NIST HANDBOOK 150-2D

National Voluntary Laboratory Accreditation Program

Calibration Laboratories

Technical Guide for Ionizing Radiation Measurements

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Preface

The Calibration Laboratories Accreditation Program was developed by the National Voluntary Laboratory Accreditation Program (NVLAP) at the National Institute of Standards and Technology (NIST) as a result of interest from private industry and at the request of the National Conference of Standards Laboratories (now the NCSL International). The goal of the program is to provide a means by which calibration laboratories can be assessed for competency. This voluntary program is not designed to serve as a means of imposing specific calibration procedures or minimum uncertainties on applicant laboratories; instead, the program allows for all scientifically valid calibration schemes and requires that laboratories derive and document their measurement uncertainties.

To accomplish this goal, NVLAP employs technical experts on a contract basis, to serve as assessors in each of the following eight fields of physical metrology calibration:

- electromagnetic dc/low frequency,
- electromagnetic rf/microwave frequency,
- time and frequency,
- ionizing radiation,
- optical radiation,
- dimensional,
- mechanical, and
- thermodynamics.

NIST Handbooks 150-2A through 150-2H are technical guides for the accreditation of calibration laboratories, with each handbook corresponding to one of the eight fields of physical metrology calibration. They are intended for information and use by:

- NVLAP technical experts in assessing laboratories,
- staff of accredited laboratories,
- those laboratories seeking accreditation,
- other laboratory accreditation systems,
- users of laboratory services, and
- others needing information on the requirements and guidelines for accreditation under the NVLAP Calibration Laboratories Accreditation Program.

NOTE The Calibration Laboratories Accreditation Program has been expanded to cover chemical calibration for the providers of proficiency testing and certifiers of spectrophotometric NTRMs. (See NIST Handbooks 150-19 and 150-21.) Other NVLAP handbooks in the chemical calibration area are expected in the future.

The assessor uses NIST Handbook 150, *NVLAP Procedures and General Requirements*, and the appropriate guides (NIST Handbooks 150-2A through 150-2H) to validate that a laboratory is capable of performing calibrations within the laboratory's stated uncertainties. These technical guides and other relevant technical information support assessors in their assessments of laboratories. Along with inspecting the facilities, documentation, equipment, and personnel, the assessor can witness a calibration, have an item recalibrated, and/or examine the results of measurement assurance programs and round-robins to collect objective evidence.

NIST Handbooks 150-2A through 150-2H supplement NIST Handbook 150, which contains Title 15 of the U.S. Code of Federal Regulations (CFR) Part 285 plus all general NVLAP procedures, criteria, and policies. The criteria in NIST Handbook 150 originally encompassed the requirements of ISO/IEC Guide 25:1990 and the relevant requirements of ISO 9002 (ANSI/ASQC Q92-1987). These handbook criteria have been updated

to incorporate the requirements of ISO/IEC 17025:1999. The entire series of Handbooks 150-2A through 150-2H comprises information specific to the Calibration Laboratories Program and neither adds to nor detracts from requirements contained in NIST Handbook 150.

Any questions or comments on this handbook should be submitted to the National Voluntary Laboratory Accreditation Program, National Institute of Standards and Technology, 100 Bureau Drive, Stop 2140, Gaithersburg, MD 20899-2140; phone (301) 975-4016; fax (301) 926-2884; e-mail NVLAP@nist.gov.

Acknowledgments

NIST Handbook 150-2 was first available as a draft covering all eight fields of physical metrology calibration in one volume. It has been separated into eight handbooks to allow easier updating and electronic downloading from the NVLAP web site. The preparation of these documents has been a joint effort, with input from representatives of other government agencies, laboratories, and the private sector. Acknowledgment of their efforts is in order; however, the listing of individual names is impractical. The submissions by individuals and companies offering suggestions for improvement to this document were also very welcome, as were the contributions of those who attended the public workshops.

We thank all the NIST measurement divisions for their work in writing or contributing to the individual handbooks. Listed below are those from the NIST measurement divisions who deserve special thanks for input to the first draft of NIST Handbook 150-2D, *Technical Guide for Ionizing Radiation Measurements*:

- Mr. Jimmy C. Humphreys (High Dose Radiation Dosimetry),
- Dr. J. M. R. Hutchinson (Radionuclide Sources), and
- Dr. Robert B. Schwartz (Neutron Dosimeter and Survey Instruments).

Also, we acknowledge and thank the entire list of contributors to NIST SP 812, *Criteria for the Operation of Federally-Owned Secondary Calibration Laboratories (Ionizing Radiation)*, October 1991.

On the second draft, we thank:

- Ms. C. Michelle O'Brien and Mr. Stephen M. Seltzer (Alpha-Particle, Beta-Particle, Gamma-Ray, and X-Ray Measurements),
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- Dr. Marc F. Desrosiers (High-Dose Radiation Dosimetry), and
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Additional thanks go to those who actively participated in the Technical Guide Workshop held November 1993 and to those who served as points of contact within fields of calibration. They include: Ms. Georgia L. Harris, Mr. Norman B. Belecki, Dr. Theodore D. Doiron, Mr. Robert M. Judish, Mr. Thomas C. Larason, Ms. Sally S. Bruce, and Dr. Donald B. Sullivan. A special thanks is owed to Mr. James L. Cigler for work in developing the content and format of this guide, and to Ms. Vanda White for her editorial expertise in making this a readable document.

Above all, we wish to thank Mr. Jon M. Crickenberger, the editor of the first three drafts of this document, for literally hundreds of hours of his work in creating this guide. It was he who tasked the contributors to produce the technical content, assembled the results of their efforts into a consistent format, and provided the general commentary. Without Jon's dedicated effort to this monumental task, this guide would never have been published.

NVLAP has edited the individual handbooks and made changes resulting from comments by individuals to earlier draft versions. This editing has been to a different extent for each parameter. Every effort was made to include all pertinent information relevant to an ISO/IEC 17025-derived technical guide.

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Summary

This guide presents the general technical requirements (i.e., on-site assessment and proficiency testing) of the laboratory accreditation program for calibration laboratories along with specific technical criteria and guidance applicable to ionizing radiation measurements. These technical guidelines are presented to indicate how the NVLAP criteria may be applied.

Any calibration laboratory (including commercial, manufacturer, university, or federal, state, or local government laboratory) engaged in calibration in ionizing radiation measurements listed in this handbook may apply for NVLAP accreditation. Accreditation will be granted to a laboratory that complies with the criteria for accreditation as defined in NIST Handbook 150. Accreditation does not guarantee laboratory performance – it is a finding of laboratory competence.

Fields of calibration covered: Specific calibration parameters and related stimulus and measurement devices in areas of ionizing radiation measurement.

Scope of accreditation:

- Calibration parameter(s), range, and uncertainty level
- Types of measuring and test equipment
- Quality assurance system for measuring and test equipment

Period of accreditation: One year, renewable annually.

On-site assessment: Visit by an assessor(s) to determine compliance with the NVLAP criteria before initial accreditation, in the first renewal year, and every two years thereafter. Preassessment and monitoring visits are conducted as required. All calibration parameters or general areas of calibration within the specific scope of accreditation requested will be assessed.

Assessors: Selected from technical experts with experience in the appropriate areas of calibration and quality systems assessment.

Proficiency testing (measurement assurance): Each laboratory is required to demonstrate its capability to successfully perform calibrations as part of on-site assessment or by documented successful completion of an approved Measurement Assurance Program (MAP) or round-robin intercomparison. Proficiency testing may be required for initial accreditation, or when other evidence of measurement assurance is not evident, and may be conducted annually thereafter. Advance notice and instructions are given before proficiency testing is scheduled.

Fees: Payments are required as listed on the NVLAP fee schedule, including the initial application fee, administrative/technical support fee, on-site assessment fee, and proficiency testing fee.

1 General information

1.1 Purpose

The purpose of this handbook is to amplify the general requirements for accreditation by NVLAP of calibration laboratories in the area of ionizing radiation measurements covered by the Calibration Laboratories Program. It complements and supplements the NVLAP programmatic procedures and general requirements found in NIST Handbook 150, *NVLAP Procedures and General Requirements*. The interpretive comments and additional guidelines contained in this handbook make the general NVLAP criteria specifically applicable to the Calibration Laboratories Program.

This handbook does not contain the general requirements for accreditation, which are listed in NIST Handbook 150, but rather provides guidelines for good calibration laboratory practices, which may be useful in achieving accreditation.

1.2 Organization of handbook

The handbook is organized in two sections. The first section provides additional explanations to the general procedures and requirements contained in NIST Handbook 150. The second section provides details and guidance specifically for ionizing radiation calibration laboratories.

1.3 Description of Calibration Laboratories Accreditation Program

On May 18, 1992, as a result of the petition and public notice process, the Director of the National Institute of Standards and Technology published in the *Federal Register* a notice of intent to develop the Calibration Laboratories Accreditation Program under the procedures of the National Voluntary Laboratory Accreditation Program . On June 2, 1994, the procedures and general requirements under which NVLAP operates, Title 15, Part 285 of the U.S. Code of Federal Regulations (CFR), were revised to:

a) expand the procedures beyond testing laboratories to include accreditation of calibration laboratories,

b) update the procedures to ensure compatibility with generally accepted conformity assurance and conformity assessment concepts,

c) incorporate international changes, especially with relevant International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) documents (e.g., ISO/IEC Guides 25 (now ISO/IEC 17025:1999), 38, 43, and 58, and the ISO 9000 series), and

d) facilitate and promote acceptance of the calibration and test results between countries to avoid barriers to trade.

Calibration laboratory accreditation is offered in eight fields of physical metrology calibration covering a wide variety of parameters and includes accreditation in multifunction measuring and test equipment calibrations. Specific requirements and criteria have been established for determining laboratory qualifications for accreditation following prescribed NVLAP procedures. The criteria address the laboratory's management organization, quality system, personnel, methods and method validation, equipment, control of environmental effects, measurement traceability, sampling methods, handling of test and calibration items, methods to assure the quality of its measurement results, reports, service to its clients, review of requests and

contracts, subcontracting, purchasing, control of nonconforming work, handling of complaints, document and record control, corrective and preventive actions, internal audits, and management reviews.

On September 18, 1992, a public workshop was held at NIST Gaithersburg and attended by a mix of private sector and government personnel. The workshop reviewed a draft handbook, which included general requirements, as well as very specific technical requirements for direct current voltage calibrations at all levels. As a result of the workshop, the draft handbook was revised to take the form of a Calibration Laboratories Program Handbook, which included the general requirements for laboratories (using ISO/IEC Guide 25 as a basis), and eight companion Technical Guides covering the specific requirements for each field of calibration offered for accreditation.

On May 18, 1993, a public workshop on the revised draft program handbook was held at NIST Boulder and attended by more than 60 industry and government personnel. Comments from this workshop, as well as responses to a survey/checklist mailing, were used to prepare the final draft of the handbook, now entitled *NVLAP Procedures and General Requirements* (NIST Handbook 150), published in March 1994. [NIST Handbook 150 was revised in 2001 to incorporate ISO/IEC 17025:1999.]

A public workshop for the Calibration Laboratories Technical Guides was held at NIST Gaithersburg, on November 22 through 24, 1993. More than 60 industry and government personnel attended and provided comments on the draft version of the Technical Guide for each of eight fields of calibration. As a result, the eight Technical Guides were incorporated into a draft Handbook 150-2, *Calibration Laboratories Technical Guide*, covering the fields being offered for accreditation. [In 2000, Handbook 150-2 (draft) was divided into eight handbooks, one for each calibration area.]

The need for technical experts to serve as assessors was advertised, and the first group of assessors was selected and trained during a four-day session held from November 16 through 19, 1993, in Gaithersburg, using materials developed by NVLAP.

The Calibration Laboratories Accreditation Program officially began accepting applications when notification was given in the *Federal Register* dated May 11, 1994. Applications are accepted and processed following procedures found in NIST Handbook 150.

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NVLAP Web site: http://www.nist.gov/nvlap

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Phone: (303) 440-3339; Fax: (303) 440-3384; E-mail: info@ncsli.org
NCSLI web site: http://www.ncsli.org

[2]ISO and ANSI documents are available from:
Global Engineering Documents (paper copies): Order phone (800) 854-7179
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1.5 Definitions

Definitions found in NIST Handbook 150 apply, but may be interpreted differently or stated differently, when necessary to amplify or clarify the meaning of specific words or phrases as they apply to specific technical criteria.

1.5.1 Absorbed dose: The quantity of main interest to the clinician for both beta and gamma sources. It is the quotient of dE by dm, that is, the differential energy absorbed in the differential mass in the medium. The unit of absorbed dose is the **gray (Gy)**, which is 1 joule per kilogram.

1.5.2 Accuracy goals: The maximum acceptable deviation from the accepted reference value of a measured quantity, where the accepted reference value is defined by the appropriate national standard.

1.5.3 Air kerma: The quotient of dE_{tr} by dm, where dE_{tr} is the sum of the initial kinetic energies of all electrons liberated by photons in a volume element of air and dm is the mass of air in that volume element. **Kerma** is the acronym for Kinetic Energy Released per unit Mass. The SI unit of air kerma is the **gray (Gy)**.

1.5.4 Air kerma strength: The quantity used to specify the strength of a gamma-ray emitting radionuclide. It is a measure of the energy released in a volume of air at some distance from a radioactive source. For photon emitting sources used in brachytherapy it has units of Gy $s^{-1}m^2$.

1.5.5 Attenuator: Absorbing material intentionally placed in the path of a radiation field or beam to reduce the intensity reaching the detector.

1.5.6 Beam quality: Used to refer to a specific x-ray beam with a characteristic half-value layer and produced by a constant potential kilovoltage. For example, the beam quality is often given in terms of the thickness of aluminum or copper required to reduce the air kerma rate to 50 % (half-value layer HVL) and to 25 % of its original value.

1.5.7 Calibration: The process whereby the response of a dosimeter or measuring instrument is characterized through comparison with an appropriate standard that is traceable to, and consistent with, a national standard.

1.5.8 Calibration coefficient: Term used when the calibration or correction has a dimension (such as Gy). See also **calibration factor**.

1.5.9 Calibration factor: Term used when the calibration or correction has no dimensions (such as (true rads)/(calculated rads)). See also **calibration coefficient**.

1.5.10 Check standard: A standard that is used routinely to calibrate or check material measures, measuring instruments or reference materials. A check standard is usually calibrated against a reference standard. A check standard is also known as a **working standard**.

1.5.11 Collimator: A device used to limit the size, shape, and direction of a radiation beam.

1.5.12 Depth dose: The relationship between the absorbed dose and depth in tissue. For example, one can define a reference depth in terms of the absorbed dose at 1 cm tissue depth for photons or 2 mm tissue depth for beta particles.

1.5.13 Dosimetry system: A system used for determining absorbed dose, consisting of dosimeters,* measurement instruments and their associated reference standards, and operating procedures.

* The types of dosimeters include reference standard dosimeters, transfer standard dosimeters, and routine dosimeters. See ASTM E 1261 for guidance on the selection and calibration of the various dosimetry systems for irradiating materials. See ANSI N13.11-2001 for personnel dosimetry systems.

1.5.14 Effective energy, E_{eff} (of radiation comprised of x rays with a range of energies): Energy of the monoenergetic x-rays which have the same **half-value layer** (see 1.5.19 below) as the spectrum in question.

1.5.15 Exposure: The quotient of dQ by dm, where dQ is the sum of the electrical charges on all the ions of one sign produced in air when all the electrons are completely stopped in air. The SI unit of exposures is

the coulomb per kilogram (C/kg); the special unit of exposure, the roentgen (R), is equal to exactly 2.58E-4 C/kg.

1.5.16 Extrapolation chamber: An ionization chamber in which the separation of electrodes is variable, thereby enabling a series of measurements with decreasing separation so that the measured ion current per unit volume can be extrapolated to the case of infinitesimal volume. An extrapolation chamber is a primary standard chamber used at the NIST to establish the surface absorbed dose rate for beta particle emitting sources.

1.5.17 Free-air facility: A calibration facility in which the radiation emitted by the source reaches the instrument under calibration with minimal scatter from nearby structures.

1.5.18 Free-field quantity: A radiation quantity, such as neutron dose equivalent, that has been corrected to remove contributions from scattered radiation (e.g., air scattering and room return).

1.5.19 Half-value layer (air kerma) (HVL): The thickness of a specified substance which, when introduced into the path of a given beam of radiation, attenuates the beam of radiation to an extent such that the air-kerma rate is reduced to half of its original value.

In this definition, the contribution of all scattered radiation, other than that which might be present initially in the beam concerned, is deemed to be excluded in determining the HVL.

1.5.20 Homogeneity coefficient (*h*): The ratio of the first half-value layer to the second half-value layer (air kerma).

1.5.21 In-air ionization chamber: A chamber that is open to the atmosphere, therefore requiring humidity, pressure, and temperature corrections. It is widely used for high activity sources, such as high-dose-rate iridium-192 sources.

1.5.22 Ionization chamber: Gas-filled enclosure in which ion pairs created by incident radiation are collected on electrodes.

1.5.23 Leakage radiation: Radiation other than the useful beam emitted from an x-ray tube housing or a source container.

1.5.24 Mean energy (mean photon energy), $\bar{E}$: Ratio defined by the formula:

$$\overline{E} = \frac{\int_0^{E_{\max}} \phi_E \, E dE}{\int_0^{E_{\max}} \phi_E \, dE}$$

where φ_E is the derivative of the fluence φ of the primary photons of energy E with respect to E, and defined as

$$\phi_E = \frac{d\phi(E)}{dE}$$

1.5.25 Monitor: Instrument used to monitor the stability of the air-kerma rate during irradiation or to compare values of air kerma after successive irradiations**.**

1.5.26 Phantom: The material used for the absorbing medium in the experimental dose measurement. Several different phantom materials are used, including **water phantoms** and those fabricated from plastics (e.g., A-150 plastic, tissure-equivalent plastic, and solid water).

1.5.27 Point source: A radiation source whose maximum dimension is small compared with the source-to-detector distance used for irradiation of a dosimeter or instrument.

1.5.28 Proficiency testing: Determination of laboratory performance by means of comparing and evaluating calibrations or tests on the same or similar items or materials by two or more laboratories in accordance with predetermined conditions. For the NVLAP Calibration Laboratories Accreditation Program, this entails using a transport standard as a measurement artifact, sending it to applicant laboratories to be measured, and then comparing the applicant's results to those of a reference laboratory on the same artifact.

1.5.29 Primary radiation (or beam): Radiation or beam emitted by the x-ray tube.

1.5.30 Primary standard dosimeter: Dosimeter of the highest metrological quality, established and maintained as an absorbed dose standard by a national or international standards organization.

1.5.31 Quarter-value layer (QVL): The thickness of the specified material added as a beam attenuator that reduces the air kerma rate to one quarter of the unattenuated beam air kerma rate value.

1.5.32 Radiation processing: The intentional irradiation of products or materials to preserve, modify, or improve their characteristics.

1.5.33 Radiation quality: The quality of a filtered x radiation is characterized by the following parameters:

- mean energy, $\bar{E}$, of a beam, expressed in kiloelectronvolts (keV),
- resolution, R_E, expressed in percent (%),
- half-value layer (air kerma), HVL, expressed in mm of Al or Cu, and
- homogeneity coefficient, h.

1.5.34 Radioactivity: The phenomenon of emissions of neutral or charged particles or electromagnetic radiations from unstable atomic nuclei (radionuclides). Radioactivity is an amount of a radionuclide in a particular energy state at a given time. Mathematically, it is defined as the quotient of dN by dt, where dN is the number of spontaneous nuclear transformations from that energy state in the time interval dt.

The unit of activity in SI units is the **becquerel (Bq)**, which is equal to the unit reciprocal second (s^{-1}). In many fields, the older unit, the **curie (Ci)**, is still in use, where 1 Ci = 3.7×10^{10} Bq (exactly).

The activity of an amount of radionuclide is given by the product of the decay constant, λ, and the number of nuclei present at time t, thus $A = \lambda N$.

The half life, $T_{1/2}$, is the time necessary for one half of the nuclei to decay. The activity at any time t can be computed using the initial activity A_0 and the decay time t according to $A = A_0 \exp(-(\ln 2)\, t/T_{1/2})$.

1.5.35 Reference standard dosimeter: A dosimeter, of high metrological quality, used as a standard to provide measurements traceable to, and consistent with, measurements made using primary standard dosimeters.

1.5.36 Residual maximum beta energy, E_{res}: The maximum energy of the beta spectrum from all beta decay branches of a radionuclide at the calibration distance.

1.5.37 Residual maximum beta range, R_{res}: The range in an absorbing material of a beta spectrum of residual maximum energy, E_{res}.

1.5.38 Resolution (spectral resolution, R_E) (full width at half maximum): Ratio, expressed as a percentage, defined by the formula:

$$R_E = \frac{\Delta E}{E} \times 100$$

where increment $\triangle E$ is the spectrum width corresponding to half the maximum ordinate of the spectrum.

In the case where fluorescence radiation is present in the spectrum, the spectrum width measured is based upon the continuum only.

1.5.39 Ripple: The periodic variation in the potential difference between the cathode and anode of an x-ray tube, resulting from rectification of an alternating current. As the ripple is decreased by the use of filtering circuits, a constant potential is more nearly approached. See also **value of peak-to-peak voltage**.

1.5.40 Room-scattered radiation: Radiation that is scattered from the walls, floor, ceiling, or other structural part of the radiation room.

1.5.41 Routine dosimeter: Dosimeter calibrated against a primary-, reference-, or transfer-standard dosimeter and used for routine absorbed dose measurement.

1.5.42 Scattered radiation: Radiation that, as the result of interaction with matter, has had its direction changed and, for some interactions, its energy changed.

1.5.43 Second half-value layer: The difference between the quarter value layer and the half-value layer.

1.5.44 Secondary (fluorescence) radiation: Radiation or beam emitted by a medium that is excited by the primary radiation and subsequently de-excites.

1.5.45 Slab source: A radiation source whose maximum dimension is large compared with the source-to-detector distance used for irradiation of a dosimeter or instrument.

1.5.46 Survey instrument: A hand-held instrument used to measure ionizing radiation for purposes of radiation protection. It does not include instruments designed as area, portal, or personnel monitors, as monitors of radioactive gases or airborne particulates, or as dose or beam calibrators for medical diagnostic or therapeutic applications.

1.5.47 Thermoluminescent dosimeter (TLD): Devices based on materials which store a fraction of the energy deposited by an external source. The stored energy may be released by heating the TLD with a thermal source or a laser.

1.5.48 Thin source: A radiation source consisting of radioactive material uniformly distributed in a thin layer over the surface of a flat metallic backing plate so as to cause minimal degradation of the energy spectrum.

1.5.49 Traceability: Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties. [VIM:1993, 6.10 – reference 1.4.1 e)]

A single measurement intercomparison is sufficient to establish uncertainty relationships only over a limited time interval (see Ehrlich and Raspberry, 1998); internal measurement assurance (see Croarkin, 1985), using control (check) standards, is required to fully demonstrate that uncertainties remain within stated levels over time. For the purposes of demonstrating traceability for NVLAP accreditation, a laboratory must demonstrate not only that there is an unbroken chain of comparisons to national standards, but also that this chain is supported by appropriate uncertainties, measurement assurance processes, continuous standard maintenance, proper calibration procedures, and proper handling of standards. In this way, traceability is related to these other areas of calibration.

1.5.50 Transfer standard dosimeter: A dosimeter, often a reference standard dosimeter, suitable for transport between different locations for use as an intermediary to compare absorbed dose measurements.

1.5.51 Transmission chamber: A thin-walled ionization chamber designed to monitor a radiation beam that is transmitted through the chamber with minimal attenuation or scatter.

1.5.52 Value of peak-to-peak voltage: Ratio, expressed as a percentage, defined for a given current by the formula:

$$\frac{U_{\max} - U_{\min}}{U_{\max}} \times 100$$

where U_{max} is the maximum value and U_{min} the minimum value between which the voltage oscillates. See also **ripple**.

1.5.53 Well ionization chamber: A sealed, pressurized ionization chamber (also called a dose calibrator) intended for use in assaying brachytherapy sources. Its response must be determined for each source type and will in general depend on the particular source jig and catheter used for the measurement.

1.5.54 Working standard: A standard that is used routinely to calibrate or check material measures, measuring instruments, or reference materials. A working standard is usually calibrated against a reference standard. This is also known as a **check standard**.

1.5.55 X-ray tube: Vacuum tube designed to produce x-rays by bombardment of the anode by a beam of electrons accelerated through a potential difference.

1.5.56 X-ray tube shielding: Fixed or mobile panel intended to reduce the contribution of scatter x-radiation to the primary or fluorescence (secondary) beam.

1.5.57 X-ray unit: Assembly comprising a high-voltage supply, an x-ray tube with its protective hosing and high-voltage electrical connections, and an x-ray controller.

1.6 NVLAP documentation

1.6.1 Accreditation documents

Laboratories granted NVLAP accreditation are provided with two documents: Scope of Accreditation and Certificate of Accreditation. The Scope of Accreditation lists the "Best Uncertainty" that an accredited laboratory can provide for a given range or nominal value within a given parameter of measurement. This "Best Uncertainty" is a statement of the smallest uncertainty that a laboratory has been assessed as capable of providing for that particular range or nominal value. The actual reported value of uncertainty for any particular measurement service that the accredited laboratory provides under its scope may vary depending on such contributors as the statistics of the test and uncertainties associated with the device under test.

1.6.2 Fields of calibration and parameters selection list

The Calibration Laboratories program encompasses eight fields of physical metrology calibration, with multiple parameters under each field. Each field is covered by a separate handbook (NIST Handbooks 150 -2A through 150-2H). (Fields of accreditation under Chemical Calibration are covered by separate handbooks.) Depending on the extent of its calibration capabilities, a laboratory may seek accreditation to all or only selected fields and parameters within the scope of the program. The fields of calibration and their related parameters are given on the Fields of Calibration and Parameters Selection List, which is provided to an applicant laboratory as part of the NVLAP application package for the program. Additional fields of calibration and/or parameters may be added to the Calibration Laboratories program upon requests of applicant laboratories and/or if decided by NVLAP to be in the best interest of the Calibration Laboratories Program.

The laboratory is requested to indicate on the Fields of Calibration/Parameters Selection List the parameter(s) for which accreditation is desired, along with appropriate ranges and uncertainties. There is also provision for an applicant laboratory to request accreditation for parameters not currently listed on the Selection List, or for accreditation of the quality system employed for assuring Measurement and Test Equipment (M & TE) used in support of product certification. Request for accreditation of quality assurance systems for M & TE will be treated as a separate field of calibration for the purpose of setting appropriate fees. Once a laboratory meets all the requirements for accreditation for the Fields of Calibration/Parameters Selection List, this information will become the basis for the Scope of Accreditation document.

1.6.3 Checklists

Checklists enable assessors to document the assessment of the laboratory against the NVLAP requirements found in NIST Handbook 150. The NVLAP Calibration Laboratories Accreditation Program incorporates the NVLAP General Operations Checklist. The questions are applicable to evaluating a laboratory's ability to operate a calibration program, and address factors such as the laboratory's organization, management, and quality system in addition to its calibration competency.

The NVLAP General Operations Checklist is numbered to correspond to the requirements in NIST Handbook 150. Comment sheets are used by the assessor to explain deficiencies noted on the checklist. Additionally, the assessor may use the sheets to make comments on aspects of the laboratory's performance other than deficiencies.

1.7 Assessing and evaluating a laboratory

1.7.1 On-site assessment

1.7.1.1 The NVLAP lead assessor will schedule with the laboratory the date for on-site evaluation, and will request the quality manual and documented quality and calibration procedures in advance of the visit to reduce time spent at the laboratory; such materials will be returned by the assessor. NVLAP and the assessor will protect the confidentiality of the materials and information provided. The laboratory should be prepared to conduct routine calibrations, have equipment in good working order, and be ready for examination according to the guidance contained in this handbook, the requirements identified in NIST Handbook 150, and the laboratory's quality manual. The assessor will need time and work space to complete assessment documentation while at the laboratory, and will discuss these needs at the opening meeting of the on-site assessment.

1.7.1.2 NVLAP technical assessors are provided with the NVLAP General Operations Checklist to help ensure the completeness, objectivity, and uniformity of the on-site assessment.

1.7.1.3 When accreditation has been requested for a considerable number of fields of calibration and parameters, the assessment may range from observing calibrations in progress, requiring repeat measurements on completed calibrations, to listening to laboratory staff describe the calibration process. The depth into which the assessor performs the assessment depends on the number of fields of calibration and associated parameters for which accreditation is requested and the time required to perform a given calibration.

1.7.1.4 The assessor, or the assessment team, does the following during a typical on-site assessment:

a) Conducts an entry briefing with the laboratory manager to explain the purpose of the on-site visit and to discuss the schedule for the day(s). At the discretion of the laboratory manager, other staff may attend the briefing.

b) Reviews quality system manual, equipment and maintenance records, record-keeping procedures, laboratory calibration reports, and personnel competency records. At least one laboratory staff member must be available to answer questions; however, the assessor may wish to review the documents alone. The assessor(s) does not usually ask to take any laboratory documents with him/her, and previously supplied documents will be returned.

c) Physically examines equipment and facilities, observes the demonstration of selected procedures by appropriate personnel assigned to perform calibrations, and interviews the personnel. The demonstrations must include preparation for calibration of devices, and the setup and use of measuring and test equipment, standards and systems.

d) Holds an exit briefing with the laboratory manager and staff to discuss the assessment findings. Deficiencies are discussed and resolutions may be mutually agreed upon. Items that must be addressed before accreditation can be granted are emphasized, and outstanding deficiencies require response to NVLAP within 30 days. Items that have been corrected during the on-site and any recommendations are specially noted.

e) Completes an On-site Assessment Report, as part of the exit briefing, summarizing the findings. The assessor(s) attaches copies of the completed checklists to this report during the exit briefing. The report is signed by the lead assessor and the laboratory's Authorized Representative to acknowledge the discussion. This signature does not necessarily indicate agreement; challenge(s) may be made through NVLAP. A copy is given to the representative for retention. All observations made by the NVLAP assessor are held in the strictest confidence allowed by applicable laws and regulations.

1.7.2 Proficiency testing

1.7.2.1 Background

Once the quality system review and on-site assessment steps have been satisfactorily completed, it is necessary to gather another set of data points to aid in deciding whether or not the applicant laboratory is competent to perform calibrations within the fields of interest to the uncertainties claimed. In the eight fields of calibration covered by Handbooks 150-2A through 150-2H, there are approximately 85 parameters of interest. Under most parameters there are several subsets, referred to as ranges. For example, in the mass field, parameters can range from 1 mg (10^{-6} kg) to 1 x 10^{6} kg level in value. In view of the many possible ranges, proficiency testing could be conducted in hundreds of areas. NVLAP reserves the right to test by sampling in any area; hence, applicant laboratories must be prepared, with reasonable notice, to demonstrate proficiency in any of a number of parameters.

1.7.2.2 Proficiency testing vs. measurement assurance

There is an important difference between proficiency testing and measurement assurance. The objective of proficiency testing is to determine through a measurement process that the laboratory's measurement results compare favorably with the measurement results of the audit laboratory (NIST or one designated by NVLAP), taking into account the relative uncertainties assigned by both the applicant and audit laboratories. The objective of proficiency testing is not to determine and certify the total uncertainty of the applicant laboratory, as is done in a Measurement Assurance Program (MAP) with NIST, but to verify (through the assessment process) that the uncertainty claimed by the applicant laboratory is reasonable, and then use the claimed uncertainty to test that the measurement result obtained through the proficiency test is acceptable.

It is neither the intention nor the mission of NVLAP to conduct MAPs or to otherwise provide traceability for laboratories. Laboratories obtain these services from the NIST measurement divisions. NVLAP assesses the implementation, application, and documentation of MAPs by laboratories. NVLAP accreditation encourages the use of MAPs by the calibration laboratory community, and MAP results produce objective evidence that NVLAP assessors look for as part of the assessment process.

1.7.2.3 Requirements

NVLAP's proficiency testing program uses a sampling approach. All applicant laboratories are required to complete an annual proficiency test in one parameter under each field of calibration for which it has applied to be accredited. For the purposes of the NVLAP Calibration Laboratories Accreditation Program, the results of the proficiency test are considered as objective evidence, along with the on-site visit, of a laboratory's ability to perform competent calibrations. Proficiency testing is conducted annually using different parameters in each field; however, those laboratories accredited in only one parameter within a field are retested in the same parameter.

1.7.2.4 Uncertainty determination

The applicant laboratory is required to perform a measurement or series of measurements on an artifact using the same calibration method, apparatus, and personnel that it uses to calibrate its customers' equipment. The laboratory must be able to identify and quantify all sources of uncertainty that affect the measurement. The laboratory should attach an overall uncertainty to the measurement by combining all uncertainty contributions, in their type A and type B components, in the root-sum-squared method as described in NIST Technical Note 1297 (Taylor, 1994). The confidence limit used should be k = 2, which is equivalent to a 95 % confidence probability.

1.7.2.5 Pass/fail criteria

The performance of the proficiency test is judged by calculating the error of the measurement, normalized with respect to the uncertainty of the measurement, using the following equation:

$$E_{normal} = \left| (Value_{lab} - Value_{ref}) / (Uncertainty_{ref}^2 + Uncertainty_{lab}^2)^{½} \right|$$

where

E_{normal} = normalized error of the applicant laboratory
$Value_{lab}$ = the value as measured by the applicant laboratory
$Value_{ref}$ = the value as measured by the reference laboratory
$Uncertainty_{ref}$ = the uncertainty of the reference laboratory
$Uncertainty_{lab}$ = the uncertainty of the applicant laboratory

To pass the proficiency test, the applicant laboratory must have a value for E_{normal} less than 1 (i.e., $E_{normal} < 1$). The results may be plotted graphically (E_{normal} vs. laboratory). The anonymity of each applicant laboratory will always be preserved.

1.7.2.6 Scheduling and handling

Proficiency testing is scheduled by NVLAP-designated reference laboratories. These sites are NIST laboratories or NVLAP-accredited laboratories that have been found to have the ability to perform the required proficiency tests to an uncertainty level appropriate for the laboratories they evaluate. The proficiency test is scheduled independently and not coincident with the on-site visit. Applicant laboratories are notified in advance of the approximate arrival time of the measurement artifact. Instructions for performing the test, reporting the results, communicating with the reference laboratory, and shipping are included along with the artifact as part of the proficiency test package. Applicant laboratories are instructed to perform all required measurements within a reasonable time and are told where to ship the artifacts once the testing has been completed.

1.7.2.7 Notification of results

NVLAP notifies each laboratory of its own results in a proficiency test. If a laboratory has received its on-site assessment prior to the completion of the proficiency test, the status of that laboratory's accreditation is contingent upon successful completion of proficiency testing. The laboratory's accreditation status may be changed to reflect a partial accreditation, or may be completely suspended pending demonstration of the laboratory's ability to successfully complete the proficiency test at a later date.

1.7.3 Traceability

1.7.3.1 Establishing traceability

Laboratories must establish an unbroken chain of comparisons leading to the appropriate international or national standard, such that the uncertainties of the comparisons support the level of uncertainty that the laboratory gives to its customers. Generally speaking, the uncertainties of the comparisons increase as they move from a higher (international or national level) to a lower level standard. This uncertainty chain is the evidence of traceability and must be documented accordingly. Traceability does not simply mean having standards calibrated at the national laboratory, but must consider how a measurement, with its corresponding uncertainty, is transferred from the national level to the calibration laboratory's customers.

1.7.3.2 Considerations in determining traceability

Without some type of measurement assurance process, one cannot be reasonably certain that the measurement results have been transferred properly to the laboratory's customers' standards. The measurement process itself must be verified to be in control over time. Therefore, traceability is not a static concept that, once established, may be ignored; it is dynamic. Process control exercised in each calibration provides the assurance that a valid transfer of the international or national standard has taken place. This assurance may be accomplished through the use of tools such as check standards and control charts. Also, the laboratory's primary standards must be maintained in such a way as to verify their integrity. Examples of this may be having more than one primary standard to use for intercomparisons, monitoring the primary standard with a check or working standard (looking for changes), and verifying a primary standard on a well-characterized measurement/calibration system. Using scientifically sound measurement procedures to transfer the primary standard value to the working level and the customer's item is essential to establishing traceability. If the procedure itself yields the wrong result, there is no way the laboratory can perform a calibration traceable to the international or national standard. Mishandling the laboratory's standards affects the measurement process, and therefore the ability to transfer the standard's value to the customer. Examples of handling problems are dirty or improperly cleaned standards, maintaining standards in an improper environment, not maintaining custody and security, and improper handling of standards during the measurement process.

The above discussion illustrates how traceability is dependent on many aspects of the measurement process and therefore must be considered in all phases of calibration. It is not just coincidental that the factors addressed above are main topics of concern in ISO/IEC 17025:1999.

1.7.4 Uncertainty

NVLAP recognizes the methodology for determining uncertainty as described in the *Guide to the Expression of Uncertainty in Measurement*, published by ISO [GUM, reference 1.4.1 d)]. To be NVLAP-accredited, a laboratory must document the derivation of the uncertainties that it reports to its customers. These uncertainties will appear on the scope issued to each accredited laboratory to an accuracy appropriate to the standards, procedures, and measuring devices used.

2 Criteria for accreditation

2.1 Introduction

2.1.1 Applicant laboratories are assessed using the requirements in NIST Handbook 150, *NVLAP Procedures and General Requirements*. This guide, NIST Handbook 150-2D, was developed from a NIST measurement laboratory perspective and provides examples and guidelines, not requirements, to assessors and interested calibration laboratories, on good laboratory practices and recommended standards. Therefore, the guide language reflects this philosophy through the use of "shoulds" instead of "shalls" (along with other less prescriptive language) when describing criteria. The guidelines presented here are not absolute since specific requirements depend on the measurement uncertainty for which an applicant laboratory wishes to be accredited. This is a business decision for each laboratory and beyond the scope of NVLAP. Simply stated, to be accredited, an applicant laboratory must have a quality system and be able to prove (and document) that it is capable of doing what it says it does (i.e., correctly calibrate to a stated uncertainty) within the framework of NIST Handbook 150. Accreditation will be granted, and therefore may be referenced in calibration reports, etc., only for those specific parameters, ranges and uncertainties using calibration methods and procedures for which a laboratory has been evaluated. Calibrations performed by a laboratory using methods and procedures not considered appropriate for the level of measurements being made, and those that have not been evaluated by the accreditation process, are outside the scope of accreditation and may not be referenced as "accredited" calibrations on calibration reports and other documents.

2.1.2 The rest of the handbook is divided into two parts. The first part, section 2.2, provides a general interpretation of NIST Handbook 150 criteria for ionizing radiation calibrations. The second part, sections 2.3 through 2.18, discusses specific calibrations parameters and lists important technical guidelines to satisfy the requirements of NIST Handbook 150.

2.1.3 Sections 2.3 through 2.18 were patterned after NIST Special Publication 812: *Criteria for the Operation of Federally-Owned Secondary Calibration Laboratories*, 1991, with appropriate updating in 2003 to recognize the technical evolution in these fields and to acknowledge the requirements now addressed by ISO/IEC 17025 that had not been made explicit in earlier requirements.

2.1.4 This document contains the criteria for accreditation of laboratories that calibrate ionizing radiation instrumentation. Adherence to these criteria will indicate that the laboratory is capable of high standards of performance in the calibration of instrumentation for use in various radiation environments.

2.2 General criteria for ionizing radiation calibrations

2.2.1 Units

2.2.1.1 Both SI Units and special units in use temporarily, as recognized in NIST Special Publication 330 (Taylor, 2001), are acceptable. Included in those two categories are the following units used in this handbook.

Quantity	SI units	Special Unit Name	Special Symbol	Conversion from SI units
energy	joule (J)	electronvolt	eV	1.602×10^{-19} J = 1 eV
air kerma[3] and absorbed dose	gray (Gy)	rad (radiation absorbed dose)	rad	1 J/kg = 1 Gy = m^2 s^{-2} 10^{-2} Gy = 1 rad
dose equivalent	sievert (Sv)	rem (Roentgen equivalent man)	rem	10^{-2} Sv = m^2 s^{-2} = 1 rem
exposure[3]	coulomb/kilogram (C/kg)	roentgen	R	2.58×10^{-4} C/kg = 1 R
activity	becquerel (Bq)	curie	Ci	3.7×10^{10} Bq = s^{-1} = 1 Ci

2.2.1.2 This document will show the special units in parentheses wherever feasible. **The SI units indicated above will be shown for the quantities of absorbed dose and dose equivalent.**

2.2.1.3 The quantity of exposure is being phased out; therefore, the SI unit coulomb/kilogram will not be shown in this document. It has no special name and it is inconvenient (especially for exposure rate). The quantity of exposure has been replaced with the quantity of air kerma, which has the SI unit joule/kilogram (J/kg) with the special name gray (Gy): 1 Gy = 1 J/kg.

2.2.1.4 Although the factor used for conversion from exposure in R to air kerma in Gy depends slightly on photon energy, that variation is insignificant for the purposes of this document and a single value will be used:

a) air kerma (Gy) = 0.00878 × exposure (R)

b) When a rounded value of the SI value of air kerma is given, the exposure in R will be rounded also (e.g., 90 μGy/h ≈ 10 mR/h).

2.2.2 Scope

The criteria contained in the General Criteria section of this document should be satisfied by all laboratories seeking accreditation. In addition, each laboratory should satisfy the specific criteria contained in other parts of this document for each category (radiation type and energy) for which accreditation is desired.

2.2.3 Personnel

2.2.3.1 The technical director of the laboratory should have a minimum of a bachelor's degree in physics, engineering, health physics, or radiological physics, and should have a graduate degree in one of these or a closely related scientific field.

2.2.3.2 The individual in charge of day-to-day operation of the laboratory should have at least three years of practical experience in radiation measurement, including the calibration of radiation instrumentation.

2.2.3.3 All handling, unpacking, and packing of dosimeters, instruments, and reference standards should be done by trained staff who are familiar with the equipment.

[3]See 2.2.1.3 and 2.2.1.4.

2.2.4 Assuring the quality of test and calibration results

2.2.4.1 The laboratory should be capable of providing calibration services with uncertainties as indicated in the appropriate parts of this document. Each uncertainty should be stated in terms of % deviation from the national standard.

2.2.4.2 Any new or amended calibration procedure that could have a significant effect on the accuracy of a calibration should be evaluated by the accrediting body before it is adopted for routine use. A copy of the latest revision of the laboratory's protocol should be available for audit at all times.

2.2.5 Accommodation and environmental conditions

2.2.5.1 The effect of external conditions on the internal environment of the laboratory should be considered in selection of the laboratory site. The laboratory should be located away from, or otherwise isolated from,

- sources of mechanical vibration and shock,
- sources of electrical and electromagnetic interference, and
- other potential sources of interference with the proper calibration of instrumentation.

If such potential sources exist, the laboratory should have documentation that demonstrates no adverse effects on calibration accuracy.

2.2.5.2 Environmental monitoring equipment should be provided for indicating the temperature, atmospheric pressure, and humidity within the laboratory at all times.

2.2.5.3 In general, strict temperature control is not essential for the calibration work covered by these criteria. It is, however, desirable that the laboratory be kept at a reasonably uniform temperature so that calibration accuracy is not adversely affected and to ensure that an adequate level of temperature stability is reached before the start of calibration measurements. The laboratory temperature should be maintained nominally within the range of 293.15 K to 297.15 K (20 to 24) °C. When using a vented ionization chamber, the temperature should not vary more than ± 2 K in any one hour during which a calibration is conducted.

2.2.5.4 The relative humidity should be within the range of 15 % to 65 % for routine laboratory operation.

2.2.5.5 The laboratory should approximate free-air conditions for all radiation beams used for calibrations.

2.2.5.6 The radiation room (or rooms) should be of sufficient size and design that room-scattered radiation at the position where instrumentation is normally placed for calibration does not introduce an error inconsistent with overall accuracy goals. If necessary, proper scatter corrections should be applied.

2.2.5.7 The level of background radiation should be kept as low as practicable and not subject to variations that could significantly affect the accuracy of calibration work. Radiation sources should not be stored in the same room in which they are used for calibration.

2.2.5.8 In uncollimated free-air calibration facilities, the radiation room should be used exclusively for calibrations to avoid variable scatter conditions. The contribution to absorbed dose by scattered radiation should be known.

2.2.5.9 The electrical power should be appropriate to the equipment used, suitably stable, and free of switching surges and significant line noise. When necessary, local auxiliary voltage stabilizers and filters should be provided.

2.2.5.10 The laboratory should be provided with an adequate grounding system. Where there is a likelihood of interference arising from equipment connected to a single grounding system, separate grounding systems should be provided and adequate precautions taken against any possible interconnection between systems.

2.2.5.11 If compressed air is used, a pressure regulator and means for removing moisture, dust, and oil from the compressed air also should be provided.

2.2.6 Equipment

2.2.6.1 The laboratory should have secondary radiation measurement standards that cover the range of calibrations performed. The secondary standards should be used only for calibration of instruments and not for any other purpose. A working standard should be used in lieu of a secondary standard for routine reference.

2.2.6.2 The laboratory should have a barometer capable of 1 % accuracy and a thermometer capable of ± 1 K accuracy. Each should have been calibrated by comparison with a tertiary or higher-level standard. A hygrometer capable of monitoring over the range of relative humidity within which the laboratory operates should be available.

2.2.6.3 The laboratory should have an instrument and radiation source positioning system. The support should be rigid and enable the reproduction of a desired source/detector geometry. It should produce minimum scattered radiation.

2.2.7 Test and calibration methods and method validation

The laboratory's written protocol should include the following:

a) A statement of policy regarding acceptance of instrumentation for calibration. Examples are policy regarding instruments that are contaminated, in need of repair, or of a particular type not accepted. Restrictions on type of customer or liability for instrument damage should also be stated.

b) A fully documented procedure for each type of instrumentation calibrated providing the appropriate operational steps to permit a knowledgeable person to reproduce a particular calibration technique with a precision consistent with the accuracy goals of the laboratory. Each calibration procedure should give the following information, as a minimum:

   1) a concise but complete account of the procedure,

   2) the scope and limitations of the procedure,

   3) any environmental constraints that should be met in calibrating the instrumentation, in addition to those stated in 2.2.5,

   4) the sequence of the calibration procedure, drawing attention to special precautions,

   5) the equipment and standards to be used in this calibration procedure,

6) an example of a completed data sheet (or computer record) for the calibrated instrumentation,

7) the method of data handling and reduction,

8) an assessment of the uncertainty associated with each calibration procedure,

9) an example of a completed calibration report, including a statement of the accuracy to which the reference value of the radiation field is known,

10) the procedure or reference for auditing calibration data and approving reports,

11) the procedure to ensure the security of calibration records.

2.2.8 Records

2.2.8.1 In addition to specific and implied requirements in ISO/IEC 17025, the laboratory's record system should include a bound day-book, or other equivalent record, in which is recorded a description, sufficient for identification, of every item of instrumentation for which a calibration service was provided and the date that the calibration was performed.

2.2.8.2 Records for all individual items of instrumentation calibrated should be maintained for a period of at least five years. Records regarding calibration of standards used should be maintained for a period of at least 50 years.

2.2.9 Reporting the results

2.2.9.1 A calibration report should be issued for each item of instrumentation calibrated under the scope of accreditation, including an appropriate statement clearly specifying the conditions (e.g., type of radiation, the dose rate(s), temperature, the electron energy for electron beams, pulse width, dose rate within the pulse, repetition rate. orientation of the detector, etc.) under which the calibration was performed. It should also state limitations to the calibration, i.e., maximum range calibrated if less than the indicated range of an instrument, scales not calibrated, application of calibration factors, etc.

2.2.9.2 Certificates or reports should state that application of the calibration results to an individual measurement is the responsibility of the user, and that care must be exercised in interpolation of the calibration results.

2.2.9.3 If the laboratory discovers a mistake in a calibration report that significantly affects the accuracy of the calibration, the person or institution that received the report should be notified within 24 h, if possible, and a written report of the mistake sent to that person or institution within 72 h. The mistake should be corrected as soon as possible by sending a corrected calibration report or recalibrating the instrumentation. The laboratory should determine the reason for the mistake and take corrective action to prevent its recurrence.

2.2.9.4 If the laboratory discovers an apparent generic error in one of its procedures or in the design of an item of instrumentation that has or could lead to an erroneous calibration, it should notify not only its clients but also the accrediting body in writing within 10 days. Other accredited laboratories may then be notified of the problem, along with recommendations for remedial action.

2.3 Alpha-particle calibration of survey instruments

2.3.1 Scope

The criteria contained in this part apply to the calibration of survey instruments at radiation protection levels using alpha radiation sources. These criteria are supplementary to the general criteria contained in 2.2. Both the general criteria and these specific criteria should be followed if this alpha-particle calibration service is offered and its inclusion in the Scope of Accreditation is desired.

2.3.2 Equipment

2.3.2.1 Planar or pseudo planar alpha radiation sources should be used for the purpose of calibrating instruments used for the detection of alpha contamination. A pseudo planar source is one made up of a closely spaced array of small sources. The combined thickness of the source media and overburden should be less than one-tenth the range of the least energetic alpha particle in these media. The following thin sources of alpha radiation are acceptable, provided that their 2π alpha emission rate (per unit area) is known and traceable to measurements from a source calibrated by the National Institute of Standards and Technology or to another national measurement institute that has participated in international key comparisons with NIST in the applicable measurement area:

a) natural or depleted uranium,

b) plutonium-238 or -239, and

c) natural thorium or thorium-230.

2.3.2.2 The radiation fields produced by the sources should cover a range of at least three decades of alpha emission rates suitable for protection-level calibration. A recommended range is 100 alpha particles per minute (2π emission rate) to 10^6 alpha particles per minute.

2.3.2.3 In addition to radiation sources, the laboratory should have as a minimum the following equipment:

a) a source and detector support and positioning system that should provide for reproducible and accurate positioning of a detector with respect to the radiation source;

b) an independent measuring system used as a means of checking the sources for any degradation of their alpha emission rate.

2.3.3 Test and calibration methods and method validation

2.3.3.1 Emission rate

The source used for calibration should be characterized in terms of the alpha emission rate per unit area. The boundary of the source should be greater than that of the detector. The relative standard deviation of the emission rate averaged over every individual segment of the source should be less than ± 6 %. The maximum area of a segment should be 10 cm^2, and a segment should not exceed 10 % of the total surface area of the source. The spacing of smaller sources to form a pseudo array should be such that the point-to-point distance between sources is less than the range of alpha radiation in air.

2.3.3.2 Uncertainty component contributed by reference value

The alpha emission rate specified by the laboratory as its reference value for each source of radiation should be within 10 % of the "true value" as defined by comparison with measurements from an appropriate standard traceable to measurements from a source calibrated by the National Institute of Standards and Technology or to another national measurement institute that has participated in international key comparisons with NIST in the applicable measurement area.

2.3.4 Handling of test and calibration items

Because of the short range of alpha particles in air, calibration measurements using an alpha source should be made in such a way that the alpha radiation emitted from the source reaches the sensitive volume of the radiation detector. To assure that this is the case, there should be no shielding materials between the alpha source and the detector, other than that inherent to the detector or source itself. Additionally, the surface of the radiation detector should be no further than 3 mm from the surface of the alpha radiation source.

2.3.5 Reporting the results

2.3.5.1 An instrument calibration report should include, as a minimum, the alpha radiation source used for calibration, the emission rate or rates at which the instrument was calibrated, and the instrument response at each calibration point.

2.3.5.2 At least one calibration point and a linearity check should be included for each range of the instrument, where applicable.

2.4 Beta-particle calibration of survey instruments

2.4.1 Scope

The criteria contained in this part apply to the calibration of health physics instruments at radiation protection levels using a beta particle source. These criteria are limited to the calibration of instruments used to measure dose rate from external beta sources and are supplementary to the general criteria contained in 2.2. Both the general criteria and these specific criteria should be followed if this beta-particle calibration service is offered and its inclusion in the Scope of Accreditation is desired.

2.4.2 Equipment

2.4.2.1 The selection of a source for beta particle calibration of an instrument will depend both on the nature of the radiation field in which the instrument is to be used and the anticipated energy of the beta radiation. It is recommended that both point sources and distributed sources be available for instrument calibration since they represent the extremes of measurement geometry. The radionuclides listed in Table 1 are recommended for use as reference sources for beta calibration; however, other sources may be used if they more accurately represent the beta energy spectrum in which the calibrated instrument is to be used.

2.4.2.2 The laboratory should have at least the following radionuclide sources of beta particles:

^{204}Tl, and ^{9O}Sr/Y.

These sources should comply with ISO 6980.

Table 1. Characteristics of Beta-Particle Sources (ISO 6980: 1996)

Radionuclide	E_{max} (MeV)	Half-Life (d)
^{12}C	0.156	2 093 000
^{146}Pm	0.225	957
^{204}Tl	0.763	1 381
$^{90}Sr/Y$ [(a)]	2.274	10 483
$^{106}Ru/Rh$	3.54	372.6

[(a)] The source should be sealed with 100 mg/cm^2 (nominal) filtration to remove the ^{90}Sr beta component.

2.4.2.3 In addition to one or more radiation sources and associated control devices, the laboratory should have as a minimum the following equipment:

a) Thin-window fixed volume ionization chambers or extrapolation chambers. The extrapolation chamber or thin-window ionization chamber response should have been verified by the NIST or by comparison to calibrated beta radiation sources whose measurements are traceable to measurements from a source calibrated by the National Institute of Standards and Technology or to another national measurement institute that has participated in international key comparisons with NIST in the applicable measurement area. The chamber response should have an accuracy equivalent to that described in 2.4.3.7 over the anticipated range of irradiation conditions, i.e., beta energy and depth of dose measurement point.

b) An electrometer to measure the charge produced in the ionization chambers.

c) A voltage source suitable for chamber polarizing potential.

d) An independent measuring system for verification of the performance of the secondary standard ionization chambers and electrometer.

e) An instrument and ionization chamber support and positioning system. The system should provide for reproducible and accurate positioning of an instrument or chamber with respect to the radiation source. For beam type irradiation configurations, the positioning system should define the central axis of the gamma beam.

f) Additional equipment should include a pulse generator, oscilloscope, current source, precision capacitors and precision resistors.

2.4.3 Test and calibration methods and method validation

2.4.3.1 Dose rate

The beta radiation fields used for calibration should be characterized in terms of absorbed dose rate (specifying tissue depth and tissue-equivalent material) at a given position or distance from the source. The dose rate should be known (traceable) at each distance used. Similarly, if calibrations are to be performed at other tissue depths (for example, simulating exposure of the lens of the eye, rather than exposure of the skin), then the dose rate at these depths should be known.

2.4.3.2 Attenuation

In order to assure that the energy of the beta radiation that reaches the detector is similar to that originating from the radionuclide, certain limits on the calibration conditions are recommended. If E_{res} refers to the

residual maximum energy of a beta particle reaching the detector of an instrument and E_{max} is the energy at which the beta particle originates, then the conditions shown in Table 2 should be met.

Table 2. Limiting Conditions for Beta Particles

E_{max}	E_{res}/E_{max}
<100 keV	≥ 0.6
100 - 800 keV	≥ 0.7
>800 keV	≥ 0.8

These conditions are recommended so that no undue attenuation from the source's self-absorption, containment, beam flattening filters, or air attenuation will significantly change the radionuclide's beta spectrum. The procedure for determining E_{res} is given in ISO 6980.

2.4.3.3 Contamination

In addition to the radiation quality considerations addressed in the preceding paragraphs, contamination by other radionuclides may also significantly change the beta or gamma radiation field from a source. Small levels of beta contamination are difficult to detect but fortunately are usually accompanied by gamma contamination. The beta spectral purity is considered adequate if the following hold:

a) the plot used to measure R_{res} (where R_{res} is the range in an absorbing material of a beta spectrum of residual maximum energy, E_{res}) has a linear section, and

b) the E_{res} value meets the criteria in Table 2.

The procedure for measurement of R_{res} is given in ISO 6980.

2.4.3.4 Measurement frequency

Measurement to determine the adequacy of beta spectral purity should be made every 2 years, or more often if needed.

2.4.3.5 Photon contamination

Photon contamination of the beta field due to sources of gamma, x-ray, and bremsstrahlung radiation should contribute less than 5 % of the total absorbed dose.

2.4.3.6 Uniformity of beta field

The beta dose rate should be uniform over the area of the detector face. The dose rate across the beam profile at a depth of 7 mg/cm^2 should not vary more than 5 % from the mean dose rate for E_{res} greater than or equal to 300 keV, and not more than 10 % for E_{res} less than 300 keV. The uniformity of the beta field should be verified by measurement with a small area detector or film.

2.4.3.7 Uncertainty component contributed by reference value

The dose rate specified by the laboratory as its reference value for each beta-particle beam should be within 10 % of the true value as defined by comparison with a national standard.

2.4.4 Handling of test and calibration items

2.4.4.1 Radiation production

The production of a beam (field) of beta radiation for instrument calibration may be achieved by means of a shutter exposing the source or by moving the source to an exposed position.

2.4.4.2 Beam parameters

The physical size of the beta ray beam (field) should have been predetermined to assure that it is sufficiently large to accommodate the instrument being calibrated. Provision should be made for identifying the central axis, and the boundaries of the useful area of the beam should be known. If necessary, beam flattening filters may be used to meet the requirements of 2.4.3.6.

2.4.4.3 Timer

If the radiation source is used for the calibration of fluence measuring instruments, the radiation beam should be controlled by a timer. The timing measurement uncertainty due to the shutter transit times should be documented, compensated for, and monitored.

2.4.5 Reporting the results

An instrument calibration report should include, as a minimum:

a) the radionuclide and radiation field type (point source or flat field) used for calibration,

b) the reference dose rate or rates with respect to a specified material or tissue phantom at which the instrument was calibrated,

c) the dose rate (or dose) indicated by the instrument at each calibration point,

d) the orientation of the instrument with respect to the radiation beam, and

e) whether the front face or the effective center of the detector was located at the point where the reference field was characterized.

2.5 Beta-particle irradiation of personnel dosimeters

2.5.1 Scope

2.5.1.1 The criteria contained in this section of the handbook apply to irradiation of dosimeters at radiation protection levels using beta-particle sources. These criteria are supplementary to the general criteria contained in 2.2, and should be followed if this specific irradiation service is offered and its inclusion in the Scope of Accreditation is desired. In that case, both the general criteria and these specific criteria should be followed.

2.5.1.2 These criteria apply to irradiation of dosimeters used for personnel monitoring.

2.5.2 Equipment

2.5.2.1 One or more sources of beta radiation should be available for irradiation services. They may take the form of point sources or slab sources. The sources should meet the requirements of national or international standards (i.e., ANSI N13.11; DOE/EH-0027, ISO 6980). The dose range covered will be a function of the mission and requirements of the laboratory, but 1.5 mGy to 100 mGy (150 mrad to 10 rad) should be sufficient for most radiation-protection purposes.

2.5.2.2 In addition to one or more radiation sources and associated control devices, the laboratory should have as a minimum the following equipment:

a) Extrapolation chamber or thin-window fixed volume ionization chamber that covers the energy and intensity ranges used for irradiation services.

b) Phantom consisting of a slab of polymethylmethacrylate with a minimum cross section of 30 × 30 cm and a minimum thickness of 5 cm. The support system for the phantom should be rigid and produce minimum scattered radiation at the dosimeter position(s).

c) An electrometer to measure the charge produced in the ionization chambers.

d) A voltage source suitable for chamber polarizing potential.

e) An independent measuring system for verification of the performance of the secondary standard ionization chambers and electrometer.

f) An instrument and ionization chamber support and positioning system. The system should provide for reproducible and accurate positioning of an instrument or chamber with respect to the radiation source. For beam type irradiation configurations, the positioning system should define the central axis of the gamma beam.

g) Pulse generator, oscilloscope, current source, precision capacitors and precision resistors.

2.5.3 Test and calibration methods and method validation

2.5.3.1 Dose rate

The beta radiation field used for irradiation should be characterized in terms of dose rate.

2.5.3.2 Uncertainty component contributed by reference value

The dose rate specified by the laboratory as its reference value should be within 3 % of the actual value defined by comparison with measurements from the National Institute of Standards and Technology or another national measurement institute that has participated in international key comparisons with NIST in the applicable measurement area. The total uncertainty of the dose delivered to an irradiated dosimeter should be less than or equal to 5 %. To meet this criterion, the use of a flattening filter and/or position-specific calibration factors may be required when several dosimeters are irradiated simultaneously.

2.5.3.3 Source containment

Source containment should be sufficiently sturdy to permit its safe and routine use. At the same time, it should be sufficiently thin to ensure the beta particle energy spectrum of sources specified in ISO 6980.

2.5.3.4 Orientation

The dosimeters should be attached to one of the two larger surfaces of the phantom, at least 5 cm from any edge of the surface, and that surface should face the radiation source. The central axis of the collimated beam should be perpendicular to that surface, and should pass through its geometric center. The position and orientation of the phantom should be reproducible and verifiable.

2.5.3.5 Distance

The distance between the radiation source and the phantom surface to which the dosimeters are attached should comply with requirements in ANSI N13.11 or DOE/EH-0027. It should be reproducible and verifiable.

2.5.3.6 Slab sources

Slab sources may be used when such irradiation geometry is more appropriate than a point source irradiation geometry.

a) ***Slab size:*** The dimensions of the source should exceed the dimensions of the irradiated dosimeter including all radiation sensitive elements.

b) ***Source characteristics:*** The slab should have a protective covering in the range of 3 to 7 mg/cm^2 inclusive. For uranium, the dose rate at 100 mg/cm^2 divided by the dose rate at 7 mg/cm^2 should be 0.58 ± 0.04. The in-phantom dose rate at 1000 mg/cm^2 should be less than 3 % of the dose rate at 7 mg/cm^2. Appropriate dosimeters should be used to confirm these relative dose rates.

c) ***Dose rate:*** The beta radiation field on or near (< 1 cm) the surface of the source should be characterized in terms of absorbed dose rate. An extrapolation ionization chamber or a thin fixed-volume ionization chamber should be used to determine the dose rate.

d) ***Uncertainty component contributed by reference value:*** The dose rate specified by the laboratory as its reference value should be within 3 % of the actual value defined by comparison with measurements from the National Institute of Standards and Technology or another national measurement institute that has participated in international key comparisons with NIST in the applicable measurement area. The total uncertainty of the dose delivered to an irradiated dosimeter should be less than or equal to 5 %.

e) ***Orientation:*** Dosimeters should lie flat on the source surface or be suspended parallel to the surface with a maximum source-to-dosimeter distance of 0.5 cm.

2.5.3.7 Verification of delivered dose

For point sources, a method should be used to verify the delivered dose independent of the timer and known dose rate. Possible verification methods include an off-axis detector, a small detector embedded in a corner of the phantom, or a passive detector exposed with each irradiation.

2.5.4 Handling of test and calibration items

2.5.4.1 Shielding

The source storage containers should provide sufficient shielding such that leakage radiation does not interfere with other uses of the radiation room by raising the background level. Background and leakage

radiation from all sources of radiation within the room should not contribute more than 0.1 % of the total dose to which dosimeters are irradiated.

2.5.4.2 Beam size and uniformity

The beam size should be sufficient to irradiate the entire phantom surface that is facing the source. If several dosimeters are irradiated simultaneously the beam should be sufficiently uniform and characterized to satisfy the requirements of 2.5.3.6 d). The use of an appropriate flattening filter might be required to achieve this.

2.5.4.3 Beam emission control

The irradiator should have a built-in device to control emission of the beta radiation. It should be possible to operate the emission control device with a timer. Any associated random timing uncertainties due to transit time of the device should be known. Any associated systematic timing uncertainties should be measured, compensated for, and monitored.

2.5.5 Reporting the results

The laboratory should report to the customer the total depth dose for each dosimeter irradiated.

2.6 Gamma-ray calibration of survey instruments

2.6.1 Scope

The criteria contained in this part apply to the calibration of health physics instruments at radiation protection levels using one or more gamma-ray sources. These criteria are supplementary to the general criteria contained in 2.2. Both the general criteria and these specific criteria should be followed if this gamma-ray calibration service is offered and its inclusion in the Scope of Accreditation is desired.

2.6.2 Equipment

2.6.2.1 One or more of the following radiation sources should be available for use in the calibration of health physics instruments:

Radionuclide	Nominal Energy
^{241}Am	60 kev
^{137}Cs	660 kev
^{60}Co	1.25 Mev

The source(s) should conform to ISO 4037-1.

2.6.2.2 The radiation fields produced by the sources should cover a range of air kerma (exposure) rates suitable for protection-level calibration. A minimal range is 9 μGy/h to 40 mGy/h (1 mR/h to 5 R/h) and a more desirable range is 4 μGy/h (0.5 mR/h) to at least 0.9 Gy/h (100 R/h).

2.6.2.3 In addition to one or more radiation sources and associated control devices, the laboratory should have as a minimum the following equipment:

a) Secondary standard ionization chambers suitable for the photon energy and intensity ranges for which calibration services are offered.

b) An electrometer to measure the charge produced in the ionization chambers.

c) A voltage source suitable for chamber polarizing potential.

d) An independent measuring system for verification of the performance of the secondary standard ionization chambers and electrometer.

e) Additional equipment including a pulse generator, oscilloscope, current source, precision capacitors and precision resistors.

f) An instrument and ionization chamber support and positioning system. The instrument and ionization chamber support and positioning system should provide for reproducible and accurate positioning of an instrument or chamber with respect to the radiation source. For beam type irradiation configurations, the positioning system should define the central axis of the gamma beam.

2.6.3 Test and calibration methods and method validation

2.6.3.1 Air-kerma rate (exposure rate)

The gamma radiation field used for calibration should be characterized in terms of air-kerma rate at a given position or distance from the source. The air-kerma rate should be known and traceable at each distance used.

2.6.3.2 Scattered radiation

The effect of room-scattered radiation (relative to a radiation field with minimal room scatter) on the accuracy of calibration of each instrument type should be known at each location where a detector is placed for instrument calibration.

2.6.3.3 Attenuation

If an attenuator is used to reduce the air-kerma rate at any location in the radiation field, the effect of the altered radiation spectrum (relative to an unattenuated radiation spectrum) on the uncertainty of calibration of each instrument type should be known. The approximate energy spectrum of the attenuated radiation field should be known. Secondary electron equilibrium at the calibration position should be documented for attenuated beams.

2.6.3.4 Uncertainty component contributed by reference value

The air-kerma rate specified by the laboratory as its reference value for each source of radiation should be within 5 % of the true value as defined by comparison with a national standard above 90 μGy/h (10 mR/h), and within 7 % of the true value from 4 μGy/h (0.5 mR/h) to 90 μGy/h (10 mR/h).

2.6.4 Handling of test and calibration items

2.6.4.1 Shielding

Radiation barriers and/or storage containers for sources should provide sufficient shielding so that radiation added to natural background radiation in the calibration area is sufficiently low as to not interfere with

ongoing calibration work. Added background radiation and leakage radiation from all sources in the calibration area should not contribute more than 1 % of the total air-kerma rate at which an instrument is calibrated or it should be well characterized and accounted for in the calibration.

2.6.4.2 Beam collimation

The gamma radiation beam emitted from a source that has been exposed for calibration should be collimated so that its size is limited to an area consistent with calibration requirements. An exception to this requirement is calibration facilities sufficiently large to provide a low room-scatter radiation environment for instrument calibration, e.g., an uncollimated source in a low scatter room.

2.6.4.3 Source exposure

The source storage container should have a mechanism to control exposure in the gamma beam. If the radiation source is used for calibration of air-kerma measuring (as contrasted with air kerma-rate measuring) instruments, the shutter or source transit time and its effect on the total air kerma should be known.

2.6.4.4 Air kerma (exposure) control

If the radiation source is used for the calibration of air-kerma measuring instruments (see 2.6.4.3 above), the shutter or source transfer should be initiated and terminated by a timer, or the air kerma should be monitored by use of a transmission chamber. Any associated systematic timing uncertainties should be documented and compensated for.

2.6.5 Reporting the results

2.6.5.1 An instrument calibration report should include, as a minimum:

a) the radionuclide or photon energy used;

b) for air kerma rate measurements,

   1) the reference air-kerma rate or rates at which the instrument was calibrated,

   2) the air-kerma rate indicated by the instrument, and

   3) the calibration factor at each calibration point;

c) for air kerma measurements, in addition to the radionuclide and air-kerma rate,

   1) the reference air kerma,

   2) instrument reading, and

   3) calibration factor.

2.6.5.2 At least one calibration point should be included for each range of the instrument, where applicable.

2.6.5.3 The orientation of the instrument with respect to the radiation beam should be described or illustrated in the calibration report, and the use of a build-up cap should be noted.

2.6.5.4 For instruments that use a vented ionization chamber, the reported values should be referenced to a temperature of 295.15 K (22 °C) and a barometric pressure of 1.013 kPa, and the equation needed to convert to other temperatures and pressures should be provided.

2.7 Gamma-ray irradiation of personnel dosimeters

2.7.1 Scope

2.7.1.1 The criteria contained in this part of the document apply to irradiation of dosimeters at radiation protection and accident levels (as defined in ANSI N13.11) using gamma-ray sources. These criteria are supplementary to the general criteria contained in 2.2, and should be followed if this specific irradiation service is offered and its inclusion in the Scope of Accreditation is desired. In that case, both the general criteria and these specific criteria should be followed.

2.7.1.2 These criteria apply to irradiation of dosimeters used for personnel monitoring. They do not apply to dosimeters used for high-level dosimetry in applications such as radiation processing or sterilization.

2.7.2 Equipment

2.7.2.1 One or more ^{137}Cs source(s) of gamma rays should be available for irradiation services. The radiation fields produced by the sources should cover a range of exposures (air kerma) suitable for protection-level irradiations. The range covered will be a function of the mission and requirements of the laboratory, but 0.3 mGy to 4 Gy (30 mR to 500 R) will suffice for most radiation protection purposes.

2.7.2.2 In addition to radiation source(s) and the associated beam control devices, the laboratory should have as a minimum the following equipment:

a) Secondary standard ionization chambers that are calibrated for ^{137}Cs gamma rays and that cover the air-kerma rate ranges used for irradiation services.

b) A phantom consisting of a slab of polymethylmethacrylate with a minimum cross section of 30 cm × 30 cm and a thickness of 15 cm, with a support system for the phantom that is rigid and produces minimum scattered radiation at the dosimeter position(s).

c) An electrometer to measure the charge produced in the ionization chambers.

d) A voltage source suitable for chamber polarizing potential.

e) An independent measuring system for verification of the performance of the secondary standard ionization chambers and electrometer.

f) Additional equipment including a pulse generator, oscilloscope, current source, precision capacitors and precision resistors.

g) An instrument and ionization chamber support and positioning system. The instrument and ionization chamber support and positioning system should provide for reproducible and accurate positioning of an instrument or chamber with respect to the radiation source. For beam type irradiation configurations, the positioning system should define the central axis of the gamma beam.

2.7.3 Test and calibration methods and method validation

2.7.3.1 Air-kerma rate (exposure rate)

The gamma radiation field used for irradiation should be characterized in terms of air-kerma rate in the absence of a phantom at the location where the center of the front surface of the phantom is placed for irradiation.

2.7.3.2 Scatter

The contribution from room-scattered radiation should be determined with the phantom removed from the beam and should not exceed 5 % of the air-kerma rate at any location where a dosimeter is placed for irradiation. The approximate energy spectrum of room-scattered radiation should be known. The relationship between shallow dose and deep dose should be measured for each facility because the charged particle surplus or deficit is highly dependent on local scattering conditions.

2.7.3.3 Uncertainty component contributed by reference value

The air-kerma rate specified by the laboratory as its reference value should be within 3 % of the actual value defined by comparison with the national standard. The total uncertainty of the dose delivered to an irradiated dosimeter should be less than or equal to 5 %. To meet this criterion, it might be necessary to use position-specific calibration factors when several dosimeters are irradiated simultaneously.

2.7.4 Handling of test and calibration items

2.7.4.1 Shielding

Source storage containers should provide sufficient shielding such that leakage radiation does not interfere with other uses of the radiation room by raising the background level. Background radiation and leakage radiation from all sources in the radiation room should not contribute more than 0.1 % of the total air kerma at which dosimeters are irradiated.

2.7.4.2 Beam size and uniformity

The gamma beam emitted from the irradiator should be collimated so that its size is limited to the minimum area consistent with irradiation requirements. All dosimeters should be irradiated with phantom backing, and the beam size should be sufficient to irradiate the entire phantom surface that is facing the source. If several dosimeters are irradiated simultaneously, the beam should be sufficiently uniform and characterized to satisfy the requirements of 2.7.3.3.

2.7.4.3 Beam emission control

The irradiator should have a built-in device to control emission of the gamma beam. It should be possible to operate the emission control device with a timer. Any associated random timing uncertainties due to transit time of the device should be known. Any associated systematic timing uncertainties should be measured, compensated for, and monitored.

2.7.4.4 Orientation

The dosimeters should be attached to one of the two larger surfaces of the phantom, at least 5 cm from any edge of the surface, and that surface should face the radiation source. The central axis of the collimated beam

should be perpendicular to that surface, and should pass through its geometric center. The position and orientation of the phantom should be reproducible and verifiable.

2.7.4.5 Distance

The distance between the radiation source and the phantom surface to which the dosimeters are attached should be one meter or more. The distance should be reproducible and verifiable.

2.7.4.6 Total air kerma

A method should be used to verify the total air kerma independent of the timer and known air-kerma rate.

2.7.5 Reporting the results

The laboratory should report to the customer the total air kerma for each dosimeter irradiated.

2.8 Gamma-ray source calibration for air-kerma rate

2.8.1 Scope

The criteria contained in this part apply to the calibration of gamma-ray sources in terms of air-kerma rate in free air. These criteria are supplementary to the general criteria contained in 2.2, and are to be followed if this specific calibration service is offered and its inclusion in the Scope of Accreditation is desired. In that case, both the general and these specific criteria should be met.

2.8.2 Equipment

2.8.2.1 The laboratory should have a source of gamma radiation greater than or equal to the activity of the radiation source to be calibrated. It should have been calibrated in terms of air-kerma rate as a function of distance, and be subject to periodic quality assurance on at least an annual basis.

2.8.2.2 In addition, the laboratory should have as a minimum the following equipment:

a) Secondary standard ionization chambers suitable for the photon energy and intensity ranges for which calibration services are offered.

b) An electrometer to measure the charge produced in the ionization chambers.

c) A voltage source suitable for chamber polarizing potential.

d) An independent measuring system for verification of the performance of the secondary standard ionization chambers and electrometer.

e) Additional equipment including a pulse generator, oscilloscope, current source, precision capacitors and precision resistors.

f) An instrument and ionization chamber support and positioning system. The instrument and ionization chamber support and positioning system should provide for reproducible and accurate positioning of an instrument or chamber with respect to the radiation source. For beam type irradiation configurations, the positioning system should define the central axis of the gamma beam.

2.8.3 Test and calibration methods and method validation

2.8.3.1 Method

The calibration should be performed by measurement of the source output using secondary standard ionization chambers or working standard ionization chambers that were calibrated against the secondary standards. The energy dependence of the standard chamber(s) should be known over the range of photon energies to be measured.

2.8.3.2 Geometry

The source-detector geometry should be carefully defined. Scattering (excluding that from the source and collimator) from the surroundings should be minimal and should not exceed 10 % of the air-kerma rate at any location where a detector is placed for source calibration. The approximate energy spectrum of scattered radiation should be known.

2.8.3.3 Attenuation

If an attenuator is used by the laboratory to deliberately reduce the air-kerma rate produced by the source, the effect of the attenuator on the energy spectrum of the gamma radiation should be known and the actual attenuation factor should be determined by the laboratory. The effect of any secondary electron fluence at the calibration position should be considered.

2.8.3.4 Uncertainty component contributed by reference value

The laboratory should state the estimated uncertainty of the measured output of the source being calibrated, and this should not exceed 5 % total. This total uncertainty should be calculated on the basis of a thorough analysis of possible errors. Accuracy should be maintained through periodic intercomparison with a national standard as measured by the National Institute of Standards and Technology or another national measurement institute that has participated in international key comparisons with NIST in the applicable measurement area.

2.8.4 Handling of test and calibration items

These criteria are to allow sealed sources in transportable containers, which can be shipped easily, to be calibrated and shipped back to the user. The range of air-kerma rates should be from 20 μGy/h to 0.4 Gy/h (2 mR/h to 50 R/h) measured at the 1 m point in free air. The following sources should be allowed for this type of calibration: ^{241}Am, ^{137}Cs, or ^{60}Co.

2.8.5 Reporting the results

The calibration report should include the following information for each source calibration:

a) a complete description of the source-detector geometry used,

b) the measured air-kerma rate at the distance(s) of calibration, with and without specified attenuators,

c) a description of attenuator(s) used, and

d) the estimated uncertainty in the reported air-kerma rate.

2.9 Gamma-ray calibration of reference-class instruments

2.9.1 Scope

The criteria contained in this part apply to the calibration of reference-class instruments at radiation-protection levels using one or more gamma-ray sources. The reference-class instruments calibrated according to these criteria are intended for use by a customer and are not intended for use as working standards in the laboratory performing the calibration. These criteria are supplementary to the general criteria contained in 2.2. Both the general criteria and these specific criteria should be followed if inclusion of this calibration service in the Scope of Accreditation is desired.

2.9.2 Equipment

2.9.2.1 One or more of the following radiation sources should be available for use in the calibration of reference-class instruments:

Radionuclide	Nominal Energy
^{137}Cs	660 keV
^{60}Co	1.25 MeV

The radiation fields produced by the sources should cover a range of air-kerma rates suitable for protection-level calibration.

2.9.2.2 In addition to one or more radiation sources and associated control devices, the laboratory should have the same minimum equipment as that required for gamma-ray calibration (see 2.6.2.3).

2.9.3 Test and calibration methods and method validation

2.9.3.1 Air-kerma rate (exposure rate)

The gamma radiation field used for calibration should be characterized in terms of air-kerma rate at a given position or distance from the source. The air-kerma rate should be known at each distance used.

2.9.3.2 Scattered radiation

The effect of room-scattered radiation (relative to a radiation field with minimal room scatter) on the accuracy of calibration of each instrument type should be known at each location where a detector is placed for instrument calibration.

2.9.3.3 Attenuation

If an attenuator is used to reduce the air-kerma rate at any location in the radiation field, the effect of the altered radiation spectrum (relative to an unattenuated radiation spectrum) on the accuracy of calibration of each instrument type should be known. The effect of any secondary electron fluence at the calibration position should be considered. The approximate energy spectrum of the attenuated radiation field should be known.

2.9.3.4 Uncertainty component contributed by reference value

The chamber or instrument calibration coefficient specified by the laboratory for each source of radiation should be within 3 % of the true value as defined by comparison with a national standard as measured by the National Institute of Standards and Technology or another national measurement institute that has participated in international key comparisons with NIST in the applicable measurement area.

2.9.4 Handling of test and calibration items

2.9.4.1 Shielding

Radiation barriers and/or storage containers for sources should provide sufficient shielding so that background radiation in the calibration area is sufficiently low as to not interfere with ongoing calibration work.

2.9.4.2 Beam collimation

The gamma radiation beam emitted from a source that is used for calibration should be collimated so that its size is limited to an area consistent with calibration requirements. An exception to this requirement is a calibration facility sufficiently large to provide a low room-scatter radiation environment for instrument calibration, e.g., an uncollimated source in a low-scatter room.

2.9.4.3 Source exposure and exposure control

The source storage container should have a mechanism to control exposure in the gamma beam. If the radiation source is used for calibration of air-kerma-measuring (as contrasted with air-kerma-rate-measuring) instruments, the shutter or source transfer should be initiated and terminated by a timer or the air kerma should be controlled by use of a transmission chamber such that the shutter or source transit time and its effect on the total radiation air kerma can be determined. Any associated systematic timing uncertainties should be documented, compensated for, and monitored.

2.9.5 Reporting the results

2.9.5.1 An ionization-chamber calibration report should include, as a minimum, the radionuclide or photon energy used, the reference air-kerma rate or rates at which the chamber was calibrated, and the calibration coefficient of the chamber at each calibration point in terms of air kerma per unit charge. Orientation of the chamber with respect to the radiation beam should be described, the polarity and magnitude of the polarizing potential should be stated, and the use of a build-up cap should be noted.

2.9.5.2 An instrument calibration report should include, as a minimum, the radionuclide or photon energy used, the reference air-kerma rate or rates at which the instrument was calibrated, the air-kerma rate indicated by the instrument, and the calibration factor at each calibration point. In the case of integrating instruments, in addition to the radionuclide and air-kerma rate, the reference air kerma, instrument reading, and calibration factor should be included. One calibration point and a linearity check should be included for each range of the instrument, where applicable. The orientation of the instrument with respect to the radiation beam should be described or illustrated in the calibration report, and the use of a build-up cap should be noted.

2.9.5.3 For a vented ionization chamber or an instrument that uses such a chamber, the reported values should be referenced to a temperature of 295.15 K (22 °C) and a barometric pressure of 1.013 kPa, and the equation needed to convert to other temperatures and pressures should be provided.

2.10 X-ray calibration of survey instruments

2.10.1 Scope

The criteria contained in this part apply to the calibration of health physics instruments at radiation protection levels using an x-ray source. These criteria are supplementary to the general criteria contained in 2.2. Both the general criteria and these specific criteria should be followed if this x-ray calibration service is offered and its inclusion in the Scope of Accreditation is desired. Criteria for calibration of instruments for diagnostic levels using an x-ray source are contained in 2.12.

2.10.2 Equipment

2.10.2.1 A constant potential x-ray generator should be available for use in the calibration of health physics instruments. Its maximum ripple should not exceed 2 % and it should be operable over a minimum range of 30 kV to 150 kV, 1 mA to 10 mA.

2.10.2.2 In addition to one or more x-ray machines and associated control devices, the laboratory should have the same minimum equipment as that required for gamma ray calibration (see 2.6.2) with the following exception—the secondary standard ionization chambers should be appropriate to the energy and intensity of x rays for which calibration services are offered.

2.10.2.3 Additionally, the laboratory should be equipped with filters to permit the production of a variety of x-ray beam qualities, either NIST beams or ISO beams (Tables 3 or 4).

2.10.3 Test and calibration methods and method validation

2.10.3.1 Air-kerma rate (exposure rate)

The x-ray radiation field used for calibration should be characterized in terms of air-kerma rate at a given position or distance from the anode of the x-ray tube. The air-kerma rate should be known at each distance used. During calibration of an instrument, the air-kerma rate should not vary by more than 2 % from the nominal rate when it is 90 μGy/h (10 mR/h) or higher, and should not vary by more than 4 % from the nominal rate when it is below 90 μGy/h (10 mR/h) .

2.10.3.2 Scattered radiation

The effect of room-scattered radiation (relative to a radiation field with minimal room scatter) on the accuracy of calibration of each instrument type should be known at each location where a detector is placed for instrument calibration.

2.10.3.3 Beam quality

The x-ray beam emitted from the tube housing should be filtered before use to provide the appropriate beam quality meeting either Tables 3 or 4 (see reference 1.4.5 d)). If ISO beams (Table 4) are to be used, then ISO 4037-1 requirements should be met. ISO 4037-1 is also a good guide for developing the beams in general. If a transmission chamber is used for routine beam monitoring, it should be considered to be added filter material. Three or more of the beams shown in Tables 3 or 4 should be available.

2.10.3.4 Half-value layer and homogeneity coefficients

The first half-value layer and homogeneity coefficients for a given x-ray beam should be within 5 % and 7 %, respectively, of the values shown in Table 3. If necessary, the indicated tube voltage or added filter, or both, may be adjusted by 5 % to achieve those values.

2.10.3.5 Air-kerma rate

The air-kerma rate should not vary more than 5 % across the useful area of the beam.

2.10.3.6 Radiation quality

The radiation quality should be checked for stability at least annually. Whenever any part that could affect the beam quality is repaired or replaced, either Table 3 or ISO 4037-1 requirements for beam quality should be met.

2.10.3.7 Uncertainty component contributed by reference value

The air-kerma rate specified by the laboratory as its reference value for each x-ray beam should be within 5 % of the true value as defined by comparison with a national standard above 90 μGy/h (10 mR/h) , and within 7 % of the true value from 4 μGy/h (0.5 mR/h) to 90 μGy/h (10 mR/h).

2.10.4 Handling of test and calibration items

2.10.4.1 Radiation production

The production of a useful beam of radiation may be by applying high voltage to the x-ray tube or by opening a mechanical shutter (which normally acts as a shield to the x-ray beam).

2.10.4.2 Beam collimation

The x-ray beam emitted from the tube housing should be collimated so that its size is limited to an area consistent with calibration requirements. Provision should be made for identifying the central axis, and the boundaries of the useful area of the beam should be known.

2.10.4.3 Exposure control

When a radiation source is used for the calibration of air-kerma measuring instruments, the radiation beam should be controlled by a timer, or the air kerma should be monitored by use of a transmission chamber. The timing uncertainty due to the shutter transit times or high voltage ramping should be known.

2.10.5 Reporting the results

2.10.5.1 An instrument calibration report should include, as a minimum:

a) the x-ray beam used for calibration;

b) in the case of air-kerma rate measurements,

   1) the reference air-kerma rate or rates at which the instrument was calibrated,

2) the air-kerma rate indicated by the instrument, and

3) the calibration factor at each calibration point;

c) in the case of integrating instruments, in addition to the x-ray beam and air-kerma rate,

1) the reference air kerma,

2) the instrument reading, and

3) the calibration factor.

2.10.5.2 At least one calibration point should be included for each range of the instrument, where possible.

2.10.5.3 The orientation of the instrument with respect to the radiation beam should be described or illustrated in the calibration report.

2.10.5.4 For instruments that use a vented ionization chamber, the reported values should be referenced to a temperature of 295.15 K (22 °C) and a barometric pressure of 1.013 kPa, and the equation needed to convert to other temperatures and pressures should be provided.

Table 3. NIST Calibration Conditions for X- and Gamma-Ray Measuring Instruments (Lamperti and O'Brien, 2001)

Beam code [c]	Additional Filtration[a]				Half-value layer[b] (HVL)		Homogeneity coefficient (HC)		Effective energy
	Al (mm)	Cu (mm)	Sn (mm)	Pb (mm)	Al (mm)	Cu (mm)	Al	Cu	(keV)
X-Ray Beam Qualities									
L10					0.037		86		
L15					0.059		70		
L20					0.070		72		
L30	0.30				0.23		60		
L40	0.53				0.52		61		
L50	0.71				0.79		63		
L80	1.45				1.81		56		
L100	1.98				2.80		58		
M20	0.27				0.15		72		
M30	0.5				0.36		65		
M40	0.89				0.74		67		
M50	1.07				1.04		68		
M60	1.81				1.64	0.052	63	60	
M80	2.86				2.98	0.10	68	61	
M100	5.25				5.00	0.20	74	55	
M120	7.12				6.72	0.31	77	53	
M150	5.25	0.25			10.1	0.66	88	63	
M200	4.35	1.12			14.7	1.64	94	68	
M250	5.25	3.2			18.3	3.2	98	85	
M300	4.25		6.5		21.7	5.3	100	97	
H10	0.105				0.051		77		
H15	0.5				0.16		87		
H20	1.01				0.36		89		
H30	4.50				1.20		86		
H40	4.53	0.26			2.93		94		
H50	4.0			0.1	4.2	0.14	93	93	38
H60	4.0	0.61			6.0	0.25	94	94	46
H100	4.0	5.2			13.4	1.15	97	92	80
H150	4.0	4.0	1.51		16.9	2.43	100	96	120
H200	4.0	0.6	4.16	0.77	19.7	4.10	99	99	166
H250	4.0	0.6	1.04	2.72	22	5.19	99	98	211
H300	4.1		3.0	5.0	23	6.19	99	98	252
S60	4.35				2.79	0.09	76	66	
S75	1.50				1.81		58		
Gamma-Ray Beam Qualities									
^{137}Cs						10.8			662
^{60}Co						14.9			1250

[a]The additional filtration value does not include the inherent filtration. The inherent filtration is approximately 1.0 mm Be for beam codes L10-L100, M20-M50, H10-H40 and S75; and 3.0 mm Be for beam codes M60-M300, H50-H300 and S60.
[b]The HVL values were measured directly using the two new x-ray tubes installed in November of 2001 and May of 2002.
[c]The NIST H group of beam qualities agrees with the ISO narrow spectrum (NS) qualities recommended in ISO 4037-1 (see also Table 4). The NIST M group of beam qualities agrees with the recommendation for radiation therapy calibration in IEC Publication 60731. H qualities are usually used for calibration for radiation protection instrumentation since they have the narrowest spectrum at each generating potential and probably most nearly approximate radiation that has penetrated a protective barrier. M qualities are usually used for calibration radiation therapy instruments. L qualities are predominately used for calibration of instruments used for measurement of unfiltered or lightly filtered beams that give high exposure rates, such as in radiation biology and Grenz-ray therapy. For more information, contact the Radiation Interactions and Dosimetry Group, NIST, 100 Bureau Drive, Stop 8460, Gaithersburg, MD 20899-8460, fax: 301-869-7682.

Table 4. ISO X-Ray Beam Quality Parameters Offered at NIST (Lamperti and O'Brien, 2001)

Beam Code[b]	Additional Filtration (mm)[a]				First HVL		Second HVL	
	Al	Cu	Sn	Pb	mm Al	mm Cu	mm Al	mm Cu
HK10					0.042		0.045	
HK20	0.15				0.128		0.170	
HK30	0.52				0.408		0.596	
HK60	3.19					0.079		0.113
HK100	3.90	0.15				0.298		0.463
HK200		1.15				1.669		2.447
HK250		1.60				2.463		3.37
HK280		3.06				3.493		4.089
HK300		2.51				3.474		4.205
WS60		0.3				0.179		0.206
WS80		0.529				0.337		0.44
WS110		2.029				0.97		1.13
WS150			1.03			1.88		2.13
WS200			2.01			3.09		3.35
WS250			4.01			4.30		4.50
WS300			6.54			5.23		5.38
NS10	0.095				0.049		0.061	
NS15	0.49				0.153		0.167	
NS20	0.90				0.324		0.351	
NS25	2.04				0.691		0.762	
NS30	4.02				1.154		1.396	
NS40		0.21				0.082		0.094
NS60		0.6				0.241		0.271
NS80		2.0				0.59		0.62
NS100		5.0				1.15		1.19
NS120		4.99	1.04			1.70		1.85
NS150			2.50			2.40		2.52
NS200		2.04	2.98			4.09		4.20
NS250			2.01	2.97		5.26		5.32
NS300			2.99	4.99		6.17		6.30
LK10	0.30				0.061			
LK20	2.04				0.441			
LK30	3.98	0.18			1.492			
LK35		0.25			2.21			
LK55		1.19				0.260		
LK70		2.64				0.509		
LK100		0.52	2.0			1.27		
LK125		1.0	4.0			2.107		2.094
LK170		1.0	3.0	1.5		3.565		3.592
LK210		0.5	2.0	3.5		4.726		4.733
LK240		0.5	2.0	5.5		5.515		5.542

[a]The additional filtration does not include the inherent filtration. The inherent filtration is a combination of the filtration due to the monitor chamber plus 1 mm Be for beam codes LK10-LK30, NS10-NS30, HK10-HK30 and for all other techniques the inherent filtration is adjusted to 4 mm Al.
[b]LK indicates low air kerma rate; HK high air kerma rate; NS narrow spectrum; WS wide spectrum; number indicates the constant potential in kilovolts.

2.11 X-ray irradiation of personnel dosimeters

2.11.1 Scope

2.11.1.1 The criteria contained in this part of the document apply to the irradiation of dosimeters at radiation protection levels using x-ray beam sources. These criteria are supplementary to the general criteria contained in 2.2, and should be followed if this specific irradiation service is offered and its inclusion in the Scope of Accreditation is desired. In that case, both the general criteria and these specific criteria should be followed.

2.11.1.2 These criteria apply to the irradiation of dosimeters used for personnel monitoring.

2.11.2 Equipment

2.11.2.1 At least one constant potential x-ray generator should be available to cover a range of exposures (air kerma) for protection-level irradiations. The range covered will be a function of the mission and requirements of the laboratory but a minimal range is 0.3 mGy to 4 Gy (30 mR to 500 R). The laboratory should be able to perform irradiations using three or more of the filtered beams described in ANSI N13.11 and DOE/EH-0027.

2.11.2.2 In addition to one or more x-ray machines and the associated beam control devices, the laboratory should have the same minimum equipment as that required for gamma-ray calibration (see 2.6.2.3), plus the following:

a) a phantom consisting of a slab of polymethylmethacrylate with a minimum cross section of 30 cm × 30 cm and a thickness of 15 cm, with a support system for the phantom that is rigid and produces minimum scattered radiation at the dosimeter position(s);

b) secondary standard ionization chambers appropriate to the energy and intensity of x-rays for which irradiation services are offered.

2.11.3 Test and calibration methods and method validation

2.11.3.1 Air-kerma rate (exposure rate)

The radiation field should be characterized in terms of air-kerma rate in the absence of a phantom at the location where the center of the front surface of the phantom is placed for irradiation.

2.11.3.2 Scatter

The contribution from room-scattered radiation should be determined with the phantom removed from the beam and should not exceed 5 % of the air-kerma rate at any location where a dosimeter is placed for irradiation. The approximate energy spectrum of room-scattered radiation should be known.

2.11.3.3 Beam quality

The x-ray beam emitted from the tube housing should be filtered before use to provide the appropriate beam quality meeting Tables 3 or 4. The first half-value layer and homogeneity coefficients for a given x-ray beam should be within 5 % and 7 %, respectively, of the values shown in Tables 3 or 4. If necessary, the indicated tube voltage or added filter, or both, may be adjusted by 5 % to achieve those values. The intensity of the x-ray beam should not vary more than 5 % across the useful area of the beam. If a transmission chamber is used for routine beam monitoring, it should be considered to be added filter material. The radiation quality should

be checked for stability at least annually. Whenever any part that could affect the beam quality is repaired or replaced, the above requirements for radiation quality should be met. Three or more of the beams shown in Tables 3 or 4 should be available.

2.11.3.4 Uncertainty component contributed by reference value

The air kerma rate specified by the laboratory as its reference value should be within 3 % of the actual value defined by comparison with the national standard. The total uncertainty of the dose delivered to an irradiated dosimeter should be less than or equal to 5 %. To meet this criterion, it may be necessary to use position-specific correction factors when several dosimeters are irradiated simultaneously.

2.11.3.5 Orientation

The dosimeters should be attached to one of the two larger surfaces of the phantom, at least 5 cm from any edge of the surface, and that surface should face the radiation source. The central axis of the collimated beam should be perpendicular to the surface, and should pass through its geometric center. The position and orientation of the phantom should be reproducible and verifiable.

2.11.3.6 Distance

The distance between the radiation source and the phantom surface to which the dosimeters are attached should be one meter or more. The distance should be reproducible and verifiable.

2.11.3.7 Total air kerma

A method should be used to verify the total air kerma independent of the timer and known air-kerma rate.

2.11.4 Handling of test and calibration items

2.11.4.1 Shielding

Leakage radiation through a closed shutter or x-ray tube head shielding should be less than 0.1 % of the open-shutter rates at the position of the dosimeters.

2.11.4.2 Beam size and uniformity

The x-ray beams should be collimated and their size should be limited to an area consistent with the irradiation requirements. All dosimeters should be irradiated with phantom backing, and the beam size should be sufficient to irradiate the entire phantom surface that is facing the tube head. If several dosimeters are being irradiated simultaneously, the beam size and beam uniformity should be sufficiently uniform and characterized to satisfy the requirements of ANSI N13.11.

2.11.4.3 Exposure control

If a shutter is used to control the beam, the shutter transit time should be known. If a shutter is not used, radiation produced prior to achieving beam stability should be known in all cases and should be compensated. The uncertainties associated with stabilization should be known. Any associated systematic timing uncertainties should be documented, compensated for, and monitored.

2.11.5 Reporting the results

The laboratory should report to the customer the total air kerma for each dosimeter irradiated. For conversion to dose or dose equivalent, the value of the exposure should be multiplied by the factors given in ANSI N13.11 or DOE/EH-0027. The reference(s) for the factor(s) used should also be given.

2.12 X-ray calibration of instruments for diagnostic radiology levels

2.12.1 Scope

2.12.1.1 The criteria contained in this part of the document apply to calibration of instruments at diagnostic radiology levels using an x-ray source. These criteria are supplementary to the general criteria contained in 2.2 and should be followed if this specific calibration service is offered and its inclusion in the laboratory's Scope of Accreditation is desired. Both the general criteria and these specific criteria should be followed in that case.

2.12.1.2 Although not part of NVLAP criteria, other requirements for performance of calibration instruments for diagnostic application may apply. The American Association of Physicists in Medicine (AAPM) Accredited Dosimetry Calibration Laboratory (ADCL) Program follows regulations under the Mammography Quality Standards Act published by the Food and Drug Administration and the American College of Radiology (ACR) standards for professional credentials, equipment specifications, monitoring and maintenance schedules, record keeping, and data review. Familiarity with these standards and requirements will assist the NVLAP assessor in his/her review.

2.12.2 Equipment

2.12.2.1 The laboratory should have a constant potential x-ray machine available for calibration of instruments. It should operate at potentials from 20 kV to 150 kV as a minimum range. The radiation field produced should cover, as a minimum range, air-kerma rates from 180 mGy/h to 900 mGy/h (20 R/h to 100 R/h), with a stability sufficient to calibrate instruments according to documented laboratory procedures. During calibration of an instrument, the air-kerma rate should not vary by more than ± 1 %.

2.12.2.2 In addition to one or more x-ray machines and associated control devices, the laboratory should have the same minimum equipment as that required for gamma ray calibration (see 2.6.2.3).

2.12.2.3 Additionally, the laboratory should be equipped with filters to permit the production of a variety of x-ray beam qualities (see 2.12.3.4).

2.12.3 Test and calibration methods and method validation

2.12.3.1 Air-kerma rate (exposure rate)

The x-ray field used for calibration should be characterized in terms of air-kerma rate at the location where the effective center of the instrument's detector is placed for calibrations.

2.12.3.2 Scatter

The effect of room-scattered radiation (relative to a radiation field with minimal room scatter) on the accuracy of calibration of each instrument type should be known at each location where a detector is placed for instrument calibration.

2.12.3.3 Uncertainty component contributed by reference value

The air-kerma rate specified by the laboratory as its reference value should be within ± 5 % of the actual value defined by comparison with the national standard.

2.12.3.4 Beam quality

The first half-value layer and homogeneity coefficients for a given x-ray beam should be within 5 % and 7 %, respectively, of the values shown in Table 5. If necessary, the indicated tube voltage or added filter, or both, may be adjusted by as much as 5 % to achieve those values. If a transmission chamber is used for routine beam monitoring, it should be considered to be added filter material.

Table 5. Mammography X-Ray Beam-Quality Parameters at NIST (Lamperti and O'Brien, 2001)

Beam Code	Tube Voltage (kV)	Added Filter (mm)	Half-Value Layer (mm Al)	Homogeneity Coefficient (Al)
Mo Anode				
Mo/Mo23	23	0.032 Mo	0.271	0.702
Mo/Mo25	25	0.032 Mo	0.296	0.719
Mo/Mo28	28	0.032 Mo	0.332	0.743
Mo/Mo30	30	0.032 Mo	0.351	0.752
Mo/Mo35	35	0.032 Mo	0.392	0.784
Mo/Rh28	28	0.029 Rh	0.408	0.796
Mo/Rh32	32	0.029 Rh	0.445	0.821
Mo/Mo25x	25	0.030 Mo + 2.0 Al	0.566	0.91
Mo/Mo28x	28	0.030 Mo + 2.0 Al	0.626	0.964
Mo/Mo30x	30	0.030 Mo + 2.0 Al	0.660	0.947
Mo/Mo35x	35	0.030 Mo + 2.0 Al	0.748	0.902
Rh Anode				
Rh/Rh25	25	0.029 Rh	0.351	0.755
Rh/Rh30	30	0.029 Rh	0.438	0.812
Rh/Rh35	35	0.029 Rh	0.512	0.858
Rh/Rh40	40	0.029 Rh	0.559	0.895
Rh/Rh30x	30	0.029 Rh + 2.0 Al	0.814	0.964
Rh/Rh35x	35	0.029 Rh + 2.0 Al	0.898	0.945

The beam codes are a combination of the chemical symbol of the anode and the filter, respectively, followed by the constant potential in kilovolts. The letter "x" ends the beam codes which denote "exit" beams. The exit beam qualities, which are intended to represent the transmission of the x-rays through the breast, are generated by an additional filtration of 2.0 mm of aluminum.

The inherent filtration is 1 mm Be for all beam qualities. The calibration distance is 1 m. The half-value layers were determined through direct measurements with the primary standard free-air ionization chamber. The air kerma rates for the entrance beams are between 0.5 mGy/s, and less than 0.2 mGy/s for the exit beams.

2.12.3.5 Intensity of x-ray beam

The intensity of the x-ray beam should not vary more than 5 % across the useful area of the beam.

2.12.3.6 Radiation quality

The radiation quality should be checked for stability at least annually. Whenever any part that could affect the beam quality is repaired or replaced, the above requirements for radiation quality should be met.

2.12.4 Handling of test and calibration items

2.12.4.1 Beam collimation

The x-ray beam emitted from the tube housing should be collimated so that its size is limited to the minimum area consistent with calibration requirements. Provision should be made for identifying the central axis, and the boundaries of the useful area of the beam should be known.

2.12.4.2 Shutter and exposure control

A shutter should be used to control emission of the x-ray beam from the tube housing. If the beam is used for calibration of air-kerma-measuring instruments, the shutter should be operated by a timer or a suitable charge integrating device, so that the shutter transit time can be measured and recorded. Any associated errors due to shutter transit times should be documented, compensated for, and monitored.

2.12.5 Reporting the results

2.12.5.1 An instrument calibration report should include, as a minimum,

a) the x-ray beam quality used for calibration;

b) in the case of air-kerma rate measurements,

   1) the reference air-kerma rate or rates at which the instrument was calibrated,

   2) the air-kerma rate indicated by the instrument, and

   3) the calibration factor at each calibration point;

c) in the case of integrating instruments, in addition to the x-ray beam and air-kerma rate,

   1) the reference air kerma,

   2) the instrument reading, and

   3) the calibration factor.

2.12.5.2 One calibration point and a linearity check should be included for each range of the instrument, where possible.

2.12.5.3 The orientation of the instrument with respect to the radiation beam should be described or illustrated in the calibration report.

2.12.5.4 For instruments that use a vented ionization chamber, the reported values should be referenced to a temperature of 295.15 K (22 °C) and a barometric pressure of 1.013 kPa, and the equation needed to convert to other temperatures and pressures should be provided.

2.13 X-ray calibration of reference-class instruments

2.13.1 Scope

The criteria contained in this part apply to the calibration of reference-class instruments at radiation protection or diagnostic levels using an x-ray source. The reference-class instruments calibrated according to these criteria are intended for use by a customer and are not intended for use as working standards in the laboratory performing the calibration. These criteria are supplementary to the general criteria contained in 2.2. Both the general criteria and these specific criteria should be followed if inclusion of this calibration service in the Scope of Accreditation is desired.

2.13.2 Equipment

2.13.2.1 A constant potential x-ray generator should be available for use in the calibration of reference-class instruments. Its maximum ripple should not exceed 2 % and it should be operable over a minimum range of 30 kV to 150 kV, 1 mA to 10 mA. The radiation fields produced by the x-ray generator should cover a range of air-kerma rates suitable for protection-level and diagnostic calibration. During calibration of an instrument, the air-kerma rate should not vary by more than 1 % from the nominal rate.

2.13.2.2 In addition to one or more x-ray machines and associated control devices, the laboratory should have the same minimum equipment as that required for gamma ray calibration (see 2.6.2.3) with the following exception: the secondary standard ionization chambers should be appropriate to the energy and intensity of x-rays for which calibration services are offered.

2.13.2.3 Additionally, the laboratory should be equipped with filters to permit the production of a variety of x-ray beam qualities (see 2.13.3.3 through 2.13.3.6).

2.13.3 Test and calibration methods and method validation

2.13.3.1 The x-ray radiation field used for calibration should be characterized in terms of air-kerma rate at a given position or distance from the anode of the x-ray tube. The air-kerma rate should be known at each distance used.

2.13.3.2 The effect of room-scattered radiation (relative to a radiation field with minimal room scatter) on the accuracy of calibration of each instrument type should be known at each location where a detector is placed for instrument calibration.

2.13.3.3 The x-ray beam emitted from the tube housing should be filtered before use to provide the appropriate radiation quality for calibration purposes. If a transmission chamber is used for routine beam monitoring, it should be considered to be added filter material. Three or more of the beams shown in Tables 3 or 4 should be available.

2.13.3.4 The first half-value layer and homogeneity coefficients for a given x-ray beam should be within 5 % and 7 %, respectively, of the values shown in Tables 3 or 4. If necessary the indicated tube voltage or added filter, or both, may be adjusted within 5 % to achieve those values.

2.13.3.5 The intensity of the x-ray beam should not vary more than 5 % across the useful area of the beam.

2.13.3.6 The radiation quality should be checked for stability at least annually. Whenever any part that could affect the beam quality is repaired or replaced, the above requirements for radiation quality should be met.

2.13.3.7 The chamber or instrument calibration factor specified by the laboratory for each x-ray beam should be within 3 % of the true value as defined by comparison with a national standard.

2.13.4 Handling of test and calibration items

2.13.4.1 Radiation production

The production of a useful beam of radiation may be by means of the application of high voltage to the x-ray tube or the opening of a mechanical shutter (which normally acts as a shield to the x-ray beam).

2.13.4.2 Beam collimation

The x-ray beam emitted from the tube housing should be collimated so that its size is limited to an area consistent with calibration requirements. Provision should be made for identifying the central axis, and the boundaries of the useful area of the beam should be known.

2.13.4.3 Exposure control

If the radiation source is used for the calibration of air kerma measuring instruments, the radiation beam should be controlled by a timer or the air kerma should be controlled by use of a transmission chamber. The timing error due to the shutter transit times or high voltage ramping should be documented, compensated for, and monitored.

2.13.5 Reporting the results

2.13.5.1 An ionization-chamber calibration report should include, as a minimum, a description of beam quality in terms of the codes in Tables 3 or 4 or an equivalent method, the reference air-kerma rate or rates at which the chamber was calibrated, and the calibration coefficient of the chamber at each calibration point in terms of air kerma per unit charge. Orientation of the chamber with respect to the radiation beam should be described, and the polarity and magnitude of the polarizing potential should be stated.

2.13.5.2 An instrument calibration report should include, as a minimum, the x-ray beam used for calibration, the reference air-kerma rate or rates at which the instrument was calibrated, the air-kerma rate indicated by the instrument, and the calibration factor at each calibration point. In the case of integrating instruments, in addition to the x-ray beam and air-kerma rate, the reference air kerma, instrument reading, and calibration factor should be included. One calibration point and a linearity check should be included for each range of the instrument, where possible. The orientation of the instrument with respect to the radiation beam should be described or illustrated in the calibration report.

2.13.5.3 For a vented ionization chamber or an instrument that uses such a chamber, the reported values should be referenced to a temperature of 295.15 K (22 °C) and a barometric pressure of 1.013 kPa, and the equation needed to convert to other temperatures and pressures should be provided.

2.14 Neutron calibration of survey instruments

2.14.1 Scope

The criteria contained in this part apply to the calibration of health physics instruments at radiation protection levels using neutron radiation. These criteria are supplementary to the general criteria contained in 2.2. Both the general criteria and these specific criteria should be followed if this neutron radiation calibration service is offered and its inclusion in the Scope of Accreditation is desired.

2.14.2 Equipment

2.14.2.1 The selection of a source for neutron radiation calibration of an instrument will depend on the nature of the radiation field in which the instrument is to be used, including the anticipated neutron energy spectrum. The neutron sources described in Table 6 are frequently used for instrument calibration. As a minimum, a laboratory should have at least one of the sources shown in Table 6 with appropriate strength for the dose equivalent or dose-equivalent-rate range of the instruments to be calibrated. A minimum dose-equivalent rate range is 0.1 mSv/h to 10 mSv/h (10 mrem/h to 1 rem/h). The measurements of the neutron source strength should be known and traceable. If a ^{252}Cf source is used, the laboratory should be capable of calibrating an instrument using both the bare source and the moderated configuration.

Table 6. Characteristics of Commonly Used Fast Neutron Sources for Calibration of Neutron Survey Instruments (Lorenz, 1972)

Source	Method of Neutron Production	Half-life	Neutron Energy (MeV) Max.	Average
^{238}Pu (Be)	(α,n)	86.4 Y	11.3	5.0
^{239}Pu (Be)	(α,n)	24390 Y	10.74	4.5-5
^{241}Am (Be)	(α,n)	458 Y	11.5	5.0
^{252}Cf	SF	2.654 Y	15	2
^{252}Cf Moderated with 15 cm D_2O (e.g., Schwartz, 1980; Prevo, 1983)	SF	2.654 Y	15	0.54

The radiation field produced by a neutron source used for calibration should provide an energy spectrum and dose-equivalent rates appropriate for the instrument undergoing calibration.

2.14.2.2 In addition to a selection of one or more neutron sources appropriate to the radiation field(s) in which instruments are being calibrated, the laboratory should have the same minimum equipment as that required for gamma-ray calibration (see 2.6.2.3), with the exception of secondary standard ionization chambers and that equipment associated with their use.

2.14.3 Test and calibration methods and method validation

2.14.3.1 Dose equivalent rate

The neutron radiation field used for calibration should be characterized in terms of the fluence rate and spectral composition at the point of calibration. The dose equivalent rate should be calculated on the basis of these characteristics (see Table 6) as a means of setting calibration points for specific instrument types.

2.14.3.2 Radiation quality

In addition to the radiation quality considerations addressed in the preceding paragraphs, contamination of the neutron field by other types of radiation may also contribute to erroneous instrument response. If this is the case and the instrument is sensitive to photon and/or beta radiation as well as neutrons, the extent of this contamination should be known and accounted for when calibrating a given instrument. Photon contamination of the neutron field should be known and should be less than 20 % of the total dose equivalent rate.

Table 7. Characterization of neutron sources in terms of dose equivalent

Radionuclide source	Mean neutron fluence to dose equivalent conversion factor[a] [b] ($Sv \cdot cm^2$)	Specific source strength ($s^{-1} \cdot Bq^{-1}$)	Specific neutron dose equivalent rate at 1 m[b] ($mSv \cdot h^{-1} \cdot Bq^{-1}$)
^{238}Pu(Be)		5.4×10^{-3}	
^{239}Pu(Be)		4.1×10^{-3}	
^{241}Am(Be)	3.9×10^{-10}	6.5×10^{-3}	7.3×10^{-10}
		($s^{-1} \cdot mg^{-1}$)	($mSv \cdot h^{-1} \cdot mg^{-1}$)
^{252}Cf	3.85×10^{-10}	2.4×10^{9}	2.3×10
^{252}Cf moderated	1.05×10^{-10}	2.1×10^{9}	5.4

$$\textit{Conversion Coefficient}\ h_{\varphi} = \frac{1}{B}\int_{0}^{\infty} B_E\, h_{\phi}(E)\, dE$$

[a] The conversion coefficients were calculated from the equation above, where B is the neutron source strength, B_E is the spectral distribution of neutron source strength, and h_{φ} is the energy averaged neutron-fluence-to-dose equivalent conversion coefficient, i.e., the quotient of the dose equivalent and the neutron fluence (see ISO 8529-1:2001).

[b] These are typical numbers. B_E and hence, the dose equivalent rate from a particular source depends upon variable factors such as purity, internal absorption, construction details, and encapsulation.

2.14.3.3 Uncertainty component contributed by reference value

The dose-equivalent rate specified by the laboratory as its reference value for each neutron field should be within 10 % of the true value as defined by comparison with a national standard as measured by the National Institute of Standards and Technology or another national measurement institute that has participated in international key comparisons with NIST in the applicable measurement area.

2.14.4 Handling of test and calibration items

2.14.4.1 Radiation production

The production of a field of neutron radiation for instrument calibration should be achieved by moving the source from a shielded to an exposed position, preferably in a low-scatter environment in an open area or at the center of a large room (for example, 10 m × 10 m square with the source 4 m from both floor and ceiling). The neutron radiation field used for calibration should be carefully monitored and controlled. The response due to room-scattered neutrons at the point of calibration should be less than 25 % of the total instrument response, and the appropriate corrections should be made.

2.14.4.2 Timer

If the neutron source is used for the calibration of integrated dose equivalent measuring instruments, the radiation field should be controlled by a timer. Any associated systematic timing uncertainties should be documented, compensated for, and monitored.

2.14.5 Reporting the results

2.14.5.1 An instrument calibration report should include, as a minimum, the radionuclide and radiation field type (moderated or unmoderated) used for calibration, the free-field dose equivalent rate or rates at which the instrument was calibrated, the scatter-corrected instrument reading at each calibration point, and the basis for any calculation of dose-equivalent rate from source emission rate.

2.14.5.2 At least one calibration point should be included for each decade range of the instrument, where possible.

2.14.5.3 The orientation of the instrument with respect to the radiation field should be described or illustrated in the calibration report.

2.14.5.4 The value of the scatter correction should be provided.

2.15 Neutron irradiation of personnel dosimeters

2.15.1 Scope

2.15.1.1 The criteria contained in this part of the document apply to irradiation of dosimeters at radiation protection levels using neutron sources. These criteria are supplementary to the general criteria contained in 2.2 and should be followed if this specific irradiation service is offered and its inclusion in the Scope of Accreditation is desired. In that case, both the general criteria and these specific criteria should be followed.

2.15.1.2 These criteria apply to irradiation of dosimeters used for personnel monitoring. They do not apply to dosimeters that use neutron activation foils to determine accident level doses.

2.15.2 Equipment

2.15.2.1 These criteria apply to neutrons from radionuclide sources, including sources in a moderator. They do not apply to accelerator-produced neutrons or neutrons from reactors. Neutron sources specified by ANSI N13.11 or DOE/EH-0027 should be available. Additional sources may be used if their spectral distributions, neutron emission rates, and dose equivalent conversion factors are well documented. The range of dose equivalents covered will be a function of the mission and requirements of the laboratory, but 1.5 to 50 mSv (150 mrem to 5 rem) will suffice for most radiation protection purposes. All irradiations should refer to free-field quantities and should be performed with phantom backing.

2.15.2.2 In addition to one or more radiation sources and the associated source transport system, the laboratory should have at least a phantom consisting of a slab of polymethylmethacrylate with a cross section of 40 × 40 cm and a thickness of 15 cm. The support system for the phantom should be rigid and produce minimum scattered radiation at the dosimeter position(s). The system should provide for reproducible and accurate positioning of the phantom with respect to the radiation source.

2.15.3 Test and calibration methods and method validation

2.15.3.1 Dose-equivalent rates

The neutron radiation fields used for irradiation should be characterized in terms of the free-field dose-equivalent rate at the center of the front surface of the phantom. The neutron emission rate for each source should be determined by the NIST. Procedures for determining the dose equivalent for dosimeters exposed to a ^{252}Cf source should follow Eisenhauer, Hunt, and Schwartz, 1985. Procedures for other sources should be documented. The contribution to the dose equivalent due to photon emission from the neutron source should be measured and documented. There should be verification of the expected dose-equivalent rate during irradiation.

2.15.3.2 Scatter

The contribution of air scattering, room return and source scattering should be determined for all irradiation geometries and distances so that free-field dose equivalents can be determined. To minimize room scatter, the irradiation room should be as large as is practically possible and irradiations should be conducted near the center of the room.

2.15.3.3 Uncertainty component contributed by reference value

The dose-equivalent rate specified by the laboratory as its reference value should be within 10 % of the actual value defined by comparison with the national standard. The total uncertainty in the assigned neutron dose equivalent for irradiated dosimeters should be less than or equal to 10 %, excluding uncertainties in the dose equivalent conversion factors and the photon component of the neutron irradiations. To meet this criterion, it may be necessary to use position-specific calibration factors when several dosimeters are irradiated simultaneously.

2.15.3.4 Orientation

The dosimeters should be attached to one of the two larger surfaces of the phantom, at least 10 cm from any edge of the surface, and that surface should face the radiation source. That surface should be perpendicular to a radial line from the source center to the phantom center. The position and orientation of the phantom should be reproducible and verifiable.

2.15.3.5 Distance

The distance between the center of the radiation source and the center of the phantom surface to which the dosimeters are attached should be at least 50 cm. The dose equivalent should be calculated at the location of each dosimeter. It should be reproducible and verifiable.

2.15.3.6 Delivered dose equivalent

A method should be used to verify the delivered dose equivalent independent of the timer and known dose equivalent rate. Possible verification methods include an off-axis detector or a passive detector exposed with each irradiation.

2.15.4 Handling of test and calibration items

2.15.4.1 Shielding

The source storage container should provide sufficient shielding such that leakage radiation does not interfere with other uses of the radiation room by raising the background level. Background radiation and leakage radiation from all sources in the radiation room should not contribute more than 0.1 % of the total dose equivalent to which dosimeters are irradiated.

2.15.4.2 Irradiation control

A source transport system should be provided to transport the source from the storage container to the irradiation position. Both the transit time from storage to irradiation position and the associated dose-equivalent contribution to dosimeter irradiation should be known. It should be possible to operate the source transport system with a timer. Any associated random timing uncertainties due to the transit time of the source should be known. Any associated systematic timing uncertainties should be measured, compensated for, and monitored.

2.15.5 Reporting the results

The laboratory should report to the customer the free-field dose equivalent for each dosimeter irradiated. The ratio of the dose equivalent arising from photon emission by the radiation source to the neutron dose equivalent should be reported.

2.16 Neutron dosimeters and survey instruments

2.16.1 Scope

The criteria contained in this part of the document apply to laboratories that calibrate neutron measuring instruments; in particular, neutron radiation protection instrumentation such as neutron dosimeters and neutron area survey meters. These criteria are supplementary to the general criteria contained in 2.2 and should be followed if this specific irradiation service is offered and its inclusion in the Scope of Accreditation is desired. In that case, both the general criteria and these specific criteria should be followed.

2.16.2 Assuring the quality of test and calibration results

2.16.2.1 The laboratory should have one or more radionuclide neutron sources whose emission rate is traceable to measurements from National Institute of Standards and Technology or to another national measurement institute that has participated in international key comparisons with NIST in the applicable measurement area.

2.16.2.2 The laboratory should have a neutron measuring device, calibrated at NIST, to use as a system check.

2.16.3 Accommodation and environmental conditions

2.16.3.1 The facility should consist of at least one irradiation room and suitable storage, set-up, and office space, all designed to meet local safety codes and regulations. It should be sufficiently shielded from extraneous radiation sources so that the neutron-background dose-equivalent rate ($\dot{H}$) due to such sources is $\dot{H} < 10^{-3}$ mSv·h^{-1}. It should be provided with air conditioning and heating adequate to keep the temperature in the range (295.15 ± 4) K (22 °C ± 4 °C) and the relative humidity between 20 % and 65 %. The laboratory should be free of undue vibration, shock, and noise.

2.16.3.2 The irradiation room may be either "open" or "closed." An open room is one in which the walls and ceiling are generally of low-mass, non-hydrogenous material essentially transparent to neutrons. Radiation protection is provided by means of a sufficiently large exclusion area. A closed room is one in which the walls and ceiling are sufficiently massive (usually concrete) to provide adequate shielding. A closed room should be as large as possible to minimize room-scattered neutrons, and, in any case, the inside linear dimensions should be > 6 m.

2.16.3.3 The source should be used in the center of the room or, in the case of an open facility, as high as practical above the ground. In use, the source should be supported by a non-hydrogenous structure with as low a mass as possible.

2.16.3.4 When not in use, the source should be stored in a well-shielded location such that it generates a background of $\dot{H} < 10^{-3}$ mSv·h^{-1} at the position of the test instrument. A method should be provided to move the source from its shielded position to the "in use" position. The transit time to move the source should be < 5 s, if practical; otherwise, for times > 5 s, a calibration factor should be applied and any additional uncertainty accounted for in the uncertainty determination.

2.16.3.5 A support system should be used to position the instrument under test at a known distance and angle relative to the calibration source. The support should be rigid, but designed to minimize scattered radiation. It should be possible to move the instrument such that the instrument-to-source separation distance can be varied, and this distance should be measurable to within an uncertainty of 1 mm.

2.16.3.6 An appropriate phantom should be used for mounting dosimeters for irradiation. At this writing, ANSI, ISO, and ICRU all recommend slightly different phantoms. Until this situation is resolved, the choice of phantom should be decided in consultation with NIST.

2.16.4 Equipment

The neutron source(s) should be selected from among those recommended in ISO 8529-1:2001 (^{252}Cf, D_2O-moderated ^{252}Cf, ^{241}Am-Be(α,n), ^{241}Am-B(α,n)). More than one type of source may be required. In addition, sources of different strengths might be required to cover the entire range of required dose equivalents without the irradiation times becoming either inconveniently long, or so short that the source transit time introduces a significant uncertainty. The emission rates for the sources should be traceable to the National Institute of Standards and Technology or to another national measurement institute that has participated in international key comparisons with NIST in the applicable measurement area.

2.16.5 Test and calibration methods and method validation

2.16.5.1 At this writing, NIST recommends the use of the fluence-to-dose equivalent conversion coefficients given in ISO 8529:2001. Since this will probably change within the next year or two, it is recommended that the conversion coefficients be decided upon in consultation with NIST.

2.16.5.2 It is very important that corrections be made for neutron scattering from the surfaces of the calibration room, and from the air in the room. Various aspects of these corrections are discussed in Schwartz and Eisenhauer, 1982; ISO/DIS 10646:1992; Eisenhauer, 1989; Kluge, Weise, and Hunt, 1990; and Eisenhauer, Schwartz, and McCall, 1987. The correction method should be worked out in consultation with NIST, and should be completely documented.

2.16.6 Handling of test and calibration items

All the dosimeters of a particular batch, including controls, should be kept together at all times, except when the irradiations are actually being performed. During the irradiations, all dosimeters except those actually being irradiated should be kept in an area well-shielded from any radiation sources.

2.16.7 Reporting the results

2.16.7.1 The calibration report is a permanent archival document. The original should be sent to the institution for which the calibration was done, and copies kept on file at the laboratory. The calibration report should contain at least the following information, as appropriate:

a) General information

1) type and serial number(s) of item(s) irradiated,

2) date of irradiation,

3) identification number(s) of source(s) used and their emission rate(s) at time of irradiation,

4) fluence-to-dose equivalent conversion coefficients used (these may be referenced or provided under separate cover, and

5) average temperature and relative humidity during irradiation.

b) Specific irradiation data

1) source-phantom or source-detector distance,

2) calculated "free field" dose equivalent,

3) length of time of irradiation,

4) total dose equivalent,

5) corrections applied, and

6) estimated uncertainty in the total dose equivalent.

c) Narrative description

All calibration reports should also include a brief narrative description of the physical arrangement for the irradiations and a brief discussion of the uncertainties. The description may be a drawing or a combination of text and drawing.

2.16.7.2 Uncertainties

ISO/DIS 10647:1992 contains a complete discussion of the uncertainties involved in these irradiations; this should be used as the basis for assigning an uncertainty to the calibration.

2.17 Criteria for a high-dose radiation dosimetry calibration laboratory

2.17.1 Scope

The criteria contained in this part of the document apply to laboratories that calibrate high- dose dosimeters at absorbed-dose levels appropriate for radiation processing (gamma rays, electron beams, or x-ray (bremsstrahlung) beams. These criteria are supplementary to the general criteria contained in 2.2 and should be followed if this specific irradiation service is offered and its inclusion in the Scope of Accreditation is desired. In that case, both the general criteria and these specific criteria should be followed.

2.17.2 Definitions

See ASTM E 170 and section 1.5 of this handbook.

2.17.3 Specific criteria for calibrations using photons and electrons

2.17.3.1 Scope

This section sets specific requirements to which a laboratory should adhere if it is to be accredited for calibrations using gamma rays, electron beams, or x-ray (bremsstrahlung) beams. The criteria contained in this section apply to high-dose calibration of dosimeters at absorbed-dose levels appropriate for radiation processing.

2.17.3.2 Quality system

The absorbed-dose rate of the high dose calibration facility of the laboratory should be within ±5 % of the value defined by comparison with the appropriate national standard. This level of agreement with the national standard should be demonstrated through periodic proficiency tests of the laboratory by a national or international standards laboratory.

2.17.3.3 Facilities and environment

a) If interpretation of the response of a particular type of dosimeter requires a history of the environmental conditions, the temperature and humidity should be recorded.

b) Fluorescence lamps, sunlight, and other sources of ultraviolet light should be filtered, if the dosimeters are adversely affected by ultraviolet radiation.

c) Any area used for storage of dosimeters should have its temperature and relative humidity controlled as required for the specific dosimetry system employed.

2.17.3.4 Equipment

2.17.3.4.1 Radiation source(s) for high-dose calibration facilities

a) The laboratory should have access to a source of gamma radiation, either ^{60}Co or ^{137}Cs, with a fluence rate sufficient to deliver an absorbed dose within the range of 10 Gy to 10^5 Gy (10^3 rad to 10^7 rad) within a reasonable time.

b) In addition, the laboratory may have an electron beam or x-ray beam (bremsstrahlung) radiation source, or both, that can provide dose rates appropriate to radiation processing conditions.

2.17.3.4.2 Characterization of the radiation field

a) Determine the absorbed-dose rate in each location in which dosimeters are irradiated using reference standard dosimetry systems. Assure that dosimeters are irradiated in the locations where the dose rate is determined. Dose rates should be traceable to appropriate national standards by direct measurement intercomparisons.

b) Ensure that the absorbed-dose rate over the volume in which dosimeters are irradiated does not vary more than ±1 % (at a 95 % level of confidence) from its average value.

c) If the dosimeters are irradiated in open air (for example, with a beam-port or panoramic irradiator), ensure that the room is of sufficient size and design such that scattered radiation at each position where dosimeters are placed for irradiation does not compromise the specified overall accuracy goals.

d) Monitor and control the temperature of the irradiation volume during irradiation to the degree required by the characteristics of the dosimeter. Measure this temperature during a simulated irradiation of dosimeters or in a manner that will not perturb the radiation field during the irradiation of dosimeters.

e) Maintain information related to the photon or electron energy spectrum at each dosimeter irradiation location.

f) Minimize low-energy components of the photon source spectrum through the use of a filter box when dosimeters used for radiation hardness testing are irradiated. For additional information see ASTM E 1249 and ASTM E 1250.

2.18 Criteria for a radionuclide source calibration laboratory

2.18.1 Scope

The criteria contained in this part of the document apply to laboratories that calibrate or manufacture and certify radionuclide sources. These criteria are supplementary to the general criteria contained in 2.2 and should be followed if either of these specific services is offered and its inclusion in the Scope of Accreditation is desired.

2.18.2 Assuring the quality of test and calibration results

2.18.2.1 Periodic performance tests should be performed to demonstrate the operability and accuracy of measuring equipment. These tests should be performed daily or prior to use.

2.18.2.2 The laboratory should have control standard sources, traceable to the National Institute of Standards and Technology or to another national measurement institute that has participated in international key comparisons with NIST in the applicable measurement area. The laboratory should use these control standard sources as a system check prior to calibrations.

2.18.2.3 Sources derived from material which are certified to have traceable measurements should be tested prior to distribution to verify the certificate value. For derived sources made in batches, appropriate sampling of the batch is acceptable if the process has been demonstrated to produce reproducible sources or that it is unlikely to have significant differences between sources.

2.18.2.4 Appropriate tests should be performed to demonstrate the stability of sources over their expected lifetimes. Examples of areas of concern include: radiation damage for high-level sources, plateout of radionuclides from solution, and homogeneity of solid sources.

2.18.3 Accommodation and environmental conditions

2.18.3.1 The laboratory facilities should include space and utilities appropriate for the scope of work performed. This should include control of environmental factors such as temperature, humidity and other parameters that could impact the quality of radionuclide sources. If a facility is utilized for the production of both low-level sources (less than 100 μCi) and high-level sources (greater than 100 μCi), then production areas should be physically separated to prevent cross contamination of samples.

2.18.3.2 The laboratory areas should include appropriate equipment such as fume hoods, glove boxes, safety showers, and other appropriate personnel safety gear. Adequate bench space for the number of employees working in the facility should be provided. Laboratory areas should be maintained to ensure the work areas are neat, clean, and orderly. Environmental conditions should be maintained as appropriate for specific operations. For example, analytical balances should be used in areas that are relatively free from dust, air currents, and excessive vibration. A stable source of electrical power, preferably regulated and uninterruptible, should be available for radiation detection instrumentation.

2.18.4 Equipment

Equipment for the calibration of radionuclide sources should be maintained and controlled by the laboratory performing calibrations. Instrumentation should be "state of the art," with respect to current technology for calibrating radionuclides. The calibration facility should maintain equipment necessary to measure potential contaminants or interferences. For example, if gamma-ray emitting radionuclides are calibrated with an ionization chamber, then high-resolution gamma spectroscopy should be available for assaying gamma-emitting impurities. Alpha-particle spectrometry may be necessary to assay impurities in alpha-emitting sources that are calibrated by liquid-scintillation counting.

2.18.5 Test and calibration methods and method validation

2.18.5.1 The calibration of radionuclides and production of sources should be documented so that each step of the process can be verified or checked.

2.18.5.2 More than one technique should be utilized for calibrations or a different technique utilized for verification of the primary technique.

2.18.6 Handling of test and calibration items

2.18.6.1 Contamination levels in laboratory areas should be strictly controlled to prevent contamination of personnel and samples. This may require more stringent control of radionuclide contamination than required for personnel safety by applicable regulatory requirements. Appropriate instrumentation and monitoring procedures should be used to monitor the cleanliness of work areas utilizing radioactive material.

2.18.6.2 Radiation-detection equipment should be physically separated from process areas for radioactive materials. If common facilities are utilized for both low-level and high-level radionuclide measurements, then strict contamination-control procedures should be employed before samples are transferred from production areas to the counting room(s).

2.18.6.3 The packing and shipping area should be separate from the production areas. The exteriors of all packages of radioactive material should be monitored for removable contamination before transfer to the shipping area.

2.18.7 Reporting the results

2.18.7.1 Minimum information

The calibration laboratory should provide a certificate for each standard that should include at least the following information:

a) Producer.

b) Radionuclide calibrated.

c) Identification number.

d) Activity or emission rate with associated uncertainties—The certificate should contain a clear and unambiguous statement of overall uncertainty with the method by which the different components of error were combined. The stated uncertainty should not be lower than those verified by the national measurement institute for a given technique.

e) Calibration date and time (if appropriate for the half-life* of the radionuclide)—The certificate should include decay data and references relevant to the calibration and intended use of the source.

   Notes accompanying the sources should provide warnings about any special precautions to be taken in the use of the source (such as those relating to fragility or sensitivity to moisture). Application notes dealing with common problems (cascade summing, interference from Compton edge, etc.) affecting complex applications such as gamma spectrometry should be included.

f) Physical and/or chemical description of the source (see 2.18.7.2 a)).

g) Radiochemical purity (see 2.18.7.2 c)) (identification and assay of contaminants is recommended).

2.18.7.2 Supplemental information

Supplemental information, including preparation and use, may be presented in accompanying notes or attachments to the certificate. In addition to the information required above, supplemental information should be provided in the following areas.

a) Physical description of the source

Liquid sources to be dispensed quantitatively by the user should be described in terms of chemical composition, acidity, carrier concentration, density, and total quantity in grams. Special information needed for further dilution or deposition should be given in notes. For mixtures of solid particles (soil, dried biological materials, etc.), the details of homogeneity tests and the limiting sample size for which the standard may be used should be stated. Gas-mixture certificates should include descriptions of diluting gases when applicable. Sources to be used directly should address radiation scattering and absorption unless the sources are exact replicates of samples to be measured by the user. Source dimensions including active area for filters and radionuclide distribution for charcoal cartridges should be specified as part of the certificate. Blank samples or construction material (i.e., mylar covering) should be available to a user for evaluating

transmission or attenuation when necessary. Resolution tests for alpha-particle or low-energy photon sources should be described in sufficient detail to permit the user to determine applicability for use. Large-area sources (greater than 10 cm^2) should be characterized with respect to surface uniformity.

b) Calibration method

The calibration method should be specified. For comparative measurements, both the comparison instrument and the origin of its calibration should be specified. Literature reference may be given if the method is not generally used, or if special corrections or calculations are required.

c) Purity

All identified impurities, including progeny, should be listed together with their measured activity and uncertainty. A limit should be indicated for other possible impurities, as inferred from the known sensitivity of the stated measurement technique, with special mention of any impurities likely to have been produced with the primary nuclide.