



American National Standard

ANSI/HPS N13.11-2022

Personnel Dosimetry Performance – Criteria for Testing

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American National Standards Institute, Inc.



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The ANSI/HPS N13.11 Working Group responsible for the development of this 2022 standard revision wishes to acknowledge the members of previous working groups, whose work we are continuing, and without whose efforts the current standard would not exist. The current Working Group had the following members:

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Foreword

(This foreword is not a part of American National Standard ANSI/HPS N13.11-2022.)

This American National Standard provides a procedure for testing the performance of dosimetry systems (i.e., the hardware, the software, and the processor supplying the services, or in some cases, the user of the services) for the purpose of monitoring personnel exposure to ionizing radiation. In 1973, the Conference of Radiation Control Program Directors appointed a task force with state and federal participation. The purpose of this task force was to implement the Conference recommendation for the establishment of a program for testing of personnel dosimetry performance throughout the United States on a continuing basis. After ten years of development and pilot testing, the first standard was issued in 1983 as ANSI N13.11-1983. That standard formed the basis of the Nuclear Regulatory Commission's (NRC) test program administered by the National Voluntary Laboratory Accreditation Program (NVLAP). The Department of Energy (DOE) modified ANSI N13.11-1983 for use at DOE facilities and, in 1986, issued DOE/EH-0027 as the standard that formed the basis of DOE's test program known as the DOE Laboratory Accreditation Program (DOELAP).

By ANSI policy, standards must undergo periodic review and modification if necessary. After extensive review, the first modification of ANSI N13.11-1983 was issued in 1993 as HPS N13.11-1993. The Working Group for that effort believed that it was not possible to write a useful standard without considering how the standard is applied in the real world. Consequently, it had hoped to produce a product that would be acceptable to both the DOE and the NRC, but the DOE did not accept it. The third version, HPS N13.11-2001, was developed by a Working Group that convened in 1996 and worked through 2000. The overarching objective of this Group was to produce one standard to suit the needs of both the DOE and the NRC (and the states) for their DOELAP and NVLAP programs. This objective is prudent because it makes sense for the United States to have a single dosimeter performance test program. Other Group objectives were to simplify the standard, to reduce the number of test dosimeters required, and to take no action that would prevent or preclude the use of electronic dosimeters or other future technology. Still, the DOE did not adopt the standard.

The fourth version of the standard, ANSI/HPS N13.11-2009, was developed by a Working Group convened in 2005, which worked through 2007. This Group was made up of people with widely varied backgrounds, including DOELAP and NVLAP assessors, dosimeter vendors, government, military, national standards laboratories, and the nuclear power industry. The Group held eight meetings over a period of three years to create this third revision of the original standard. The members of the present Working Group reaffirmed this version in 2015. It has proven to have been successful in achieving the goal of having a single standard for both the NVLAP and DOELAP accreditation programs.

The members of this Working Group (WG) met annually at the Health Physics Society conferences, then nearly monthly online during the 2020-2021 coronavirus pandemic. As a result of these discussions, many issues were identified that were considered in the writing of this version of the standard. The following paragraphs describe how the Group implemented the resolution of many of the issues. Some of these items are treated in detail in the appendices.

The test category structure remains the same as the 2009 version of the standard, except for the addition of a fourth subcategory in Category V, Neutron/Photon mixtures, which uses an $^{241}\text{AmBe}$ source for testing. The number of photon spectra used for testing was slightly lowered with the removal of the two NIST Special (S) series beam codes. The WG added greater detail in the exact

application of the testing in the various categories, including limits to the number of dosimeters used in photon testing. Test irradiation ranges remain unchanged.

The performance criteria remain unchanged from the 2009 revision of this standard. The tolerance equation, first instituted in the extremity dosimeter performance testing standard, ANSI/HPS N13.32-2008, is $B^2 + S^2 \leq L^2$, where B is the bias, S is the standard deviation, and L is the tolerance level. The values of L (0.24 for the accident photon category and 0.3 for all other categories) remain unchanged, as well as the conversion coefficients for photons.

Finally, the WG discussed the possibility of adding testing for the dose to the lens of the eye. In the end it was decided that this would not be added to this revision. The details of this discussion are given in Appendix J.

Suggestions and comments for improvement of this standard are welcome. Send suggestions to the Health Physics Society Standard Coordinator at 950 Herndon Parkway, Suite 450, Herndon, VA 20170; or by email to: awride-graney@burkinc.com.

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American National Standard for Dosimetry

Personnel Dosimetry Performance – Criteria for Testing

1. Purpose and Scope

1.1 Purpose. This standard establishes the test conditions and performance criteria for evaluating personnel dosimetry systems.

1.2 Scope. This standard applies to dosimetry systems used to determine personal dose equivalent for occupational conditions and absorbed dose for accident conditions. Tests are conducted under controlled conditions and include irradiation with photons, beta particles, neutrons, and selected mixtures of these radiations. The range of delivered absorbed doses or personal dose equivalents and tolerance levels are based on considerations of radiation protection expressed in current publications of the National Council on Radiation Protection and Measurements (NCRP) [1], the International Commission on Radiation Units and Measurements (ICRU) [2], and the International Commission on Radiological Protection (ICRP) [3-4]. Organizations should be tested in those categories which best represent the dosimetry services they provide or use. The tests outlined in this standard may be used to test the suppliers of dosimetry services (processors).

The standard integrates angular testing using photon fields incident at various angles to the plane of the dosimeter. Such tests provide the test participant with:

- a method to continuously evaluate long-term changes in dosimeter construction, and
- information for improving absorbed dose or personal dose equivalent estimation under field conditions.

There are several dosimetry uses and radiological conditions that are outside the scope of this standard because of dosimeter design, limitations of dosimetry systems, and practical considerations of testing equipment and sources. These include:

- thermal neutrons,
- high energy neutrons ($\bar{E} \geq 5$ MeV)

- extremity dosimeters (covered in ANSI/HPS N13.32-2018)
- lens of the eye dosimeters, and
- nuclear criticality accident dosimeters.

The scope of this standard is sufficiently comprehensive that satisfactory performance implies that a dosimetry processor or user is competent to assess personal dose under a broad range of field conditions using the dosimetry system for those categories for which they were tested.

2. Definitions

absorbed dose, D . The quotient of $d\bar{\epsilon}$ by dm where $d\bar{\epsilon}$ is the mean energy imparted by ionizing radiation to matter of mass dm , thus

$$D = \frac{d\bar{\epsilon}}{dm} \quad (\text{Eq. 1})$$

Unit: J kg⁻¹

NOTE 1: The special name for the unit of absorbed dose is gray (Gy). The special unit of absorbed dose, rad, is 10⁻² Gy.

NOTE 2: The definition of the absorbed dose, D , as a point function, allows the specification of the spatial variations of D as well as the distribution of the absorbed dose in linear energy transfer at the point of interest.

NOTE 3: Shallow absorbed dose is defined as the absorbed dose at a depth of 0.07 mm in ICRU tissue and is denoted by $D(0.07)$. Deep absorbed dose is defined as the absorbed dose at a depth of 10 mm in ICRU tissue and is denoted by $D(10)$.

air kerma, K_a . 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 of mass dm , thus

$$K_a = \frac{dE_{tr}}{dm} \quad (\text{Eq. 2})$$

NOTE: The unit of the air kerma is gray which has units of joules per kilogram (J kg⁻¹)

average energy, $\bar{E}$. The fluence-weighted average energy of a field of photons, beta-particles, or neutrons calculated as

$$\bar{E} = \frac{\int_{E_{min}}^{E_{max}} N(E)E dE}{\int_{E_{min}}^{E_{max}} N(E)dE} \quad (\text{Eq. 3})$$

where,

$N(E)$ is the fluence with energy between E and $E+dE$,

E_{max} is the maximum energy present in the spectrum, and

E_{min} is the minimum energy considered for the average.

bias, B . The mean value of the performance quotient, P_i , of a set of dosimeter test results

$$B \equiv \bar{P} = \left(\frac{1}{n}\right) \sum_{i=1}^n P_i \quad (\text{Eq. 4})$$

where the sum is extended over all n values of P_i for a particular test in a given radiation category (or subcategory), and for a particular phantom depth (shallow or deep), and where n is the number of test dosimeters included in the test for that category and depth.

calibration. The quantitative determination, under a controlled set of standard test conditions, of the reading given by a dosimeter as a function of the value of the quantity to be measured.

conventional true value. The quantity value attributed by agreement to a quantity for a given purpose.

NOTE 1: The conventional true value is the best estimate of the value of the quantity to be measured, determined by a primary standard or a transfer standard that is traceable to a primary standard. Within an organization, the result of a measurement obtained with a secondary standard instrument may be taken as the conventional value of the quantity to be measured.

NOTE 2: A conventional true value is, in general, regarded as being sufficiently close to the true quantity value for the difference to be insignificant for the given purpose.

conversion coefficient. The quotient of personal dose equivalent, $H_p(d, \alpha)$, by the quantity for which the field is calibrated ("field quantity"), air kerma or fluence, averaged over the field spectrum, thus

$$\bar{c}_{K,d,\alpha} = \frac{H_p(d, \alpha)}{K_a}$$

for photons

(Eq. 5)

$$\bar{c}_\varphi = \frac{H_p(10)}{\varphi_n}$$

for neutrons

(Eq. 6)

where for photons, d is 0.07 mm in ICRU tissue for the shallow depth and 10 mm for the deep depth, and α is the angle of radiation incidence.

NOTE 1: The unit of the conversion coefficient is Sv Gy^{-1} (rem rad^{-1}) for photons and Sv m^{-2} (rem m^{-2}) for neutrons.

NOTE 2: For the purposes of this standard, photon conversion coefficients for ISO x-ray beam codes and ^{241}Am are taken from [5] and for the NIST x-ray beam codes, ^{137}Cs , and ^{60}Co from [6]. For neutrons, values for the conversion coefficients are taken from [7].

NOTE 3: For beta particles, since the field quantity is absorbed dose and the quality factor is unity, the conversion coefficient is unity.

NOTE 4: For accident-level dosimetry, the delivered quantity is expressed in terms of absorbed dose to tissue, and the conversion coefficients are expressed in terms of absorbed dose to tissue per air kerma, D_T/K_a .

dosimeter. A device to assess the absorbed dose or personal dose equivalent from ionizing radiation received by a person. The dosimeter consists of radiation-sensitive elements and their surrounding packaging.

equivalent dose, $H_{T,R}$. The product of $D_{T,R}$ and w_R , where $D_{T,R}$ is the mean absorbed dose in an organ or tissue, T , and w_R is the radiation weighting factor for the radiation, R , incident on the body, thus

$$H_{T,R} = w_R D_{T,R} \quad (7)$$

NOTE 1: The unit of the equivalent dose is joules per kilogram (J kg^{-1}) with the special name sievert (Sv). The special unit of equivalent dose, rem, is 10^{-2} Sv.

NOTE 2: For the purposes of this standard, for photon and beta radiation, the radiation weighting factor has the value unity.

full width at half maximum, FWHM. The width of a continuum spectrum at half of its maximum value, neglecting any monoenergetic lines.

half-value layer. The thickness of material that reduces the air kerma of a radiation beam by one-half.

homogeneity coefficient. The ratio of the first and second half-value layers times 100.

ICRU tissue. A tissue-equivalent (TE) material defined in ICRU Report 33 [8] having a density of 1 g cm^{-3} and composition by mass of 76.2% oxygen, 10.1% hydrogen, 11.1% carbon and 2.6% nitrogen.

irradiating laboratory, IL. A laboratory possessing radiation sources, calibration equipment, and associated facilities that is able to irradiate dosimeters to radiation quantities known to a high degree of certainty.

particle fluence, ϕ . The quotient of dN by da , where dN is the number of particles incident on a sphere of cross-sectional area da

$$\phi = \frac{dN}{da}$$

(Eq. 8)

NOTE: The unit of particle fluence is m^{-2} .

performance criteria. Performance in a given category is considered adequate if, for the personal dose equivalent or absorbed dose,

$$B^2 + S^2 \leq L^2$$

(Eq. 9)

where B is the bias and S is the standard deviation for a particular category or subcategory, and L is the tolerance level.

The values of the tolerance level, L , is $L = 0.24$ in the accident category (Category I) and $L = 0.30$ in the other categories.

performance quotient, P_i . For the i^{th} dosimeter

$$P_i \equiv [H_R(d)_i - H_p(d)_i]/H_p(d)_i$$

(Eq. 10)

where $H_p(d)_i$ is the conventional true value of the personal dose equivalent assigned by the irradiating laboratory to the irradiated dosimeter and $H_R(d)_i$ is the corresponding personal dose equivalent reported by the test participant.

For the accident category, the same definition applies with the absorbed dose, D , replacing the personal dose equivalent, $H_p(d)$.

personal dose equivalent, $H_p(d)$. The dose equivalent in soft tissue as defined in ICRU 51 [9] below a specified point on the body at an appropriate depth d .

NOTE 1: The individual equivalent dose defined in ICRP 60 [4] is equivalent to the personal dose equivalent defined in ICRU 47 [2].

NOTE 2: The unit of the personal dose equivalent is joule per kilogram (J kg^{-1}) with the special name sievert (Sv). The special unit of personal dose equivalent, rem, is 10^{-2} Sv.

NOTE 3: Any statement of personal dose equivalent should include a specification of the depth, d , expressed in millimeters.

NOTE 4: Shallow dose equivalent is defined as the personal dose equivalent at a depth of 0.07 mm in ICRU tissue and is denoted by $H_p(0.07)$. In ICRP 60 [4], shallow dose equivalent is given the name individual dose equivalent, superficial. Deep dose equivalent is defined as the personal dose equivalent at a depth of 10 mm in ICRU tissue and is denoted by $H_p(10)$. In ICRP 60, deep dose equivalent is given the name individual dose equivalent, penetrating.

processor. A supplier of personnel dosimetry services. These services may include:

- (1) furnishing dosimeters to the user,
- (2) evaluating the readings of the dosimeters in terms of the absorbed dose or personal dose equivalent as prescribed in this standard,
- (3) recording the results, and
- (4) reporting the results to the user.

radiation field, R . A region in which ionizing radiation of a known type, energy, and direction is present, and for which intensity can be quantified at one or more points in terms of a field quantity such as fluence or air kerma rate.

reference dose point, RDP. The point in the radiation field at which the field quantity is specified. For the tests described in this

standard, the RDP is on the surface of the phantom along the central ray of the radiation field passing through the center of the phantom.

reference orientation. The orientation for which the direction of incident radiation coincides with the reference direction (as specified by the test participant) of the dosimeter.

residual maximum beta energy, E_{res} . The highest value of the energy of a beta particle spectrum at the reference dose point after having been modified by scatter and absorption.

standard deviation, S . A statistical measure of the variation in the results, defined as

$$S \equiv \sqrt{\frac{\sum_{i=1}^n (P_i - \bar{P})^2}{n-1}}$$

(Eq. 11)

where the sum is extended over all n values of P_i included in the test for a particular test depth and test category or subcategory, and $\bar{P}$, the mean performance quotient, is defined as

$$\bar{P} = \left(\frac{1}{n}\right) \sum_{i=1}^n P_i$$

(Eq. 12)

standard test conditions. The range of values of a set of influence quantities under which irradiation of dosimeters is carried out.

NOTE: Ideally, IL dosimeter irradiations should be carried out under reference conditions. As this is not always achievable (e.g., for ambient air pressure) or convenient (e.g., for ambient temperature), adjustments are made for deviations from reference conditions. The standard test conditions, together with the reference conditions applicable to this standard, are given in Appendix G.

testing organization. A group, independent of the test participant's operation, that administers and evaluates the performance testing of participants. The testing organization may include the IL.

tolerance level, L . The boundary of acceptable performance of a dosimetry system.

3. Test Procedure

This section specifies the performance test procedure. The procedure is summarized below.

- The test participant selects the categories for which evaluation is sought.
- The test participant submits dosimeters, representative of those supplied to customers, to the IL. The participant supplies the number of dosimeters required for testing in the requested test categories.
- The IL irradiates the dosimeters in the radiation field(s) specified for applicable categories.
- The IL returns the dosimeters to the test participant for evaluation.
- The test participant evaluates the response of the irradiated dosimeters in terms of the absorbed dose or personal dose equivalent at the specified test depths.
- The test participant reports the results of the dosimeter evaluation to the IL.
- The testing organization evaluates the dosimeter performance based on criteria in this standard.
- The testing organization notifies the test participant of the dosimeter performance.

3.1 Administrative Procedure

3.1.1 Information to be Supplied to the Irradiating Laboratory. Prior to the start of a test, the test participant shall provide the following information to the IL:

- The test categories and subcategories.
- A description of dosimeter design, including nomenclature, holder, pictures, or schematics showing construction.
- Specification of the reference orientation and/or associated sensitive element offset.
- Whether a clip is used that would normally be situated behind the dosimeter holder (i.e., in such a way that it would create an offset under normal wear circumstances). If such a clip is applied, representative clips shall be furnished with and mounted upon the proficiency testing dosimeters.
- Instructions necessary to prepare for irradiation, obtain intermediate readings or final readings via telemetry that may be applicable to either electronic or hybrid dosimeters being tested.

- Identification of the dosimeter algorithm and revision applied to the test.

The test participant may supply the distance from the phantom face to the sensitive element(s) with the dosimeter mounted parallel to the phantom face. This parameter is optional and, if provided, may be used by the IL to adjust absorbed doses or personal dose equivalents delivered to dosimeters to account for displacement of the sensitive element(s) from the reference dose point. If it is not supplied, the IL will cite the dose delivered at the RDP.

Following each test round, the participant shall supply the following for each set of irradiated dosimeters:

- The assessed personal dose equivalent (absorbed dose to tissue, if Category I) at the depth(s) in tissue required for each category (see Table 1a) for each dosimeter irradiated. Dosimeter results shall be reported to the same level of precision as is reported to users.
- Situations requiring an irradiated dosimeter to be voided (see section 3.1.3).

3.1.2 Test Schedule. A test shall consist of three separate iterations (or rounds) performed over a period of approximately three months. According to the testing organization's or IL's direction, at the start of the testing period, the participant will submit to the IL either the total number of dosimeters required for testing, or only the dosimeters necessary for the first round of testing. In this latter case, additional dosimeters are submitted for each successive round. The IL will irradiate the dosimeters in each of the three rounds and return irradiated dosimeters to the test participant within 15 calendar days from the end of each round. The test participant should report results within 15 calendar days of receiving the dosimeters. Failure to submit all dosimeter evaluations by the requested date may, at the discretion of the testing organization, result in failure. If for technical reasons the test participant needs to void a reported result, this must be done prior to the IL reporting the test results.

3.1.3 Voiding Dosimeters. For a situation in which the result of a dosimeter is in doubt due to inadvertent problems in the normal analytical process, the test participant is allowed to void a reported result prior to the reporting of the test results by the IL. No more than one (1) dosimeter

per round may be voided. If a dosimeter must be voided from the first or second rounds, the processor may request replacement irradiations during the remaining round(s). Replacement irradiations will be at the discretion of the IL.

All categories contain one (1) or more subcategories that require a minimum number of dosimeters to be exposed using a specified condition (e.g., irradiated at angles, under mixtures of radiation energies, within specific energy bounds, etc.). Under some conditions, voiding dosimeters may result in not reaching these minimum criteria. If this occurs, replacement irradiations shall suit the requirement of the subcategory to the extent possible.

For any dosimeters that are voided without replacement irradiations, the participant shall retain objective evidence of the technical justification, and a succinct explanation of why the void was necessary shall be provided to the IL for inclusion in the summary report.

The IL may void mis-irradiated dosimeters. When these occur and are noted during the round, the IL should provide correctly irradiated replacements using provided spare dosimeters in the round during which the mis-irradiation occurred or in subsequent rounds. When such mis-irradiations are not noted until after all irradiations have been completed, the IL may request the participant to provide additional dosimeters to provide corrected irradiations or void any suspect or confirmed mis-irradiated dosimeters from the testing. If more than one dosimeter per category has been mis-irradiated, the participant is strongly encouraged to submit dosimeters for replacement irradiations.

3.1.4 Number of Test Dosimeters. The test participant shall submit fifteen (15) dosimeters (five (5) per round) for each subcategory selected for evaluation, except for the subcategories of Category II, which will require 21 dosimeters (seven (7) per round). Additional dosimeters, as specified by the IL, shall be included with each round as control and replacement dosimeters in case problems are encountered. All dosimeters submitted for testing shall be randomly selected from the general population supplied to customers.

3.1.5 Information to be Supplied to Test Participants.

The IL will report the following information to the test participant:

- The range of irradiation dates for each round of testing that would facilitate correction of dosimeter response for fade.
- The identities of dosimeters irradiated in each of:
 - Category I (accidents),
 - Subcategory VA (neutron/photon mixtures), however, the specific neutron source is not identified,
 - Subcategories VB, VC, and VD (neutron/photon mixtures), and
 - Subcategory IIID, if tests are simultaneously being conducted in other subcategories of Category III.
- If Category IA is selected, identities of the photon field (M150 or ^{137}Cs) used for irradiation of specific dosimeters.
- The identities of specific dosimeters when the testing laboratory returns the dosimeters. These include dosimeters:
 - designated (by the participant) as transit controls,
 - mis-irradiated,
 - designated as unused spares, and
 - voided by the IL (applicable to current or earlier test rounds)

No information shall be divulged to the test participant for other dosimeters until the test results are released.

The IL will record the readings of all electronic dosimeters prior to shipping them back to the test participant. However, this will only be used in the event that electronic dosimeter measurements are not recoverable by the test participant.

3.1.6 Dissemination of Proficiency Test Results. The IL or testing organization shall report the proficiency results to the participant after the test is completed, including an estimate for the uncertainty of the assigned values of absorbed dose or personal dose equivalent.

3.2 Test Categories

The test categories are given in Table 1a and are described in further detail below. Further discussion is included in Appendix A. Each participant should be tested in the categories which best represent the services they provide.

3.2.1 Category I - Accident, Photons. High doses of photons from ^{137}Cs and NIST x-ray beam code M150 are used for the accident Category I. In the general subcategory IA, the radiation field in which each dosimeter is to be irradiated shall be chosen at random by the IL with the provision that at least three (3) dosimeters will be irradiated using each source. The participant will be informed of the radiation field used for each irradiated dosimeter. Subcategories IB and IC use only the specified source for all irradiations.

3.2.2 Category II - Photons/Photon Mixtures. This category comprises irradiations to single and mixed photon radiation fields. Its four (4) subcategories provide testing for different workplace environments. The IL will select 21 test dosimeters per subcategory chosen by the participant in Category II. Specific photon radiation fields and angle of radiation incidence shall be chosen at random by the IL for each irradiation, subject to the limits on numbers of dosimeters irradiated at non-perpendicular incidence, in mixture combinations, or with low average photon energies as specified in Table 1b. While that table is more comprehensive in its requirements, its major provisions include:

- At least five (5) dosimeters are to be irradiated in a non-mixture, high-energy photon field ($\bar{E} \geq 500 \text{ keV}$) at perpendicular incidence.
- For testing subcategory IIA, no more than five (5) dosimeters will be irradiated with photons with average energies below 70 keV.
- For subcategory IIB, all dosimeters will be irradiated in a non-mixture, high-energy photon field ($\bar{E} \geq 500 \text{ keV}$) produced using either ^{137}Cs or ^{60}Co . For subcategories IIA, IIC, and IID, at least five (5) and no more than ten (10) dosimeters shall be irradiated with mixtures. Mixtures always include one (1) irradiation with $\bar{E} \geq 500 \text{ keV}$ and one (1) irradiation with $\bar{E} < 500 \text{ keV}$.
- For subcategory IID, the specific low energy photon spectra chosen for testing by the IL are representative of plutonium environments (see Appendix A Section A2).
- If any dosimeter is irradiated with average photon energy less than or equal to 70 keV or is irradiated as a mixture, the irradiation(s) shall be conducted at perpendicular incidence.

- If the average energy of the photon field is greater than 70 keV, the angle of incidence for each irradiation shall be chosen at random by the IL from horizontal and vertical dosimeter orientations at angles of 0° , $\pm 40^\circ$ or $\pm 60^\circ$.
- The maximum number of dosimeters in any given subcategory irradiated at non-perpendicular incidence is specified in Table 1b.

3.2.3 Category III - Betas. This category comprises irradiations in a single beta particle radiation field. There are four (4) subcategories that provide testing for different workplace environments. All dosimeters are irradiated at perpendicular incidence. For the general beta subcategory IIIA, the specific beta irradiation field shall be chosen at random from the sources in subcategories IIIB and IIIC by the IL, with the provision that at least three (3) dosimeters shall be irradiated using the high-energy ($\bar{E} \geq 500$ keV) beta source and at least three using the low-energy ($\bar{E} < 500$ keV) beta source. Categories IIIB, IIIC, and IIID use only the specified source for all irradiations.

3.2.4 Category IV - Photon/Beta Mixtures. This category comprises irradiations to mixed photon and beta particle radiation fields. Dosimeters tested in this category shall be irradiated at perpendicular incidence in a beta field corresponding to the subcategory in which the participant is tested in Category III and in a photon field corresponding to the subcategory in which the participant is tested in Category II, with the exception that ^{60}Co shall not be used in this category. If the participant tested in Category IIIA, then a beta source shall be chosen at random by the IL for each irradiation with the provision that at least three (3) of the 15 dosimeters submitted for testing in this category shall be irradiated using the high-energy beta source ($\bar{E} \geq 500$ keV) and at least three (3) dosimeters using the low-energy beta source ($\bar{E} < 500$ keV). Specific photon radiation fields shall be chosen at random by the IL with the provision that at least three (3) of the dosimeters shall be irradiated with ^{137}Cs . If the specific beta radiation field is low-energy ($\bar{E} < 500$ keV), the ^{137}Cs field shall be chosen. If two (2) or more subcategories are tested in Category II and Category III, then multiple tests shall be performed as determined by the testing organization.

3.2.5 Category V – Neutron/Photon Mixtures.

This category comprises irradiations to mixed neutron and photon radiation fields. Dosimeters tested in this category shall be irradiated at perpendicular incidence. The specific neutron radiation field used for the general neutron-photon subcategory VA shall be chosen at random by the IL from the D_2O -moderated ^{252}Cf source and the unmoderated ^{252}Cf source with the provision that at least three (3) of the 15 dosimeters submitted for testing shall be irradiated using each source. Subcategories VB, VC, and VD use only the specified neutron source for all dosimeter irradiations. The specific photon radiation field in Category V shall be chosen at random by the IL from the fields in which the dosimeters were tested in Category II, with the exception that ^{60}Co shall not be used in this category, and with the provision that at least three (3) of the 15 dosimeters shall be irradiated using ^{137}Cs . If two or more subcategories are tested in Category II, then multiple tests shall be performed as determined by the testing organization.

3.3 Radiation Sources

The following radiation sources shall be available in the IL, as a minimum:

- (1) At least one (1) ^{137}Cs and, optionally, one (1) ^{60}Co gamma-ray source. The sources may be used either in a beam-type irradiator equipped with a collimator or free in air. The collimator may be either similar to those described in ISO 4037-1 [10] or of a design that does not significantly increase the scatter at the reference dose point (RDP; see Appendix A, Section A4). Similarly, the room dimensions in a free-in-air source geometry shall be sufficient to keep the expected value of the air kerma rate within 5% of that predicted by inverse square dependence. The IL will make measurements and verify that the shallow and deep personal dose equivalents agree to within 5%. Some adjustment of the field at the RDP may be necessary (see Appendix B, Section B1).
- (2) One or more constant potential x-ray machines to cover the range between 30 kV and 300 kV. Among the accessories shall be beam filters of compositions and thicknesses appropriate to produce the continuous x-ray spectra provided by the ISO [10] and NIST beam codes [11] specified in Tables 2a and 2b, respectively.

- (3) An ^{241}Am gamma-ray source, equipped with filtration sufficient to attenuate the low energy photons (< 40 keV) to less than 1% of the fluence of the 59.5 keV gamma radiation.
- (4) A sealed $^{90}\text{Sr}/^{90}\text{Y}$ beta-particle source encapsulated with 100 mg cm^{-2} (nominal) to absorb the ^{90}Sr beta particle. A beam-flattening filter as defined in ISO 6980-1 [12], or as needed to accommodate the dimensions of the source/irradiator, should be used. The produced reference field shall meet the following specifications:
- The residual maximum beta energy, E_{res} , as defined in the ISO 6980-1 [12] shall equal or exceed 1.80 MeV.
 - The in-phantom absorbed dose at 100 mg cm^{-2} , $D(1)$, divided by the in-phantom absorbed dose at 7 mg cm^{-2} , $D(0.07)$, shall be 1.01 ± 0.03 . [13] See Appendix E for details on the measurement approach.
 - The in-phantom absorbed dose at $1,000\text{ mg cm}^{-2}$, $D(10)$, shall be less than 1% of the in-phantom absorbed dose at 7 mg cm^{-2} , $D(0.07)$. [13] See Appendix E for details on the measurement approach.
- (5) A sealed ^{85}Kr beta-particle source. A beam-flattening filter as defined in ISO 6980-1 [12], or as needed to accommodate the dimensions of the source/irradiator, shall be used. The produced reference field shall meet the following specifications:
- The residual maximum beta energy as defined in ISO 6980 [12], shall equal or exceed 0.53 MeV.
 - The in-phantom absorbed dose at 20 mg cm^{-2} , $D(0.2)$ divided by the in-phantom absorbed dose at 7 mg cm^{-2} shall be 0.80 ± 0.05 . See Appendix E for details on the measurement approach.
- (6) A slab of natural or depleted uranium, of dimensions exceeding the dimensions of the dosimeters being irradiated, covered by between 3 and 7 mg cm^{-2} of polyethylene terephthalate (e.g., Mylar®) and meeting the following specifications:
- The in-phantom absorbed dose at 100 mg cm^{-2} , $D(1)$, divided by the in-phantom absorbed dose at 7 mg cm^{-2} , $D(0.07)$, shall be 0.58 ± 0.04 . See Appendix E for details on the measurement approach.
 - The in-phantom absorbed dose at 1000 mg cm^{-2} , $D(10)$, shall be less than 3% of the in-phantom absorbed dose at 7 mg cm^{-2} , $D(0.07)$. See Appendix E for details on the measurement approach.
- (7) One or more sealed ^{252}Cf neutron source(s), able to be used bare and at the center of a D_2O moderating sphere 30 cm in diameter covered with a cadmium shell with a thickness in the range of 0.5 mm to 1 mm to produce energy distributions consistent with specifications in ISO 8529-1 [14]. For the purposes of this standard, this latter configuration is referred to as "moderated."
- (8) A sealed $^{241}\text{AmBe}$ neutron source filtered to reduce low-energy photons. The photon dose equivalent rate should be $< 5\%$ of the neutron dose equivalent rate. Detailed features of an ideal $^{241}\text{AmBe}$ neutron energy distribution is provided in ISO 8529-1 [14].

Details associated with each of the radiation sources are presented in Tables 2a, 2b, 2c, and 2d.

3.4 Phantom Construction

Photon and neutron performance tests shall be performed on a slab of polymethyl methacrylate (PMMA) with a thickness of 15 cm and a face no smaller than 30 cm x 30 cm. For $^{90}\text{Sr}/^{90}\text{Y}$ and ^{85}Kr performance tests, the phantom shall have a thickness of at least 5 cm and a face no smaller than 30 cm x 30 cm (see Section A6 of Appendix A).

A measurement shall be performed on phantoms used for photon irradiations to ensure that the phantoms provide the correct amount of backscatter. The measured backscatter from a NIST-traceable H60 x-ray beam code, as determined with a small volume ionization chamber (see Appendix A Section A6), shall be 1.54 ± 0.03 .

3.5 Irradiation Conditions. The dosimeters shall be irradiated using a phantom backing, except for on-contact uranium slab-source exposures. The IL shall mount dosimeters on the phantom surface facing the source ("front face"). The backplanes of the mounted dosimeters shall be parallel to the surface of the phantom. The IL shall position the surface of the phantom at the

RDP. For irradiations conducted at non-perpendicular incidence, the phantom will be rotated about the RDP; angles of incidence (α) are measured with respect to a line drawn through the center of the source and the center of the phantom. The angle of incidence (α) shall be the angle between this line and a line drawn through the center of the front face and perpendicular to it.

The irradiation distance between the center of the irradiation sources and the center of the phantom front face shall be:

- not less than 1 m for all photon sources except ^{241}Am , which shall be not less than 0.5 m,
- not less than 0.3 m for $^{90}\text{Sr}/^{90}\text{Y}$ beta sources, at 0.3 m for ^{85}Kr , in contact for natural or depleted uranium, and
- not less than 0.5 m nor greater than 1.0 m for neutron sources (see Appendix B Section B3).

The IL may elect to irradiate several dosimeters simultaneously. The laboratory should take reasonable precautions to keep the mutual interference from the dosimeters low in comparison with the uncertainty of the absorbed dose or personal dose equivalent delivered to the dosimeters.

In the case of neutron irradiations, the laboratory shall not position the sensitive element(s) of the dosimeter closer than 10 cm to the phantom edge. In the case of photon irradiations, the sensitive element(s) shall not be closer than 7.5 cm to the phantom edge.

3.6 Selection of Irradiation Levels

In each category, the values of the logarithms of the personal dose equivalent (or absorbed dose) shall be chosen at random within the acceptable range of testing. No more than two dosimeters shall be irradiated to less than twice the minimum dose level in any given category. No more than two dosimeters shall be irradiated at greater than half of the maximum dose in any given category.

In categories dealing with mixed radiation fields, the applicable ratios shall also be selected at random within the acceptable range, as indicated in Table 1a. No component of a photon/photon mixture at either depth shall be less than 0.25 mSv (25 mrem). No neutron personal dose

equivalent shall be less than 1 mSv (100 mrem). Specifications for dose levels and mixture ratios are summarized in Table 1a.

3.7 Assignment of Personal Dose Equivalent (or Absorbed Dose) Values

The IL shall assign values for the shallow and deep personal dose equivalent, $H_p(0.07)$ and $H_p(10)$, or the deep absorbed dose, $D(10)$, to each dosimeter.

3.7.1 For a given photon spectrum, numerical values for the shallow and deep personal dose equivalents, $H_p(0.07)$ and $H_p(10)$, and the deep absorbed dose, $D(10)$, shall be assigned as

$$H_p(0.07) = \bar{c}_{K,s,\alpha} K_a$$

(Eq. 13)

$$H_p(10) = \bar{c}_{K,d,\alpha} K_a$$

(Eq. 14)

and

$$D(10) = \bar{c}_{K,d,\alpha} K_a$$

(Eq. 15)

where K_a is the air kerma measured at the RDP, but in the absence of the phantom, and $\bar{c}_{K,d,\alpha}$ and $\bar{c}_{K,s,\alpha}$ are conversion coefficients from air kerma for the spectrum (see Appendix C Section C2). The values for the conversion coefficients shall be taken from Table 3a and 3b. Note that for accident levels, Eq. 15 is used as described in the definition of conversion coefficient in Section 2.

3.7.2 For beta particles from a source standardized in terms of absorbed dose in a phantom, numerical values for the shallow personal dose equivalent shall be assigned as

$$H_p(0.07) \equiv D(0.07)$$

(Eq. 16)

where $D(0.07)$ is the numerical value of the absorbed dose to tissue at the depth of 0.07 mm in an ICRU tissue phantom.

3.7.3 For neutron sources calibrated in terms of emission rate, numerical values for the neutron component of the deep personal dose equivalent shall be assigned as the product of the fluence, ϕ_n , determined at the RDP, including scattered neutrons originating from the walls and air of the facility (see Appendix B3), and the personal dose equivalent conversion coefficient, $\bar{c}_\phi$, as

$$H_p(10) = \bar{c}_\phi \phi_n$$

(Eq. 17)

Conversion coefficients for $^{241}\text{AmBe}$ and unmoderated and D_2O -moderated ^{252}Cf must be determined specifically for the neutron fields provided due to influences of the source encapsulation and configuration of the source within the D_2O moderator as per the guidance of ISO 8529-1 [14]. For source and/or moderator configurations that result in the spectra shown in ISO 8529-1, $\bar{c}_\phi$ may be taken as 411 pSv cm² (41.1 nrem cm²) for $^{241}\text{AmBe}$, 400 pSv cm² (40.0 nrem cm²) for the unmoderated ^{252}Cf source, and 110 pSv cm² (11.0 nrem cm²) for the D_2O -moderated ^{252}Cf source (see Appendix C2).

For the spectra of photons associated with these three neutron test spectra, personal dose equivalent shall be assigned as

$$H_p(10) = \bar{c}_\phi \phi_n \gamma$$

(Eq. 18)

where γ is the ratio of the associated photon personal dose equivalent to the neutron personal dose equivalent. Values of γ depend on the source, encapsulation, room geometry, and the irradiation distance. Examples of typical values are given in Table 2d. The specific values used for testing shall be determined by the IL.

3.7.4 In the test categories involving mixed radiation fields, the values for the shallow (or the deep) personal dose equivalent delivered to the dosimeter for each type of radiation shall be added. The photon personal dose equivalent from the neutron source calculated with Eq. 18 shall be included in the photon component when determining the ratio of neutron to photon dose equivalents.

3.7.5 Dosimeters irradiated simultaneously cannot all be positioned at the RDP; therefore,

the IL shall assign personal dose equivalent to account for the displacement of the dosimeters on the plane of the phantom surface. Since dosimeters come in many configurations and not all dosimeter elements are at the same distance from the phantom surface, the IL may also adjust the assigned personal dose equivalent for displacement of the sensitive elements away from the phantom surface if the test participant supplies the IL with the distance between the sensitive elements and the phantom surface.

3.7.6 The uncertainty of the personal dose equivalent or absorbed dose assigned by the IL to each irradiation of x-rays, high energy photons and high energy beta particles shall not exceed $\pm 5\%$, excluding uncertainties in the personal dose equivalent conversion coefficients. The assigned uncertainty shall include uncertainties in source calibration, uncertainty in the distance between the source and the RDP, uncertainties in any adjustment to the assigned personal dose equivalent due to dosimeter displacement from the RDP, and the uncertainty due to scattered radiation not stemming from the phantom. The individual components shall be combined in quadrature, and a coverage factor of two (i.e., $k=2$) applied to the sum, which implies a 95% confidence interval [15].

The uncertainty due to the reproducibility of the reported personal dose equivalent or absorbed dose involving irradiations using neutron sources and low-energy beta sources shall not exceed $\pm 5\%$. Potential contributors to reproducibility include irradiation interval averaging of half-life corrections (i.e., applying a single decayed rate over a range of dates), dose-rate rounding, reference field non-uniformity, shimming variability, including that related to source-to-dosimeter distance and potential phantom backscatter influences, irradiation timing and source transit. The individual components shall be combined in quadrature, and a coverage factor of two (i.e., $k=2$) applied to the sum, which implies a 95% confidence interval.

4. Characterizing the Performance

4.1 Performance Criteria

Performance in a given category shall be considered adequate if, for the appropriate test depths,