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Nuclear energy — Reference beta-particle radiation —

Part 3: Calibration of area and personal dosemeters and the determination of their response as a function of beta radiation energy and angle of incidence

Énergie nucléaire — Rayonnement bêta de référence —

Partie 3: Étalonnage des dosimètres individuels et des dosimètres de zone et détermination de leur réponse en fonction de l'énergie des particules bêta et de l'angle d'incidence du rayonnement bêta

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Foreword

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This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiological protection*.

This third edition of ISO 6980-3 cancels and replaces ISO 6980-3:2022, of which it constitutes a minor revision.

The main changes are the following:

— editorial changes throughout the document.

A list of all the parts in the ISO 6980 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

ISO 6980 series covers the production, calibration, and use of beta-particle reference radiation fields for the calibration of dosemeters and dose-rate meters for protection purposes. This document describes procedures for the calibration of dosemeters and dose-rate meters and the determination of their response as a function of beta-particle energy and angle of beta-particle incidence. ISO 6980-1 describes the methods of production and characterization of the reference radiation. ISO 6980-2 describes procedures for the determination of absorbed dose rate at a reference depth of tissue from beta particle reference radiation fields.

For beta particles, the calibration and the determination of the response of dosemeters and dose-rate meters is essentially a three-step process. First, the basic field quantity, absorbed dose to tissue at a depth of 0,07 mm (and optionally also at a depth of 3 mm) in a tissue-equivalent slab geometry is measured at the point of test, using methods described in ISO 6980-2. Then, the appropriate operational quantity is derived by the application of a conversion coefficient that relates the quantity measured (reference absorbed dose) to the selected operational quantity for the selected irradiation geometry. Finally, the reference point of the device under test is placed at the point of test for the calibration and determination of the response of the dosemeter. Depending on the type of dosemeter under test, the irradiation is either carried out on a phantom or free-in-air for personal and area dosemeters, respectively. For individual and area monitoring, this document describes the methods and the conversion coefficients to be used for the determination of the response of dosemeters and dose-rate meters in terms of the ICRU operational quantities, i.e., directional dose equivalent, $H'(0{,}07;\Omega)$ and $H'(3;\Omega)$, as well as personal dose equivalent, $H_p(0{,}07)$ and $H_p(3)$.

Nuclear energy — Reference beta-particle radiation —

Part 3: Calibration of area and personal dosemeters and the determination of their response as a function of beta radiation energy and angle of incidence

1 Scope

This document describes procedures for calibrating and determining the response of dosemeters and dose-rate meters in terms of the operational quantities for radiation protection purposes defined by the International Commission on Radiation Units and Measurements (ICRU). However, as noted in ICRU 56[2], the ambient dose equivalent, $H^*(10)$, used for area monitoring, and the personal dose equivalent, $H_p(10)$, as used for individual monitoring, of strongly penetrating radiation, are not appropriate quantities for any beta radiation, even that which penetrates 10 mm of tissue (E_{max} > 2 MeV).

This document is a guide for those who calibrate protection-level dosemeters and dose-rate meters with beta-reference radiation and determine their response as a function of beta-particle energy and angle of incidence. Such measurements can represent part of a type test during the course of which the effect of other influence quantities on the response is examined. This document does not cover the in-situ calibration of fixed, installed area dosemeters. The term “dosemeter” is used as a generic term denoting any dose or dose-rate meter for individual or area monitoring. In addition to the description of calibration procedures, this document includes recommendations for appropriate phantoms and the way to determine appropriate conversion coefficients. Guidance is provided on the statement of measurement uncertainties and the preparation of calibration records and certificates.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6980-1, *Nuclear energy — Reference beta-particle radiations — Part 1: Methods of production*

ISO 6980-2, *Nuclear energy — Reference beta-particle radiation — Part 2: Calibration fundamentals related to basic quantities characterizing the radiation field*

ISO/IEC 17025:2017, *General requirements for the competence of testing and calibration laboratories*

ISO 29661, *Reference radiation fields for radiation protection — Definitions and fundamental concepts*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 29661, ISO/IEC Guide 99 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
maximum beta energy
E_{max}
highest value of the energy of beta particles emitted by a particular radionuclide which can emit one or several continuous spectra of beta particles with different maximum energies

3.2
mean beta energy
E_{mean}
fluence averaged energy of the beta particle spectrum at the calibration distance free in air

3.3
residual maximum beta energy
E_{res}
highest value of the energy of a beta particle spectrum at the calibration distance, after having been modified by scattering and absorption

3.4
reference absorbed dose
D_R
absorbed dose to tissue, $D_t(0{,}07)$, in a slab phantom made of ICRU 4-element tissue with an orientation of the phantom in which the normal to the phantom surface coincides with the (mean) direction of the incident radiation

Note 1 to entry: The absorbed dose to tissue, $D_t(0{,}07)$, is defined in ICRU 51[1] as personal absorbed dose, $D_p(0{,}07)$. For the purposes of this document, this definition is extended to a slab phantom.

Note 2 to entry: The slab phantom is approximated with sufficient accuracy by the material surrounding the standard instrument (extrapolation chamber) used for the measurement of the beta radiation field[3][4].

Note 3 to entry: $H_p(0{,}07)$ is obtained by the multiplication of the absorbed dose to tissue at 0,07 mm depth, $D_t(0{,}07) = D_R$, with the conversion coefficient 1 Sv Gy^{-1}, see ISO 6980-3:—, 5.2.2.2, Formula (3).

3.5
reference beta-particle absorbed dose
$D_{R\beta}$
reference absorbed dose, D_R, (3.4) at a depth of 0,07 mm only due to beta particles

Note 1 to entry: As a first approximation, the ratio $D_{R\beta} / D_R$ is given by the bremsstrahlung correction k_{br} (see ISO 6980-2:—, D.3).

3.6
reference calibration factor
N_0
calibration factor for a reference value, $H_{t,0}$, of the quantity to be measured. With $M_{r,0}$ being the indicated value:

$$N_0 = \frac{H_{t,0}}{M_{r,0}}$$

Note 1 to entry: This definition is of special importance for dosemeters having a non-linear response.

3.7
correction factor for beta-particle energy and angle of incidence
$k_{E,\alpha}$
correction factor for mean beta energy, E, and mean angle, α, of beta particle incidence

Note 1 to entry: α represents the angle of incidence from the source. Due to the scattering of the electrons, the electrons are incident at a wide range of angles and α can be considered a mean representation of the angles of incidence of the electrons. α is the angle between the reference direction of the source and the direction of incidence of radiation from the source.

4 Symbols and abbreviated terms, and reference and standard test conditions

A list of symbols and abbreviated terms is given in Table 1.

Table 1 — Symbols and abbreviated terms

Symbol	Meaning	Unit
α	(mean) angle of beta-particle incidence under calibration conditions	deg
Ω	direction of the radius vector of the ICRU sphere	deg
D	absorbed dose	Gy
D_R	reference absorbed dose	Gy
$\dot{D}_R$	rate of reference dose	Gy·h^{-1}
$D_{R\beta}$	reference beta-particle absorbed dose	Gy
$\dot{D}_{R\beta}$	reference beta-particle absorbed dose rate	Gy·h^{-1}
E_{mean}	mean particle energy (photon energy or electron kinetic energy)	keV
E_{max}	maximum kinetic energy of a beta-particle spectrum	keV
E_{res}	residual maximum energy of a beta-particle spectrum	keV
H	dose equivalent	Sv
$H^*(10)$	ambient dose equivalent	Sv
$\dot{H}^*(10)$	rate of ambient dose equivalent	Sv·h^{-1}
$H'(0,07;\Omega)$	directional dose equivalent at 0,07 mm depth measured in the direction Ω	Sv
$\dot{H}'(0,07;\Omega)$	rate of directional dose equivalent at 0,07 mm depth measured in the direction Ω	Sv·h^{-1}
$H'(3;\Omega)$	directional dose equivalent at 3 mm depth measured in the direction Ω	Sv
$\dot{H}'(3;\Omega)$	rate of directional dose equivalent at 3 mm depth measured in the direction Ω	Sv·h^{-1}
$H_p(0,07)$	personal dose equivalent at 0,07 mm depth	Sv
$H_p(3)$	personal dose equivalent at 3 mm depth	Sv
h_D	absorbed-dose-to-dose-equivalent conversion coefficient from D_R to H	Sv Gy^{-1}
$h'_D(0,07;E,\alpha)$	conversion coefficient from D_R to $H'(0,07)$ for angle, α, and energy, E	Sv Gy^{-1}
$h_{p,D}(0,07;E,\alpha)$	conversion coefficient from D_R to $H_p(0,07)$ for angle, α, and energy, E	Sv Gy^{-1}
$h'_D(3;E,\alpha)$	conversion coefficient from D_R to $H'(3)$ for angle, α, and energy, E	Sv Gy^{-1}
$h_{p,D}(3;E,\alpha)$	conversion coefficient from D_R to $H_p(3)$ for angle, α, and energy, E	Sv Gy^{-1}
H_t	conventional true value of H	Sv
$H_{t,0}$	conventional true value in the reference conditions	Sv
H'_t	conventional true value of directional dose equivalent	Sv
$H'_t(0,07;\Omega)$	conventional true value of directional dose equivalent at 0,07 mm depth measured in the direction Ω	Sv
$H'_t(3;\Omega)$	conventional true value of directional dose equivalent at 3 mm depth measured in the direction Ω	Sv
$H_{p,t}$	conventional true value of the personal dose equivalent	Sv
$H_{p,t}(0,07)$	conventional true value of the personal dose equivalent at 0,07 mm depth	Sv

Table 1 *(continued)*

Symbol	Meaning	Unit
$H_{p,t}(3)$	conventional true value of the personal dose equivalent at 3 mm depth	Sv
k_n	correction factor for non-linear response	—
$k_{E,\alpha}$	correction factor for beta-particle energy and angle of incidence	—
M	indicated value	Sv
M_r	indicated value under reference conditions	Sv
$M_{r,0}$	indicated value under reference conditions for a reference value of H	Sv
N	calibration factor	—
N_0	reference calibration factor	—
R	response	—

The reference conditions as well as the standard test conditions are as given in Annex A.

5 Procedures applicable to all area and personal dosemeters

5.1 General principles

5.1.1 Selection of sources and radiation qualities

Two series of reference radiation sources are specified in ISO 6980-1. The series 1 sources use beam-flattening filters to produce a uniform dose rate over an area of about 15 cm in diameter, e.g. for the calibration of an area monitor or a number of personal dosemeters simultaneously. The calibration distances, filter distances and filter types are specified in and shall be performed in accordance with ISO 6980-1. Deviations from those specifications shall not be made.

Series 2 reference radiation may be produced without the use of beam-flattening filters and have the advantage of extending the energy and dose rate beyond those of series 1. Calibrations and response determinations shall specify the series of reference radiation used and the source-to-detector distance.

Although special sources and geometries may be established for beta calibrations, secondary laboratories shall, as a minimum, have available a series 1 $^{90}Sr/^{90}Y$ source. These standard sources provide consistent and reproducible results, permitting comparison of results from laboratory to laboratory.

The dosimetry in these radiation fields shall be conducted in accordance with ISO 6980-2.

The beta radiation field produced by all these radionuclides except $^{106}Ru/^{106}Rh$ is practically free of photon radiation, apart from bremsstrahlung generated in the surrounding materials or in the beta particle source itself. $^{106}Ru/^{106}Rh$ is used because of the high maximum energy of the emitted beta particles. Only beta-particle sources with small self-absorption and thin encapsulation can fulfil the specifications in ISO 6980-1, since it is necessary that the maximum energy of the beta particles at the calibration distance, E_{res} (residual maximum beta energy), be higher than a specified E_{res} value.

5.1.2 Reference absorbed dose rate

The basic quantity in beta dosimetry, i.e., the absorbed-dose rate to tissue due to beta particles, $\dot{D}_{R\beta}$ is determined in accordance with ISO 6980-2:—, 7.2. From this, the reference absorbed dose rate, $\dot{D}_R$, is derived (see also ISO 6980-2:—, 3.11 and 3.12) as given by Formula (1):

$$\dot{D}_R = \frac{\dot{D}_{R\beta}}{k_{br}} \quad (1)$$

5.1.3 Conversion coefficients

5.1.3.1 General dose equivalent quantities

According to ISO 29661:2012, 3.2.2, it is necessary to calculate the dose equivalent, $H(d;\,source;\alpha)$, where H is equivalent to H' and H_p and d is the depth 0,07 mm or 3 mm for beta radiation, from the reference absorbed dose, D_R, using the absorbed-dose-to-dose-equivalent conversion coefficient, $h_D(d;\,source;\alpha)$. It is necessary to measure the reference absorbed dose, D_R, in a slab phantom at a depth of 0,07 mm and at an incidence angle, α, of 0° between the source and the reference orientation of the slab phantom at the distance of the point of test. Due to the scattering of the beta particles in air and within optional beam-flattening filters, all real beta fields are far from unidirectional. Therefore, the above-mentioned angle, α, is only the mean angle of an unknown distribution.

It is necessary to determine $h_D(d;\,source;\alpha)$ separately for any radiation field (given by the type of radiation sources, the holder and the surrounding structures) and for any distance. The value of $h_D(d;\,source;\alpha)$ depends also on the phantom used.

It is, therefore, not possible to give a generally applicable table of conversion coefficients. Measurements and/or radiation transport simulations are necessary for any type of radiation field.

5.1.3.2 Determination of conversion coefficients

The determination of the conversion coefficients $h_{\mathrm{p}D}(d;\,source;\alpha)$ for the slab phantom can be done with the same instrument used for the measurement of the reference absorbed dose, D_R. For other phantoms and other quantities, the most up to date method is Monte Carlo particle transport simulation. As an example, the beta reference radiation fields from the beta secondary standard 2, BSS 2[5][6], have been determined and are freely available[3]. Also, values of conversion coefficients $h_D(d;\,source;\alpha)$ have been determined for the beta-particle radiation fields of the BSS 2 for the quantities $H_\mathrm{p}(0{,}07)$ –for the slab and the rod phantom–, for the quantity $H_\mathrm{p}(3)$ – for the cylinder phantom–, as well as for the quantities $H'(0{,}07;\Omega)$ and $H'(3;\Omega)$, all for different angles of incidence α[4]. They are given in Annex B.

5.1.3.3 Phantom dependence

ISO 4037-3[7] specifies four types of phantoms: the ISO water-slab phantom, the ISO water-cylinder phantom, the ISO water-pillar phantom and the ISO polymethylmethacrylate (PMMA)-rod phantom. Contrary to photon and neutron radiation, the size and shape of the phantom have only a very small influence on the beta radiation field in front of the phantom. However, the conventional quantity values, and the associated conversion coefficients, slightly depend on the phantom. This is especially the case for oblique radiation incidence where the differences can largely be attributed to the direct penetration length to the measurement point[4]. The conversion coefficients for the slab phantom can be used for the pillar phantom up to 60° angle of incidence. Doing so, however, leads to larger uncertainties which shall be assessed when doing so.

5.1.4 Reference conditions and standard test conditions

Calibrations and the determination of response shall be conducted under standard test conditions in accordance with Tables A.1 and A.2. The range of values of influence quantities within the standard test conditions are given in Tables A.1 and A.2 for radiation-related and other parameters, respectively.

5.1.5 Variation of influence quantities

For those measurements intended to determine the effects of variation of one influence quantity on the response, the other influence quantities should be maintained at fixed values within the standard test conditions unless otherwise specified.

There can be cases in which it is important that an influence quantity is varied in such a way that the indicated value, M, of the instrument under test is constant. For example, if the energy dependence of a dosemeter is to be examined in a dose-rate region where there is a substantial dead-time, it can