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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

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

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

This second edition of ISO 6980-3 cancels and replaces ISO 6980-3:2006, which has been technically revised. The main changes are the following:

- inclusion of the quantities $H_p(3)$ and $H'(3;\Omega)$;
- inclusion of ^{106}Ru/^{106}Rh series 1 sources;
- inclusion of energy-reduced beta-particle fields produced by ^{90}Sr/^{90}Y sources;
- removal of ^{14}C sources;
- reference to ISO 29661 and its terms and definitions in Clause 3.
- inclusion of correction factors for the differentiation between different quantities at the same depth, such as $H_p(0{,}07)$ and $H'(0{,}07;\Omega)$ and $H_p(3)$ vs. $H'(3;\Omega)$;
- inclusion of correction factors for the differentiation between different phantoms for the same quantity, such as the slab and rod or slab and cylinder phantom for the quantities $H_p(0{,}07)$ and $H_p(3)$, respectively;
- addition of many conversion coefficients to Annex C.

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 to 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, $H_\mathrm{p}(0{,}07)$ and $H_\mathrm{p}(3)$.

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 International Commission on Radiation Units and Measurements (ICRU) operational quantities for radiation protection purposes. 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 http://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 average energy of the beta particle spectrum at the calibration distance at 0,07 mm tissue depth in an ICRU 4-element tissue phantom

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}

personal dose equivalent, $H_{\mathrm{p}}(0{,}07)$, 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 personal dose equivalent, $H_{\mathrm{p}}(0{,}07)$, is defined in ICRU 51[1]. 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].

3.5
reference beta-particle absorbed dose

$D_{\mathrm{R}\beta}$

reference absorbed dose, D_{R}, (3.4) at a depth of 0,07 mm due only to beta particles

Note 1 to entry: As a first approximation, the ratio $D_{\mathrm{R}\beta}/D_{\mathrm{R}}$ is given by the bremsstrahlung correction k_{br} (see ISO 6980-2:2022, D.3).

3.6
reference calibration factor

N_0

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

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

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 variety 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
$\dot{D}_\mathrm{R}$	rate of reference dose	$\mathrm{Gy{\cdot}h^{-1}}$
$D_{\mathrm{R}\beta}$	reference beta-particle absorbed dose	Gy
$\dot{D}_{\mathrm{R}\beta}$	rate of reference beta-particle dose	$\mathrm{Gy{\cdot}h^{-1}}$
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	$\mathrm{Sv{\cdot}h^{-1}}$
$H'(0{,}07;\Omega)$	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	$\mathrm{Sv{\cdot}h^{-1}}$
$H'(3;\Omega)$	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	$\mathrm{Sv{\cdot}h^{-1}}$
$H_\mathrm{p}(0{,}07)$	personal dose equivalent at 0,07 mm depth	Sv
$H_\mathrm{p}(3)$	personal dose equivalent at 3 mm depth	Sv
h_D	absorbed-dose-to-dose-equivalent conversion coefficient from D_R to H	$\mathrm{Sv\ Gy^{-1}}$
$h'_D(0{,}07;E,\alpha)$	conversion coefficient from D_R to $H'(0{,}07)$ for angle, α, and energy, E	$\mathrm{Sv\ Gy^{-1}}$
$h_{\mathrm{p},D}(0{,}07;E,\alpha)$	conversion coefficient from D_R to $H_\mathrm{p}(0{,}07)$ for angle, α, and energy, E	$\mathrm{Sv\ Gy^{-1}}$
$h'_D(3;E,\alpha)$	conversion coefficient from D_R to $H'(3)$ for angle, α, and energy, E	$\mathrm{Sv\ Gy^{-1}}$
$h_{\mathrm{p},D}(3;E,\alpha)$	conversion coefficient from D_R to $H_\mathrm{p}(3)$ for angle, α, and energy, E	$\mathrm{Sv\ Gy^{-1}}$
H_t	conventional true value of H	Sv
$H_{\mathrm{t},0}$	conventional true value in the reference conditions	Sv
H'_t	conventional true value of directional dose equivalent	Sv
$H'_\mathrm{t}(0{,}07;\Omega)$	conventional true value of directional dose equivalent at 0,07 mm depth measured in the direction Ω	Sv
$H'_\mathrm{t}(3;\Omega)$	conventional true value of directional dose equivalent at 3 mm depth measured in the direction Ω	Sv
$H_{\mathrm{p,t}}$	conventional true value of the personal dose equivalent	Sv
$H_{\mathrm{p,t}}(0{,}07)$	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 individual 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 the series 1 sources. 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 6980-2:2022, 7.2. From this, the reference absorbed dose rate, $\dot{D}_R$, is derived (see also ISO 6980-2:2022, 3.11 and 3.12) as given by Formula (1):

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

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 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 be desirable that the measurements with the various radiation qualities are carried out at constant indication and not at constant dose rate. The same holds true for thermoluminescence dosemeters exhibiting a so-called supra-linearity. However, it should be added that it is usually advisable to carry out the examination of an instrument under conditions in which the response to dose or to dose-rate is essentially linear.

5.1.6 Point of test and reference point

Measurements shall be carried out by positioning the reference point of the dosemeter at the point of test. In the absence of information on the reference point or on the reference direction of the dosemeter to be tested, these parameters shall be fixed by the testing laboratory. They shall be stated in the test certificate.

NOTE 1 Placing the reference point of the dosemeter at the point of test has two practical advantages. The first one is that the dose due to the primary radiation coming from the source is always measured correctly irrespective of the effect of the beam divergence on the backscattered radiation. For beta-particle radiation, this part of the dose always represents the majority contribution to the total dose, including the scattered radiation from the phantom. The convention adopted implies that the calibration factor of the dosemeter does not depend unnecessarily on the distance between the source and the point of test. The second advantage arises in an experimental determination of the angular response. If the reference point and the point of test coincide, the reading of the dosemeter under test does not have to be corrected for a variation of the distance between source and reference point with the angle of rotation.

NOTE 2 If portable area dosemeters are used under conditions where the distance from the source to the detector volume is small compared with the dimensions of the detector volume, the radiation fields in the detector are non-uniform. Portable area dosemeter readings under such conditions are an average of the energy deposition rate within the detector. The readings are significantly less than the actual dose equivalent rates existing at the surface of the entrance window[8].

5.1.7 Axes of rotation

For examining the effect of the direction of radiation incidence, a rotation of the dosemeter or of the combination of dosemeter and phantom can be required. The variation of response with direction of radiation incidence shall be examined by a rotation around at least two axes. The direction of the axes shall be mutually perpendicular. The axes of rotation shall pass through the reference point of the dosemeter.

5.1.8 Condition of the dosemeter to be calibrated

Before any calibration is made, the dosemeter shall be examined to confirm that it is in a good, serviceable condition and free from radioactive contamination. The set-up procedure and the mode of operation of the dosemeter shall be in accordance with its instruction manual.

5.1.9 Influence of photon contribution

The influence of the photon contribution of the radiation field shall be taken into account by the method described in ISO 6980-1:2022, 6.1.4.

5.2 Determination of the calibration factors and of the correction factors

5.2.1 Determination of the reference dose rate by a standard instrument

Dosimetry of beta-particle reference fields is described in ISO 6980-2. In general, the reference dose-rate, $\dot{D}_{\mathrm{R}}$ is determined with an extrapolation chamber. Corrections for source decay and the ambient air conditions shall be performed.

5.2.2 Determination of reference calibration factor and correction factor for non-linear response

5.2.2.1 General aspects

The reference calibration factor, N_0, is obtained for the reference value, $H_{t,0}$, of the quantity to be measured. The correction factor for non-linear response is given by $k_n = N / N_0$.

5.2.2.2 Calibration factor for personal dosemeters

The calibration factor, N, for a personal dosemeter for the depth of 0,07 mm or 3 mm mounted on a specified phantom (slab, cylinder, pillar, rod) at an angle of incidence of 0°, is obtained from Formula (2):

$$N = \frac{H_{\mathrm{p,t}}(0{,}07)}{M_r} \text{ or } N = \frac{H_{\mathrm{p,t}}(3)}{M_r} \tag{2}$$

where M_r is the indicated value of the dosemeter on the specified phantom under reference conditions as given by Formula (3):

$$H_{p,t}(0{,}07) = h_{p,D}(0{,}07; source; 0°) \cdot D_R \text{ or } H_{p,t}(3) = h_{p,D}(3; source; 0°) \cdot D_R \tag{3}$$

where

D_R is the reference absorbed dose;

$h_{p,D}(0{,}07; source; 0°)$ or $h_{p,D}(3; source; 0°)$ is the conversion coefficient (see 5.1.3) for the source and conditions used.

For the sources and the slab phantom used in this document, $h_{p,D}(0{,}07; source; 0°)$ can be considered to be 1 Sv Gy^{-1}.

5.2.2.3 Calibration factor for area dosemeters

The calibration factor, N, for an area dosemeter for the depth of 0,07 mm or 3 mm at an angle of incidence of 0°, is obtained from Formula (4) and (5):

$$N = \frac{H'_{\mathrm{t}}\left(0{,}07;0^\circ\right)}{M_{\mathrm{r}}} \text{ or } N = \frac{H'_{\mathrm{t}}\left(3;0^\circ\right)}{M_{\mathrm{r}}} \tag{4}$$

where M_r is the indicated value of the dosemeter under reference conditions;

$$H_t'(0{,}07; 0°) = h'_D(0{,}07; source; 0°) \cdot D_R \text{ or } H_t'(3; 0°) = h'_D(3; source; 0°) \cdot D_R \tag{5}$$

where

$h'_D(0{,}07; source; 0°)$ or $h'_D(3; source; 0°)$ is the conversion coefficient for the source and conditions used.

D_R is the reference absorbed dose.

5.2.3 Determination of the correction factor for beta-particle energy and angle of incidence, $k_{E,\alpha}$

The correction factor for the depth of 0,07 mm or 3 mm, $k_{E,\alpha}$, for mean beta energy, E_{mean}, and mean angle, α, of beta-particle incidence is determined by means of D_R for the various reference radiation fields given in ISO 6980-1.

For personal dosemeters Formula (6) is valid:

$$k_{E,\alpha} = \frac{h_{\mathrm{p},D}(0{,}07; source; \alpha) \cdot D_{\mathrm{R}}}{N \cdot M(0{,}07; E; \alpha)} \text{ or } k_{E,\alpha} = \frac{h_{\mathrm{p},D}(3; source; \alpha) \cdot D_{\mathrm{R}}}{N \cdot M(3; E; \alpha)} \tag{6}$$

For area dosemeters Formula (7) is valid:

$$k'_{E,\alpha} = \frac{h'_D(0{,}07; source; \alpha) \cdot D_{\mathrm{R}}}{N \cdot M(0{,}07; E; \alpha)} \text{ or } k'_{E,\alpha} = \frac{h'_D(3; source; \alpha) \cdot D_{\mathrm{R}}}{N \cdot M(3; E; \alpha)} \tag{7}$$

Deviations from reference conditions shall be considered by proper correction factors; see ISO 29661:2012, 6.2 and Formulae therein.

NOTE The relative response of the dosemeter with respect to its response under reference conditions is the inverse of the correction factor $k_{E,\alpha}$. The relative response can be a useful quantity for describing the variation of response as a function of beta-particle energy, E, or angle of incidence, α, as it easily visualizes such variation see ISO 29661:2012, 6.3.

6 Particular procedures for area dosemeters

6.1 General principles

These principles apply to the calibration of portable and installed area dosemeters in reference radiations, where the term “area dosemeter” comprises both active and passive devices. It does not apply to in situ calibrations of installed area dosemeters. Dosemeters for area monitoring shall be irradiated in free air (without a phantom).

6.2 Quantity to be measured

For area dosemeters, the quantity to be measured shall be the directional dose equivalent at 0,07 mm, $H'(0{,}07;\Omega)$, or the directional dose equivalent at 3 mm, $H'(3;\Omega)$.

7 Particular procedures for personal dosemeters

7.1 General principles

These principles apply to the calibration of personal dosemeters, i.e. whole-body, skin and extremity as well as eye lens dosemeters. The irradiation should be performed on a phantom.

7.2 Quantity to be measured

The quantity to be measured for individual monitoring is the personal dose equivalent at 0,07 mm, $H_{\mathrm{p}}(0{,}07)$, or the personal dose equivalent at 3 mm, $H_{\mathrm{p}}(3)$.

7.3 Experimental conditions

7.3.1 Use of phantoms

Calibrations of personal dosemeters, measurements of the correction factor $k_{E,\alpha}$ and the response as a function of radiation energy and angle of radiation incidence should be carried out on an appropriate phantom.

Calibrations should be carried out on the ISO water-slab phantom for whole body dosemeters, ISO water-cylinder phantom for eye lens dosemeters, and on the ISO water-pillar or rod phantom for skin and extremity dosemeters[7]. For beta radiations, a PMMA slab of at least 20 cm × 20 cm in cross-section and at least 2 cm in thickness may be used to substitute the ISO water-slab or -cylinder phantom.

When these phantoms are used as described above, no correction factors shall be applied to the indication of the dosemeter under test, due to possible differences in backscatter properties between these phantoms and the ICRU tissue slab.

In a simplified procedure, it is not always necessary to perform routine calibrations on a phantom but they may sometimes be done more simply, free-in-air or with another type of radiation than that which the dosemeter is intended to measure. Such simplifications, if they are to be applied, shall be justified prior to their adoption by demonstrating that they lead to results identical to those from procedures described in this document or that reliable corrections can be made for any differences. This may be done on the basis of the results of a type test and production checks on the consistency of important components of the dosemeter, for example the film covering a thermoluminescent chip and the dimensions of that chip.

7.3.2 Geometrical considerations in divergent beams

The point of test shall be chosen at a distance from the source such that the field size in the plane of measurement is at least as large as the instrument under test. The value of the quantity to be measured shall be determined by positioning the reference point of the standard instrument at the point of test or by using a pre-calibrated test point provided for the source, see 5.1.6. Then the reference point of the dosemeter under test shall be positioned at the point of test with its reference direction oriented at the required angle, α, to the direction of radiation incidence.

Whole body, extremity, skin and eye lens dosemeters should be attached to the phantom in the way they are attached to the body during routine use. For dosemeters usually not worn directly on the body but attached to personal protective equipment or other additional equipment, e.g., (protection) glasses, an alternative method shall be used to attach them to the phantom. Such dosemeters shall be irradiated without the additional equipment, e.g., without (protection) glasses. The phantom shall be positioned in such a way that its front surface is in contact with the rear side of the dosemeter and is at the required angle, α, to the beam axis. The irradiation of the dosemeter under test shall be made under conditions identical to those prevailing during the irradiation of the standard instrument, but now with the phantom present, see ISO 29661:2012, 6.6.1.

The calibration factor or the energy and/or angle dependence of the response shall be obtained with the Formulae in 5.2.2 and 5.2.3.

NOTE 1 In this document, the entity of the personal dosemeter and phantom is considered as the dosemeter to be tested. The reference point of the entity is the reference point of the dosemeter. The value of the quantity to be measured pertains to the value of the dose equivalent at a depth of 0,07 mm or 3 mm inside the reference phantom in the absence of the dosemeter.

NOTE 2 For an irradiation on the slab phantom, it can be practical to rotate the phantom around only one axis and to locate the dosemeter in two mutually perpendicular orientations on the surface of the phantom.

7.3.3 Simultaneous irradiation of several dosemeters

If more than one dosemeter is irradiated simultaneously, several effects require additional attention.

By positioning several dosemeters on the phantom surface, the backscatter can be reduced due to the attenuation of the primary radiation passing through the dosemeters.

It is necessary to consider possibly different distances of the reference points from the radiation source.

The dosemeters can influence their indications by scattering radiation from each other.

The radiation field shall be homogeneous across all dosemeters.

Before such a practice is adopted, it shall be verified that it leads to results that do not differ more than 20 % of the uncertainty stated of those results obtained when one dosemeter alone is irradiated in the centered position of the phantom. Otherwise, appropriate corrections and/or appropriately enlarged uncertainties shall be applied.

For a simultaneous determination of the response of several dosemeters as a function of the direction of radiation incidence, the reference points of the dosemeters shall be positioned on the axis of rotation.

If the inhomogeneity of the radiation field is taken into account (by correction or increased uncertainty), several dosemeters can be attached to the phantom.

8 Uncertainties

The determination of uncertainty shall be consistent with the approaches recommended by ISO/IEC Guide 98-3, preferably using an uncertainty budget, see e.g. Table 4.1 of Reference [9].

Examples of for the determination of uncertainty during calibration and measurements with an instrument are outlined in IEC TR 62461[10].

The following uncertainty components shall be taken into account:

a) uncertainty of the conventional true value either directly taken the uncertainty analysis in accordance with ISO 6980-2 or taken from the calibration certificate of the beta source used for the calibration or irradiation;

b) uncertainty in the exact positioning of test instrument;

c) uncertainty due to field inhomogeneities over the cross-sectional area of the beam in the plane of measurement owing to beam divergence and the effect of beam-flattening filters, if any;

d) uncertainties due to simultaneous irradiation of several dosemeters and other simplified procedures (see 7.3.3), where applicable;

e) uncertainty due to corrections for source decay;

f) uncertainty due to long-term variation of response of standard instrument;

g) uncertainty due to temperature/pressure/humidity corrections or lack thereof;

h) uncertainty introduced by radiation contamination;

i) uncertainties introduced by the instruments calibrated due to non-linearity, instrument geotropism, instrument precision, etc;

j) uncertainties in dose determinations introduced by timing errors.

Further information can be found in standards dealing with beta radiation[11][12][13][14][15].

9 Reporting of results according to ISO 17025

Calibration certificates and irradiation reports shall be prepared in accordance with ISO/IEC 17025:2017, 7.8.

Annex A
(normative)

Reference conditions and standard test conditions

A.1 Radiological parameters

See Table A.1.

Table A.1 — Reference conditions and standard test conditions for radiological parameters

Influence quantities	**Reference conditions**	**Standard test conditions** (unless otherwise indicated)
Beta-particle radiation reference field	$^{90}\text{Sr}/^{90}\text{Y}$ [a]	$^{90}\text{Sr}/^{90}\text{Y}$ [a]
Phantom (only in the case of personal dosemeters)	Slab of ICRU tissue 30 cm × 30 cm × 15 cm (for whole body dosemeters)	**ISO water slab phantom**[b]**:** 30 cm × 30 cm × 15 cm phantom filled with water with 2,5 mm front plate (irradiation side) of PMMA and other walls of 10 mm PMMA or substitute, see 7.3.1
	Straight circular cylinder of ICRU tissue with 200 mm diameter and 200 mm length (for eye lens dosemeters)	**ISO water cylinder phantom**[b]**:** straight circular cylinder 200 mm diameter and 200 mm length filled with water; walls of PMMA: side and end walls 5 mm thick or substitute, see 7.3.1
	Straight circular cylinder of ICRU tissue with 73 mm diameter and 300 mm length (for wrist or ankle dosemeters)	**ISO water pillar phantom:** straight circular cylinder 73 mm diameter and 300 mm length filled with water; walls of PMMA: side walls 2,5 mm thickness and end walls of 10 mm thickness
	Straight circular cylinder of ICRU tissue with 19 mm diameter and 300 mm length (for ring dosemeters)	**ISO rod phantom:** straight circular cylinder of PMMA; 19 mm diameter, 300 mm length
Angle of radiation incidence	Reference orientation	Reference orientation ±5°
Contamination by radioactive elements	Negligible[c]	Negligible[c]
Radiation background	Ambient dose equivalent rate $\dot{H}^*(10) < 0{,}1\ \mu\text{Sv}\cdot\text{h}^{-1}$ and directional dose equivalent rate $\dot{H}'(0{,}07;\Omega)$ and $\dot{H}'(3;\Omega) < 0{,}1\ \mu\text{Sv}\cdot\text{h}^{-1}$	Ambient dose equivalent rate $\dot{H}^*(10) < 0{,}25\ \mu\text{Sv}\cdot\text{h}^{-1}$ and directional dose equivalent rate $\dot{H}'(0{,}07;\Omega)$ and $\dot{H}'(3;\Omega) < 0{,}25\ \mu\text{Sv}\cdot\text{h}^{-1}$

[a] Another radiation quality can be used if this is more appropriate.

[b] A PMMA slab of at least 20 cm x 20 cm in cross-section and at least 2 cm in thickness may be used to substitute the ISO water-slab or -cylinder phantom.

[c] Allowable limits on surface contamination are established by local governments. “Negligible” indicates levels of contamination that do not affect the accuracy of the calibration nor pose a risk to the calibration personnel or facility.

A.2 Other parameters

See Table A.2.

Table A.2 — Reference conditions and standard test conditions for other parameters

Influence quantities	Reference conditions	Standard test conditions (unless otherwise indicated)
Ambient temperature	20 °C	15 °C to 25 °C[bc]
Relative humidity	65 %	30 % to 75 %[bc]
Atmospheric pressure	101,3 kPa	86 kPa to 106 kPa[bcd]
Stabilization time	15 min	>15 min
Power supply voltage	Nominal power supply voltage	Nominal power supply voltage ±3 %
Frequency [a]	Nominal frequency	Nominal frequency ±1 %
AC power supply [a]	Sinusoidal	Sinusoidal with total wave-form harmonic distortion less than 5 % [a]
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

[a] Only for assemblies that are operated from a mains voltage supply.

[b] The actual values of these quantities at the time of test shall be stated.

[c] The 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 instruments are to be used at higher altitudes.

[d] For pressure values outside of this range see ISO 6980-2:2022, C.10.

Annex B

(informative)

Conversion coefficients for some beta reference radiation fields

For some beta reference radiation fields[5][6] conversion coefficients for different quantities and phantoms were determined for several calibration distances[4][16]. In Tables B.1 to B.5 these coefficients and their uncertainties are stated.

Table B.1 — Conversion coefficients $h_{\mathrm{p},D}(0{,}07;source;\alpha)_{\mathrm{slab}}$ for the slab phantom dependent on the angle of incidence for commercial beta sources

Source			Conversion coefficient $h_{\mathrm{p},D}(0{,}07;source;\alpha)_{\mathrm{slab}}$ and its relative standard uncertainty for a value of α of											
Radionuclide	Beam-flattening filter	Distance	0°	$u_{\mathrm{rel}}(0°)$ [a]	15°	$u_{\mathrm{rel}}(15°)$	30°	$u_{\mathrm{rel}}(30°)$	45°	$u_{\mathrm{rel}}(45°)$	60°	$u_{\mathrm{rel}}(60°)$	75°	$u_{\mathrm{rel}}(75°)$
		cm	Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}	
^{147}Pm	no	11	1,00	0 %	n.a.[b]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{147}Pm	yes	20	1,00	0 %	0,96	0,20 %	0,87	0,80 %	0,72	1,76 %	0,53	3,00 %	n.a.	n.a.
^{85}Kr	yes	30	1,00	0 %	0,99	0,14 %	0,96	0,54 %	0,88	1,17 %	0,72	2,00 %	0,49	2,96 %
^{85}Kr	yes	50	1,00	0 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{90}Sr/^{90}Y	3 mm absorber	20	1,00	0 %	1,019	0,14 %	1,065	0,54 %	1,124	1,17 %	1,109	2,00 %	n.a.	n.a.
^{90}Sr/^{90}Y	4 mm absorber	20	1,00	0 %	1,015	0,14 %	1,056	0,54 %	1,099	1,17 %	1,054	2,00 %	n.a.	n.a.
^{90}Sr/^{90}Y	no	11	1,00	0 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{90}Sr/^{90}Y	no	20	1,00	0 %	1,02	0,14 %	1,06	0,54 %	1,14	1,17 %	1,21	2,00 %	n.a.	n.a.
^{90}Sr/^{90}Y	no	30	1,00	0 %	1,01	0,14 %	1,06	0,54 %	1,13	1,17 %	1,16	2,00 %	0,91	2,96 %
^{90}Sr/^{90}Y	no	50	1,00	0 %	1,01	0,14 %	1,05	0,54 %	1,10	1,17 %	1,10	2,00 %	0,84	2,96 %
^{90}Sr/^{90}Y	yes	30	1,00	0 %	1,01	0,14 %	1,06	0,54 %	1,12	1,17 %	1,14	2,00 %	0,86	2,96 %
^{90}Sr/^{90}Y	yes	50	1,00	0 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{106}Ru/^{106}Rh	no	11	1,00	0 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{106}Ru/^{106}Rh	no	20	1,00	0 %	1,011	0,14 %	1,060	0,54 %	1,151	1,17 %	1,256	2,00 %	n.a.	n.a.
^{106}Ru/^{106}Rh	yes	30	1,00	0 %	0,998	0,14 %	1,039	0,54 %	1,127	1,17 %	1,195	2,00 %	1,003	2,96 %
^{106}Ru/^{106}Rh	yes	50	1,00	0 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

[a] The uncertainty of $h_{\mathrm{p},D}(0{,}07;\,0°)_{\mathrm{slab}}$ is zero as $H_{\mathrm{p}}(0{,}07;\,0°)$ is directly given by the reference dose rate, $\dot{D}_{\mathrm{R}}$.

[b] These values have not yet been measured.

Table B.2 — Conversion coefficients $h_{p,D}(0,07;source;\alpha)_{rod}$ for the rod phantom dependent on the angle of incidence for commercial beta sources

Source			Conversion coefficient $h_{p,D}(0,07;source;\alpha)_{rod}$ and its relative standard uncertainty for a value of α of											
Radionuclide	Beam-flattening filter	Distance	0°	$u_{rel}(0°)$	15°	$u_{rel}(15°)$	30°	$u_{rel}(30°)$	45°	$u_{rel}(45°)$	60°	$u_{rel}(60°)$	75°	$u_{rel}(75°)$
		cm	Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}	
^{147}Pm	no	11	1,000	0,50 %	n.a.[a]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{147}Pm	yes	20	1,000	0,50 %	0,960	0,55 %	0,870	0,96 %	0,720	1,86 %	0,534	3,04 %	n.a.	n.a.
^{85}Kr	yes	30	1,000	0,50 %	0,990	0,52 %	0,960	0,76 %	0,880	1,47 %	0,728	2,15 %	0,506	3,01 %
^{85}Kr	yes	50	1,000	0,50 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{90}Sr/^{90}Y	3 mm absorber	20	0,990	0,51 %	1,006	0,53 %	1,051	0,74 %	1,115	1,27 %	1,136	2,06 %	n.a.	n.a.
^{90}Sr/^{90}Y	4 mm absorber	20	0,990	0,51 %	1,003	0,52 %	1,045	0,74 %	1,092	1,27 %	1,078	2,06 %	n.a.	n.a.
^{90}Sr/^{90}Y	no	11	0,987	0,51 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{90}Sr/^{90}Y	no	20	0,987	0,51 %	1,006	0,53 %	1,042	0,74 %	1,122	1,28 %	1,227	2,06 %	n.a.	n.a.
^{90}Sr/^{90}Y	no	30	0,987	0,51 %	0,996	0,53 %	1,042	0,74 %	1,112	1,28 %	1,176	2,06 %	1,052	3,03 %
^{90}Sr/^{90}Y	no	50	0,987	0,51 %	0,996	0,53 %	1,032	0,74 %	1,082	1,28 %	1,115	2,06 %	0,971	3,03 %
^{90}Sr/^{90}Y	yes	30	0,987	0,51 %	0,996	0,53 %	1,042	0,74 %	1,102	1,28 %	1,156	2,06 %	0,994	3,03 %
^{90}Sr/^{90}Y	yes	50	0,987	0,51 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{106}Ru/^{106}Rh	no	11	0,987	0,55 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{106}Ru/^{106}Rh	no	20	0,987	0,55 %	0,993	0,58 %	1,037	0,77 %	1,120	1,28 %	1,251	2,10 %	n.a.	n.a.
^{106}Ru/^{106}Rh	yes	30	0,987	0,55 %	0,980	0,58 %	1,016	0,77 %	1,097	1,28 %	1,190	2,10 %	1,156	3,01 %
^{106}Ru/^{106}Rh	yes	50	0,987	0,55 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

[a] These values are not available as the corresponding values for $h_{p,D}(0,07;source;\alpha)_{slab}$ have not yet been measured, see Table C.1.

Table B.3 — Conversion coefficients $h'_D(0{,}07;source;\alpha)$ dependent on the angle of incidence for commercial beta sources

Radionuclide	Source Beam-flattening filter	Distance	Conversion coefficient $h'_D(0{,}07;source;\alpha)$ and its relative standard uncertainty for a value of α of[a]											
		cm	0°	$u_{\text{rel}}(0°)$	15°	$u_{\text{rel}}(15°)$	30°	$u_{\text{rel}}(30°)$	45°	$u_{\text{rel}}(45°)$	60°	$u_{\text{rel}}(60°)$	75°	$u_{\text{rel}}(75°)$
		cm	Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}	
^{147}Pm	no	11	1,000	0,64 %	n.a.[b]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{147}Pm	yes	20	1,000	0,64 %	0,960	0,73 %	0,870	1,39 %	0,720	1,88 %	0,530	3,06 %	n.a.	n.a.
^{85}Kr	yes	30	1,000	0,63 %	0,990	0,74 %	0,960	0,98 %	0,880	1,45 %	0,720	2,59 %	0,490	3,28 %
^{85}Kr	yes	50	1,000	0,63 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{90}Sr/^{90}Y	3 mm absorber	20	1,000	0,50 %	1,019	0,52 %	1,065	0,74 %	1,124	1,27 %	1,109	2,06 %	n.a.	n.a.
^{90}Sr/^{90}Y	4 mm absorber	20	1,000	0,50 %	1,015	0,52 %	1,056	0,74 %	1,099	1,27 %	1,054	2,06 %	n.a.	n.a.
^{90}Sr/^{90}Y	no	11	1,000	0,50 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{90}Sr/^{90}Y	no	20	1,000	0,50 %	1,020	0,52 %	1,060	0,75 %	1,140	1,37 %	1,210	2,06 %	n.a.	n.a.
^{90}Sr/^{90}Y	no	30	1,000	0,50 %	1,010	0,52 %	1,060	0,75 %	1,130	1,37 %	1,160	2,06 %	0,910	3,10 %
^{90}Sr/^{90}Y	no	50	1,000	0,50 %	1,010	0,52 %	1,050	0,75 %	1,100	1,37 %	1,100	2,06 %	0,840	3,10 %
^{90}Sr/^{90}Y	yes	30	1,000	0,50 %	1,010	0,52 %	1,060	0,75 %	1,120	1,37 %	1,140	2,06 %	0,860	3,10 %
^{90}Sr/^{90}Y	yes	50	1,000	0,50 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{106}Ru/^{106}Rh	no	11	1,000	0,71 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{106}Ru/^{106}Rh	no	20	1,000	0,71 %	1,011	0,81 %	1,060	0,92 %	1,151	1,40 %	1,256	2,06 %	n.a.	n.a.
^{106}Ru/^{106}Rh	yes	30	1,000	0,71 %	0,998	0,81 %	1,039	0,92 %	1,127	1,40 %	1,195	2,06 %	1,003	3,04 %
^{106}Ru/^{106}Rh	yes	50	1,000	0,71 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

[a] These values are equivalent to $h_{\text{p},D}(0{,}07;source;\alpha)_{\text{slab}}$, see Table C.1; only their uncertainties are larger.

[b] These values are not available as the corresponding values for $h_{\text{p},D}(0{,}07;source;\alpha)_{\text{slab}}$ have not yet been measured, see Table C.1.

Table B.4 — Conversion coefficients $h_{p,D}(3;source;\alpha)_{cyl}$ for the cylinder phantom dependent on the angle of incidence for commercial beta sources

Source			Conversion coefficient $h_{p,D}(3;source;\alpha)_{cyl}$ and its relative standard uncertainty for a value of α of											
Radionuclide	Beam-flattening filter	Distance												
		cm	0°	u_{rel}(0°)	15°	u_{rel}(15°)	30°	u_{rel}(30°)	45°	u_{rel}(45°)	60°	u_{rel}(60°)	75°	u_{rel}(75°)
		cm	Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}	
^{90}Sr/^{90}Y	3 mm absorber	20	0,182	0,71 %	0,167	0,74 %	0,128	1,07 %	0,076 9	1,90 %	0,033 9	3,08 %	n.a.	n.a.
^{90}Sr/^{90}Y	4 mm absorber	20	0,071 5	0,71 %	0,065 5	0,74 %	0,048 3	1,07 %	0,027 0	1,93 %	0,012 3	3,16 %	n.a.	n.a.
^{90}Sr/^{90}Y	no	11	0,501	0,88 %	n.a.[a]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{90}Sr/^{90}Y	no	20	0,495	0,89 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{90}Sr/^{90}Y	no	30	0,476	0,88 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{90}Sr/^{90}Y	no	50	0,440	0,89 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{90}Sr/^{90}Y	yes	30	0,431	0,89 %	0,407	0,95 %	0,321	1,33 %	0,210	2,10 %	0,105	3,38 %	0,037	4,99 %
^{90}Sr/^{90}Y	yes	50	0,384	0,89 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{106}Ru/^{106}Rh	no	11	0,760	0,77 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{106}Ru/^{106}Rh	no	20	0,771	0,77 %	0,743	0,83 %	0,659	1,16 %	0,500	1,99 %	0,291	3,19 %	n.a.	n.a.
^{106}Ru/^{106}Rh	yes	30	0,757	0,76 %	0,716	0,82 %	0,641	1,16 %	0,486	1,99 %	0,284	3,19 %	0,114	4,80 %
^{106}Ru/^{106}Rh	yes	50	0,715	0,77 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

[a] These values are not available as the corresponding values for $h_{p,D}(0{,}07;source;\ \alpha)_{slab}$ have not yet been measured, see Table C.1.

Table B.5 — Conversion coefficients $h'_D(3;source;\alpha)$ dependent on the angle of incidence for commercial beta sources

Source			Conversion coefficient $h'_D(3;source;\alpha)$ and its relative standard uncertainty for a value of α of[a]											
Radionuclide	Beam-flattening filter	Distance												
		cm	0°	$u_{rel}(0°)$	15°	$u_{rel}(15°)$	30°	$u_{rel}(30°)$	45°	$u_{rel}(45°)$	60°	$u_{rel}(60°)$	75°	$u_{rel}(75°)$
		cm	Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}		Sv Gy^{-1}	
^{90}Sr/^{90}Y	3 mm absorber	20	0,182	0,71 %	0,167	0,74 %	0,127	1,07 %	0,075 9	1,90 %	0,033 7	3,08 %	n.a.	n.a.
^{90}Sr/^{90}Y	4 mm absorber	20	0,071 5	0,71 %	0,064 9	0,74 %	0,048 2	1,07 %	0,027 0	1,93 %	0,012 1	3,16 %	n.a.	n.a.
^{90}Sr/^{90}Y	no	11	0,501	0,90 %	n.a. [a]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{90}Sr/^{90}Y	no	20	0,495	0,91 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{90}Sr/^{90}Y	no	30	0,476	0,90 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{90}Sr/^{90}Y	no	50	0,440	0,91 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{90}Sr/^{90}Y	yes	30	0,431	0,91 %	0,402	1,00 %	0,320	1,31 %	0,208	2,12 %	0,104	3,40 %	0,035	4,99 %
^{90}Sr/^{90}Y	yes	50	0,384	0,91 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{106}Ru/^{106}Rh	no	11	0,760	0,87 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
^{106}Ru/^{106}Rh	no	20	0,771	0,87 %	0,743	0,85 %	0,657	1,24 %	0,496	2,06 %	0,284	3,20 %	n.a.	n.a.
^{106}Ru/^{106}Rh	yes	30	0,757	0,87 %	0,716	0,84 %	0,639	1,24 %	0,483	2,05 %	0,277	3,20 %	0,107	4,84 %
^{106}Ru/^{106}Rh	yes	50	0,715	0,87 %	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

[a] These values are not available as the corresponding values for $h_{p,D}(0{,}07;source;\alpha)_{slab}$ have not yet been measured, see Table C,1,

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