NIGERIAN NUCLEAR REGULATORY AUTHORITY

... Protecting life and the environment

NIGERIAN NATIONAL STANDARD FOR DOSIMETRY: PERSONNEL DOSIMETRY PERFORMANCE – CRITERIA FOR TESTING

OUR CORE VALUES:

***Integrity *Commitment *Professionalism *Transparency *Sustainability**

PROLOGUE

Nigerian Nuclear Regulatory Authority (NNRA) was established by Nuclear Safety and Radiation Protection Act No. 19 of 1995 (the Act). Section (6) (b) of the Act empowers the NNRA to review and approve safety standards and documentation. The sets of test criteria for dosimetry systems contained in this Standard (to be referred to as ‘’Nigerian National Standard for Dosimetry: Personnel Dosimetry Performance – Criteria for Testing) aims to aid the NNRA in actualizing its mandate of protecting life, property and the environment from the harmful effect of ionizing radiation, by ensuring that the dosimetry services used in monitoring personnel exposure to ionizing radiation is carried out in line with approved standards..

The set of standards in this Standard is based on the requirements established in the International Atomic Energy Agency (IAEA) Safety Guide No. GS-G-3.2, American National Standard ANSI/HPS N13.11-2009, American National Standards Institute/Health Physics Society (ANSI/HPS) N13.32-2008, Technical and Quality Assurance Requirements for Dosimetry Services of the Canadian Nuclear Safety Commission, Ionizing Radiation Dosimetry of the National Voluntary Laboratory Accreditation Program (NVLAP) and Nigerian Secondary Standard Dosimetry Laboratory (SSDL) Guide of the National Institute for Radiation Protection and Research (NIRPR) – Ibadan. They are also derived extant Regulations made pursuant to the Act.

This Standard provides a procedure for testing the performance of dosimetry systems (that is, the hardware, the software, DSPs providing the services, or in some cases the classified personnel) used to monitor the personnel exposure to the whole body and extremities from ionizing radiation. The Standards applies for intending DSPs applying for accreditation for the first time, those introducing new models of dosimeters and others on routine or periodic calibration testing. Test procedures are designed to fully simulate the variety of conditions that dosimetry systems may be designed to assess, hence, the categories for testing are based on the radiation types: photons, betas, neutron, or mixtures of various radiations.

This Standard is structured into Two (2) sections, with each part having its distinct purpose, scope, test procedures, test categories and measures of characterizing the performance; in a way that allows for easy comprehension and quick reference. Part I outlines the test criteria for whole body dosimetry while Part II takes care of the test criteria for extremity dosimeters.

There are Nine (9) Appendices to this Standard, each establishing further explanations to the contents and other references. These are:

A. Instructions for Participating in Proficiency Testing for whole body, Electronic and Extremity Dosimeters;
B. Source Standardization
C. Interpretation of the Response of Dosimeters for Personnel Monitoring
D. Performance Criteria and Performance Analysis
E. Irradiating Laboratory (NIRPR) Guidance
F. Components of an External Dosimetry System
G. Reference Conditions and Standard TEST Conditions

H. List of Symbols and Acronyms
I. Checklist for Verification of Result of Proficiency Testing for Whole body, Electronic and Extremity Dosimeters

TABLE OF CONTENTS

Part 1

Test Criteria for Whole Body Dosimetry

Part 2

Test Criteria for Extremity Dosimeters

LIST OF TABLES

PART 1

TEST CRITERIA FOR WHOLE BODY DOSIMETRY

1.1 Purpose

The purpose of this Standard is to establish the test conditions and performance criteria for evaluating personnel dosimetry systems so as to ensure that accredited Dosimetry Service Providers (DSPs) meets the technical requirements and implement the quality assurance measures, in accordance with the mandate of the NNRA to protect lives from the harmful effects of ionizing radiation.

X . 3 0 **Scope.**

i. This standard applies to dosimetry systems used to determine personal dose equivalent for occupational conditions and absorbed dose for accident conditions.
ii. Tests are conducted under controlled conditions and include irradiation with photons, beta particles, neutrons and selected mixtures of these radiations.
iii. 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), the International Commission on Radiation Units and Measurements (ICRU), and the International Commission on Radiological Protection (ICRP).
iv. Each Dosimetry Service Provider (DSP) shall be tested in those categories which best represent the dosimetry services that is provided or used.
v. The tests outlined in this Part may be used to test the suppliers of dosimetry services (processors).
vi. 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.

X.30 **Definitions**

Absorbed Dose, ***D.*** The quotient of $d\bar{\varepsilon}$ by *dm* where dm is the mean energy imparted by ionizing radiation to matter of mass dm, thus

$$D = \frac{d\bar{\varepsilon}}{dm} \qquad \text{(Equation 1)}$$

Unit: Jkg^{-1}

NOTE 1: The special name for the unit of absorbed dose is Gray (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)*

NOTE 4: 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

$$K_a = \frac{dE_{tr}}{dm} \qquad \textit{(Equation 2)}$$

NOTE: The unit of the air kerma is Gray which has units of Joules per kilogram (Jkg^{-1})

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

$$\bar{E} = \frac{\int_{E_{min}}^{E_{max}} N(E)EdE}{\int_{E_{min}}^{E_{max}} N(E)dE} \qquad \textit{(Equation 3)}$$

Where:
N(E) is the fluence with energy between *E* and *E* + d*E***,**
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

$$B \equiv \overline{P} = (1/n)\sum_{i=1}^{n} P_i \qquad \textit{(Equation 4)}$$

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 Quantity Value. The quantity value attributed by agreement to a quantity for a given purpose.

NOTE 1: The conventional quantity value is the best estimate of the value of quantity to be measured, determined by a primary standard or a transfer standard which 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 quantity 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

$$\overline{C}_{K,d,\alpha} = \frac{H_P(d,\alpha)}{K_a} \qquad \text{for photons} \qquad \textit{(Equation 5)}$$

$\overline{C}_{\varphi} = \frac{H_P(10)}{\varphi_n}$ for neutrons *(Equation 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} for photons and Sv m^{-2} for neutrons.

NOTE 2. For beta particles, since the field quantity is absorbed dose and the quantity factor is unity, the conversion coefficient is unity.

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.

Dosimetry Service Provider (DSP) Entities accredited by NNRA to carry out quantitative measurement of "personal dose equivalent", $H_p(d)$, on classified workers of licenced operators.

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 and w_R is the radiation weighting factor for the radiation incident on the body, thus

$H_{T,R} = w_R D_{T,R}$ (*Equation 7)*

NOTE 1: The unit of the equivalent dose is Joules per kilogram (Jkg^{-1}) with the special name sievert (Sv).

NOTE 2: For this standard, for photon and beta radiation, the radiation weighting factor has the value of 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 having a density of 1 g cm^{-3} and a 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 can irradiate dosimeters to radiation quantities known to a high degree of certainty (National Institute for Radiation Protection and Research, **NIRPR**-Ibadan).

Particle Fluence, *φ*. The quotient of d*N* by d*a*, where d*N* is the number of particles incident on a sphere of cross-sectional area d*a*

$\varphi = \frac{dN}{da}$ *(Equation 8)*

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

Performance Criteria. Performance in each category shall be considered adequate if, for the personal dose equivalent or absorbed dose,

$$B^2 + S^2 \leq L^2 \qquad \textit{(Equation 9)}$$

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, shall be $L = 0.24$ in the accident category (category I) and $L = 0.30$ in the other categories.

Performance Quotient, P_i. for the i^{th} dosimeter

$$P_i \equiv [H_R(d)_i - H_P(d)_i]/H_P(d)_i \qquad \textit{(Equation 10)}$$

where $H_p(d)_I$ is the conventional quantity value of the personal dose equivalent assigned by NIRPR 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 below a specified point on the body at an appropriate depth d.

NOTE 1: The unit of the personal dose equivalent is Joule per kilogram (Jkg-1) with the special name sievert (Sv).

NOTE 2: Any statement of personal dose equivalent should include a specification of the depth, *d,* expressed in millimeters.

NOTE 1: 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, 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 10mm in ICRU tissue and is denoted by $HP(10)$. In ICRP 60, deep dose equivalent is given the name individual dose equivalent, penetrating.

Processor. A supplier of personnel dosimetry services. These services include:
(1) furnishing dosimeters to the user,
(2) evaluating the readings of the dosimeters after their return 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. 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 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. A statistical measure of the variation in the results, defined as

$$S \equiv \sqrt{\frac{\sum_{i=1}^{n}\left(P_i-\overline{P}\right)^2}{n-1}} \qquad \textit{(Equation 11)}$$

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 P , the mean performance quotient, is defined as

$$\overline{P} = (1/n)\sum_{i=1}^{n} P_i \qquad (\textit{Equation 12})$$

Standard Test Conditions. The range of values of a set of influence quantities under which irradiation of dosimeters is carried out.

NOTE: Ideally, NIRPR 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), the calibration factor should, in principle, be adjusted for deviations from reference conditions. The standard test conditions together with the reference conditions applicable to this standard are given in Appendix F.

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 NIRPR.

Tolerance Level, *L*. The boundary of acceptable performance of a dosimetry system.

Type test: A test performed on a small number of dosimeters of a given whole body or extremity dosimeter systems to determine performance characteristics of that dosimetry system and considered to be a one-time determination based on some generally acceptable criteria.

Wrist dosimeter. Any dosimeter worn on the wrist or ankle to measure personnel extremity dose

1.4 Test Procedure

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

i. The DSP and other test participant select the categories for which evaluation is sought.
ii. The DSP and other test participant submit dosimeters, representative of those supplied to its clients, to the NIRPR. The participant supplies the number of dosimeters required for testing in the requested test categories.
iii. The NIRPR irradiates the dosimeters in the radiation field(s) specified for applicable categories.
iv. The NIRPR returns the dosimeters to the DSP and other test participant for evaluation.
v. The DSP and other test participant evaluate the response of the irradiated dosimeters in terms of the absorbed dose or personal dose equivalent at the specified test depths.
vi. The DSP and other test participant report the results of the dosimeter evaluation to the NIRPR.
vii. The testing organization (NIRPR) evaluates the dosimeter performance based on criteria in this standard.
viii. The NIRPR notifies the DSP and other test participant of the dosimeter performance.

Administrative Procedure

1.4.1 Information to be Supplied to the Irradiating Laboratory (NIRPR).

The DSP and other test participant shall provide the following information to the irradiating laboratory, (NIRPR):

i. The test categories desired.
ii. A description of dosimeter design including nomenclature, holder, pictures, or schematics showing construction.
iii. Specification of what is the normal wearing (vertical) orientation, and the reference direction of the dosimeter.
iv. Operating instructions if electronic dosimeters are being tested.

The DSP and other 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 NIRPR 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 NIRPR will use the Reference Dose Point (RDP).

1.4.2 Test Schedule.

i. A test shall consist of three separate iterations (or rounds) performed over a period of approximately three months.
ii. According to NIRPR's direction, at the start of the testing period the participant will submit 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.
iii. NIRPR will irradiate the dosimeters in each of the three rounds and return irradiated dosimeters to the participants within 15 calendar days from the end of each round, And they are to 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.

1.4.3 Number of Test Dosimeters.

The DSP and other test participant shall submit fifteen dosimeters (five per round) for each

subcategory selected for evaluation except for the subcategories of category II which will require 21 dosimeters each (seven per round). Additional dosimeters, as specified by NIRPR, shall be included with each round as control and replacement dosimeters in case problems are encountered.

1.4.4 Information to be Supplied to DSPs and other Test Participants.

NIRPR shall report the range of irradiation dates (within a 7 to 10 day window) to the participant to allow correction of dosimeter response for fade. The identities of dosimeters irradiated in category I (accidents), and category V (neutron/photon mixtures), along with control, mis-irradiated, and voided dosimeters, will be reported to the DSP and other test participant when the testing laboratory returns the dosimeters. In addition, if subcategory IIID is selected with another subcategory in category III, then the identities of dosimeters irradiated with the slab betas will be provided. No information shall be divulged to the test participant for other dosimeters until the test results are released.

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

1.4.5 Dissemination of Test Results.

NIRPR shall report all test 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.

1.5 Test Categories

The test categories in this Part for whole-body and/or extremities dosimetry are given in Table 1a and are described below. Each DSP or other participant should be tested in the categories which best represent the services they provide or intend to provide.

1.5.1 Category I – accident, photons.

High doses from photons from ^{137}Cs and NIRPR Procedure No. SSDLP-RPT.007 (which was developed in line with the requirement of ISO 17025) 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 NIRPR with the provision that at least three dosimeters will be irradiated using each source. Subcategories IB and IC use only the specified source for all irradiations.

1.5.2 Category II – photons/photon mixtures.

This category comprises irradiations to single and mixed photon radiation fields. Its four subcategories provide testing for different workplace environments. NIRPR shall select 21 dosimeters for testing in Category II, regardless of the number or combination of subcategories selected by the DSP or other test participant. Specific photon radiation fields shall be chosen at random by NIRPR 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:

i. At least five dosimeters are to be irradiated in a single high-energy photon field ($E \geq 500$ keV) at perpendicular incidence only.
ii. For testing subcategory IIA, no more than five dosimeters will be irradiated with photons with average energies below 100 keV.
iii. For subcategories IIA, IIC and IID, at least five and no more than ten shall be irradiated with mixtures. Mixtures always include one irradiation with $E \geq 500$ keV and one irradiation with $E < 500$ keV.
iv. For subcategory IID, the specific spectra chosen for testing by NIRPR are representative of plutonium environments (see Appendix 1 Section 1A).

Note that each of the four subcategories includes photons with E ≥500 keV, so photon/photon mixture irradiations and irradiations at non-perpendicular incidence are included regardless of the subcategory(ies) selected for testing. If any dosimeter is irradiated with an 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 from horizontal and vertical dosimeter orientations at angles of 0°, ± 40° or ± 60°. The maximum number of dosimeters in any given subcategory irradiated at non-perpendicular incidence is specified in Table 1b.

1.5.3 Category III – betas.
This category comprises irradiations in a single beta particle radiation field. There are four 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, with the provision that at least three dosimeters shall be irradiated using the high-energy (E ≥500 keV) beta source and at least three using the low-energy (E <500 keV) beta source. Subcategories IIIB, IIIC and IIID use only the specified
source for all irradiations.

1.5.4 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. If the participant tested in subcategory IIIA, then a beta source shall be chosen at random for each irradiation with the provision that at least three of the 15 dosimeters submitted for testing in this category shall be irradiated using the high-energy beta source (E ≥500 keV) and at least three dosimeters using the low-energy beta source (E <500 keV). Specific photon radiation fields shall be chosen at random with the provision that at least three of the dosimeters shall be irradiated in the high-energy (E ≥500 keV) photon category. If the specific beta radiation field is low-energy (E <500 keV), the high-energy (E ≥500 keV) photon field shall be chosen. The ^{60}Co source shall not be used in this category. If two or more subcategories are tested in categories II and III then multiple tests shall be performed as determined by the testing organization (NIRPR).

1.5.5 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 from the D_2O-moderated ^{252}Cf source and the unmoderated ^{252}Cf source with the provision that at least three of the 15 dosimeters submitted for testing shall be irradiated using each source. The specific photon radiation field in category V shall be chosen at random from the fields in which the dosimeters were tested in category II with the provision that at least three of the 15 dosimeters shall be irradiated using a high-energy (E ≥500 keV) photon source. If two or more subcategories are tested in category II then multiple tests shall be performed as determined by the testing organization.

1 . 6 Radiation Sources
The following radiation sources shall be available in NIRPR, as a minimum:

1. At least one ^{137}Cs and optionally, one ^{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, or of a design

that does not significantly increase the scatter at the reference dose point. 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. Measurements should be made to 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. At least one constant potential x-ray machine operable in the range between 30 kV or less 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 and NIST techniques specified in Table 2a and 2b.
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}Sr/^{90}Y beta-particle source equipped with a 100-mg cm^{-2} filter (nominal) to absorb the ^{90}Sr beta particle. It shall meet the following specifications:
    a. The residual maximum energy, E_{res}, as defined in the ISO 6980-1 shall equal or exceed 1.80MeV.
    b. 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.
    c. The in-phantom absorbed dose at 1000 mg cm^{-2}, $D(10)$, shall be less than 1% of the in-phantom absorbed dose at 7 mg cm^{-2}.
5. A sealed ^{85}Kr beta-particle source meeting the following specifications:
    a. The residual maximum energy as defined in ISO 6980 , shall equal or exceed 0.53 MeV.
    b. 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.
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 (Mylar®) and meeting the following specifications:
    a. The in-phantom absorbed dose at 100 mg cm^{-2}, $D(1)$ divided by the in-phantom absorbed dose at 7 mg cm^{-2} shall be 0.58 ± 0.04.
    b. 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}.
7. A sealed ^{252}Cf neutron source(s), able to be used bare, and at the center of a D_2O moderating sphere 30cm in diameter covered with a cadmium shell with a thickness in the range of 0.5 mm to 1 mm to produce energy and direction distributions consistent with specifications in ISO 8529-1. For the purposes of this standard, this latter configuration is referred to as “moderated”.

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

1.7 Phantom Construction

Photon and neutron performance tests shall be performed on a slab of polymethylmethacrylate (PMMA) with a thickness of 15 cm, and a face no smaller than 30 cm x 30 cm. For beta performance tests, the slab shall have a thickness of at least 5 cm, and a face no smaller than 30 cm x 30 cm.

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 as determined with a small volume ionization chamber shall be 1.54 ± 0.03.

1.8 Irradiation Conditions.

The NIRPR shall mount dosimeters on the phantom surface facing the source (“front face”). The back-planes of the mounted dosimeters shall be parallel to the surface of the phantom. The surface of the phantom shall be positioned 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:

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

NIRPR 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.

1.9 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.

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

The NIRPR 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.

(A). 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:

$$H_P(0.07) = \overline{C}_{K,s,\alpha} K_a$$

(Equation 13)

$$H_P(10) = \overline{C}_{K,d,\alpha} K_a \qquad \textit{(Equation 14)}$$

and

$$D(10) = \overline{C}_{K,d,\alpha} K_a \qquad \textit{(Equation 15)}$$

where K_a is the air kerma measured at the RDP, but in the absence of the phantom, and $\overline{C}_{K,d,\alpha}$ *and* $\overline{C}_{K,d,\alpha}$ are conversion coefficients from air kerma for this 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 with the understanding that the units for $\overline{C}_{K,d,\alpha}$ are dimensionless.

(B). 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

$$H_P(0.07) \equiv D(0.07) \qquad \textit{(Equation 16)}$$

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

I. 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 in air at the RDP and the conversion coefficient, $\overline{C}_{\varphi}$, as

$$H_P(10) = \overline{C}_{\varphi}\varphi_n \qquad \textit{(Equation 17)}$$

Where $\overline{C}_{\varphi}$ shall be taken as 110 pSv cm^2 for the D_2O moderated ^{252}Cf source, and 400 pSv cm^2 for the unmoderated ^{252}Cf source (see Appendix C Section C2).

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

$$H_P(10) = \overline{C}_{\varphi}\varphi_n\gamma \qquad \textit{(Equation 18)}$$

Where γ is the ratio of the associated photon personal dose equivalent to the neutron personal dose equivalent. Values of γ depend on the 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 NIRPR.

(D). 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 photons from the neutron source calculated with *Equation 18* shall be included in the photon component when determining the ratio of neutron to photon dose equivalents.

(E). Dosimeters irradiated simultaneously cannot all be positioned at the RDP; therefore, the laboratory will 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 laboratory 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 laboratory with the distance between the sensitive elements and the phantom surface.

(F). The uncertainty of the personal dose equivalent or absorbed dose assigned by the NIRPR to each irradiation of x-rays, high energy photons and high energy beta particles shall not exceed ±5% excluding uncertainties in the personal dose equivalent

conversion coefficients. The reproducibility of the irradiations from the remaining sources shall not exceed ±5%. 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 applied to the sum, which implies a 95% confidence interval.

Characterizing the Performance

1.11 Performance Criteria

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

$$B^2 + S^2 \leq L^2 \qquad \text{(Equation 19)}$$

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

Table 1a contains a complete listing of tolerance levels for deep and shallow personal dose equivalents.

1.12 Performance Analysis

Equation 19 is used to determine a test participant's performance for:
(1) Deep absorbed dose in category I.
(2) Deep and shallow personal dose equivalent in categories II and IV.
(3) Shallow personal dose equivalent only in category III.
(4) Total deep personal dose equivalent in category V.

Table 1a: Test Categories, Test Irradiation Ranges, and Tolerance Levels

Test Category	Test Irradiation Range	Tolerance Level (L) Deep	Tolerance Level (L) Shallow
I. Accidents, Photons **A. General** (B and C, random) **B. ^{137}Cs** **C. NIRPR Procedure No. SSDLP-RPT.007**	**0.05 – 5 Gy**	**0.24**	**No test**
II. Photons/Photon Mixtures **A. General[1]** ($E \geq 20\ keV$; $\perp$ **if** ≤ 70 **keV**) **B. High E** (^{137}Cs, ^{60}Co; α ≤ 60°) **C. Medium E[1]** ($E > 70\ keV$; $\alpha \leq 60^{o}$) **D. Plutonium Specific[1]** (see Appendix A Section A2)	**0.05 – 50 mSv**	**0.3**	**0.3**
III. Betas **A. General** (B and C, random) **B. High E** (^{90}Sr/^{90}Y) **C. Low E** (^{85}Kr) **D. U Slab**	**2.5 – 250 mSv**	**No test**	**0.3**
IV. Photon/Beta[2] Mixtures Shallow	**3.0 – 300 mSv**	**-**	**0.3**

Deep	**0.5 – 50 mSv**	**0.3**	**-**
V. Neutron/Photon Mixtures[3] **A. General** (B and C, random) **B. ^{252}Cf + II** **C. ^{252}Cf(D_2O) + II**	**1.5 – 50 mSv**	**0.3**	**No test**

[1] Ratios of $H_p(10)$ for mixtures shall be in the range of 1:3 to 3:1 for subcategories IIA, IIC, IID. Mixtures shall always include one source from subcategory IIB.

X **The ratio of the [photon $H_p(0.07)$]: [beta particle $H_p(0.07)$] is restricted to be in the range of 1:1 to 1:6, inclusive. There shall be no testing with ^{60}Co.**

X **The ratio of the $H_p(10)$ for neutrons : photons shall be in the range 1:3 to 3:1. The ratio includes the photon component from the neutron irradiation.**

Notes:

- Acceptable sources for various categories are defined in the text.
- Non-perpendicular angles are used for single source irradiations in category II only. The angles are 0°,±40°, ±60° and include horizontal and vertical dosimeter orientations (see Appendix E, Figure E1).
- No low energy ($\boldsymbol{E}$ <500 keV) beta particles shall be used with photons with $\overline{\boldsymbol{E}}$ <500 keV in category IV.
- The subcategories chosen in categories II and III shall be used in category IV. The subcategory chosen in category II shall be used in category V.
- For category V, the test applies only to the total value of $H_p(10)$ from neutrons and photons combined (including those from the neutron source).
- No neutron personal dose equivalent <1 mSv shall be delivered.
- No more than two dosimeters shall be irradiated to less than twice the minimum dose level.
- No more than two dosimeters shall be irradiated to greater than half of the maximum dose level.
- No component of a photon/photon mixture at either depth shall be less than 0.25 mSv.

Table 1b: Limits on Number of Dosimeters Irradiated in Particular Conditions in Category II

	Subcategory IIA		**Subcategory IIB**		**Subcategory IIC**		**Subcategory IID**	
	At least	**No more than**	**At least**	**No more than**	**At least**	**No more than**	**At least**	**No more than**
Non-⊥ angles	**3**	**5**	**3**	**7**	**3**	**5**	**3**	**5**
$\boldsymbol{E} < 70keV$	**3**	**5**	**-**	**-**	**-**	**-**	**5**	**10**
Mixtures with ^{137}Cs, ^{60}Co	**5**	**10**	**-**	**-**	**5**	**10**	**5**	**10**
^{137}Cs, ^{60}Co ⊥ only	**5**	**10**	**-**	**-**	**5**	**10**	**5**	**10**

Table 2a: Characteristics of ISO Photon Beam Techniques

ISO Tech. Beam Code	Added Filter[a]				Half-Value Layer		Homogeneity Coefficient[b]		$\overline{E}\ (keV)$	FWHM (keV)
	Al (mm)	Cu (mm)	Sn (mm)	Pb (mm)	Al (mm)	Cu (mm)	Al	Cu		
USED FOR TESTING										
HK30	0.52				0.38	0.013	63	72	20	13
HK60	3.2				2.42	0.079	74	72	37	26
HK100	3.9	0.15			6.56	0.3	81	64	57	43[d]
HK200		1.15			14.7	1.7	95	71	102	87[d]
HK250		1.6			16.6	2.47	96	75	122	106[d]
HK280		3			18.6	3.37	98	84	146	79[d]
HK300		2.5			18.7	3.4	97	82	147	121[d]
WS60		0.3				0.18		86	45	21
WS80		0.5				0.35		80	57	29[d]
WS110		2				0.96		86	79	40[d]
WS150			1			1.86		89	104	57[d]
WS200			2			3.08		93	137	78
WS250			4			4.22		96	173	96
WS300			6.5			5.2		97	208	115
^{241}Am									59	
INFORMATIONAL ONLY										
HK10					0.036	0.01	88	90	7.5	2.7
HK20	0.15				0.12	0.007	75	78	13	8.8[c]
NS10	0.1				0.047		90		8	2.2
NS15	0.5				0.14		88		12	4.3
NS20	1				0.32		86		16	5.2
NS25	2				0.66		90		20	6.9
NS30	4				1.15		88		24	7.5
NS40		0.21				0.084		92	33	9.9
NS60		0.6				0.24		92	48	17
NS80		2				0.58		94	65	21[d]
NS100		5				1.11		95	83	23[d]
NS120		5	1			1.71		97	100	28
NS150			2.5			2.36		96	118	45
NS200		2	3	1		3.99		99	164	49
NS250			2	3		5.19		99	208	58
NS300			3	5		6.12		100	250	68
LK10	0.3				0.058		99		8.5	1.8
LK20	2				0.42		99		17	3.6
LK30	4	0.18			1.47		99		26	5.5
LK35		0.25			2.2		99		30	6.8

LK55	1.2			0.25	99	48	11
LK70	2.5			0.49	99	60	14
LK100	0.5	2		1.24	99	87	19
LK125	1	4		2.04	99	109	23
LK170	1	3	1.5	3.47	99	149	28
LK210	0.5	2	3.5	4.54	100	185	34
LK240	0.5	2	5.5	5.26	100	211	37

See footnotes on Table 2b

Table 2b: Characteristics of NIST Photon Beam Techniques

NIST Tech. Beam Code	Added Filter[a]				Half-Value Layer		Homogeneity Coefficient[b]		$\overline{E}\ (keV)$	FWHM (keV)
	Al (mm)	Cu (mm)	Sn (mm)	Pb (mm)	Al (mm)	Cu (mm)	Al	Cu		
USED FOR TESTING										
L40	0.53				0.5		59		23	19
L50	0.71				0.76		60		28	23
L80	1.45				1.83		57		40	35
L100	1.98				2.77		57		48	46[d]
M30	0.5				0.36		65		20	13
M40	0.89				0.73		69		25	18
M50	1.07				1.02		66		29	23
M60	1.56				1.68		66		35	28
M100	5				5.02		73		53	42[d]
M150	5	0.25			10.2	0.67	87	62	73	59[d]
M200	4.1	1.12			14.9	1.69	95	69	100	87[d]
M250	5	3.2			18.5	3.2	98	86	139	105
M300	4		6.5		22	5.3	100	97	206	115
H150	4	4	1.51		17	2.5	100	95	118	44
H200	4	0.6	4.16	0.77	19.8	4.1	100	99	162	52
H250	4	0.6	1.04	2.72	22	5.2	100	98	204	61
H300	4.1		3	5	23	6.2	99	98	251	68
S60	4.35				2.77		72		38	27
S75	1.5				1.86		63		40	35
^{137}Cs						10.8			662	
^{60}Co						14.9			1250	
INFORMATIONAL ONLY										
L10	0				0.04		89			
L15	0				0.06		68		9.9	5.9[c]
L20	0				0.07		73		11	11[c]
L30	0.3				0.22		63		18	14[c]
M20	0.27				0.15		69		14	8.1[c]
H10	0.105				0.05		91		8	2.2
H15	0.5				0.153		86		12	4.3
H20	1.01				0.36		91		16	5.2
H30	4.5				1.23		93		24	7.5
H40	4.53	0.26			2.9		90		33	9.1
H50	4			0.1	4.2	0.142	92	90	39	14
H60	4	0.61			6	0.24	94	89	47	17
H100	4	5.2			13.5	1.14	100	94	83	23

[a] The inherent filtration is approximately 1.0 mm Be for beam codes LK10-LK30, NS10-NS30, HK10-HK30; for all other techniques, the inherent filtration is adjusted to 4 mm Al (Table 2a only).

[b] The specified half-value layers should be duplicated to within 5% and the homogeneity coefficients to within 10%, if necessary by adjusting the tube potential.

[c] Prominent L characteristic lines present from the W target.

[d] Prominent K characteristic lines present from the W target.

[e] The inherent filtration is approximately 1.0 mm Be for beam codes L10-L100, M20-M50, H10-H40, S75 and 3.0 mm Be for beam codes M60-M300, H50-H300, and S60 (Table 2b only).

Table 2c: Characteristics of Beta Particle Sources and Fields

Source	Half-life (y)	Filter	$\overline{E}$ (MeV)	Min. E_{res} (MeV)	$\frac{D(0.2)}{D(0.07)}$	$\frac{D(1)}{D(0.07)}$	$\frac{D(10)}{D(0.07)}$
^{85}Kr	10.8	1 PET disc of radius 4 cm and thickness 50 µm, plus 1 PET concentric disc of radius 2.75 cm and thickness 190 µm[a]	0.26	0.53	0.80 ± 0.05	-	-
^{90}Sr/^{90}Y	28.8	-	0.84	1.80	-	1.01 ± 0.03	< 0.01
Depleted or Natural Uranium	4.5 x 10^9	Between 3 and 7 mg cm^{-2}	0.62[b]	-	-	0.58 ± 0.04	< 0.03

[a] The filter shall be mounted at a distance of 10 cm from the source surface.
[b] This is the average energy of beta particles emerging from the filtered source.

Table 2d: Characteristics of Neutron Sources and Fields

Source	Half-life (y)	Fluence average energy (MeV)	Specific Source Strength (s^{-1}kg^{-1})	Specific neutron personal dose equivalent rate at 1 m distance (Sv s^{-1} kg^{-1})	γ, Typical ratio of photon to neutron personal dose equivalent rate
^{252}Cf(D_2O moderated)	2.65	0.55	2.1 x 10^{15}	2.1	0.18
^{252}Cf	2.65	2.13	2.4 x 10^{15}	6.7	0.05[a]

[a] For a 2.5 mm thick steel encapsulation.

Table 3a: Coefficients to Convert from Air Kerma to Deep and Shallow Personal Dose Equivalent (ISO Beams and ^{241}Am)

ISO Beam Code	Deep Personal Dose Equivalent Conversion Coefficient ($\overline{C}_{K,d,\alpha}$)			Shallow Personal Dose Equivalent Conversion Coefficient ($\overline{C}_{K,s,\alpha}$)		
	α = 0°	α = 40°	α = 60°	α = 0°	α = 40°	α = 60°
USED FOR TESTING						
HK30	0.39	0.32	0.20	1.01	1.00	0.99
HK60	1.19	1.07	0.86	1.29	1.27	1.22
HK100	1.68	1.56	1.31	1.58	1.53	1.46
HK200	1.75	1.66	1.46	1.62	1.59	1.54
HK250	1.67	1.59	1.43	1.56	1.55	1.51
HK280	1.60	1.54	1.39	1.51	1.51	1.48
HK300	1.59	1.53	1.39	1.51	1.50	1.48
WS60	1.55	1.42	1.18	1.49	1.44	1.37
WS80	1.77	1.65	1.39	1.64	1.58	1.50
WS110	1.87	1.76	1.52	1.71	1.67	1.59
WS150	1.77	1.68	1.49	1.64	1.61	1.56
WS200	1.65	1.57	1.42	1.55	1.53	1.50
WS250	1.54	1.49	1.36	1.47	1.47	1.45
WS300	1.47	1.44	1.33	1.42	1.43	1.43
^{241}Am[a]	1.89	1.77	1.50	1.72	1.66	1.57
INFORMATIONAL ONLY						
HK10	0.00	0.00	0.00	0.89	0.86	0.80
HK20	0.14	0.09	0.04	0.95	0.94	0.92
NS10	0.00	0.00	0.00	0.91	0.89	0.84
NS15	0.06	0.03	0.01	0.96	0.95	0.93
NS20	0.27	0.20	0.09	0.98	0.98	0.97
NS25	0.55	0.44	0.28	1.03	1.02	1.02
NS30	0.79	0.68	0.49	1.10	1.09	1.07
NS40	1.17	1.06	0.85	1.27	1.24	1.19
NS60	1.65	1.52	1.27	1.55	1.50	1.42
NS80	1.88	1.76	1.50	1.72	1.66	1.58
NS100	1.88	1.76	1.53	1.72	1.68	1.6
NS120	1.81	1.71	1.51	1.67	1.63	1.58
NS150	1.73	1.64	1.46	1.61	1.58	1.54
NS200	1.57	1.51	1.38	1.49	1.49	1.46
NS250	1.48	1.44	1.33	1.42	1.43	1.43
NS300	1.42	1.40	1.30	1.38	1.40	1.40
LK10	0.00	0.00	0.00	0.93	0.91	0.87
LK20	0.37	0.28	0.15	1.00	0.99	0.99
LK30	0.91	0.79	0.60	1.14	1.13	1.10
LK35	1.09	0.98	0.77	1.22	1.20	1.16
LK55	1.67	1.54	1.29	1.57	1.52	1.43

LK70	1.87	1.75	1.49	1.71	1.65	1.56
LK100	1.87	1.76	1.53	1.71	1.67	1.60
LK125	1.77	1.68	1.49	1.64	1.61	1.56
LK170	1.62	1.55	1.41	1.53	1.52	1.49
LK210	1.52	1.47	1.36	1.45	1.46	1.44
LK240	1.47	1.44	1.33	1.42	1.43	1.42

[a] Measured values are to be used when measurements are statistically different than the c_K values published in this standard, but within the 5% of the values given in this table.

See note under Table 3b

Table 3b: Coefficients to Convert from Air Kerma to Deep and Shallow Personal Dose Equivalent (NIST Beams, ^{137}Cs, and ^{60}Co)

NIST Beam Code	Deep Personal Dose Equivalent Conversion Coefficient ($\overline{C}_{K,d,\alpha}$)			Shallow Personal Dose Equivalent Conversion Coefficient ($\overline{C}_{K,s,\alpha}$)		
	α = 0º	α = 40º	α = 60º	α = 0º	α = 40º	α = 60º
	USED FOR TESTING					
L40	0.50	0.41	0.28	1.04	1.03	1.01
L50	0.70	0.60	0.43	1.10	1.09	1.05
L80	1.09	0.97	0.76	1.26	1.23	1.18
L100	1.23	1.11	0.89	1.34	1.31	1.25
M30	0.42	0.34	0.22	1.02	1.01	0.99
M40	0.63	0.53	0.37	1.07	1.06	1.03
M50	0.79	0.69	0.51	1.13	1.11	1.08
M60	1.00	0.89	0.68	1.21	1.19	1.14
M100	1.52	1.39	1.14	1.49	1.45	1.37
M150	1.78	1.65	1.40	1.64	1.60	1.50
M200	1.74	1.64	1.41	1.62	1.58	1.50
M250	1.62	1.54	1.36	1.53	1.51	1.44
M300	1.47	1.42	1.28	1.42	1.41	1.37
H150	1.71	1.61	1.40	1.60	1.57	1.48
H200	1.57	1.50	1.33	1.49	1.47	1.42
H250	1.48	1.42	1.29	1.42	1.42	1.38
H300	1.42	1.38	1.26	1.37	1.38	1.35
S60	1.24	1.12	0.89	1.31	1.28	1.22
S75	1.09	0.98	0.76	1.26	1.23	1.18
^{137}Cs[a]	1.21	1.20	1.16	1.21	1.23	1.24
^{60}Co[a]	1.17	1.16	1.14	1.18	1.18	1.19
	INFORMATIONAL ONLY					
L10	0.00	0.00	0.00	0.89	0.86	0.80
L15	0.02	0.01	0.00	0.93	0.92	0.88
L20	0.07	0.05	0.02	0.95	0.94	0.92

L30	0.28	0.22	0.13	0.99	0.98	0.96
M20	0.14	0.09	0.04	0.97	0.96	0.94
H10	0.00	0.00	0.00	0.91	0.89	0.85
H15	0.06	0.03	0.01	0.96	0.95	0.94
H20	0.28	0.20	0.10	0.99	0.98	0.97
H30	0.79	0.68	0.49	1.10	1.08	1.05
H40	1.17	1.06	0.83	1.26	1.23	1.18
H50	1.40	1.28	1.03	1.40	1.36	1.29
H60	1.65	1.52	1.25	1.55	1.51	1.42
H100	1.87	1.74	1.48	1.71	1.66	1.56

[a] Measured values are to be used when measurements are statistically different than the c_K values published in this standard, but within the 5% of the values given in this table.

Multiplying kerma by the conversion coefficient yields the personal dose equivalent. If kerma is in Gy, the personal dose equivalent will be in Sv. If kerma is in rad, the personal dose equivalent will be in rem.

PART 2 - Test Criteria for Extremity Dosimeters

2.0 Purpose

The standard in this part establishes standardized testing conditions and criteria to evaluate the performance of personnel extremity dosimetry services.

2.1 Scope

Specifications are given in this part for test categories, test irradiation ranges, and acceptable models with associated levels of performance. A test is conducted when dosimeters are sent from Dosimetry Service Provider (DSP) to a Secondary Standard Dosimetry Laboratory (that is, National Institute for Radiation Protection and Research – NIRPR) that facilitates the irradiation of the dosimeters under controlled conditions specified in this standard. The dosimeters are returned to the processor for evaluation. The results of dosimeter processing are returned to the testing laboratory (NIRPR) for evaluation under the criteria given in this standard.

The standard in this part applies to dosimetry systems used to assess personal dose equivalent at a depth of 0.07 mm in ICRU tissue in extremities, specifically, hands or feet and forearms or legs. As such, the standard applies to the performance of dosimeters worn on fingers and on wrists or ankles, because the basis of the performance test is the personal dose equivalent at a depth of 0.07mm. The standard in this part does not apply to dosimeters used to assess the dose to the lens of the eye or the personal dose equivalent to the whole body.

The basis of absorbed dose and dose equivalent in this standard is the personal dose equivalent at 0.07 mm specified in both the International Commission of Radiological Protection (ICRP) and the International Commission on Radiation Units and Measurements (ICRU). Specifically, factors that convert air kerma in photon fields to personal dose equivalent for rod and pillar phantoms are given in ISO 4037-3 (ISO 1999).

The standard in this part applies to the evaluation of dosimetry performed for radiation protection under low-dose and high-dose conditions in photon and beta fields. The tests for accident dosimetry are approximately represented by the high-dose category.

There is no compelling evidence to implement a neutron dose equivalent test for extremity dosimeters at this time.

A concerted effort has been made in this standard to segregate type-testing issues, typically performed once in the lifetime of a dosimeter system, from periodic performance testing issues. As such, there is no specific requirement to conduct a one-time evaluation of dosimeter performance under conditions of non-perpendicular angular incidence. Neither is there a requirement to conduct a study to evaluate the lower limit of detectability. These tests are important in the interpretation of dosimeter results but should be addressed in a type-testing standard.

Following the example set in the standard for testing whole-body personnel dosimeter systems in Part 1, ancillary information to clarify and support the positions in this part is included in the appendices.

The scope of standard testing for extremity dosimetry is sufficiently comprehensive that satisfactory performance implies that a DSP is competent to assess personal extremity dose under a broad range of field conditions using the tested dosimetry system.

2.2 Test Procedure

The procedure is summarized below.

- The DSP and other test participant selects the categories for which evaluation is sought.
- The DSP and other test participant indicates whether the blind testing option is desired.
- The test participant indicates whether wrist or ring dosimeters are being submitted.
- The test participant submits dosimeters, representative of those supplied to users, to the NIRPR over a period of several months. The DSP and other test participant supplies the number of dosimeters required for testing in the requested test categories.
- The NIRPR irradiates the dosimeters in the radiation field(s) specified for applicable categories.
- The NIRPR returns the dosimeters to the test participant for evaluation.
- The DSP and other test participant evaluates the response of the irradiated dosimeters in terms of the absorbed dose or personal dose equivalent at the specified test depth.
- The DSP and other test participant reports the results of the dosimeter evaluation to the NIRPR in the required time.
- The NIRPR evaluates the dosimeter performance based on criteria in this standard.
- The NIRPR notifies the DSP and other test participant of the dosimeter's performance.

Administrative Procedure

2.3 Information to be Supplied to the NIRPR

The DSP and other test participant shall provide the following information to the NIRPR:

i. A certification that the dosimeters submitted for each test are representative of those supplied to customers.
ii. The test categories desired.
iii. An indication of whether blind testing (test category not disclosed to participant before test results are reported) is desired.
iv. An indication of whether dosimeters are worn on the wrist or as a ring.
v. A brief description of dosimeter design, construction, and processing (including a reference to the software version of the dose algorithm).
vi. A brief description of the dosimeter's orientation on the phantom.
vii. Known or suspected limiting conditions (e.g., exposure to ambient lighting, dose rate limitations, exposure duration, etc.) that might influence the response of the dosimeter.

2.4 Test Schedule

A test shall consist of three separate iterations (or rounds) performed over a period of 3 to 6 months. The NIRPR will return test dosimeters to the DSP and

other test participant/user within 45 days of the start of the testing round. The DSP and other test participant shall report results of evaluations to the NIRPR within 45 days of receiving the dosimeters. Failure by a participant to submit all dosimeter evaluations in a given category within the required 45 days will result in failure of the category.

2 . 5 Number of Test Dosimeters

The test participant shall submit 15 dosimeters (five per round) for each subcategory selected for evaluation. Two additional dosimeters shall be included in each round as replacement dosimeters in case problems are encountered at the NIRPR. Control dosimeters may be included in each round to evaluate transit doses.

The NIRPR shall not conduct a test for fewer than three processors at a time or the NIRPR shall use an independent and simultaneous method to verify the dose delivered to test dosimeters.

The minimum number of dosimeters that constitute a test for a dosimeter type submitted for testing is 13 in any category. If the dose interpretations from more than 2 of the dosimeters irradiated in a given category are voided because of problems caused by either the NIRPR or the DSP and other participant, statistical analysis of the results in this category shall be delayed until replacement dosimeters have been submitted and irradiated and the results reported by the DSP or other Test Participant to the NIRPR.

2.6 Dissemination of Test Results

The NIRPR shall report all test results to the DSP and other test participant after the test is completed. An estimate for the uncertainty of the assigned values of shallow dose equivalent shall be available from the NIRPR. The DSP and other test participant shall not be permitted to change or void reported results after the NIRPR releases the test results. (Note: circumstances can arise requiring the participant to modify reported doses before the NIRPR distributes the final test reports. After the final test report has been released, each participant is given access to the delivered dose levels for the test and, therefore, cannot modify the test results at that time.

2 . 7 Test Categories

Test categories and test dose-equivalent or absorbed dose ranges to be used during the evaluation of extremity dosimetry systems are specified in Table 4. To clarify the notation in the text of Table 4 , *E* is meant to be the mean energy of the particular radiation field.

Table 4. Irradiation categories, test irradiation ranges and tolerance levels.

Test Category	Test Irradiation Range	Tolerance Level (L) (for $B^2 + S^2 = L^2$)
VI. High-dose, Photons **D. General** (B and C, random) **E. ^{137}Cs ($\bar{E}$ = 662 keV)** **F. NIRPR Procedure No. SSDLP-RPT.007/NIST Procedure: M150 ($\bar{E}$ = 73.0 keV)**	**0.1 – 5 Gy**	**0.24**

VII. Photons/Photon Mixtures **E. General** ($\overline{E} \geq 20\ keV$) **F. High E** ($\overline{E} \geq 500$ keV) **G. Medium E** ($\overline{E} \geq 70\ keV$) **H. Narrow spectrum**	**1.0 – 100 mSv**	**0.35**
VIII. Betas **E. General** (B and C, random) **I. High E** ($\overline{E} \geq 500$ keV) **J. Low E point source** ($\overline{E} < 500$ keV) **K. Slab Uranium** ($\overline{E} \geq 500$ keV)	**2.5 – 100 mSv**	**0.35**
IX. Photon/Beta Mixtures **A. General photon + beta** **B. Gamma + beta**	**3.5 – 100 mSv**	**0.35**

Notes:

1. Only one irradiation below 2.5 mSv is allowed in Category II.
2. Acceptable sources for each category are described in the text.
3. Subcategories chosen in Categories II and III shall be used in Category IV where no subcategories are specified.
4. In Category IV, mixed exposures range from 1:1 to 5:1 (beta: photons), based on the personal dose equivalent.
5. In Category IV, only high-energy ($\overline{E} \geq 500$ keV) photons should be used for mixed source exposures with low-energy ($\overline{E} < 500$ keV) betas

It is intended that each DSP and other test participant be tested in the categories that best represent the services they provide or intend to provide. It is also intended that DSPs employ the same methodology as is normally used for processing personnel extremity dosimeters for a client/user.

Tests in Categories I, II, and III (including all subcategories) are single-field exposures. That is, each individual dosimeter is exposed in only one field.

Tests in Category IV are mixed-field exposures. That is, each individual dosimeter is exposed to two fields, a photon field and a beta field. Mixed-field exposures are not typically performed at the same time because most irradiation laboratories are not equipped for simultaneous exposures from two fields. Typically, mixed-field exposures are performed one at a time with the assumption that the response of the dosimeter would be then same for either method.

Two modes of testing are offered: non-blind and blind. When a participating laboratory only tests in categories I, II, and/or III (i.e., they do not choose Category IV), then dosimeters will be tested with the non-blind option. That is, for each dosimeter tested the participant will be told the irradiation source for the purpose of allowing the participant to apply a specific correction factor to determine a more accurate personal dose equivalent. This is consistent with the way NIRPR calculates the extremity dose for most single-element extremity dosimeter designs in practice. In these cases, the occupational field is known so a specific correction factor can be used to give a more accurate measurement.

When a DSP and other Test Participant chooses Category IV, dosimeters will be blind-tested in all categories tested. The DSP and other test participant will not

be told which sources were used to expose any of the dosimeters, with the exception that the participant would be told which dosimeters were exposed in the high-dose category (Category I). However, under blind testing, if the DSP and other test participant choose the "General" subcategory in Category I, he or she will not be told whether the irradiating field was ^{137}Cs or M150.

DSP and other test participant may choose the blind option to demonstrate greater capabilities of their dosimetry system. Dosimeters capable of blind testing generally have one or both of these design features:
(1) they have multiple elements that are used to perform source/energy discrimination, and/or
(2) they use nearly tissue-equivalent materials such that source/energy discrimination is unnecessary.

2.7.1 Category I: High-Dose Photons

For the "General (B and C, random)" subcategory IA, the radiation field in which each dosimeter is to be irradiated shall be chosen at random by the NIRPR with the provision that at least three dosimeters will be irradiated using each source (^{137}Cs and M150).

2.7.2 Category II: Photons

For the photon subcategories IIA (General, ($\overline{E}$ ≥ 20 keV)) and IIC (Medium Energy (E ≥ 70 keV)), specific photon radiation fields shall be chosen at random by the NIRPR for each irradiation with the provision that at least 3 dosimeters of the 15 submitted for testing shall be irradiated in high-energy photon fields ($\overline{E}$ ≥ 500 keV). For the photon subcategories IIB (High E ($\overline{E}$ ≥ 500 keV)) and IID (Narrow Spectrum), specific photon radiation fields shall be chosen at random by the ILNIRPR for each irradiation. Additionally, for all subcategories under Category II, only one dosimeter shall receive an assigned test irradiation less than 2.5 mSv (250 mrem).

2.7.3 Category III: Betas

For the "General (B and C, random)" subcategory IIIA, the specific beta irradiation field shall be chosen at random from subcategories IIIB (High E Point Source ($\overline{E}$ ≥ 500 keV)) and IIIC (Low E Point Source ($\overline{E}$ < 500 keV)) by the NIRPR with the provision that at least three dosimeters shall be irradiated using the high-energy ($\overline{E}$ ≥ 500 keV) beta source and at least three shall be irradiated using the low-energy ($\overline{E}$ < 500 keV) beta source. The slab uranium (Category IID) source will not be included in the random selection of sources in Category IIIA.

Note 1: For high energy ($\overline{E}$ ≥ 500 keV), ^{90}Sr/^{90}Y sources are used, where the ^{90}Sr and ^{90}Y are in secular equilibrium. The theoretical maximum beta particle energies from the beta decay of ^{90}Sr/^{90}Y are 0.55/2.28MeV, respectively. A 100 mg cm^{-2} filter (nominal) is used to absorb the ^{90}Sr beta particle.

Note 2: For low energy ($\overline{E}$ < 500 keV), ^{85}Kr sources are used, where the theoretical maximum beta particle energy from the beta decay of ^{85}Kr is 0.687 MeV. In the past, ^{204}Tl sources were also used with a theoretical maximum beta particle energy of 0.760 MeV.

2.7.4 Category IV: Beta/Photon Mixtures

This category is for blind testing only. Dosimeters tested in this category shall be irradiated in a beta field corresponding to the subcategory in which the participant is tested in Category III (betas) and in a photon field corresponding to the subcategory in which the participant is tested in Category II (photons).

For all mixed-field irradiations, the specific photon radiation fields used for the photon portion will be chosen at random from those available in that subcategory, with the provision that at least three of the exposures will be from high-energy photons ($\overline{E} \geq 500$ keV).

For all mixed-field irradiations, the specific beta radiation fields used for the beta portion will be chosen at random from those available in that subcategory, with the following provisions:

1. A high-energy photon ($\overline{E} \geq 500$ keV) will always be used for mixed-field exposures with low-energy beta sources ($\overline{E} < 500$). Low-energy photon and low-energy beta exposures will never be used in combination for mixed-field exposures in performance testing.

2. If the participant tested in beta subcategory IIIA (General), then at least three exposures will be from the high-energy beta source ($\overline{E} \geq 500$ keV) and at least three exposures will be from the low-energy beta source ($\overline{E} <$ 500 keV).
3. Beta Subcategory IIID (Slab Uranium) will never be used for mixed-field exposures.

2.8 Radiation Sources

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

1. At least one ^{137}Cs and/or one ^{60}Co gamma-ray source. The sources may be used either in a beam-type irradiator equipped with a collimator or in free air. The NIRPR will make measurements and verify that the shallow and deep personal dose equivalents agree to within 5%.
2. At least one constant potential x-ray machine operating at an appropriate tube potential and with appropriate beam filters to produce the x-ray spectra listed in Table 5a of this standard such that (1) the first half-value thickness is within 5% and (2) the homogeneity coefficient is within 7% of those listed in Table 5a.
3. Sources of narrow-spectra photons to include at least a ^{241}Am source or an NS80 x-ray beam to represent plutonium spectral emissions at 60 keV.*
4. A sealed ^{90}Sr/^{90}Y beta-particle source equipped with a 100 mg cm^{-2} filter (nominal) to absorb the ^{90}Sr beta particle. It shall meet the following specifications:

   a) The residual maximum energy, E_{res}, shall equal or exceed 1.80 MeV.
   b) The in-phantom absorbed dose at 100 mg cm^{-2}, $D(1)$, divided by the in-phantom absorbed dose at 7mg cm^{-2} , $D(0.07)$, shall be 1.01 ± 0.03.
   c) The in-phantom absorbed dose at 1g cm^{-2}, $D(10)$, shall be less than 1% of the in-phantom absorbed dose at 7 mg cm^{-2}.

If an accreditation program requires a narrow spectrum, or k-fluorescence, x-ray field to adequately test personnel extremity dosimeters in low-energy plutonium fields (e.g., between 17 and 30 keV), then it is recommended that a

field specified in ISO-4037, part 1 be chosen as a reference and a conversion coefficient determined by fitting published shallow-dose conversion coefficients to the measured energy fluence spectrum using an appropriate interpolation methodology.

Note 1. The in-phantom depths for these depth-dose specifications are not depths in the extremity phantoms, but are depths in the solid slab phantom of PMMA with a thickness of 15cm and a face no smaller than 30 cm × 30 cm and no larger than 40 cm × 40 cm

Note 2. A summary of characteristics for beta particle sources and fields is given in Table 2b of this document.

5. A sealed ^{85}Kr beta-particle source meeting the following specifications:

a) The residual maximum energy as defined in ISO 6980-1 (ISO 2006) shall equal or exceed 0.53 MeV.

b) 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.

X. A slab natural or depleted uranium source (typically 3 inches wide and 24 inches long).

Note: The uranium slab source should be of sufficient width and length to simulate an infinite plane source to the dosimeter-phantom system being irradiated.

Table 5a. Characteristics of (NIST) photon beam techniques.

NIST Tech.	Added filter[b]				Half-value[a] layer		Homogeneity[a] coefficient		$\overline{E}$ (keV)	FWHM (keV)
Beam code	Al (mm)	Cu (mm)	Sn (mm)	Pb (mm)	Al (mm)	Cu (mm)	Al	Cu		
M30	0.5				0.36		65		20	13
M60	1.56				1.68		66		35	28
H50	4				4.2	0.14	92	90	39	14
M100	5				5.02		73		53	42
M150	5	0.25			10.2	0.67	87	62	73	59
H150	4	4	1.51		17	2.5	100	95	118	44
M250	5	3.2			18.5	3.2	90	86	139	105
H250	4	0.6	1.04	2.72	22	5.2	100	98	204	61
NS80	4	2				0.58		94	65	21
^{137}Cs						10.8			662	
^{60}Co						14.9			1,250	

[a] The specified half-value layers should be duplicated to within 5% and the homogeneity coefficients to within 7%, if necessary by adjusting the tube potential.

[b] The inherent filtration is approximately 1.0 mm Be for beam codes M20–M50 and 3.0 mm Be for beam codes M60–M300, H50–H300 and NS80.

Table 5b. Characteristics of beta particle sources and fields.

Source	Half-life (y)	Filter	$\overline{E}$ (MeV)	Min. E_{res} (MeV)	$\frac{D(0.2)}{D(0.07)}$	$\frac{D(1)}{D(0.07)}$	$\frac{D(10)}{D(0.07)}$
^{85}Kr	10.77	1 PET[a] disc of radius 4 cm and thickness 50 µm, plus 1 PET concentric disc of radius 2.75 cm and thickness 190 µm[b]	0.26	0.53	0.80 ± 0.05	-	-
^{90}Sr/^{90}Y	28.8	-	0.84	1.80	-	1.01 ± 0.03	< 0.01
Depleted or Natural Uranium	4.5 x 10^9	Between 3 and 7 mg cm^{-2}	0.62[c]	-	-	0.58 ± 0.04	< 0.03

[a] PET is polyethylene terephthalate.
[b] The filter shall be mounted at a distance of 10 cm from the source surface.
[c] This is the average energy of beta particles emerging from the filtered source.

2.9 Phantom Construction

Two phantom types shall be used for dosimeter irradiations: one (denoted as a pillar phantom in ISO 4037-3) to represent a lower arm or leg to test wrist or ankle dosimeters and one to represent a finger to test ring or hand dosimeters (denoted as a rod phantom in ISO 4037-3). The rod phantom shall be a solid, right-circular cylinder constructed of PMMA having a diameter of 19 mm (3/4 inches) and a length of 300 mm (about 1 foot) or more. The arm phantom shall be a solid, right-circular cylinder of PMMA having a diameter of 73 mm (2 7/8 inches) and a length of 300 mm (about 1 foot) or -longer. For the uranium slab irradiations, the phantom lengths may be smaller than specified above.

2.10 Irradiation Conditions

The dosimeters shall be irradiated on the appropriate phantom. The reference dose point shall coincide with the center of the surface of the phantom facing the source. The dosimeters shall be attached to the surface of the phantom, so they are facing the source. The phantom shall be positioned so that the central beam axis is perpendicular to and passes through the central axis of the phantom (the axis of the cylinder along its length). For the uranium slab exposure, the dosimeters will be placed on a phantom (truncated if necessary) that is then placed on the slab so that the surface of the dosimeter is in contact with the uranium slab. For the purposes of the test, the reference dose point is 7 mg cm^{-2} beyond the plane of the source covering. (Normally, uranium slabs used for testing are covered with approximately 7mgcm^{-2} of PET (polyethylene terephthalate) to preclude the spread of contamination to test dosimeters.) Dosimeter irradiation geometries are summarized in Table 6.

For photon and point geometry beta-particle irradiations, the scatter from the room surfaces, the source, and phantom support hardware shall be measured and controlled so as to contribute only a small fraction of the uncertainty in the assigned dose equivalent (see Section 2.12). The NIRPR may elect to irradiate several dosimeters simultaneously. The laboratory

shall take 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.

The NIRPR shall adhere to standard good practices for the irradiations.

Table 6. Dosimeter irradiation geometries.

Source type	Minimum distance[a]	Maximum useful field diameter, cm[b]
Photon sources		
^{241}Am	50	15
^{137}Cs, ^{60}Co	100	15
NIRPR Procedure No. SSDLP-RPT.007	100	15
Beta sources		
Point-isotropic	30	10
Slab	On contact	-

[a] Distance from the source center to the front surface of the phantom.
[b] Dosimeters are positioned so that the sensitive elements are on the front face of the phantom and fall within the maximum useful interval. The maximum useful interval defines the area of the phantom face that can be used for irradiation without causing a resulting dose that exceeds the total uncertainty by ± 5%. The useful interval could conceivably be and may be smaller than the maximum listed in this table if the resulting dose yields a total uncertainty that exceeds ± 5%.

2.11 Selection of Irradiation Levels

For Categories I (High-Dose, Photons), II (Photons), and III (Betas), the NIRPR's target delivered absorbed dose (for Category I) or target delivered personal dose equivalent (for Categories II and III) shall be determined by the following equation:

$$\log (D \text{ or } H) = \log (D_1 \text{ or } H_1) + \rho [\log (D_u \text{ or } H_u) - \log (D_1 \text{ or } H_1)] \quad (\textit{Equation 20})$$

where D (or H) is the NIRPR's target delivered absorbed dose (for Category I) or target delivered personal dose equivalent (for Categories II and III),

D_l (or H_l) and D_u (or H_u) are the lower (l) and upper (u) limits of the delivered absorbed dose (or personal dose equivalent) of the range of test irradiation levels, and

ρ equals a random variable between 0 and 1.

For Category II (Photons), no more than 1 of the 15 dosimeters in any given subcategory shall be irradiated with a delivered personal dose equivalent less than 2.50 mSv.

For Category IV (Beta/Photon Mixtures) the target delivered personal dose equivalent of the photon exposure is first determined and then used to determine the target delivered personal dose equivalent for the beta

exposure. The photon portion of the dose is determined by Eq. (1), as if it were a Category II (Photon) exposure. The photon exposure plan can have no more than 1 of 15 dosimeters irradiated with a delivered personal dose equivalent less than 2.50 mSv (250 mrem), but the total dose equivalent has to be greater than 3.50 mSv (350 mrem). After the target delivered photon personal dose equivalent is calculated for each dosimeter, the target beta personal dose equivalent is determined by the following equation:

$H_{Beta} = \delta H_{Photon}$ *(Equation 21)*

where H_{Beta} and H_{photon} are the NIRPR's target delivered beta and photon personal dose equivalents and δ equals a random variable between and including 1 and 5. The beta personal dose equivalent is to be a multiple of one to five times that of the photon personal dose equivalent, that is, the ratio of the personal dose equivalents of the two types of radiation qualities shall range between 1:1 and 5:1 (beta:photon).

The NIRPR will attempt to expose the dosimeters to the calculated targeted values, but obtaining the exact values is not critical to the test. The NIRPR will determine the *B* and *S* using the actual delivered doses.

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

The NIRPR shall assign to each dosimeter a value for the shallow dose equivalent $H_p(0.07)$ or absorbed dose (D_s).

2.12.1 Photons

For photons, the dose equivalent assigned to exposed extremity dosimeters shall be calculated using the exposure-to-dose conversion factors listed in Table 7 (provided for informational purposes).

The shallow absorbed dose (D_s) and shallow dose equivalent ($H_p(0.07)$) for radioactive source irradiations shall be calculated by:

$D_s = \dot{K}_a c_{K,s,\alpha} t$

(Equation 22)

or

$H_{s(0.07)} = \dot{K}_a c_{K,s,\alpha} t$ *(Equation 23)*

Where $\dot{K}_a$ is the air kerma rate, $c_{K,s,\alpha}$ is the air kerma-to-dose equivalent conversion factor for shallow dose(s) in Gy/Gy for high-level doses and Sv/Gy for protection-level doses, where *α*, the angle between the central ray of emanation from the source and the perpendicular tangent to the face of the dosimeter phantom, is taken to be 0˚, and *t* is the irradiation time.

Table 7. Factors to convert from air kerma to shallow personal dose equivalent

NIST beam code	Shallow personal dose equivalent conversion factor $\overline{c}_{K,s,\alpha}$		ISO beam code	Shallow personal dose equivalent conversion factor $\overline{c}_{K,s,\alpha}$	
	Phantom			Phantom	
	Finger α = 0°	Arm α = 0°		Finger α = 0°	Arm α = 0°
[a]L15	0.93	0.93	[a]Hk10	0.89	0.89
[a]L20	0.94	0.95	[a]Hk20	0.95	0.95
[a]L30	0.97	0.99	[a]Hk30	0.99	0.99
[a]L40	1.00	1.03	[a]Hk60	1.07	1.07
[a]L50	1.02	1.07	[a]Hk100	1.12	1.12
[a]L80	1.06	1.17	[a]Hk200	1.16	1.16
[a]L100	1.07	1.21	[a]Hk250	1.16	1.16
			[a]Hk280	1.16	1.16
[a]M20	0.96	0.97	[a]Hk300	1.16	1.16
[a]M30	0.99	1.01			
[a]M40	1.01	1.06	[a]WS60	1.10	1.10
[a]M50	1.03	1.09	[a]WS80	1.13	1.13
M60	1.05	1.15	[a]WS110	1.16	1.16
M100	1.10	1.29	[a]WS150	1.17	1.17
M150	1.14	1.35	[a]WS200	1.16	1.16
[a]M200	1.16	1.34	[a]WS250	1.15	1.15
M250	1.16	1.29	[a]WS300	1.15	1.15
[a]M300	1.15	1.24			
			[a]NS10	0.91	0.91
[a]H10	0.91	0.91	[a]NS15	0.95	0.95
[a]H15	0.96	0.96	[a]NS20	0.98	0.98
[a]H20	0.98	0.98	[a]NS25	1.00	1.00
[a]H30	1.03	1.08	[a]NS30	1.03	1.03
[a]H40	1.07	1.19	[a]NS40	1.07	1.07
H50	1.09	1.26	[a]NS60	1.11	1.11
[a]H60	1.11	1.33	[a]NS80	1.15	1.15
[a]H100	1.16	1.38	[a]NS100	1.17	1.17
H150	1.17	1.32	[a]NS120	1.17	1.17
[a]H200	1.16	1.27	[a]NS150	1.17	1.17
H250	1.15	1.24	[a]NS200	1.16	1.16
[a]H300	1.14	1.22	[a]NS250	1.15	1.15
			[a]NS300	1.14	1.14
[a]S60	1.07	1.21			
[a]S72	1.06	1.17	[a]LK10	0.91	0.91
			[a]LK20	0.99	1.00
^{137}Cs	1.11	1.15	[a]LK30	1.03	1.08
^{60}Co	1.11	1.13	[a]LK35	1.06	1.17
			[a]LK55	1.11	1.34
			^{241}Am	1.14	1.39

Notes:

1. Multiplying kerma by the conversion factor yields the personal dose

equivalent. If kerma is in grays, the personal dose equivalent will be in sieverts. If kerma is in rads, the personal dose equivalent will be in rems.
2. The [a] superscript denotes fields provided for informational purposes.

X . 3 0 . 2 **Beta Particles**

For beta particles, the dose equivalent ($H_p(0.07)$) assigned to exposed dosimeters shall be calculated using the following:

$$H_p(0.07) = D_t(0.07)t\ c_{QF} \qquad \textit{(Equation 24)}$$

where $D_t(0.07)$ is the absorbed dose rate at a depth of d = 0.07 mm (7 mg cm^{-2}), t is the irradiation time, and c_{QF} is the quadrant correction factor (a correction to the reference dose at the reference dose point to account for differences due to the geometric offset).

For the uranium slab irradiations, the absorbed dose rate is interpreted to be 0.07 mm (7 mg cm^{-2}) beyond the covering on the slab (nominally 2.1 mSv h^{-1} with a covering of 7 mg cm^{-2} of PET).

In the test categories involving mixed radiation fields, the values for the shallow personal dose equivalent delivered to the dosimeter for each type of radiation shall be added.

Except as noted below, the uncertainty of the personal dose equivalent or absorbed dose assigned by the NIRPR to each irradiation shall not exceed ± 5% for photons and ± 7% for betas, excluding uncertainties in the dose equivalent conversion factors. The assigned uncertainty shall include uncertainties in source standardization, uncertainty in the distance between the source and 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 applied to the sum, which implies a 95% confidence interval.

It is recognized that because of technological limitations, the uncertainty in the assigned personal dose equivalent for low-energy ($\overline{E}$ < 500 keV) beta particles may exceed ± 7%. The effects of these uncertainties can be minimized by participants having dosimeter calibrations performed by the NIRPR prior to testing.

X.30 **Performance Criteria**

Performance in each category shall be considered adequate if, for the shallow dose equivalent or absorbed dose,

$$B^2 + S^2 \leq L^2 \qquad (\textit{Equation 25})$$

where B is the bias of the performance quotients for a particular category or subcategory, S is the standard deviation of the performance quotients for the

category or subcategory, and L is the tolerance level.

The values of the tolerance level, L, shall be: $L = 0.24$ in the high-dose category (Category I) and $L = 0.35$ in the low-dose categories.

REFERENCES

1. American National Standard for Dosimetry – Personnel Dosimetry Performance – Criteria for Testing, ANSI/HPS N13.11-2009, American National Standards Institute, Inc. 2009.
2. American National Standard: Performance Testing of Extremity Dosimeters, ANSI/HPS N13.32-2008, American National Standards Institute, Inc., November, 2008.
3. Conversion Coefficients for Use in Radiological Protection Against External Radiation, ICRU Report 57. Bethesda, MD: International Commission on Radiation Units and Measurements; 1998.
4. Department of Energy Standard for the performance testing of personnel dosimetry systems, DOE/EH-0027. Washington, DC: U. S. Department of Energy; 1986.
5. General principles of monitoring for radiation protection of workers, ICRP Publication 75. Oxford: Pergamon Press; 1997.
6. *Guide to the Expression of Uncertainty in Measurement*. Geneva, Switzerland: International Organization for Standardization (ISO); 1995.
7. Instructions for Participating in Proficiency Testing for Wholebody, Electronic and Extremity Dosimeters, National Voluntary Laboratory Accreditation Program (NVLAP), January 2013.
8. Ionizing Radiation Dosimetry, NIST Handbook 150-4, 2005 Edition, National Voluntary Laboratory Accreditation Program (NVLAP), August 2005.
9. Lamperti, P. J. and O'Brien, M. Calibration of x-ray and gamma-ray measuring instruments. NIST Special Publication 250-58. Washington, DC: U. S. Department of Commerce; 2001.
10. Limitation of Exposure to Ionizing Radiation, NCRP Report 116. Bethesda, MD: National Council on Radiation Protection and Measurements; 1993.
11. Measurement of Dose Equivalents from External Photon and Electron Radiation, ICRU Report 47. Bethesda, MD: International Commission on Radiation Units and Measurements; 1992.
12. National Institute of Radiation Protection and Research (NIRPR) Procedure No. SSDLP-RPT.007 for Proficiency Testing of Dosimetry Systems in Nigeria.
13. Nuclear Energy – Reference beta-particle radiation – Part 1: Methods of production, ISO 6980-1. Geneva, Switzerland: International Organization for Standardization (ISO); 2006.
14. Quantities and Units in Radiation Protection Dosimetry. ICRU Report 51. Bethesda, MD: International Commission on Radiation Units and Measurements; 1993.
15. Radiation Quantities and Units, ICRU Report 33. Bethesda, MD: International Commission on Radiation Units and Measurements; 1980.
16. Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, New York, NY: Pergamon Press; 1991.
17. Reference neutron radiations – Part 1: Characteristics and methods of production, ISO 8529-1. Geneva, Switzerland: International Organization for Standardization (ISO); 2001.
18. Reference neutron radiations – Part 3: Calibration of area and personal dosimeters and determination of their response as a function of neutron energy and angle of incidence. ISO 8529-3. Geneva, Switzerland: International Organization for Standardization (ISO); 1998.
19. Soares, C. G. and Martin, P. R. A consistent set of conversion coefficients for personnel and environmental dosimetry. Proceedings of the Panasonic User's Group Meeting, Somerset, PA; June 5-9, 1995.

20. Technical and Quality Assurance Requirements for Dosimetry Services, S-106 Revision 1, Canadian Nuclear Safety Commission, May 2006.
21. The Management System for Technical Services in Radiation Safety, Safety Guide No. GS-G-3.2, International Atomic Energy Agency (IAEA), July 2008.
22. X and gamma reference radiation for calibrating dosemeters and dose rate meters and for determining their response as a function of photon energy – Part 1: Radiation characteristics and production methods, ISO 4037-1. Geneva, Switzerland: International Organization for Standardization (ISO); 1996.

APPENDIX A

INSTRUCTIONS FOR PARTICIPATING IN PROFICIENCY TESTING

FOR WHOLE BODY, ELECTRONIC and EXTREMITY DOSIMETERS

A1 INTRODUCTION

A complete test of a dosimeter model requires 15 dosimeters (21 dosimeters for category II) to be irradiated over a 3-month period in each radiation category for which accreditation is desired. The dosimeters are evaluated in terms of shallow and deep dose equivalent, as applicable.

DSP and other Test Participant applying for accreditation for the first time, those introducing new models, or those required to retest failures, may select a starting date of their choice according to the following testing schedule.

1st Quarter – Whole Body (Initial/Renewal/Retest)
2nd Quarter – Extremity/EPD (Initial/Renewal)
3rd Quarter – Whole Body (Initial/Renewal/Retest)
4th Quarter – Extremity/EPD (Retest ONLY)

After the initial accreditation, DSPs must perform proficiency testing of the dosimeter(s) at least Six (6) Months before the expiration of their accreditation as this is the basis for renewal of their accreditation.

Dosimeters are shimmed to be parallel to the front face of the phantom and delivered doses are normally reported to the front face of the phantom. If DSPs want the doses reported to the active element of the dosimeter, the offset between the phantom face and the active element must be reported on the registration form.

Each individual dosimeter sent for testing must use a barcode provided by the NIRPR. The supplied barcode should be placed in a visible location on the front of the dosimeter. This code will be used to document/report the performance of each dosimeter.

Place all identical dosimeters in a separate container (plastic bag) and mark each container with the designation used for that model/type dosimeter.

The dosimeters must be shipped to allow sufficient time for them to arrive at NIRPR at least 2 (TWO) business days before the beginning of each month. Dosimeters received after the FIFTH day of a month may be returned unirradiated.

Each month after the dosimeters have been irradiated, they will be returned to you via a private parcel system for evaluation. In addition, a reporting

template specific to the dosimeters tested will be provided to you by NIRPR. *Please provide NIRPR with a name and an adequate shipping address (no P.O. Box) for the return of the dosimeters and a valid e-mail address for the reporting template on the attached registration documents.*

All evaluated doses must be reported back to NIRPR using the supplied reporting template within 15 business days of your receipt of the irradiated dosimeters. *Failure to comply with this 15-day limit may result in all dosimeters in any affected test category being voided.*

NIRPR will send the results of your testing to the Legal Person within 3 weeks of receiving all of the Performance Test participants evaluated doses.

If satisfactory performance is not demonstrated for a dosimeter in any category attempted, you will be informed along with the test results. You will also be notified as to what retesting will be required.

A2 NEUTRON CALIBRATION IRRADIATIONS

Since it is proper to calibrate neutron dosimeters to the neutron spectrum in which they will be used, NIRPR will provide free calibration irradiations for neutron dosimeters.

THESE CALIBRATION IRRADIATIONS WILL BE PROVIDED ONLY THE FIRST TIME A DOSIMETER MODEL IS SUBMITTED FOR TESTING. This calibration should be adequate for all future use unless otherwise notified.

If you wish to obtain a calibration irradiation, include FIVE dosimeters (TEN dosimeters if testing ^{252}Cf Bare and ^{252}Cf D_2O moderated) in a separate container that is clearly marked “FOR NEUTRON CALIBRATION” with the first monthly shipment. These dosimeters will be returned to you along with a report showing the neutron dose delivered.

A3 SPECIFIC INSTRUCTIONS FOR ELECTRONIC PERSONNEL DOSIMETERS (EPDs) PROFICIENCY TESTING

The registration form is the same as the one used for whole body personnel dosimeters.

X. DSPs and other Test Participants will submit five (5) EPD dosimeters (seven [7] if testing category II) each month, randomly selected from the dosimeter population used by the laboratory for personnel monitoring, for each category to be tested.

X. The maximum dose will be limited to the range of the EPD for all categories including the accident categories. The processor must specify the dose range and, if applicable, the dose-rate range of the EPD. If the range is not specified, NIRPR will assume that there is no limit.

X. The units must be capable of being reset by the NIRPR.

X. Each unit needs a barcode supplied by NIRPR in a visible location on the front of the EPD.

X. **The EPDs shall be shipped with <u>ALL</u> alarms turned off.**

X. Each model will be photographed in order to verify that the dosimeter model proficiency tested is the one used by the laboratory/processor. The dosimeters will not be taken apart unless specified otherwise.

X . The units should be shipped in such a state that they are clear of any recorded dose so NIRPR does not overload the memory or display.

8. If it is necessary to use a separate read-out unit with the EPDs, then this unit, and the appropriate software and cables, must also be shipped to NIRPR.

9. All units must be shipped with operating instructions; a complete manual should NOT be sent.

10. The laboratory must include six spares to be used in the case of obvious dosimeter malfunctions, such as battery failures, display failures, erratic function, and if the dosimeter indicates no response to the radiation exposure at all.

11. The participant should place a mark on the EPD if it is necessary to center the device at somewhere other than the geometrical center of the case. Unless this marking is called out to NIRPR, it will be assumed that the case should be centered over the reference point on the phantom.

12. REPORTING EPD RESULTS: DSPs and other Test Participants or Processors will read the EPDs and report the readings for all required and appropriate (e.g., some EPDs do not respond to shallow dose) test depths to NIRPR via the supplied reporting template. Some EPDs report response in units other than personal dose equivalent (e.g., exposure (R or mR)). In such cases, NIRPR will interpret the response as personal dose equivalent.

Appendix B
Source Standardization

B1. Photons

Source standardization identifies the critical parameters that must be reproduced in order to achieve a radiation source whose energy spectrum conforms to that used to establish the conversion coefficients relating the primary calibration quantity, air kerma, to the personal dose equivalent. Failure to closely reproduce the source characteristics will result in an incorrect determination of the absorbed dose or personal dose equivalent delivered at the reference depth in tissue. Similarly, the accuracy of a measurement using a transfer standard (e.g., ionization chamber) depends on the degree that the measured source or field corresponds to that used to calibrate the standard. It is not the purpose of this standard to serve as a primer on source calibration and standardization. The key parameters that must be matched to use the personal dose equivalent conversion coefficients presented in the standard appear in Tables 2a-d. For x-rays, the first half-value layer should be reproduced to within 5% and the homogeneity coefficient to within 10%. The applied tube kilovoltage may be adjusted to achieve the beam quality specifications. Calibration of higher energy photon sources must be conducted under electronic equilibrium conditions. Thin sheets of plastic placed in front of the source can help achieve this condition and remove any high energy Compton electrons created in the source housing and collimators. Ion chambers used for calibration must have build-up caps with thickness appropriate for the photon energy. The establishment of electronic equilibrium is critical to achieve the condition where the deep and shallow absorbed doses or personal dose equivalents are equal. Use of the conversion coefficients assumes that photon sources are calibrated in terms of air kerma at a point in free space. Conversion coefficients relate the free space measurement to the personal dose equivalent at different depths in an ICRU tissue slab phantom whose front surface is centered at the reference dose point. The distance between the reference dose point and source must be sufficiently large to approximate a plane, parallel beam. For photon sources, the distance should equal or exceed one meter although lesser distances may be appropriate to achieve large personal dose equivalents in reasonable periods of time.

B2. Beta Particles

Beta particle sources should be calibrated directly in terms of the absorbed dose at a depth of 0.07 mm in tissue. Source calibration can be performed with an extrapolation chamber whose front surface has a mass density of approximately 0.007 g cm^{-2}.[The average relative mass collision stopping power, necessary to determine the tissue absorbed dose from an ionization measurement, depends on the beta particle energy spectrum. A beam flattening filter must be used for ^{85}Kr irradiations to ensure uniform fluence and personal dose equivalent rates across the front surface of the phantom. Finally, calibration must account for the absorption of beta particles and degradation of the beta particle energy spectra in air. For ^{85}Kr, a fixed distance of 30 cm is required to ensure the variations in the mass of intervening air do not contribute unacceptable errors in delivering a personal dose equivalent to the RDP. The NIRPR is encouraged to use sources that have been calibrated by a primary or secondary calibration laboratory and also to perform direct measurements with a calibrated extrapolation chamber to verify or adjust the reference absorbed dose rate.

A natural or depleted uranium slab for beta particle calibrations needs to meet

the following specifications: the source protective covering shall be in the range between 3 mg cm^{-2} and 7 mg cm^{-2}; the dose rate at 100 mg cm^{-2} divided by the dose rate at 7 mg cm^{-2} shall be 0.58 ± 0.04; and the in-phantom dose rate at 1000 mg cm^{-2} shall be less than 3% of the dose rate at 7 mg cm^{-2}. The measurement specification shall take precedence over the source covering specification. The dimensions of the source must exceed the dimensions of the irradiated dosimeters.

B3. Neutrons

The neutron sources specified in this standard are to be characterized in terms of fluence rates (m^{-2} s^{-1}) and emission spectra. Coefficients have been computed to convert the fluence to personal dose equivalent. The coefficients presented in the standard have been derived by weighting the energy specific conversion coefficients by the relative abundance of each energy in the emission spectrum determined for the moderated and unmoderated californium sources. see Appendix C2.

The irradiation facility can impart significant influence on the neutron spectra reaching the dosimeter. Neutron irradiation is accomplished commonly with the source suspended in free space with neutrons emitted in all directions. This configuration introduces the need to estimate the personal dose equivalent contribution from neutrons scattered from the walls of the irradiation facility as well as any fixtures required to suspend the source and support any phantoms on which dosimeters are mounted. Numerous methods to evaluate the scatter contribution have been reported . The NIRPR shall quantify and adjust for the effect of neutron scatter. Other facility-specific effects such as source anisotropy and source transport effects shall be considered, as appropriate, in terms of total calculated uncertainty and/or adjustments to delivered quantities.

The distance between the bare neutron source and the front surface of the dosimeter phantom (assuming that the plane of the front face of the phantom is perpendicular to the central ray of the neutron “beam”) should be initially set to minimize geometry effects and effects from air out-scatter and room in-scatter. . Typically, the distance between the source and phantom surface should be between 50 and 100 cm.

For the D_2O-moderated ^{252}Cf source, consideration should be given to limiting the smallest source-to-phantom distance to between 65 and 100 cm. At 50 cm, the dosimeter phantom is only 35 cm from the surface of the source moderator.

Appendix C

Interpretation of the Response of Dosimeters for Personnel Monitoring

C1. Personal Dose Equivalent

The procedures of this standard test the ability of dosimetry systems to evaluate the personal dose equivalent at depths of 0.07 mm [$H_p(0.07)$] and 10 mm [$H_p(10)$] in a simplistic ICRU tissue slab phantom representing the body. International radiation protection experts have identified the personal dose equivalent as the operational quantity to use for assessing and controlling radiation exposure. Extensive computer models reveal that under the majority of exposure conditions $H_p(10)$ represents a conservative estimate for the effective dose while $H_p(0.07)$ adequately addresses the skin dose. NNRA regulations have adopted different names and call the doses at these two depths the deep dose equivalent and shallow dose equivalent.

The Regulations require their use to demonstrate compliance with the permissible limits of exposure to radiation. The personal dose equivalent as used in this standard satisfies the definitions given by international guidelines. As such, the quantitative dose data provided by dosimetry systems satisfying this standard should be acceptable from a regulatory perspective.

Although the water phantom may be an adequate substitute, the ICRU tissue composition is used by the international community to derive the coefficients predicting absorbed dose at the different depths in the phantom. The shape of the phantom influences the amount of backscatter and, consequently, the personal dose equivalent. For photons found in diagnostic radiology, the $H_p(10)$ occurring in a 30 cm diameter sphere of tissue can be 15% less than that occurring in a 30 cm x 30 cm x 15 cm slab. The slab enables several dosimeters to be irradiated together in the same plane parallel to the phantom surface and perpendicular to the irradiation beam. The curvature of the sphere limits irradiation to a single dosimeter.

C2. Conversion Coefficients Relating the Calibration Quantity to the Personal Dose Equivalent

Much information, largely the result of computer calculations, exists about the relation of the calibration quantity (air kerma for photons, fluence for neutrons) to $H_p(10)$ and (for photons) $H_p(0.07)$. Included in this standard are the adjustments to be made when irradiations are made at non-perpendicular incidence.

The coefficients used in this Standard to convert neutron fluence to personal dose equivalent was a cylindrical phantom of radius 15 cm and height 60 cm constructed of 10.5 % (by weight) hydrogen, 18.8% carbon, 3.1% nitrogen and 67.6% oxygen . In contrast, the current ISO coefficients apply to a 30 cm by 30 cm by 15 cm slab phantom constructed of 10.1 % hydrogen, 11.1 % carbon, 2.6 % nitrogen and 76.2 % oxygen . Additionally, the reference depth for dose equivalent in earlier models was “element 57,” the outer slice of the cylinder 2 cm thick (2000 mg cm^{-2}) coincident with the central ray of the neutron beam incident on the phantom. The reference depth for personal dose equivalent is now taken at a depth of 1 cm (1000 mg cm^{-2}) also coincident with the central ray of the neutron beam incident on the phantom.

Appendix D
Performance Criteria and Performance Analysis

Since the adoption of performance standards for film dosimeters in the early 1970s, criteria used to evaluate passive dosimetry systems have been based on group statistics, bias or standard deviation, or a combination of both. This standard specifies a limit on the sum of bias and standard deviation and individual limits on each of those statistics. The absolute value of the bias was used, so the criteria were symmetric about zero.

Periodic testing is a form of protracted process control and that an adequate model for testing the performance of dosimetry systems has been described as the Average Loss per Unit of Production. The Average Loss is directly proportional to the Mean Square Deviation about a Target (MSD) defined as the combination of the variance (σ^2) and the square of the deviation from the target value $(\overline{X} - \tau)$. Since the target values are spread over a range of values, the square of the deviation from the target should be normalized and redefined as the Bias. The MSD is then just the acceptable limit on performance. This approach embraces the philosophy of operating a process "On Target with Minimum Variation,"

$$MSD(\tau) = \left[\sigma^2 + \left(\overline{X} - \tau\right)^2\right] \qquad \textit{(Equation D1)}$$

Pursuant to the above approach, the philosophy of "On Target with Minimum Variation" could be described as given below,

$$B^2 + S^2 \leq L^2 \qquad \textit{Equation D2)}$$

The *B* and S statistics are immediately recognizable as being identical with the bias and standard deviation in this and other standards. The *L* is the limit of acceptable performance. By representing the *L* as L^2 it can be seen that the area of acceptable performance describes a semi-circle with $-L \leq B \leq L$ and $0 \leq S \leq L$.

The *Limit of acceptable Performance, L,* criteria was applied to historical dosimetry data (2002-2004) from the National Voluntary Laboratory Accreditation Program (NVLAP). The model was used with two different limits for the high-dose and protection-level categories. The tolerance limit for the protection categories (II through V) was found to be to 0.30 (30%), and that for accident 0.24 (24%) (see Figures D1 and D2). While it is difficult to assess the impact of the reduction of the available test sources on performance, the evidence from tests conducted with the procedures of this standard, which contained an angular irradiation test, suggests that a tolerance limit of 0.30 (30%) would not be unduly restrictive.

Figure D1. Accident Category Historical Dosimetry Performance Data Plotted with the Previous and Current Performance Models

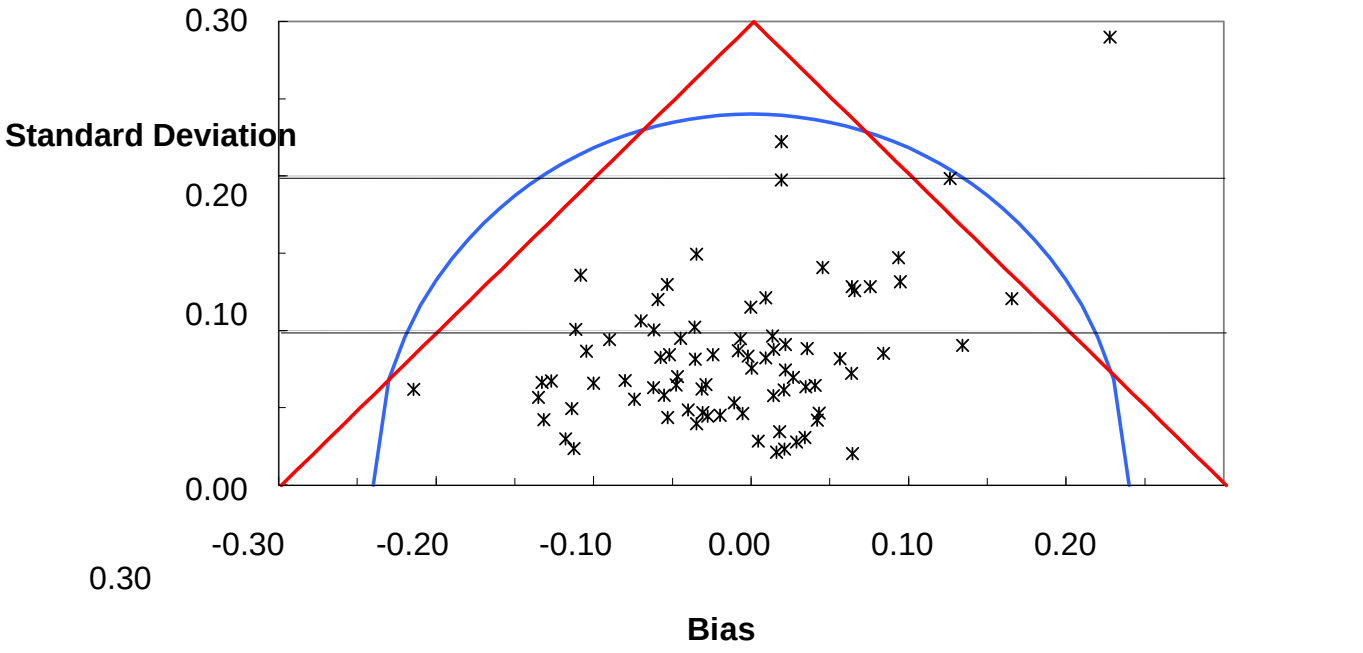
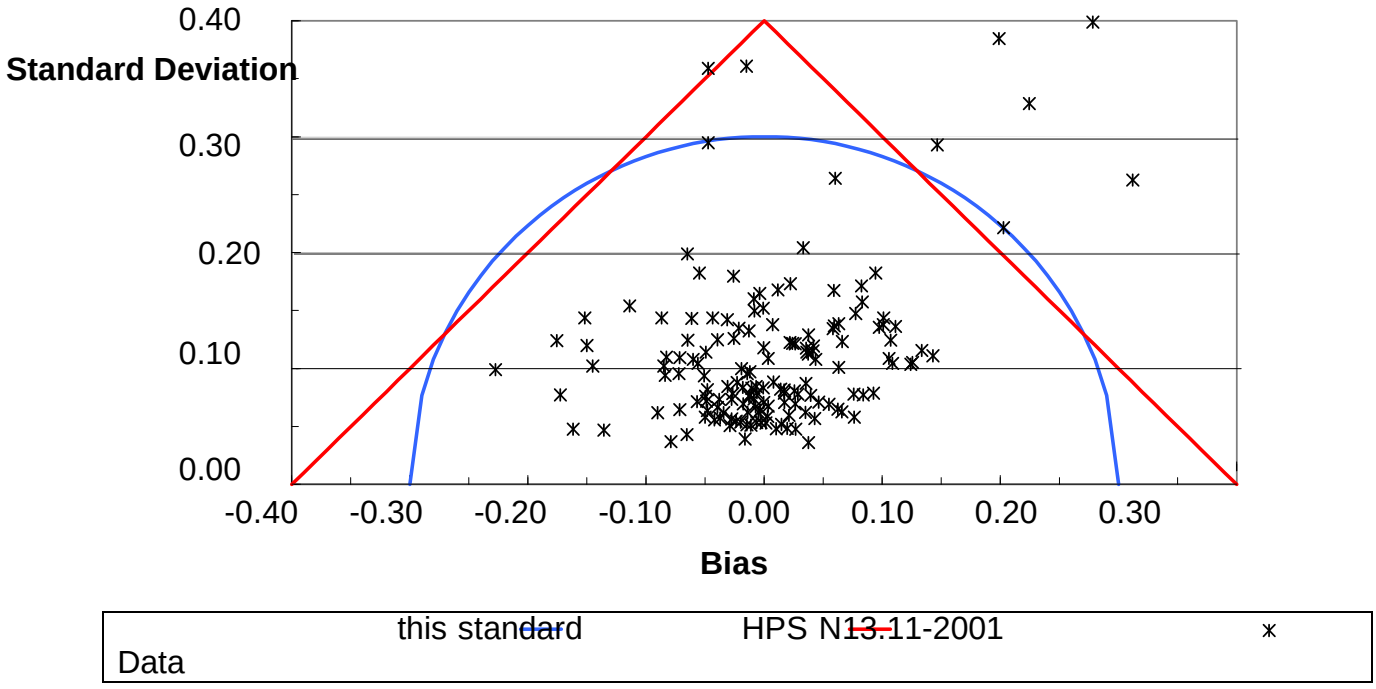


Figure D2. Category II & IV Historical Dosimetry Performance Deep Data Plotted with the Previous and Current Performance Models



Appendix E
Irradiating Laboratory (NIRPR) Guidance

E1 Introduction

The NIRPR performs the procedures in this standard. This appendix provides guidance for the NIRPR to facilitate proper testing.

E2 Receipt and Handling of Dosimeters for Testing

The NIRPR records the date dosimeters are received and the DSPs and other test participant name, and should assign the project a unique reference number. The NIRPR inspects all dosimeter shipments received for testing and notes any areas of boxes or shipping containers in poor condition or that otherwise might indicate damage to contents. If damage to the box or container appears severe, it should document receipt condition. If tamper-proof seals or tape are present and appear breached, it notes their condition. The NIRPR notifies the DSPs and other test participant if there is obvious or suspected damage to the contents of the box. Any damaged dosimeters found are noted, withheld from testing and replaced using spare dosimeters furnished by the DSPs and other test participant. In cases where an inadequate number of spares are available, NIRPR contacts the DSPs and other test participant for further instructions.

Performance testing dosimeters are to be stored in a controlled-access, background-monitored, low-background area whenever possible. If a low or unmonitored background area is unavailable or not identified, dosimeters should be stored in shielded storage to minimize background exposure. If control dosimeters are submitted by the DSPs and other test participant, they should remain at all times with the dosimeters that are to be irradiated, with the exception of those limited durations that dosimeters are being irradiated, in transit to/from the irradiation area or within shielded staging areas prior or subsequent to exposure.

E3 Dosimeter Tracking

The NIRPR verifies that the correct number and type of dosimeters have been submitted. Each dosimeter number is recorded and a unique indicator (such as a barcode) is assigned and recorded for each dosimeter used for testing. The NIRPR or the DSPs and other test participant (by mutual agreement or by procedure) is to maintain a record that cross-references the participant's dosimeter number and the NIRPR assigned number.

E4 Dosimeter Mounting

Dosimeters shall be mounted with the front side of the dosimeter facing the source of radiation consistent with the DSPs and other test participant's instructions. Dosimeters should be mounted in an orientation consistent with normal wear.

Dosimeters are to be shimmed with low-density materials (such as expanded polystyrene) so that their back planes are parallel to the phantom surface.

E5 Multiple Dosimeter Irradiations

Dosimeters from several test participants should be irradiated simultaneously, when possible, to enhance quality control. The possible number of dosimeters irradiated simultaneously will depend upon the size and

orientation of the dosimeters. Typically, five dosimeters are irradiated simultaneously at normal incidence on a phantom. The sensitive element(s) of each dosimeter must remain within the characterized and uniform area of the radiation field, but also should be separated from other dosimeters to limit the amount of mutually scattered radiation.

E6 Irradiation Quality Control Measures

The NIRPR should evaluate the irradiations with quality control devices (such as ionization chambers or thermoluminescent dosimeters) to verify that the expected absorbed dose or personal dose equivalent was delivered to the dosimeters. Quality control devices should be selected such that they will not induce a significant scatter influence upon the dosimeters being tested. Selection should be optimized to produce an indication/confirmation of delivered radiation with adequate precision for the various anticipated reference fields. Upon selection of suitable quality control devices, statistical control limits should be established for use in confirming delivered radiation quantities.

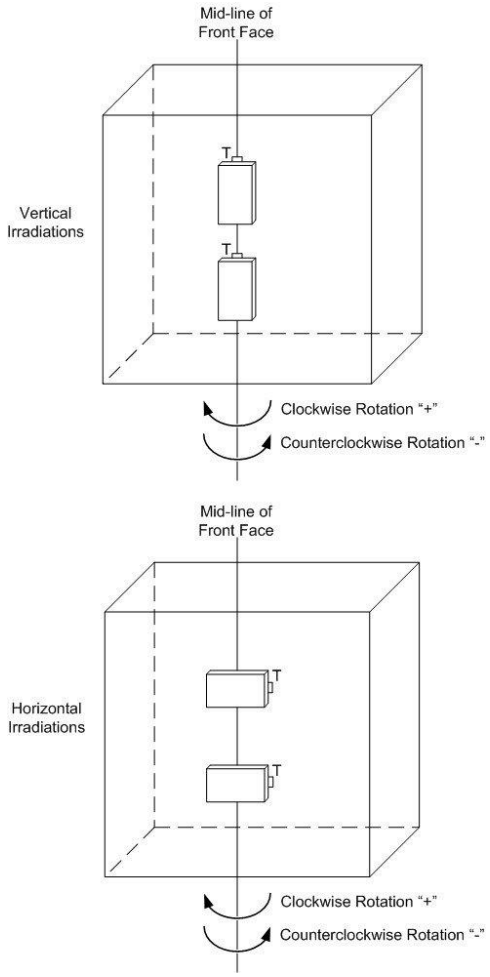
E7 Adjustment for Non-uniformity

Dosimeters are irradiated within a defined area (see Section 3.5) in the center of the phantom face. The NIRPR measures the uniformity of the field in each exposure position and adjusts the absorbed dose or personal dose equivalent for non-uniformity. An alternate approach is to take an average correction for dosimeter positioning effect and include the resulting uncertainty into the overall estimation of uncertainty.

E8 Angular Testing

The NIRPR determines the angle and orientation for delivering photon irradiations at non-perpendicular incidence.
The orientation is either Vertical or Horizontal in the ‘+’ or ‘-‘ direction. If the orientation is ‘Vertical’, then the dosimeter is mounted on the center-line of the front face of the phantom as it is normally worn by the user. If the orientation is ‘Horizontal’, the dosimeter is mounted with the top of the dosimeter rotated 90° clockwise when viewed from the source. When the dosimeter has been properly positioned, the phantom is rotated counter-clockwise (‘- direction‘) or clockwise (‘+ direction’), when viewed from above the phantom, about the vertical centerline of the phantom face to the proper angle for the irradiation (see Figure E1).

Figure E1. Dosimeter orientations for irradiations at non-perpendicular orientations



In Figure E1, the DSPs and other test participant has identified the normal wearing (vertical) orientation with the long axis of the dosimeter being perpendicular to the floor.

E9 Returning Test Dosimeters

The dosimeters are to be re-inventoried to verify that all dosimeters submitted for testing are being returned to the clients. The NIRPR checks the number of samples against the receipt inventory and resolves any discrepancies, and shall inform the client of any lost dosimeters.

Dosimeters are to be suitably protected and appropriately identified with respect to test categories as stipulated by this standard. Controls and/or spare dosimeters, as well as any misirradiated or damaged dosimeters, are separated and appropriately identified. Shipping boxes or containers are labeled to caution the shipping company of the sensitivity of the contents to radiation (e.g., "Keep away from radioactive material and excessive heat. Do not x-ray."). Warning labels should be selected that are specifically recognized by the transport company. The package should be augmented with tamper-proof warning tape or labels. The NIRPR should return the irradiated test dosimeters to the DSPs and other test participants.

E10 Traceability

The reference fields for establishing calibration and test conditions at the NIRPR rely on the following quantities for traceability.

Table E1. Reference field quantities and traceability methods

Radiation Field	Reference Quantity	National Standard	Transfer Method
Gamma	Air Kerma Rate (Gy s^{-1})	Cavity Ionization Chambers	Ionization Chamber (Reference Transfer Standard)
X-rays	Air Kerma Rate (Gy s^{-1})	Free Air Ionization Chamber	Ionization Chamber (Reference Transfer Standard)
Beta	Absorbed Dose Rate Gy s^{-1})	Extrapolation Ionization Chamber	Extrapolation Ionization Chamber or Calibrated Source
Neutron	Neutron Fluence Rate (m^{-2} s^{-1})	Manganese Bath	Calibrated Source and/or Tissue Equivalent Proportional Counter

Ideally, the NIRPR shall maintain traceability to NIST to within 5% for standard fields, however it is recognized that because of technological limitations, the agreement with NIST for neutrons and low energy beta particles may exceed ±5% (see 3.7.6) for accuracy. Precision should remain below ±5% for all fields.

E11 Field Quality

The NIRPRshall determine the half-value layer and homogeneity coefficients for x-ray fields using the protocol established in ISO 4037-1. The ionization chamber used to determine these quantities should have an essentially energy-independent response over the energies resulting from the addition of absorber materials. Filter and absorber materials shall be controlled to the purity levels specified in ISO 4037-1. The scatter influence at the RDP shall be evaluated and be less than 5%. Guidance for such evaluations is provided in ISO 4037-1.

Gamma fields are to be produced with sources of adequate encapsulation to attenuate the beta component (^{137}Cs and ^{60}Co) and low energy photon (< 30 keV) emissions of ^{241}Am to less than 1% of the primary radiation fluence. As with x-ray facilities, the potential scatter influence in each gamma irradiation facility shall be evaluated and its contribution to the field at the RDP is to be less than 5%. Encapsulation specifications and guidance for scatter evaluations are provided in ISO 4037-1. For ^{137}Cs and ^{60}Co reference fields, electronic equilibrium shall be established at the RDP. If lead attenuators are

used to reduce the intensity of the field strength, a distance of at least 100 cm between the lead and the RDP shall be maintained to reduce the distortion of electronic equilibrium.

An extrapolation ionization chamber is used to determine the ratio of $D(0.07)$ and $D(10)$. A standard 30 cm x 30 cm x 15 cm PMMA phantom can be modified to accept the extrapolation ionization chamber internally.

PET and PMMA plates are placed over the front of the extrapolation ionization chamber to increase the effective depth of the measurement. A dual polarity method is used to determine the signal at each depth. If the ratio of the signals at the two depths is within 5% of the ratio published by Grosswendt for the PMMA slab phantom, then the irradiation field conforms to the published c_K values used in this standard. Measured values for the isotopic photon sources (^{60}Co, ^{241}Am, and ^{137}Cs) are to be used when measurements are statistically different than the c_K values published in this standard, but within the 5% requirement. Similarly, the NIRPR determines the depth (transmission) dose profiles in the PMMA phantom for the beta fields.

Measurements are conducted from approximately 1 mg cm^{-2} through 1000 mg cm^{-2} and the appropriate quantities used to judge the penetrability of the field.

E12 Delivered Dose Formula

The NIRPR determines the delivered absorbed dose or personal dose equivalent as the product of the field quantity and a conversion coefficient to obtain the reference absorbed dose or personal dose equivalent for the irradiation. The RDP is at the center of the phantom face. The delivered absorbed dose or personal dose equivalent (referred to below more simply as “Delivered Dose”) for irradiations is determined as:

$$\text{Delivered Dose} = Q_{\text{ref}} c_{Hp} c_{QF} \qquad \textit{(Equation E1)}$$

where Q_{ref} is the reference field quantity traceable back to national standards, c_{Hp} is the conversion from the field quantity to the absorbed dose or personal dose equivalent at the depth in tissue under the reference dose point, and c_{QF} is a correction for off-axis irradiations. Other factors may be considered, as appropriate.

Appendix F (informative)
Components of an External Dosimetry System

F1 Introduction

Merely achieving the technical requirements in this standard does not indicate that a dosimetry program has sufficient quality. While adequate metrology is at the heart of dosimetry, considerations such as legal defensibility and worker confidence must also be taken under consideration.

A quality dosimetry system will have to apply resources to each of these general areas:

- **quality assurance**,
- **personnel**,
- **equipment and facilities**,
- **dosimeters**,
- **calibration**,
- **processing**, and
- **testing**.

Further discussion on each of these areas is found below.

F2 Quality Assurance

Deciding what constitutes "quality" can be difficult. Some dosimetry systems have standard(s) of quality imposed upon them, which may be a military specification, quality "order," national or international standard, or a combination of standards. Other standards may also be adequate, and indeed may be required by extant laws.

There should be a quality manual (by any name, or consisting of a collection of documents) that identifies all of the components of the dosimetry system, the level of quality expected in each of the components, and how the levels of quality will be achieved. Procedures should be used to implement each component of the dosimetry system. A system for identifying problems (and potential problems) and for their correction should be in place. If dosimetry processing is contracted, adequate controls (contractual and administrative) should be in place to ensure that the dosimetry results are of the expected quality. Processing controls (e.g., light source readings, microprocessor controls, blind-audit dosimeters, and unexposed dosimeters) should be used in each processing run.

F3 Personnel

Dosimetry programs must have adequate personnel (both in quality and in quantity) with defined responsibilities. Education and experience should be taken under consideration when selecting personnel. Training should be in place to ensure that all personnel are able to properly and consistently perform their dosimetry functions. The individual who has overall technical responsibility must ensure that all dosimetry data are reviewed and approved, including those data that indicate no dose or dose below detection capabilities.

F4 Equipment and Facilities

Simply stated, equipment and facilities must be adequate to support the level of quality necessary.

Environmental conditions (temperature, lighting, humidity, radiation background, etc.) must be adequate for proper, stable operation of the equipment.

F5 Dosimeters

Procurement and testing of dosimeter materials should be well-defined. Representative samples of dosimeters, their elements, and their filters should be tested to ensure that the desired sensitivity, accuracy, and precision can be obtained. Periodic checks should be made to ensure that the dosimeters continue to function as expected. There must be a system in place to ensure that all monitored personnel are assigned a dose for every dosimeter used, and that the dosimeter results are assigned to the correct user. Dosimeters used for calibration and processing controls should under no circumstances be used as field-use dosimeters; field-use dosimeters should also not be converted to calibration dosimeters or process controls. Test dosimeters (blind spikes, blanks, and proficiency testing dosimeters), however, should represent the normal population of dosimeters. There are specific needs for each type of dosimetry system (TLD, track etch, etc.) that must be well understood, but which are beyond the scope of this appendix.

F6 Calibration

Dosimetry systems must be calibrated with radiation sources traceable to the Secondary Standard Dosimetry Laboratory (SSDL).

As a result of this traceability, the dosimetry processor will be able to state their best estimate of uncertainty of the dose that a wearer would have received if exposed to the same radiological conditions to which the dosimeter was exposed (“best uncertainty”). Unfortunately, this estimate will only be one part of the real overall uncertainty. In real life conditions, no one is exposed to standard test conditions. The workers are moving, the dosimeters are not always positioned in the same spot on the body, the sources are often variable, etc. A dosimetry program should not confuse this theoretical uncertainty related to traceability with those resulting from real life conditions.

F7 Processing

Standard, documented processing protocols should be followed whenever possible, using approved, validated*procedures. If alternate processing protocols are used (as in the case of a suspected high or unusual exposure), they should be well-documented and tested prior to use. Data transfer should always be verified for accuracy and integrity through systematic checks. All dosimetry data should be reviewed and approved by a designated individual, preferably the person who has ultimate responsibility for dose assignment. Algorithms should be well-identified and documented. Historical records should be able to identify the hardware and software algorithm in use at the time of any particular dosimeter’s processing run. Quality control dosimeters (spikes and blanks) should be interspersed at regular intervals during processing. A method should be in place to stop processing and to reconstruct dose for all dosimeters processed after the last good quality control dosimeter until the failure is identified and the processing stopped.

F8 Testing

Type Testing. The following items are usually, but not exclusively, included in type tests:

- Dosimeter self-irradiation;
- Batch homogeneity;
- Reproducibility after repeated processing;
- Batch reproducibility;
- Post-irradiation fading of the radiation-induced signal;
- Residual signal after high dose;
- Dose rate dependence;
- Environmental effects – temperature, humidity, static discharge, physical shock, radio frequency fields, electromagnetic fields, electric fields, etc.;
- Energy dependence;
- Angular dependence;
- Lower limit of detection (see below).

Periodic Testing. Routine proficiency testing to this standard is highly recommended. A suggested period is 2 – 3 years between tests. Blind testing (blanks and spikes) should occur, to a limited extent, in every processing period. While it is difficult to construct routine testing in a way that is completely blind to the processor, it is recommended that there be an independent organization (even within the same company) that irradiates dosimeters to levels that are consistent with routine occupational exposure levels, or to some reasonable level measurably above the lower level of detectability. The dosimeters should be submitted for processing along with the normal personnel dosimeters so that the processor does not know that they are

F9 Lower limit of detection (LLD)

The following procedures are recommended for determining the LLD.

Suggested Method for the LLD Study

For each dosimeter design, at least 10 dosimeters for irradiation per category, plus 10 dosimeters for background evaluation shall be selected from the routine-processed pool of dosimeters for this study. The dosimeters shall be placed in an unshielded environment for a time sufficient to obtain an unirradiated background signal typical of routinely processed dosimeters. At least 10 dosimeters shall be irradiated for each category to a dose significantly greater (e.g., 5 mSv) than the estimated lower limit of detectability. Both the irradiated and unirradiated dosimeters shall be processed and evaluated. The following quantities shall be calculated:

$$H_o = \frac{1}{n} \sum_{i=1}^{n} X_{io} \qquad \text{(Equation F1)}$$

$$S_o = \sqrt{\frac{\sum_{i=1}^{n} (X_{io} - H_o)^2}{n-1}} \qquad \text{(Equation F2)}$$

$$H_1 = \frac{1}{n} \sum_{i=1}^{n} X_{i1} \qquad \text{(Equation F3)}$$

$$S_1 = \sqrt{\frac{\sum_{i=1}^{n}(X_{i1}-H_1)^2}{n-1}}$$ (Equation F4)

where X_{io} are unirradiated dosimeter values and X_{i1} are irradiated dosimeter values. The values H_o and H_1 are the mean evaluated dose-equivalent values for the unirradiated and irradiated dosimeters, respectively, and S_o and S_1 are the associated standard deviations. The dosimeter readings shall be processed through the dose algorithms without truncation or distortion (i.e., do not zero any readings). If a background is subtracted, negative values shall be retained for the calculation of S_o. The algorithms for the calculation of shallow dose equivalent shall be used to calculate H_o and H_1. The lower limit of detection, L_D, shall be calculated as follows:

$$L_D = \frac{2\left[t_p S_o + \left(t_p S_1/H_1\right)^2 H_o^{'}\right]}{\left[1 - \left(t_p S_1/H_1\right)^2\right]}$$ (Equation F5)

where t_p is the one-sided Student's t distribution for n-1 degrees of freedom and a p value of 0.95 and H'_o is the average of the unirradiated dosimeter values without subtracting a background signal.

The values of B and S from this Standard's proficiency test may be used to calculate [1.75 x S/(1 + B)], which may be used in place of $t_p S_1/H_1$ in the above equation. Only a set of unirradiated dosimeters would be required to determine L_D.

Appendix G (Informative)

Reference Conditions and Standard Test Conditions

Table G1 — Reference conditions and standard test conditions

Influence Quantities	Reference Conditions	Standard Test Conditions (unless otherwise indicated)
Ambient temperature	20 °C	18 °C to 22 °C [A,B]
Relative humidity	40 %	25 % to 75 % [A,B]
Atmospheric pressure	101.3 kPa	76 kPa to 106 kPa [A,B]
Electromagnetic field of external origin	Negligible	Less than the lowest value that causes interference
Magnetic induction of external origin	Negligible	Less than twice the value of the induction due to the earth's magnetic field
Assembly controls	Set up for normal operation	Set up for normal operation
Phantom	Slab of ICRU tissue 30 cm x 30 cm x 15 cm (for whole body dosimeters)	PMMA Slab Phantom: 30 cm x 30 cm x 15 cm
Angle of radiation incidence	Reference orientation	Reference orientation ± 5°
Contamination by radioactive elements	Negligible[c]	Negligible[c]
Radiation background	Ambient dose equivalent rate $H^*(10) \leq 0.1$ μSv h^{-1} and directional dose equivalent rate $H'(0{,}07;\ \overline{\Omega}) \leq 0.1$ μSv h^{-1}	Ambient dose equivalent rate $H^*(10)$ less than 0.25 μSv h^{-1} and directional dose equivalent rate $H'(0{,}07;\ \overline{\Omega})$ less than 0.25 μSv h^{-1}

A. The actual values of these quantities at the time of test shall be stated or accounted for in the estimation of uncertainty.
B. The influence of these values in the table are intended for calibrations performed in temperate climates. In other climates, the actual values of the quantities at the time of calibration shall be stated. Similarly, a lower limit of pressure of 70 kPa may be permitted where irradiations are to be performed at higher altitudes.
C. Allowable limits on surface contamination are established by local governments. Negligible indicates levels of contamination that will not affect the accuracy of the calibration nor pose a risk to the calibration personnel or facility.

Appendix H (Informative)

List of Symbols and Acronyms

a	cross sectional area
ANSI	American National Standards Institute
B	bias
$\overline{c}_{K,d,\alpha}$	spectrum averaged conversion coefficient from air kerma to personal dose equivalent at depth *d* and angle of incidence *α*
$\overline{c}_{\varphi}$	spectrum averaged conversion coefficient from fluence to personal dose equivalent
C_{dis}	distance correction factor
C_{Hp}	*generalized* conversion coefficient from field quantity to dose equivalent
C_{QF}	quadrant correction factor
d	depth
D	absorbed dose
$D_{T,R}$	absorbed dose to tissue T from radiation quality R
$D_{p}(d)$	personal absorbed dose at depth *d*
E	energy
$\overline{E}$	average energy
E_{max}	maximum energy
E_{res}	residual maximum energy
E_{tr}	energy transferred to electrons by photons
EPD	Electronic Personal Dosimeter
FWHM	full width at half maximum
H	dose equivalent
$H_{T,R}$	equivalent dose
$H_p(d)_I$	i th assigned dose equivalent of a series
$H_R(d)_I$	*i* th reported dose equivalent of a series
$H_p(d,\alpha)$	personal dose equivalent at depth *d* and angle of incidence *α*
HPS	Health Physics Society
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission
IL	irradiating laboratory
ISO	International Organization for Standardization
K_a	air kerma
L	tolerance level
LLD	lower limit of detection
M	mass
MSD	mean square deviation about a target value n
n	number of elements in a series
N	number of photons, beta particles or neutrons
N(E)	number of photons, beta particles or neutrons with energy *E*
NCRP	National Council on Radiation Protection and Measurement
NIST	National Institute of Standards and Technology
NIRPR	National Institute for Radiation Protection and Research
NNRA	Nigerian Nuclear Regulatory Authority
P_i	*i* th performance index in a series
PET	polyethylene terephthalate
PMMA	polymethyl methacrylate
PQL	performance quotient limit
PTB	Physikalisch-Technische Bundesanstalt
Q	quality factor
Q_{ref}	reference field quantity
RDP	reference dose point
S	standard deviation
TE	tissue equivalent

$\overline{X}$	general average of a population of measurements
A	angle of incidence
γ	ratio of photon to neutron personal dose equivalent rate
ε	mean energy imparted by ionizing radiation to matter
φ	fluence
φ_n	neutron fluence
σ^2	variance
τ	target value

Appendix I (Informative)

CHECKLIST FOR VERIFICATION OF RESULT OF PROFICIENCY TESTING FOR WHOLE BODY, ELECTRONIC and EXTREMITY DOSIMETERS

A complete test of a dosimeter model requires 15 dosimeters (except category II which will require 21 dosimeters) to be irradiated over a 3-month period in each radiation category for which accreditation is desired. The dosimeters are evaluated in terms of shallow and deep dose equivalent, as applicable.

DSP and other Test Participants applying for accreditation for the first time, those introducing new models, or those required to retest failures, may select a starting date of their choice.

After the initial accreditation, DSPs must perform proficiency testing of the dosimeter(s) at least Six (6) Months before the expiration of their accreditation as this is the basis for renewal of their accreditation.

All evaluated doses must be reported back to NIRPR using the supplied reporting template within 15 business days of your receipt of the irradiated dosimeters. *Failure to comply with this 15-day limit may result in all dosimeters in any affected test category being voided.*

With respect to the above, the following stepwise procedures are to be observed in the process of conducting the NNRA stipulated annual dosimetry equipment calibration tests. You shall:

i. Submit the required number of dosimeter of same type (e.g. Thermoluminiscence Dosimeter 100, Optically Stimulated Luminescence Dosimeters, Electronic Dosimeters etc.) representative of those supplied to your clients, to NIRPR Ibadan for required testing.
ii. Note that the NIRPR Ibadan will appropriately irradiate the Dosimeters with known doses in specified radiation field(s) applicable and return same to you after the irradiation is completed for evaluation.
iii. Evaluate the response of the irradiated dosimeters with your dosimetry equipment requiring calibration for conformity.
iv. Report the results of the Dosimeters evaluation to NIRPR Ibadan for independent evaluation of your dosimetry systems performance.
v. Send the same results of your Dosimeters evaluation to NNRA for regulatory purposes.

DATE:		DOSIMETER CODE:		NIRPR LAB CODE:	

PROFICIENCY TESTING REGISTRATION - WHOLE BODY DOSIMETERS

Instructions: Complete this sheet for each dosimeter model that will be submitted for testing, a t least **three months prior to testing**; In addition, include a copy with each group of dosimeters sent to NIRPR

Name of Facility _____

Contact Address _____

Name of Legal Person _____

Phone Number _____ **E-mail** _____

Name and Shipping Address for Dosimeter Return (if different from above): (Not P. O. Box)

_____

_____

Phone Number _____ **E-mail** _____

Calendar Year for Proficiency Testing: _____

Quarter	Scheduled Testing	Testing Status (circle one)		
☐ **Jan-Feb-Mar**	Whole Body	Initial	Renewal	Retest
☐ **Apr-May-June**	Extremity or EPD	Initial	Renewal	Retest
☐ **Jul-Aug-Sep**	Whole Body	Initial	Renewal	Retest
☐ **Oct-Nov-Dec**	Extremity or EPD	Initial	Renewal	Retest

Fill out the following information for each dosimeter model being tested (use a copy of this form for additional dosimeters if necessary) and check the appropriate categories from the Nigerian National Standard for Dosimetry — Personnel Dosimetry Performance — Criteria for Testing:

TYPE OF DOSIMETER:

Processor Dosimeter Description _____

Dosimeter Manufacturer: _____ **Holder Manufacturer** _____

Dosimeter Model No.: _____ **Holder Model No.:** _____

Reader Manufacturer: _____ **Reader Model:** _____

Dosimeter Active Element Offset from Phantom: _____

**Only include this offset if you want the doses reported to the active element of the dosimeter.*

BETA/PHOTON		***NEUTRON***	
Film	☐	TLD Albedo	☐
TLD	☐	NTA Film	☐
Electronic	☐ Range (if applicable) _____	Polycarbonate	☐
Other	☐ Specify _____	Electronic	☐ Range (if applicable) _____
		Other	☐ Specify _____

(continued on next page)

DATE: | **DOSIMETER CODE:** | **NIRPR LAB CODE:**

DOSIMETER ELEMENT DESCRIPTION

	ELEMENT 1	ELEMENT 2	ELEMENT 3	ELEMENT 4	OTHER
Detector Type (i.e, TLD, OSL)					
Detector Composition (i.e. Al_2O_3, CR29)					
Detector Thickness (mg/cm^2)					

ELEMENT FILTER DESCRIPTION

	ELEMENT 1	ELEMENT 2	ELEMENT 3	ELEMENT 4	OTHER
Filter Material					
Filter Thickness (mg/cm^2)					
Other					

HANGER FILTER DESCRIPTION

	ELEMENT 1	ELEMENT 2	ELEMENT 3	ELEMENT 4	OTHER
Filter Material					
Filter Thickness (mg/cm^2)					
Other					

WHOLE BODY

CATEGORY I: ACCIDENTS, PHOTONS

I_A	General (IB + IC Random)	☐
I_B	^{137}Cs	☐
I_C	M150	☐

CATEGORY II: PHOTONS/PHOTON MIXTURES

II_A	General	☐
II_B	High E	☐
II_C	Medium E	☐
II_D	Plutonium specific	☐

CATEGORY III: BETAS

III_A	General (IIIB + IIIC Random)	☐
III_B	High E	☐
III_C	Low E	☐
III_D	Uranium Slab	☐

CATEGORY IV: PHOTON/BETA MIXTURE

Select Photon Category

II_A ☐ II_B ☐ II_C ☐ II_D ☐

Select Beta Category

III_A ☐ III_B ☐ III_C ☐ III_D ☐

CATEGORY V: NEUTRON/ PHOTON MIXTURES

V_A General (V_B + V_C, random) ☐

V_B ^{252}Cf + II ***Select Photon Category***

II_A ☐ II_B ☐ II_C ☐ II_D ☐

V_C $^{252}Cf(D_2O)$ + II ***Select Photon Category***

II_A ☐ II_B ☐ II_C ☐ II_D ☐

EXTREMITY

CATEGORY I: HIGH-DOSE, PHOTONS

I_A	General (B and C, random)	☐
I_B	^{137}Cs	☐
I_C	M150	☐

CATEGORY II: PHOTONS

II_A	General	☐
II_B	High E	☐
II_C	Medium E	☐
II_D	Narrow spectrum	☐

CATEGORY III: BETAS

III_A	General (B and C, random)	☐
III_B	High E point source	☐
III_C	Low E point source	☐
III_D	Slab uranium	☐

CATEGORY IV: PHOTON/BETA MIXTURES

Select Photon Category

II_A ☐ II_B ☐ II_C ☐ II_D ☐

Select Beta Category

III_A ☐ III_B ☐ III_C ☐

DOSIMETERS REPORTING TEMPLATE

SN	Category	Radiation Source	Energy	Irradiation Geometry	Test Irradiation Range/Reading						
						1	2	3	4	5	Remarks
1.	**Category I – Accidents, Photons**										
	A. General (B & C, random)	^{137}Cs & M150 at random			Delivered Dose (0.05 to 5Gy)						
					Readings						
	B. ^{137}Cs	^{137}Cs			Delivered Dose (0.05 to 5Gy)						
					Readings						
	C. M150	M150			Delivered Dose (0.05 to 5Gy)						
					Readings						
2.	**Category II – Photons/Photons Mixture**										
	A. General	1:3 to 3:1 mixture of sources for subcategories IIA, IIC, IID. Mixtures shall always include one source from category IIB.	Mixture always include one irradiation with E≥500keV & one with <500keV	⊥ if ≤ 70keV, angular if >70keV (0°, ±40° or ±60°	Delivered Dose (0.5 to 50mSv)						
					Readings						
	B. High E	^{137}Cs, ^{60}Co		≤ 60°	Delivered Dose (0.5 to 50mSv)						
					Readings						
	C. Medium E	1:3 to 3:1 mixture of sources for subcategories IIA, IIC, IID. Mixtures shall always include one source from category IIB.			Delivered Dose (0.5 to 50mSv)						
					Readings						
	D. Plutonium Specific				Delivered Dose (0.5 to 50mSv)						
					Readings						
3.	**Category III - Betas**										
	A. General (B & C, random)	Random selection from the sources in subcategories IIIB and IIIC	at least 3 dosimeters irradiations with *E* >500 keV) and at least using with *E* <500keV)	Irradiation at ⊥ incidence	Delivered Dose (2.5 to 250mSv)						
					Readings						

			beta sources								
	B. High E	$^{90}Sr/^{90}Y$			Delivered Dose (2.5 to 250mSv)						
					Readings						
	C. Low E	^{85}Kr		Irradiation at ⊥ incidence	Delivered Dose (2.5 to 250mSv)						
					Readings						
	D. U Slab				Delivered Dose (2.5 to 250mSv)						
					Readings						
4.	**Category IV – Photon/Beta Mixtures**										
	Shallow	The ratio of the [photon *Hp*(0.07)]: [beta particle *Hp*(0.07)] is restricted to be in the range of 1:1 to 1:6, inclusive. There shall be no testing with ^{60}Co.	at least 3 dosimeters to be irradiated with *E* >500keV & 3 with *E* <500keV. ^{60}Co source shall not be used.	Irradiation at ⊥ incidence	Delivered Dose (3.0 to 300mSv)						
					Readings						
	Deep				Delivered Dose (0.5 to 50mSv)						
					Readings						
5.	**Category V – Neutron/Photon Mixtures**										
	A. General (B & C, random)	The ratio of the Hp(10) for neutrons : photons shall be in the range 1:3 to 3:1. The ratio includes the photon component from the neutron irradiation.	At least 3 dosimeters to be irradiated with E ≥500keV chosen at random from the fields in Category II.	Irradiation at ⊥ incidence	Delivered Dose (1.5 to 50mSv)						
					Readings						
	B. ^{252}Cf + II				Delivered Dose (1.5 to 50mSv)						
					Readings						
	C. $^{252}Cf(D_2O)$ + II				Delivered Dose (1.5 to 50mSv)						
					Readings						

*Standard Test Condition should be 18°C to22°C; relative humidity 25% to 75%; Atmospheric Pressure 76kPa to 106kPa; Negligible electromagnetic field and magnetic induction of external origin