodic Performance Test. To assure proper operation of the instrument between calibrations, the instrument shall be tested with the check source during operation and prior to each intermittent use.

Reference readings shall be obtained on each instrument when exposed to a check source in a constant and reproducible manner at the time of, or promptly after, primary calibration. If at any time the instrument response to the check source differs from the reference reading by more than ± 20 percent, the instrument shall be returned to the calibration facility for calibration or for maintenance, repair, and recalibration, as required. Reference readings should be obtained for one point on each scale or decade normally used. The check source should accompany the instrument if it is specific to that instrument.

4.7 Calibration and Performance Test Frequency

4.7.1 Primary Calibration Frequency. All instruments shall receive the precalibration inspection described in 4.1 and the primary calibration described in 4.2 prior to first use.

Primary calibration will be required at least annually even when the performance test requirements outlined in 4.6 are met.

Where instruments are subjected to extreme operational conditions, hard usage, or corrosive environments, more frequent primary calibration should be scheduled.

Recalibration shall be scheduled after any maintenance or adjustment of any kind has been performed on the instrument. For this requirement, battery change is not normally considered maintenance.

4.7.2 Calibration Frequency for Special Conditions. Calibration for special conditions need be performed only once unless (1) the instrument is modified or physicially altered, (2) the special conditions are changed, or (3) the primary calibration is altered, providing that the conditions in 4.7.1 are met.

4.7.3 Performance Test Frequency. A performance check shall be made prior to each use, during intermittent use conditions and several times a day during continuous use.

5. Calibration Equipment Required

5.1 Calibration Standards. Instruments should be calibrated either against National Standards or with Derived Standards. If National or Derived Standards are not available, Laboratory Standards, obtained in one of the following ways, should be used:

(1) Comparison of the radiation field from a user's source with the radiation field from a National or Derived Standard source in the same geometry, using a "transfer instrument" with a reproducibility of ± 2 percent. The transfer calibration shall utilize a calibration curve for the transfer instrument taken with the National or Derived source over a range that covers both the National or Derived source measurement and the user source measurement. (Such a curve reduces to a single point if the transfer calibration procedure is such

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that the transfer instrument readings are identical for both measurements.)

(2) Calibration of a user's transfer instrument with a National or Derived Standard source, followed by evaluation of a user's source with the same transfer instrument. The transfer instrument shall have a reproducibility of ± 2 percent and the procedure shall utilize a calibration curve as in 5.1(1).

(3) Where no National or Derived Standard exists, as in the case of specific energies or unusual sources, by establishment of a standard source or instrument with documented empirical and theoretical output or response characteristics.

A calibration source or sources preferably should be of a radiation energy similar to that with which the instrument will be used and of a radiation exposure rate sufficient to reach full scale of any instrument to be calibrated. If the source is a radionuclide, the half-life should be long, preferably greater than several years to minimize corrections and errors. The uncertainty of source calibration shall be no greater than ± 2 percent with respect to U.S. National Standards.

5.2 Calibration Assemblies. Instrument calibration assemblies shall be mechanically precise to ensure that positioning errors of either instruments or radiation sources do not affect the radiation field values by more than ± 2 percent.

The working conditions in the calibration facility shall not cause excessive radiation exposure of personnel. Personnel exposure shall be kept as low as practicable and shall in no case under normal operating conditions exceed permissible levels permitted by agreement or law (whichever is lower).

To meet this condition, personnel shielding, remote instrument reading and positioning facilities, automatic source handling mechanisms, and other mechanical or remote operations are recommended.

A sufficient range of radiation fields shall be available to satisfy calibration requirements.

5.3 Standard Instruments. An instrument used as a Derived Standard shall have an uncertainty no greater than ± 10 percent. Calibration shall be reestablished after maintenance or repair or at intervals specified by the manufacturer but in no case at intervals greater than three years.

A periodic instrument check procedure shall be established by the user to assure continued proper operation.

5.4 Check Sources. Check sources should provide radiation of the same type or types as provided by those sources used in instrument calibration (as described in 5.1). However, check sources may provide radiation different than that used for calibration if:

(1) The source instrument geometry is well understood and easily reproduced, or

(2) The instrument response to this radiation is well understood and is not critically dependent on instrument adjustment. (For example, the use of a photon source to check instruments sensitive to beta radiation may be acceptable; the use of a photon source to check a detector utilizing a BF_3 response to neutrons is not acceptable.)

A reproducible source detector geometry shall be established and used for all performance test measurements.

6. Maintenance of Quality of Calibration

6.1 Radiation Field. Either narrow or broad beam geometry may be used to compare the response of similar instruments with that of a standardized instrument.

For calibration of X-ray machines or particle accelerators, a calibrated instrument shall be used. If a continuous monitor is available, it can be calibrated simultaneously and used in subsequent work with periodic checks on its constancy.

Alpha radiation sources shall be standardized in terms of activity or activity per unit area of the source, or both. The reference geometry, 2π or 4π, shall be stated.

Beta radiation sources shall be standardized in terms of air or soft tissue absorbed dose rate at the surface or at a specified distance from the source, or in terms of activity.

Photon-emitting radionuclide sources shall be standardized in terms of exposure rate (in roentgens per hour) at a specified distance from the source.

Neutron sources shall be standardized in terms of (1) the number of neutrons emitted per unit time and (2) the effective or average neutron energy. Concomitant photon exposure rate should be known and stated.

For photon and neutron monitoring instru-

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ment calibrations, the source-to-detector distance shall be the distance measured between the effective center of the radioactive source and the effective center of the radiation detector. Either this distance shall be greater than seven times the maximum dimension of the source or detector, whichever is larger, or suitable corrections shall be used.

The exposure rate or the flux density of the radiation field shall be known with an estimated uncertainty no greater than ± 10 percent. A continuous monitor or other device should be used to determine whether the radiation field has changed.

6.2 Calibration Facility. Free-space geometry should be achieved for photon and neutron instrument calibration. The distance to scattering objects from the source and from the detector should be at least twice the distance between the detector and the source. Where scattering contributions to instrument readings are significant they shall be included in stating the value of the radiation field for all detector positions used for calibration purposes.

The radiation background at the calibration facility shall be low, known, and stable and shall be accounted for during calibration.

Temperature, relative humidity, and atmospheric pressure shall be noted at the time of instrument calibrations. Calibrations should be performed within the temperature range 25 ± 10°C, except when the instrument is to be used outside this temperature range.

6.3 Other. If an instrument may exhibit an extracameral response, the entire instrument should be placed in the radiation field during calibration and the results compared to calibration with just the detector in the field. The fractional contribution, if any, to the instrument reading due to an extracameral response should be determined and noted on the instrument.

A reasonable delay should occur before reading to allow warmup and to accommodate switching transients and the time constant of the instrument.

7. References

[1] ANSI N1.1-1976, Glossary of Terms in Nuclear Science and Technology.

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Appendix

(This Appendix is not a part of American National Standard Radiation Protection Instrumentation and Calibration, ANSI N323-1978.)

Radiation Sources for Instrument Calibration

A1. Electromagnetic Radiation

The calibration of photon monitoring instruments over the energy range from a few keV to several MeV is best accomplished with X-ray producing equipment and radionuclide sources. Some radionuclides may be used in lieu of X-ray machines as sources of radiation if the radiation energy and exposure rate are suitable to particular needs. Instruments used to measure X-rays with energies to a few hundred keV may be calibrated in an X-ray beam by comparison with a Derived Standard of known response. Instrument response to photons with energies from a few keV to 300 keV can be obtained with heavily filtered bremsstrahlung spectra and fluorescence X-rays [A1]–[A15][1]. When X-rays are used for calibration, the excitation voltage (kVp) filtration, and spectral characteristics should be accurately determined.

NOTE: If calibrations are made with an X-ray or accelerator target facility from which radiation field are produced in pulsed form, care must be taken to eliminate the possibility of serious calibration error.

Instruments used to monitor higher energies may be most easily calibrated in known radiation fields produced by sources of gamma rays of approximately the same energies as those to be measured. An ideal calibration source should emit photons with an energy spectrum similar to that to be measured and have a suitably long half-life. Few sources fulfill these ideal requirements. Sources covering a wide energy range which have proven useful for this purpose are shown in Table A1.

The supplier of a calibration source should provide a certificate of either the radioactive content or the exposure rate at a specified distance from the source [A19]. If the specific exposure rate constant (Γ) is used to calculate the exposure rate at various distances from the source, the dimensions of the source must be small relative to the distance to the detector. A good guideline is to make the source-to-detector distance at least seven times the largest dimension of the source or detector, whichever is larger.

Sources used for periodic calibrations should have an output appropriate to the range of the instruments to be calibrated and should be used under conditions similar to those employed in determining the exposure rate constant (Γ). The radiation field from the source should be uncollimated (if that were the condition of calibration), source-to-detector distances should be 30 to 100 cm for small detectors, and the radiation field should follow the inverse square relationship. This latter requirement can be met by minimizing the mass of material supporting the source and instrument and placing both the source and the instrument a large distance from potential large scatterers such as the ground, floors, and walls.

Instruments for standardizing photon fields include the free-air ionization chamber [A20], [A21], cavity ion chambers [A22], [A23], and calorimeters [A24], [A25]. Thermoluminescent dosimeters have also been proposed [A26]. For most laboratories, cavity ion chambers provide the best compromise among accuracy, precision, ease of use, cost, and traceability to a National Standard.

[1] Numbers in brackets refer to those of the references in Section A6 of this standard.

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A2. Beta Radiation

The beta radiation response of an instrument can be determined with a source of beta radiation which has been calibrated with an extrapolation chamber [A27], [A28]. To obtain uniform radiation fields, calibrations are commonly made with the detector window nearly in contact with a large area, flat, uniformly distributed source made of natural uranium, U_3O_8 or ^{90}Sr [A29], [A30]. However, sufficiently strong "point" sources could be used at distances that are large compared with dimensions of the detector window. At distances from a beta radiation point source, where fairly uniform irradiation of a detector's window prevails, considerable attenuation from air absorption will occur. The beta particles emitted from a source have a continuous spectrum of energy up to E_{max}. Table A2 includes a list of beta sources which are suitable for instrument calibration. Some of these sources may also emit photons. The instrument response to these photons together with any bremsstrahlung from surrounding materials should be taken into consideration in the calibration.

Another approach to the calibration of beta ray ion chamber instruments is to cover the detector with a thick sheet of air-equivalent material and then to calibrate the detector with gamma rays [A30]. In a field where the exposure rate is 1 R/h, the equivalent absorbed beta does rate under these conditions is about 0.98 rad/h for tissure. Electrons entering the thin window and producing the same current in the chamber would produce an absorbed dose rate in tissue only slightly higher than that produced by gamma rays. Thus, for practical purposes, the calibration for exposure rate in roentgens per hour is so nearly numerically equal to the desired calibration for absorbed dose rate from electrons in radians per hour that the difference is generally ignored.

A3. Alpha Radiation

Alpha radiation portable instrumentation is primarily used for the detection and sometimes the measurement of contamination. Standard reference alpha sources can be purchased from the National Bureau of Standards, commercially, or may be manufactured by electroplating a metallic alpha radiation emitter onto a stainless steel backing or other metal disc. Table A3 contains a list of alpha radiation sources which may be used in calibration. In some instances, alpha radiation may be present from impurities or daughters.

Table A1
Photon Emitting Radionuclides Suitable for Use in Instrument Calibration [A16]–[A18]
(in order of increasing effective energy)

Radionuclide	Effective Energy (keV)*	Half-Life	Specific Exposure Rate Constant R/(h•Ci) at 1 M†
^{241}Am	60	433 years	0.0129
^{57}Co	122	270 days	0.097
^{51}Cr	320	28 days	0.018
^{137}Cs	662	30.1 years	0.323
^{226}Ra	830‡	1600 years	0.825§**
^{60}Co	1250	5.27 years	1.30
^{24}Na	~2000	15 hours	1.84

*Instrument response is assumed to be negligible below 10 keV. Radiations with lower energy are not included. Effective energy will depend on instrument response.

†Assume negligible self-absorption, scattering, and bremsstrahlung.

‡ ^{226}Ra emits gamma rays of many energies from 19 to 2448 keV.

§ In equilibrium with its daughter products and with 0.5 mm Pt filtration.

**Average and Effective Energy for ^{226}Ra in Equilibrium with Daughters. KATHREN, R.L., and CHURCH, L.B. *Health Physics*, vol 30, p 143, 1976.

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Table A2
Beta Radiation Sources for Instrument Calibration [A17], [A18]
(in order of increasing E_{max})

Radionuclide	E_{max} MeV (percent)	E_{avg} (MeV)	Half-Life
^{3}H	0.0185 (100)	0.0057	12.35 years
^{14}C	0.156 (100)	0.049	5730 years
^{35}S	0.167 (100)	0.049	88.0 days
^{45}Ca	0.257 (100)	0.077	164 days
^{185}W	0.433 (100)	0.144	75 days
^{85}Kr	0.674 (99)	0.246	10.7 years
^{204}Tl	0.763 (98)	0.243	3.78 years
^{111}Ag	1.03 (93)	0.351	7.47 days
^{210}Bi	1.16 (100)	0.394	5.01 days
^{32}P	1.71 (100)	0.695	14.3 days
^{90}Sr–^{90}Y	2.27 (99)	0.566	28.5 years
^{238}U*	3.26	—	4.49×10^{9} years
^{42}K	3.52 (82)	1.43	12.4 h

*100 days after separation, approximately 95 percent equilibrium; 200 days after separation, more than 99 percent equilibrium.

Table A3
Alpha Radiation Sources for Instrument Calibration [A17], [A18]
(in order of increasing energy)

Radionuclide	Alpha Energy (MeV) Abundance (Percent)	Half-Life
^{148}Gd	3.18	93 y
^{230}Th	4.617 (24) 4.684 (76)	7.7×10^{4} years
^{239}Pu	5.105 (12) 5.143 (15) 5.156 (73)	2.44×10^{4} years
^{210}Po	5.305 (100)	138.4 days
^{241}Am	5.442 (13) 5.484 (86)	433 years
^{238}Pu	5.456 (28) 5.499 (72)	87.8 years
^{244}Cm	5.764 (23) 5.806 (77)	17.8 years
^{252}Cf	6.076 (16) 6.119 (84)	2.65 years

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A4. Neutron Radiation

Neutron monitoring instruments can be calibrated with neutrons produced by radionuclide sources [A31]–[A35], [A37]–[A42], particle accelerators [A36], [A37], or nuclear reactors [A43]–[A45].

Radionuclide neutron sources are of three types: alpha-n, gamma-n, and spontaneous fission. The alpha-n radiation sources contain an alpha emitter, such as ^{210}Po, ^{238}Pu, ^{239}Pu, or ^{241}Am in intimate contact with a low-atomic-number element or elements, such as lithium, beryllium, boron, or fluorine, and produce neutrons distributed in energy from nearly 0 MeV to the maximum allowed by reaction kinetics. These sources are physically small in in size and easily portable, can be fabricated with neutron yields up to the 10^7–10^8 neutron per second range, have relatively low-intensity accompanying photon emission, and can be calibrated by the National Bureau of Standards. ^{210}Po alpha-n radiation sources are of limited value because of the relatively short ^{210}Po half-life (138 days). Recommended alpha-n radiation sources are based on ^{238}Pu, ^{239}Pu, and ^{241}Am; however, it may be important to account for changes in neutron emission caused by in-growth of daughter alpha emitters or the initial presence of (small amounts) alpha emitters with half-lives different from the primary radionuclide, as well as decay of the primary radionuclide.

The gamma-n radiation sources consist of a gamma emitter of suitably high photon energy, such as ^{124}Sb or ^{226}Ra, placed in close proximity to a low-atomic-number element, usually deuterium or beryllium. Each reacting gamma ray, according to reaction kinetics, produces primarily monoenergetic neutrons. These sources also produce intense photon fields, which may create personnel exposure problems, as well as interference with instrument response. The low-atomic-number element is often a physically separate piece so that instrument response to photons can be assessed separately. The short half-life of ^{124}Sb (60 days) and the low neutron energy (approximately 30 keV) are important limitations for the use of this type source. ^{226}Ra gamma-n radiation sources are more generally useful, are physically small in size, can be obtained with neutron yields up to the 10^6–10^7 neutron per second range, and can be calibrated by the National Bureau of Standards.

Spontaneous fission neutrons, emitted in one branch of the decay of ^{252}Cf, have a fission-type neutron spectrum in the energy range approximately 0.5 to 15 MeV. These sources can closely approximate an idealized point source, can be obtained in the range up to 10^8–10^9 neutrons per second, have relatively low-intensity accompanying photon emission, and can be calibrated by the National Bureau of Standards. The relatively short half-life (2.65 years) is a limitation to long-term use.

Particle accelerators produce intense neutron fields by the interaction of accelerated charged particles, such as protons, deuterons, or tritons, on low-atomic-number target materials such as deuterium, tritium, and lithium. Important characteristics of these neutron fields are variable intensity up to very high values (yields in excess of 10^{12} neutrons per second in some cases), occurrence of radiation in a brief pulse, monoenergetic neutron emission for any given beam-target-detector angular relationship, and lack of portability. Neutron output is a complex function of accelerator and target parameters and may be expected to vary with time even though measured machine parameters remain constant. Therefore, neutron output must be monitored constantly during instrument calibration work, and standard instruments or techniques must be used to establish neutron field values.

Nuclear reactions may be used as a source of neutrons for instrument calibration purposes. The energy spectral characteristics of these neutron fields can vary from an unmoderated fission spectrum, such as produced by a ^{235}U fission plate, to the heavily filtered slow neutrons from a thermal column. Neutron flux densities in excess of 10^{10} neutrons per centimeter squared-second may be obtainable for calibration purposes. Standardization of the neutron fields must be accomplished with standard instruments or techniques, and continuous monitoring of the neutron flux must be performed throughout calibration work.

Radionuclide neutron sources can be conveniently sent to the National Bureau of Standards for calibration, thereby to become De-

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rived Standards suitable for in-house instrument calibration [A46]. On the other hand, since particle accelerators and nuclear reactors cannot be sent out for calibration, they must be standardized for instrument calibration by use of standard neutron instruments or techniques. In addition, the neutron output of these facilities must be monitored continuously during instrument calibrations. Standard neutron instruments and techniques include the precision long counter [A47]–[A49], associated particle counters (for certain accelerators) [A37], nuclear emulsions [A37], fission foils [A37], activation foils [A37], and manganese sufate bath [A35].

A5. Facilities for Radiation Instrument Calibration Laboratories

The building space, methods, and staff necessary to properly operate a calibration laboratory depend on the volume and type of work undertaken. Calibration facilities exist that employ from a fraction of one employee's time up to tens of people. The amount of building space needed depends on such diverse factors as volume of business, land and building costs, shielding, scatter, required accuracy, types of radioactive sources and instruments, and energy and strength of sources. Several types of rooms may be necessary including irradiation rooms, storage vaults, and offices. The methods for proper, efficient, and safe operation of the laboratory must be correctly established and should include such functions as receiving and handling of instruments, calibration of test irradiation systems, calibration of instruments and dosimeters, return of calibrated dosimeters and instruments, reporting of results, keeping records of laboratory activities, maintenance and development of calibration procedures. The number of laboratory staff would depend on the volume of business. In any case, the technical integrity of the laboratory should be above reproach. Typical laboratory buildings, staffing requirements, and laboratory facilities have been described in the literature and can be adapted to most needs [A30], [A50].

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