



American National Standard

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Performance Testing of Extremity Dosimeters

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American National Standards Institute, Inc.



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Foreword

(This foreword is not a part of ANSI/HPS N13.32-2018.)

This standard provides a procedure for testing the performance of extremity personnel dosimetry systems used to monitor personnel exposure to the extremities from ionizing radiation. This is the third revision of the original standard, HPS N13.32-1995 [1]. Evaluating the adequacy of the standard through the implementation of testing procedures for extremity dosimetry systems has been an active part of the current revision.

By American National Standards Institute (ANSI) policy, standards must be reviewed and must be reaffirmed or revised after 5 years and no more than every 10 years or the standard is withdrawn by ANSI. The ASC N13 Working Group that reviewed this and prior revisions of this standard held to three major objectives in the revision of the standard: (1) as far as possible, maintain an approach to testing that is consistent with the practical application of extremity dosimeter systems without excluding current techniques or techniques that should be available in the near future, (2) attempt to achieve a measure of consistency with related national and international standards, and (3) base major changes in the approach and content of the standard on scientific fact.

Suggestions for improving this standard are welcome. Suggestions should be sent to the HPS, 1313 Dolley Madison Blvd., Suite 402, McLean, VA 22101.

Performance Testing of Extremity Dosimeters

1.0 Purpose and Scope

1.1 Purpose

This standard establishes standardized testing conditions and criteria to evaluate the performance of personnel extremity dosimetry services.

1.2 Scope

Specifications are given in this standard for test categories, test irradiation ranges, and acceptable models with associated levels of performance. A test is conducted when dosimeters are sent from the facility that normally processes or reads the dosimeters (i.e., the “processor”) to a testing organization 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 for evaluation under the criteria given in this standard.

The standard applies to dosimetry systems used to assess personal dose equivalent at a depth of 0.07 mm in International Commission on Radiation Units and Measurements (ICRU) tissue in extremities; specifically, hand, elbow, arm below the elbow, foot, knee, leg below the knee. 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 0.07 mm, this standard 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. As in the last versions of this standard, no consideration is given to administrative aspects of dosimetry programs such as adequacy of dosimeter identification, detailed formats of reports, field calibrations, placement of dosimeters on extremities, or the assessment of dose from the placement of multiple extremity dosimeters.

The basis of absorbed dose and dose equivalent in this standard is the personal dose equivalent at 0.07 mm specified by both the International Commission of Radiological Protection (ICRP) and the 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 [2].

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

As in the earlier standards, N13.32-1995 [1] and N13.32-2008 [3], neutron exposure of the extremities still presents a special problem. The committee reviewed this issue and found no compelling evidence to implement a neutron dose equivalent test for extremity dosimeters at this time. Quoting from the 1995 standard:

“Current neutron fluence-to-dose-equivalent conversion factors specified in recommendations of the NCRP [National Council on Radiation Protection and Measurements] are derived from the maximum value of dose equivalent in a 30-cm diameter cylindrical torso phantom. These values include secondary charged particles from neutron interactions as well as contributions from gamma rays from the absorption of neutrons by hydrogen atoms. The use of data (including the quality factors) from the cylindrical torso phantom model is not applicable for the extremities. Therefore, neutron test categories are not included in this standard. This issue should be re-examined in future revisions of this document or when appropriate fluence-to-dose equivalent conversion factors are established.”

As in the previous version of this standard, type-testing issues have been segregated into two general types: those typically performed once in the lifetime of a dosimeter system and those performed as periodic performance testing. As such, and consistent with prior versions, there is no specific requirement to conduct a one-time evaluation

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of dosimeter performance under conditions of nonperpendicular angular incidence. Neither is there a requirement to conduct a study to evaluate the lower limit of detectability (LLD). These tests are important in the interpretation of dosimeter results but should be addressed in a type-testing standard.

The methodology and criteria presented in this standard provide the basis for evaluating the performance of extremity dosimeter systems. Section 2 comprises a list of terms and definitions used in the standard. Section 3 comprises the testing procedures, testing categories, specifications of testing fields, specification of testing phantoms, specification of irradiation geometries, selection of irradiation levels, and the assignment of shallow dose equivalent. Section 4 describes the criteria by which performance is judged to be acceptable.

Following the example set in the standard for testing whole-body personnel dosimeter systems, ANSI N13.11-2009(R2015) [4], ancillary information to clarify and support the positions in this standard is included in the appendices.

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

2.0 Definition of Terms

The definitions for many of the terms used in this standard are given below. The definitions presented for quantities and units are compliant with those of ICRU 51 [5].

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

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

Unit: J kg⁻¹

The special unit of absorbed dose is gray (Gy). (The traditional unit of absorbed dose, rad, is 10⁻² Gy.)

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.

Air kerma, K_a . The quotient of dE_{tr} by dm , where dE_{tr} is the sum of the initial kinetic energies of all electrons liberated by photons in a volume element of air of mass dm , thus

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

Unit: J kg⁻¹

The special unit for the unit of air kerma is gray (Gy). (The traditional unit of air kerma, rad, is 10⁻² Gy.)

Average energy, $\bar{E}$. The fluence-weighted average energy (keV or MeV) of a field of photons or beta-particles calculated as

$$\bar{E} = \frac{\int_0^{E_{\max}} N(E)E dE}{\int_0^{E_{\max}} N(E)dE} \quad (\text{Eq. 3})$$

where $N(E)$ is the fluence with energy between E and $(E + dE)$, and $E_{\max}$ is the maximum energy present in the spectrum.

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

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

where the sum is extended over all n values of P_i for a particular test in a given radiation category (or subcategory), and for a particular phantom (rod or pillar).

Blind testing. A testing protocol where the participant is not informed of the radiation source. Testing that is not blind testing is referred to as nonblind. Note that regardless of the participant choice, Category 1 (see Table 1) is always nonblind unless the "general" subcategory is chosen.

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

$$\bar{c}_{K,d,\alpha} = \frac{H_p(d, \alpha)}{K_a} \quad (\text{Eq. 5})$$

where for photons, d is 0.07 mm for the shallow depth, and α is the angle of radiation incidence.

Unit: Sievert per gray (Sv Gy^{-1} or rem rad^{-1} in traditional units) for photons

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

Dose equivalent, H .¹ The product of D and Q at a point in tissue, where D is the absorbed dose and Q is the quality factor² at that point, thus

$$H = DQ \quad (\text{Eq. 6})$$

Unit: J kg^{-1}

The special unit of dose equivalent is Sv. (The traditional unit of dose equivalent, rem, is 10^{-2} Sv.)

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.

Extremity. The hand and arm below the elbow; the foot and leg below the knee [6].

Extremity dosimetry system. A system used to assess dose equivalent resulting from external radiation to the extremities. The extremity dosimetry system includes the dosimeter, the dosimeter-processing system, and the system used to assure the quality of the dosimetry result.

¹ Beginning with ICRP Publication 60, the ICRP uses the term "equivalent dose" for dose weighted by the relative biological effectiveness related quality factor. However, since the ICRU is the Bureau International de Poids et Mesures (BIPM)-appointed body for radiation dose units, its terms and quantities are used throughout this standard (see footnote 2).

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

Homogeneity coefficient. The ratio of the first half-value layer thickness to the second half-value layer thickness times 100. The first and second half-value thicknesses may differ due to the presence of scatter.

ICRU tissue. A tissue-equivalent (TE) material defined in ICRU Report 33 [7] having a density of $1,000 \text{ mg cm}^{-3}$ and a composition by mass of 76.2% O, 10.1% H, 11.1% C, and 2.6% N.

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

Performance quotient, P_i . The relative difference of the absorbed dose or personal dose equivalent reported by the test participant from the delivered absorbed dose or personal dose equivalent, which for the i^{th} dosimeter is defined as

$$P_i \equiv [H'_i - H_i] / H_i \quad (\text{Eq. 7})$$

where H_i is the personal dose equivalent assigned by the IL to the i^{th} irradiated dosimeter and H'_i is the corresponding personal dose equivalent reported by the test participant.

For tests of high-dose dosimetry, the same definition applies with the absorbed dose, D , replacing the personal dose equivalent, H .

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 .

² Beginning with ICRP Publication 60, the ICRP uses the term "radiation-weighting factor" for absorbed dose to equivalent dose conversion. However, since the ICRU is the BIPM-appointed body for radiation dose units, its terms and quantities are used throughout this standard.

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Note 1: Any statement of personal dose equivalent should include a specification of the depth, d , expressed in mm.

Note 2: Shallow dose equivalent is defined as the personal dose equivalent at a depth of 0.07 mm in ICRU tissue and is denoted by $H_p(0.07)$.

Processor. A supplier of personnel dosimetry services. These services include:

- Furnishing dosimeters to the user.
- Evaluating the readings of the dosimeters after their return in terms of the absorbed dose or personal dose equivalent as prescribed in this standard.
- Recording the results.
- Reporting the results to the user.

Protection levels. Dose levels at which there is a reasonable expectation of accuracy for routine reporting and protection of the individual. For this standard, protection levels are considered to be below 0.1 Gy (10 rad). The upper end of the regulatory range of protection dosimetry levels is addressed in the “high-dose levels” categories.

Radiation field. A region in which ionizing radiation of a known type and known spectral and angular distribution is present and whose intensity is able to 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 coincides with the surface of the phantom along the central ray of the radiation field passing through the center of the phantom with the exception of irradiations conducted on a slab uranium source. For irradiations conducted on a slab uranium source, the reference dose point is determined empirically as 7 mg cm⁻² beyond the slab covering that is in contact with the dosimeter.

Residual maximum energy, E_{res} . The highest value of the energy (keV or MeV) of a beta-particle spectrum at the reference dose point after having been modified by scatter and absorption.

Ring dosimeter. Any dosimeter worn on the fingers of the hand to measure radiation dose, alternatively referred to as a finger or finger-ring dosimeter.

Shallow absorbed dose, $D_p(0.07)$, or Shallow dose equivalent, $H_p(0.07)$. The absorbed dose or personal dose equivalent at a depth of 0.07 mm in an appropriate phantom of ICRU tissue. Extremity doses are all expressed as shallow absorbed dose or shallow dose equivalent.

Standard deviation, S . The standard deviation of the values of the performance quotient, P_i , is

$$S \equiv \sqrt{\frac{\sum_{i=1}^n (P_i - \bar{P})^2}{n-1}} \quad (\text{Eq. 8})$$

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 and

$$\bar{P} = (1/n) \sum_{i=1}^n P_i \quad (\text{Eq. 9})$$

Target delivered absorbed dose (D) or Target delivered personal dose equivalent (H). This value of D or H is determined/calculated by the IL and used as a target value to achieve while exposing dosimeters sent for proficiency testing. Sections 5.9 and A5 use this term in the discussion of the selection of proficiency testing irradiation levels.

Test. Sequence of steps and actions needed to evaluate the performance of personnel dosimeters.

Test category. A collection of radiation qualities and absorbed dose or personal dose equivalent levels for which dosimetry testing is defined.

Test subcategory. A collection of radiation fields in a test category which may include only a limited portion of the energy range of the full category. The general subcategory in each category contains the most comprehensive set of radiation fields (see footnotes to Table 1).

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

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

Tolerance level, L. The boundary of acceptable performance of a dosimetry system. For this standard the tolerance level is determined by the following equation:

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

where B is the bias and S is the standard deviation previously defined.

Uncertainty. Parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand [8].

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

3.0 Test Procedure

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

- The test participant selects the categories for which evaluation is sought.
- The test participant 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 IL over a period of several months. The participant supplies the number of dosimeters required for testing in the requested test categories.
- The IL irradiates the dosimeters in the radiation field(s) specified for applicable categories.

- The IL returns the dosimeters to the test participant for evaluation.
- The test participant evaluates the response of the irradiated dosimeters in terms of the absorbed dose or personal dose equivalent at the specified test depth.
- The test participant reports the results of the dosimeter evaluation to the IL in the required time.
- The testing organization evaluates the dosimeter performance based on criteria in this standard.
- The testing organization notifies the test participant of the dosimeter performance.

3.1 Administrative Procedure

The test participant shall provide the following information to the testing organization:

- A certification that the dosimeters submitted for each test are representative of those supplied to customers.
- The test categories desired.
- An indication whether blind testing (test category not disclosed to participant before test results are reported) is desired.
- An indication whether dosimeters are worn on wrist or as a ring.
- A brief description of dosimeter design, construction, and processing (including a reference to the software version of the dose algorithm).
- A brief description of the dosimeter orientation on the phantom.
- 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.

3.2 Test Schedule

A test shall consist of three separate iterations (or rounds) performed over a period of approximately three months. According to the testing organization's or IL's direction, at the start of the testing period, the participant will submit to the IL either the total number of dosimeters required for testing or only the dosimeters necessary for the first round of testing. In the latter case, additional