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American National Standard Radiation Protection Instrumentation Test and Calibration, Portable Survey Instruments

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American National Standard Radiation Protection Instrumentation Test and Calibration, Portable Survey Instruments

Sponsor

National Committee on Radiation Instrumentation, N42

Accredited by the

American National Standards Institute

Secretariat

Institute of Electrical and Electronics Engineers, Inc.

Approved 3 April 1997

American National Standards Institute

Abstract: Specific requirements are established for portable radiation protection instruments used for detection and measurement of levels of ionizing radiation fields or levels of radioactive surface contamination.

Keywords: portable survey instruments, radiation measurements, radiation protection instruments, radiation survey

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Introduction

(This introduction is not part of ANSI N323A-1997, American National Standard Radiation Protection Instrumentation Test and Calibration, Portable Survey Instruments.)

This standard is the responsibility of the Accredited Standards Committee on Radiation Instrumentation, N42. Committee N42 delegated the development of this standard to its subcommittee N42.RPI. Drafts were reviewed by Committee N42, Subcommittee N42.RPI, 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 on 21 May 1996.

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

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American National Standard Radiation Protection Instrumentation Test and Calibration, Portable Survey Instruments

1. Scope

This standard establishes specific requirements 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 battery-powered instruments that are carried to a specific facility or location for use.

NOTE—These instruments are normally held during operation.

Count rate meters and scalers, when used with an appropriate probe for quantifying activity, can be considered portable radiation protection instruments and treated as a single unit for the purposes of this standard. Specific requirements for calibration of low-range [i.e., near background to < 10 μSv/h (1 mrem/h)][1] portable survey instruments will be detailed in ANSI N323B (currently under development). Specific requirements for all air monitoring instruments will be detailed in ANSI N323C (currently under development). Specific requirements for installed instruments that measure dose or dose equivalent, or dose rate or dose equivalent rate, and AC powered instruments used only to detect the presence of radioactive material contamination will be detailed in ANSI N323D (currently under development).

Radiation protection instrumentation provides direct readout of, or readout proportional to, dose or dose equivalent, dose rate or dose equivalent rate, or activity per unit area (i.e., effective probe area). Included are portable rate and integrating devices for beta, photon, and neutron radiations; and monitors for surface contamination (alpha, beta, and photon). Portable radiation protection instruments intended for use in underwater survey and monitoring are included in this standard. Personnel dosimeters (including electronic pocket dosimeters and hybrid pocket dosimeters/dose equivalent rate meters) and environmental monitoring instruments, other than portable instruments used to measure rad/h or rem/h levels, are outside the scope of this standard. Radon monitoring instruments are not within the scope of this standard. Since special-purpose

[1]SI units are used throughout this standard with conventional units shown in parenthesis.

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instrumentation, such as emergency post-accident radiological monitors, may also fall under the scope of one or more related ANSI standards, this standard is intended to supplement rather than replace these standards. For example, ANSI N42.17A-1989 [B3] sets forth requirements for instrument performance. In general, radiation protection instrumentation is considered to cover the dose and dose equivalent rate ranges for survey meters of 10 μGy/h to 10 Gy/h (1 mrad/h to 1000 rad/h) and 10 μSv/h to 10 Sv/h (1 mrem/h to 1000 rem/h), and activity-per-unit-area ranges for surface contamination monitors of 2 Bq/100 cm^2 to 20 000 Bq/100 cm^2 (120 dpm/100 cm^2 to 1.2×10^6 dpm/100 cm^2).

Throughout this standard, three verbs have been used to indicate the degree of rigor intended for each specific criterion. The word *shall* is used to denote a requirement. The word *should* is used to denote a recommendation. The word *may* is used to denote a permissible practice.

2. Definitions

Technical terminology used in this standard is generally consistent with the definitions in ANSI N1.1-1976 [B1], and ICRU 33 [B6]. The following terms are defined specifically for use within this standard:

2.1 absorbed dose: Energy deposited per unit mass of the specified absorbing medium.

2.2 acceptance testing: Evaluation or measurement of performance characteristics to verify that certain stated specifications and contractual requirements are met.

2.3 accredited calibration laboratory: A calibration laboratory that has been accredited by an authoritative body (e.g., Health Physics Society, American Association of Physicists in Medicine, National Institute of Standards and Technology) with respect to its qualifications to perform calibrations on the type of instruments covered by this standard.

2.4 accuracy: The degree of agreement between the observed value and the conventionally true value of the quantity being measured.

2.5 adjust: To alter the response by means of a variable built-in control, such as a potentiometer or software.

2.6 calibrate: (A) To adjust or determine the response or reading of an instrument relative to a series of conventionally true values for radiation sources. **(B)** To determine the activity of a radiation source relative to a standard or conventionally true value.

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

2.8 coefficient of variation: The standard deviation expressed as a percentage of the mean [i.e., (standard deviation/x) · (100)].

2.9 contamination monitor: An assembly including one or several radiation detectors and associated assemblies designed to measure activity (alpha, beta, photon, or alpha-beta) per unit surface area or activity of a localized source associated with the contamination of the examined object.

2.10 conventionally true value (CTV) of a quantity: The commonly accepted best estimate of the value of a quantity. This and the associated uncertainty will preferably be determined by a national or transfer standard, by a reference instrument that has been calibrated against a national or transfer standard, or by measurement quality assurance (MQA) with the National Institute of Standards and Technology (NIST), formerly the U.S. National Bureau of Standards, or a qualified secondary laboratory.

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2.11 correction factor: The factor by which the reading of an instrument is multiplied to obtain the conventionally true value of the quantity.

2.12 counting efficiency: The ratio, expressed as a percentage, of the instrument net reading to the surface emission rate of a source under given geometrical conditions.

2.13 decade: A range of values for which the upper value is a power of ten above the lower value.

2.14 detection limit: The extreme of detection or quantification for the radiation of interest. It is the minimum statistically quantifiable instrument response or reading. The upper measurement level is the maximum level at which the instrument meets the required accuracy.

2.15 detector: A device or component designed to produce a quantifiable response to ionizing radiation, normally measured electronically.

2.16 dose: A generic term including absorbed dose and/or dose equivalent. *See also:* **absorbed dose** and **dose equivalent.**

2.17 dose equivalent (*H*): The product of D and Q at the point of interest in tissue, where D is the absorbed dose and Q is the quality factor.

2.18 energy dependence: Variation in instrument response as a function of radiation energy for a constant radiation type and absorbed dose rate referenced to tissue or air.

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

2.20 functional check: A check (often qualitative) to determine that an instrument is operational and capable of performing its intended function. Such checks may include, for example, battery check, zero setting, or source response check.

2.21 geotropism: A change in instrument reading with a change in instrument orientation as a result of gravitational effects.

2.22 indicated value: (A) A scale or decade reading. **(B)** The displayed value of the readout. *See also:* **reading.**

2.23 instrument: A complete system consisting of one or more assemblies designed to quantify one or more characteristics of ionizing radiation or radioactive material.

2.24 national standard: An instrument, source, or other system or device maintained and promulgated by the National Institute of Standards and Technology (NIST), formerly the U.S. National Bureau of Standards.

2.25 overload response: The response of an instrument when exposed to radiation intensities greater than the upper measurement level.

2.26 performance test: An evaluation of the performance of an instrument in response to a given influence quantity.

2.27 portable survey instrument: An instrument intended to be operated while being carried by a person.

2.28 range: All values lying between the detection limit and the upper measurement level.

2.29 reading: The indicated value of the readout.

2.30 readout: The portion of the instrument that provides a visual display of the instrument response.

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2.31 reference orientation: The orientation in which the instrument is normally intended to be operated, as stated by the manufacturer.

2.32 reference point: A mark (or markings) on the outside of an instrument, used to determine the effective center of the sensitive volume at which the conventionally true absorbed dose rates are known.

2.33 reference radiation: The radiation selected for calibration of the instrument using sources relatable to national or international standards.

2.34 reproducibility (precision): The degree of agreement between repeated measurements of the same property, expressed quantitatively as the standard deviation computed from the results of the series of measurements.

2.35 response: The instrument reading produced as a result of some influence quantity.

2.36 response time: The time interval required for the instrument reading to change from 10% to 90% of the final reading (or vice versa) following a step change in the radiation field (i.e., signal) at the detector.

2.37 secondary standard: An instrument, source, or other system or device that has been compared directly with the national standard. *See also:* **national standard.**

2.38 sensitivity: The ratio of the variation of the observed variable to the corresponding variation of the measured quantity, for a given value of the measured quantity.

2.39 source response check: The check of instrument response to a source to determine that the instrument is still functional within an acceptable range.

2.40 tertiary standard: An instrument, source, or other system or device that has been compared directly with a secondary standard. Generally reserved for use as a laboratory standard. *See also:* **secondary standard.**

2.41 transfer standard: A physical measurement standard, specifically designed for transport, that has been compared directly or indirectly with the national standard. This standard is typically a measurement instrument or a radiation source used as a laboratory standard. *See also:* **national standard.**

2.42 type test: An initial test of one or more production instruments made to a specific design to show that the design meets certain specifications.

2.43 uncertainty: The estimated bounds of the deviation from the conventionally true value, generally expressed as a percent of the mean, and ordinarily taken as the square root of the sum of the squares of the two components:

a) Those components that are evaluated by statistical means; and
b) Those components that are evaluated by other means, see [B19].

2.44 upper measurement level: The maximum level at which the instrument meets the required accuracy.

2.45 working standard: An instrument, source, or other system or device calibrated by comparison to a standard other than a national standard. *Contrast:* **national standard.**

3. General requirements

The measurement accuracy requirements for radiation protection instrumentation are set forth in the recommendations of various commissions and committees, see [B15], [B17], and [B5]. Although a factor of two is considered adequate accuracy at dose levels less than one quarter of the occupational limit (MOL), at higher

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levels the measurement accuracy is required to be ±30%. MOL is interpreted as the allowable dose or dose rate for radiation workers as established for dose control practices (e.g., administrative control levels). To achieve this level of accuracy in the field, instrument performance, calibration, maintenance, and functional testing must all be adequately controlled.

3.1 Operational characteristics

The operational characteristics of an instrument, as defined by a series of type tests, will indicate how accurately the instrument can be expected to measure the dose or dose rates under variable operational conditions. Variations in radiation energy, radiation direction, temperature, humidity, instrument stability, instrument geotropism, etc. (see [B23], [B22], and [B24]), can affect the accuracy of measurements in the field. ANSI N42.17A-1989 [B3] and ANSI N42.17C-1989 [B4] set forth performance criteria and test methods for portable instruments. ANSI N42.17A-1989 should be used as a guide for test methods, and may be used as a guide in establishing the operational requirements for all instruments used at a specific facility or site. Once the operational characteristics are defined for an instrument model via type testing, each instrument shall be acceptance tested for critical requirements to ensure that the instrument performance is representative of the requirements set forth by the operator of a specific facility or site. For large numbers of instruments, it shall be considered acceptable to establish statistical criteria for testing and accepting instruments. However, basic functional tests (zero setting, battery voltage, geotropism, etc.) that are part of a normal calibration should be performed on each instrument. Instruments shall be type tested for variables critical to their performance in the intended environment, and shall be acceptance tested prior to calibration and initial use in the facility.

3.2 Acceptance tests

An acceptance test should consist of

a) A physical inspection
b) A general operations test
c) Source tests

and should precede the initial instrument calibration. The physical inspections and general operations tests should be performed on each instrument. The source tests should be performed on a random selection of 10% of the instrument batch or four instruments, whichever is larger. If one instrument in a sample of a large quantity fails the test, an additional 10% should be tested. An additional failure would result in the need to test the entire batch.

3.2.1 Physical inspection

A physical inspection is an inspection identifying any physical abnormalities that may affect instrument operation (e.g., inspecting instruments for broken parts, loose or missing screws, loose or misaligned knobs, calibration potentiometers not aligned with access holes, circuit boards not secured, loose wires, loose connectors, and loose components; testing moving parts; or ensuring that batteries are fresh and properly installed).

3.2.2 General operations test

A general operations test is a determination of nonradiological operating functions (e.g., checking battery condition, verifying the mechanical zero, testing the meter zero potentiometer, checking for switching transients, or checking for zero drift on the meter or light sensitivity, if applicable).

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3.2.3 Source tests

A determination of radiological operating functions (e.g., checking source response, geotropism, variability of readings, stability, temperature response, humidity response, or photon energy response). Temperature, humidity, and energy-response tests may consist of single data points at extremes of these variables to test against specifications.

3.2.4 Instrument calibration

The initial instrument calibration is part of the acceptance test and should include a comparison of instrument linearity and overload response against specifications.

3.3 Performance tests

Periodically, over the life of the instrument, all instruments should be performance tested to verify that they continue to meet the operational requirements. Testing and calibration of instruments should be performed under a group of controlled conditions called *standard test conditions*; see Table 1. This is recommended to ensure that performance variations are eliminated in the calibrations and that performance characteristics can be related to the calibrated instrument.

Table 1—Standard conditions

Influence quantities	Acceptable range for standard test conditions
Warm-up time	>1 min or manufacturer's specification
Relative humidity	Ambient ±10%, not to exceed 75%
Ambient temperature	20–24% °C
Atmospheric pressure	70–106 kPa
Background ambient photon radiation (external)	2.5% of full scale of the range or decade under test, but nominally should not exceed 0.5 Gy/h (50 rad/h), referenced to air
Non-ionizing electromagnetic field of external origin	Less than 50% of the lowest value that causes interference
Magnetic induction of external origin	Less than twice the induction due to the earth's magnetic field
Controls	Set for normal operation per site procedure or manufacturer's recommendations
Contamination by radionuclides	Contamination shall be low and should be less than limits for total activity listed in NRC Reg. Guide 1.86 [B20]
Reference point	Effective center [a]

[a]For larger area beta or alpha detectors, the detector source response factor should be based on contact with the detector "face."

Recalibration, maintenance, performance tests, and functional tests should be conducted periodically to ensure that the instruments continue to meet the performance requirements for field measurements. Periodic recalibration is distinct from a field test or a simple evaluation with a check source. It includes a precalibration check followed by adjustment and calibration, as described in Clause 4.

Performance tests should be repeated routinely because aging or replacement of components may affect the performance of the instrument. The performance tests that should be performed periodically (at least annu-

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ally), or performed after maintenance that could affect performance, are range, sensitivity, linearity, detection limit, and response to overload conditions. These tests may be conducted as part of the calibration procedure. If maintenance could affect instrument performance (i.e., energy response, temperature response, etc.), performance tests should be conducted to evaluate the response characteristic that may have been impacted. Any changes in the performance characteristics of the instrument shall be documented, and the documentation shall be provided to the user.

3.4 Instrument maintenance

Instrument maintenance shall be performed using components that are at least equivalent to those specified by the manufacturer. If the manufacturer does not provide maintenance instructions, maintenance instructions should be written and approved by persons in the organization responsible for performing the maintenance and/or calibration. The instructions should include requirements for training and qualification of workers, for specifying the quality of replacement components, and for control of workmanship quality. When the manufacturer does provide written instructions, the organization responsible for maintenance and/or calibration may document acceptance of the instructions.

Repairs made using unapproved instructions or components that may affect instrument performance constitute an instrument modification, and shall be considered to render invalid any type tests made on the instrument model as applied to the specific instrument. Modified instruments shall have their performance tested and documented prior to issuance for field use. If the user can document that the modifications will not affect the performance of the instrument, additional testing is not required.

3.5 Special-use conditions

If the instrument is to be used for conditions other than those for which it was performance tested (e.g., used outside the designed energy range or under different environmental conditions), calibration or performance testing for these conditions shall be performed. Similarly, if the instrument is physically altered such that the previous calibration and performance tests could be invalidated, calibration and retesting shall be performed. It should be noted that where calibration or performance tests are performed under several variables (such as temperature, dose rate, and humidity), only one variable shall be involved while other conditions shall be held constant.

Components may change values with time or even fail. A functional check shall be made by the user daily or prior to use to ensure that the instrument is operating properly (see 4.8).

4. Inspection and calibration

The following subclauses discuss the calibration requirements for specific types of portable radiation protection instruments. Requirements for all instruments are discussed first, followed by specific requirements for dose and dose rate instruments, contamination monitors, and, finally, specialized monitors. Specialized monitors generally use more sophisticated detectors and energy discrimination. Precalibration should include verifying that radioactive contamination on the instrument is low. It should be less than the NRC Reg. Guide 1.86 [B20] conditions.

4.1 Precalibration

Precalibration shall include a visual examination of the instrument condition and a documentation of the instrument response, upon return from the field, by obtaining "as found" readings for one calibration point on each scale. "As found" readings shall be taken prior to any adjustments on the instrument, unless the instrument is returned in an inoperable condition.

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4.2 Calibration

Calibration shall include adjustment and/or determination of new readings for each point selected on the scale. Electronic calibration shall be acceptable for some instrument ranges where calibration with a source is impractical, provided the electronic calibration is related to actual exposure data at one or more points. The following conditions shall be established prior to exposing the instrument to a source for adjustment and calibration:

a) The meter shall be adjusted to zero or the point specified by the manufacturer.
b) The batteries or power supply shall comply with the instrument manufacturer's specification.
c) The instrument shall be turned on and allowed to stabilize as appropriate.
d) Electronic adjustments such as high voltage shall be set either to the site specifications or to the manufacturer's specifications, as applicable.
e) The effect of geotropism shall be known for the instrument, and this effect shall be taken into account during calibration.

The specific calibration requirements for various instruments are given in the following subclauses.

4.2.1 Dose or dose rate measuring instruments

4.2.1.1 Linear readout instruments

Linear readout instruments with a single calibration control for all scales shall be adjusted either at the point recommended by the manufacturer or at a point within the normal range of use. Instruments with calibration controls for each scale shall be adjusted on each scale.

NOTE—If instruments have ranges that are not calibrated, a limited calibration tag that notes the limits of calibration shall be attached to the instrument. The same principles should be applied to microprocessor-controlled instruments.

After adjustment, the response of the instrument shall be checked near the end points of each scale (approximately 20% and 80% of full scale).

NOTE—For microprocessor-based instruments that have been proven linear through type testing and/or acceptance testing, only one point on each scale or decade is required.

Instrument readings shall be within ±15% of conventionally true values (CTV) for the lower point and ±10% of CTV for the upper point. Readings within ±20% shall be acceptable if a calibration chart or graph is prepared and provided with the instrument.

4.2.1.2 Logarithmic readout instruments

Logarithmic readout instruments, which commonly have a single readout scale spanning several decades, normally have two or more adjustments. The instrument shall be adjusted for each scale according to the site specifications or the manufacturer's specifications. Alternatively, it shall be permissible to calibrate at points of particular importance to the user if the reasons for the change and the impact on accuracy are documented and justified.

After adjustment, calibration shall be checked at a minimum of one point on each decade. Instrument readings shall have a maximum deviation from the CTV of no more than 10% of the full decade value. If the display is not marked at intervals corresponding to ±10% of the point (i.e., a calibration at a mark frequently does not have graduations to 10% in the next decade), it is permissible to use the spacing on the low side of the calibration point to estimate the calibration limit on the high side of the calibration point.

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4.2.1.3 Digital readout instruments

Digital instruments shall be calibrated as in 4.2.1.1.

NOTE—For microprocessor-based instruments that have been proven linear through type testing and/or acceptance testing, only one point on each scale or decade is required.

If the instrument is designed to auto scale, the calibration point should be selected far enough from the auto scaling point that auto scaling will not affect the reading. Instruments should be cycled through a complete test of all display segments or indicators, either electronically or radiologically.

4.2.1.4 Integrating instruments

Instruments that integrate dose shall be checked at a minimum of two dose rates at approximately 20% and 80% of the stated dose rate range or as recommended by the manufacturer.

NOTE—If the full instrument dose rate range is not intended for use, then the range acceptable for use shall be noted on the instrument.

The integrations shall continue to a value sufficient to ensure a statistically valid reading that shall be within 15% of the CTV. For digital instrumentation, integration should be checked to the maximum reading obtainable on the display. If it is not practical to accomplish the full-scale radiological integration, the electronics and display may be checked electronically at the maximum integration point, with the radiological integration being performed at a lower point that is achievable.

4.2.1.5 Neutron dose equivalent instruments

Instruments designed to read out in units of neutron dose equivalent or dose equivalent rate shall be calibrated as in 4.2.1.1 through 4.2.1.4; except that the calibration accuracy for ranges from 0–100 Sv/h or 0–100 Sv (0–10 mrem/h or 0–10 mrem) shall be ±30%, and the calibration accuracy for ranges from 100 Sv/h or 100 Sv (10 mrem/h or 10 mrem) and above shall be ±20%.

4.2.1.6 Beta dose measuring instruments

Correction factors for beta dose/dose rate measurements shall be determined using either ISO 6980: 1994 [B9] sources for point sources and standard distributed sources (e.g., depleted uranium slabs), or transfer sources relatable to the ISO 6980: 1994 sources.

Instrument correction factors shall be determined with an accuracy of ±20%.

At least one correction factor should be checked annually or after any modification or repair that may affect the correction factor.

NOTE—The geometry at the source (point vs. distributed) used for the calibration shall be stated. For distributed sources, the geometry and dimensions of the source and the source detector distance used shall be provided to enable the user to make corrections for field conditions.

4.2.1.7 Digital/analog readout

Calibration of both the digital and the analog scales shall be performed.

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4.2.2 Surface contamination measurement instruments

Alpha and beta-gamma detection instruments normally consist of two assemblies (a count rate meter and a detector). It shall be permissible to calibrate either the electronics and the detector together using radiation sources traceable to NIST, or the electronic package and the detector separately using an electronic pulser and radiation sources. Each detector should be calibrated with the radionuclide to be detected, if possible. However, the detector shall be calibrated with an energy that is less than or similar to beta energies in the field.

Where the instrument is calibrated as an integral unit, a minimum of one point on each scale shall be calibrated up to 10^3 Bq/100 cm^2 ($\sim 6 \times 10^4$ dpm/100cm^2). If each scale has a calibration potentiometer, the reading shall be adjusted to read the CTV at approximately 80% of full scale, and the reading at approximately 20% of full scale shall be observed. If only one calibration potentiometer is available, the reading shall be adjusted at mid-scale on one of the scales, and readings on the other scales shall be observed. Readings shall be within 20% of the CTV.

Where the electronic package and detector are calibrated separately, the count rate meter shall be calibrated with the electronic pulser. The detector shall be calibrated radiologically with sources traceable to NIST. When dead-time correction is supplied, it should be disabled when calibrating with a pulser and re-engaged when calibrating with a source.

It shall be permissible for the probe and the count rate meters to be calibrated separately. The exchange of probes shall be permitted if the variation between combinations of units provided to a given location has been documented to be within 20% of the CTV. This shall be documented for all combinations of probe and count rate meter models and ranges. The range of acceptable count rates for a specific check source shall be documented. If the exchange of probes is permitted, the new detector shall respond within the same range of acceptable count rates as the previous probe using the same check source as used with the original probe.

The counting efficiency or relationship (e.g., *x* cpm/dpm) shall be documented on the detector after each calibration, or on the instrument if the probes are not exchanged in the field.

4.2.2.1 Beta-gamma contamination measurement instruments

Counting efficiencies should be determined for the type of activity expected to be measured. Where mixed or unknown contamination is to be measured, a number of different radionuclides with different energies, including low-energy photons, should be utilized. The distance from the source to the face of the detector shall be included with the recorded counting efficiencies.

Where GM tubes are used as detectors, the unit shall be tested to ensure that saturation does not occur unless the maximum indicated value of the instrument is exceeded by at least a factor of two. The instrument shall continue to indicate a full-scale reading until the radiation field is reduced to less than the maximum display value. Digital readouts shall convey that the radiation level present exceeds the upper measurement level of the instrument in a manner described by the instrument manufacturer.

4.2.2.2 Alpha contamination measurement instruments

All scintillation and air or gas proportional detectors shall be checked for light leaks or holes in the window material before calibration is initiated. A maximum acceptable background count rate shall be determined, documented, and used to test instruments prior to calibration.

Counting efficiencies shall be determined with the radionuclide to be detected, if possible, or with a radionuclide with similar energy.

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4.2.3 Specialized survey instruments

Specialized instruments (e.g., portable area monitors, portable scalers, portable monitors for special nuclear materials, and scintillation counters for surface monitoring) may be included under the test and calibration provisions for radiation protection instruments. In many cases, such instruments consist of a common count rate meter with a specialized detector. Where applicable, the principles described for common dose rate and contamination monitors should apply to these instruments.

4.2.3.1 Calibration

Instruments shall be calibrated in a radiation field appropriate to the instrument, see [B16]. In some cases (such as special nuclear material monitors), a full calibration to the specific radiations and/or levels is not practical on a routine basis. For such applications, a full calibration shall be performed once and related to a controlled and reproducible geometry for subsequent special calibrations (i.e., source and test fixture). Test sources should include a range of activities to permit testing of detector linearity and multiple ranges, as appropriate. Overload response shall be tested as appropriate. The bases for the special calibration shall be documented and, where possible, should be traceable to NIST.

4.3 Calibration for special conditions

4.3.1 General

When an instrument is to be adjusted and calibrated for use only under special conditions that are outside the manufacturer's specifications (i.e., radiation energy, temperature and pressure, or source/detector geometry), a special-use identification label (or other means of identification) shall be attached, in addition to any required calibration labels, to indicate its applicability *for this special use.* If the instrument is also to be used within its design limits, the adjustments made during calibration shall be done under standard conditions (see Table 1); and instrument readings for the special conditions shall be corrected using correction factors obtained from appropriate evaluations of instrument performance. The bases for the calibration to special conditions shall be documented.

Determination of corrections for special conditions shall be performed only once, unless

a) The instrument is modified or physically altered, or
b) The special conditions are changed, or
c) The normal calibration suggests that a change or deterioration has occurred in instrument performance.

4.3.2 Detector geometry dependence

If dose or dose equivalent rate instruments are used under conditions that do not uniformly irradiate the detector volume (close to a source or in a beam), the instrument response may vary significantly with source geometry, source energy, detector geometry, and detector distance. Correction factors should be determined and documented for the use of instruments under such conditions.

4.4 Discrimination against interfering radiations

Results should be available to document instrument discrimination against a range of ionizing and nonionizing radiation interferences. If adjustments or changes are made that might alter the instrument response to interfering ionizing and nonionizing radiations, the discrimination against interfering radiation should be determined for all interfering radiation types that may be encountered.

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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 and shall be readily retrievable. ANSI N13.6-1966 [B2] provides additional information.

4.6 Instrument information

4.6.1 Instrument information labeling

Each instrument shall be labeled with the following information:

a) Date of most recent calibration
b) Initials or other specific identifying mark of calibrator
c) Date that primary calibration is again required
d) Special-use or limited calibration label (if applicable)
e) Serial number of the instrument or other unique identification number used by the facility to identify a specific instrument

4.6.2 Additional instrument documentation

The following information shall be documented and made available to the user for each instrument:

a) Energy correction factors, where appropriate.
b) Graph or table of calibration factors, where necessary, for each type of radiation for which the instrument was calibrated. This should relate the scale reading to the units required if units are not provided on the scale.
c) Instrument response to an identified check source (to be provided either by calibrator or user).
d) Unusual or special use conditions or limitations, where appropriate.

4.7 Facility documentation

A comprehensive and readily available record system shall be maintained by the calibration facility. All records of data shall identify the individual who collected the data on which the record is based. The record system shall include at least the following:

a) An inventory of all standards and calibration equipment.
b) A full history and calibration data, including certificates, for all standards and applicable calibration equipment.
c) All procedures used for providing calibration services.
d) Routine quality control records.
e) The results of all performance testing.
f) Records of instrumentation for which a calibration service was provided, and the date that the calibration was performed including a description, sufficient for identification, of every item. The record system shall also include or reference a detailed report for that specific calibration.
g) Copies of all calibration reports issued and/or all electronic records.
h) Information essential to the analysis and reconstruction of the calibration of a specific item of instrumentation.
i) Records detailing the education, experience, and training of all operating staff and supervisory personnel.
j) A documented analysis of calibration uncertainties.

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4.8 Source response check

To ensure proper operation of the instrument between calibrations, each instrument (with the exception of neutron instruments and high-dose equivalent rate photon instruments) shall be checked with a source during operation at least daily or prior to each intermittent use, whichever is less frequent. If at any time the instrument response to the source differs from the reference reading by more than ±20% (for any photon instrument the reading should be at least ten times background), the instrument shall be returned to the calibration facility for calibration or for maintenance, repair, and recalibration, as required. Reference readings shall be obtained for each instrument when exposed to a source in a constant and reproducible manner, either at the time that the instrument is received in the field or before its first use. Where it is shown that readings for a specific model of instrument fall within ±20%, it shall be permissible to obtain generic reference readings for a given source. Reference readings should be obtained for one point on each scale or decade used. The source should accompany the instrument if it is specific to that instrument.

NOTE—A source response check may not be practical for some instruments, such as high-range instruments and neutron exposure rate instruments. In these cases, the facility should develop compensatory methods to demonstrate that the instrument is operable before use.

4.9 Calibration frequency

Calibration shall be required at least annually, even when the source response check requirements outlined in 4.8 are met.

Where instruments are subjected to extreme operational conditions, hard usage, multishift use, or corrosive environments, more frequent primary calibration should be scheduled. As-found readings shall be documented to demonstrate the response of the instrument upon return to the laboratory. If greater than 10% of the instruments are out of calibration, consideration should be given to increasing the calibration frequency.

Calibration shall be scheduled after any maintenance or adjustment that can affect instrument performance. Exchange of detectors in the field shall be permitted only after a specific procedure, such as the one described in 4.2.2, has been documented and implemented.

5. Calibration equipment required

5.1 Calibration standards

Instruments shall be calibrated with appropriate standards that are traceable to NIST or its international equivalents. Working standards derived from secondary or tertiary standards shall be used and shall be compared at least annually against the secondary or tertiary standards. Calibrations of the reference radiation field or source shall be obtained in one of the following ways:

a) By calibration of a user's transfer instrument with a national or secondary standard source, followed by evaluation of the user's reference source with the same transfer instrument. The transfer instrument shall have a reproducibility within 2% (one standard deviation).
b) By comparison of the radiation field from a user's reference source with the radiation field from a national or secondary standard source in the same geometry, using a "transfer instrument" that has a reproducibility within 2% (one standard deviation).
c) Where no national or secondary standard exists (as in the case of specific energies, unusual sources, or unusual source configuration), by establishment of a standard source or instrument with documented empirical and theoretical output or response characteristics.

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A calibration source or sources should provide a radiation dose rate sufficient to reach the 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 uncertainties. Calibration sources should be taken from Table 2 and shall comply with applicable standards. The uncertainty of source calibration shall be no greater than 5% with respect to national or secondary standards for photons and 10% for alpha and beta particles and neutrons.

Table 2—Reference sources for calibration

Radiation type	Reference source	Reference
Dose rate		
Gamma	$^{137}Cs^a$, $^{60}Co^a$, ^{241}Am	ISO 4037: 1979 [B8], ANSI N42.17A-1989 [B3]
X-ray	M30[a], H50[a], H100[a], H150[a], H200[a], H250[a], H300[a], M150,	NBS Spec. Pub. 250 (1989) [B14]
X-ray (K fluorescence)	16, 24, 34, 43, 58, 78, 100 keV	ISO 4037: 1979 [B8]
Neutron	$^{252}Cf^a$, ^{241}Am-Be^a $^{252}Cf+D_2O$ Moderator	ISO 8529: 1989 [B12], ANSI N42.17A-1989 [B3]
Beta	^{90}Sr-$^{90}Y^a$, $^{204}Tl^a$	ISO 6980: 1984 [B9], ANSI N42.17A-1989 [B3]
Surface contamination		
Alpha	^{241}Am, $^{230}Th^a$, $^{239}Pu^a$	ISO 8769: 1988 [B13], ANSI N42.17A-1989 [B3]
Beta	^{90}Sr-$^{90}Y^a$ ^{14}C, ^{147}Pm, ^{36}Cl $^{204}Tl^a$, ^{106}Ru-^{106}Rh, U-Nat, U-Dep ^{3}H	ISO 7503-1: 1988 [B10], ANSI N42.17A-1989 [B3] ISO 7503-2: 1988 [B11]

[a]Reference source for instrument type testing, from ANSI N42.17A-1989 [B3].

5.2 Calibration assemblies

Instrument calibration assemblies should be mechanically precise to ensure that positioning uncertainties of either instruments or radiation sources do not affect the radiation field values by more than ±2%, see [B2]. Personnel shielding, remote instrument reading and positioning facilities, automatic source-handling mechanisms, and other mechanical or remote operations are recommended.

5.3 Maintenance of standards

Calibration standards shall be maintained through an ongoing measurement quality assurance program with NIST or an appropriate secondary laboratory, see [B18] and [B21]. Laboratories may participate in a calibration accreditation program to demonstrate the competence of the calibration laboratory. Accreditation programs are run through the Conference of Radiation Control Program Directors (CRCPD), the Health Physics Society (HPS), and the National Voluntary Laboratory Accreditation Program (NVLAP), see [B18] and [B21]. Whenever possible, laboratories should derive their calibration standards from national standards maintained by the National Institute of Standards and Technology (NIST), its international equivalents, or secondary standards maintained by other accredited laboratories. Direct comparison with national or second-

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ary standards shall be undertaken when the measurement quality assurance program indicates that such actions are needed. Quality control procedures shall be in place to ensure that a working relationship is maintained between the working and derived standards at a facility.

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

a) The source/instrument geometry is well understood and easily reproduced.
b) The instrument response to this radiation is well understood and is not critically dependent on instrument adjustment (e.g., the use of a beta source to check instruments sensitive to photon radiation may be acceptable while the use of a photon source to check a detector utilizing a BF_3 tube is not acceptable). A reproducible source/detector geometry shall be established and used for all source response checks.

6. Calibration quality

6.1 Calibration sources

Sources to be used for calibrations shall comply with national/international standards. Calibration fields shall be known with an accuracy compared to secondary or national standards as noted in Table 3.

Table 3—Calibration field accuracies[a] and quantities

Radiation type	Accuracy (%)	Quantity
Gamma	5	Deep dose equivalent
X-ray	5	Deep dose equivalent
Neutron	10	Deep dose equivalent
Beta	10	Shallow dose equivalent
Alpha contamination	10	Activity/unit area
Beta contamination	10	Activity/unit area

[a]Accuracies are for dose rates greater than 100 Gy/h, 100 Sv/h, or 10^3 Bq/cm^2 (10 mrad/h or 6×10^4 dpm/100 cm^2).

Radiation fields used for calibration shall be characterized and documented in terms of quantity and reproducibility. Such considerations as charged particle equilibrium, scattered or unwanted radiations from the source, and ambient background radiation should be accounted for during standardization of the calibration assembly. Fields used for instrument calibration should be such that a uniform fluence exists throughout the entire volume of the detector. A separation between the calibration source and the detector should exceed five times the maximum dimensions of the larger of the source or the detector, see [B14].

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NOTE—The beta calibration source-to-detector distance can be reduced to two or three times the source-to-detector distance.

Instruments may be calibrated in nonuniform fields (e.g., box calibrators) by using an instrument of the same model as a transfer instrument, thus transferring the calibration from a uniform irradiation geometry (free-in-air) to the nonuniform geometry. Radiation sources and standard instruments used in calibration are discussed in Tables 2 and 3. A good review of calibration assemblies, see [B25], should be consulted by those responsible for the calibration facility and calibration of instruments.

With the exception of a calibration facility where an uncollimated source is used in a large room (i.e., free space), calibration beams shall be collimated so that their size is limited to an area consistent with calibration requirements. Constancy checks shall be performed annually as a minimum for all sources. Machine-generated beams shall employ continuous beam monitors as a working standard for calibration purposes. Continuous beam monitors shall be calibrated at least annually with secondary or tertiary standards.

The energy spectrum for all calibration sources should be known. If absorbers, collimators, or high-scatter geometries are employed, the effect on the calibration accuracy relative to a low-scatter geometry shall be known. When shutters or other source control devices are used, the effect of transit time on dose equivalent shall be known and accounted for as required.

6.2 Calibration facility

When free-in-air geometry is utilized 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. When free-in-air geometry is not practical, the distance to scattering objects from the source and from the detector should be sufficient to maintain the required accuracy in Clause 4.

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

Calibrations should be performed within the limits of standard conditions as noted in Table 1.

6.3 Other

If an instrument has a demonstrated extracameral response, the entire instrument should be placed in the radiation field during calibration. The fractional contribution, if any, to the instrument reading due to an extracameral response should be determined and noted in the calibration records.

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