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Radiological protection — X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy —

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

Radioprotection — Rayonnements X et gamma de référence pour l'étalonnage des dosimètres et des débitmètres et pour la détermination de leur réponse en fonction de l'énergie des photons —

Partie 3: Étalonnage des dosimètres de zone et individuels et mesurage de leur réponse en fonction de l'énergie et de l'angle d'incidence

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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).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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 cancels and replaces the first edition (ISO 4037-3:1999), which has been technically revised.

A list of all the parts in the ISO 4037 series can be found on the ISO website.

Introduction

The maintenance release of this document incorporates the improvements to high voltage generators from 1996 to 2017 (e.g., the use of high frequency switching supplies providing nearly constant potential), and the spectral measurements at irradiation facilities equipped with such generators (e.g., the catalogue of X-ray spectra by Ankerhold[1]). It also incorporates all published information with the aim to adjust the requirements for the technical parameters of the reference fields to the targeted overall uncertainty of about 6 % to 10 % for the phantom related operational quantities of the International Commission on Radiation Units and Measurements (ICRU)[2]. It does not change the general concept of the existing ISO 4037.

ISO 4037, focusing on photon reference radiation fields, is divided into four parts. ISO 4037-1 gives the methods of production and characterization of reference radiation fields in terms of the quantities spectral photon fluence and air kerma free-in-air. ISO 4037-2 describes the dosimetry of the reference radiation qualities in terms of air kerma and in terms of the phantom related operational quantities of the International Commission on Radiation Units and Measurements (ICRU)[2]. This document describes the methods for calibrating and determining the response of dosemeters and doserate meters in terms of the phantom related operational quantities of the ICRU[2]. ISO 4037-4 gives special considerations and additional requirements for calibration of area and personal dosemeters in low energy X reference radiation fields, which are reference fields with generating potential ≤30 kV.

The determination of the response of dosemeters and doserate meters is essentially a three-step or two-step process. First, a basic quantity such as air kerma is measured free-in-air at the point of test. Then the appropriate operational quantity is derived by the application of the conversion coefficient that relates the quantity measured to the selected operational quantity. These two steps may be merged into a single-step if a standard for the phantom related quantities is used. Finally, the device under test is placed at the point of test for the determination of its response. 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 area and individual monitoring this document describes details of the methods and provides, if applicable, the recommended conversion coefficients to be used for the determination of the response of dosemeters and doserate meters in terms of the phantom related operational quantities of the ICRU for photons. The use of these recommended conversion coefficients requires that the corresponding radiation quality of the reference field used for the irradiation is validated. For all non-validated radiation qualities, the recommended conversion coefficients cannot be used. For these radiation qualities, the dosimetry with respect to the phantom related operational quantities of the ICRU – see ISO 4037-2:2019, Clause 6 – or the spectrometry – see ISO 4037-2:2019, Annex B – should be performed. For tube potentials of 30 kV and below ISO 4037-4 gives special requirements.

The general procedures described in ISO 29661 are used as far as possible in this document. In addition, the symbols used are in line with ISO 29661.

Radiological protection — X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy —

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

1 Scope

This document specifies additional procedures and data for the calibration of dosemeters and doserate meters used for individual and area monitoring in radiation protection. The general procedure for the calibration and the determination of the response of radiation protection dose(rate)meters is described in ISO 29661 and is followed as far as possible. For this purpose, the photon reference radiation fields with mean energies between 8 keV and 9 MeV, as specified in ISO 4037-1, are used. In Annex D some additional information on reference conditions, required standard test conditions and effects associated with electron ranges are given. For individual monitoring, both whole body and extremity dosemeters are covered and for area monitoring, both portable and installed dose(rate)meters are covered.

Charged particle equilibrium is needed for the reference fields although this is not always established in the workplace fields for which the dosemeter should be calibrated. This is especially true at photon energies without inherent charged particle equilibrium at the reference depth *d*, which depends on the actual combination of energy and reference depth *d*. Electrons of energies above 65 keV, 0,75 MeV and 2,1 MeV can just penetrate 0,07 mm, 3 mm and 10 mm of ICRU tissue, respectively, and the radiation qualities with photon energies above these values are considered as radiation qualities without inherent charged particle equilibrium for the quantities defined at these depths. This document also deals with the determination of the response as a function of photon energy and angle of radiation incidence. Such measurements can represent part of a type test in the course of which the effect of further influence quantities on the response is examined.

This document is only applicable for air kerma rates above 1 µGy/h.

This document does not cover the in-situ calibration of fixed installed area dosemeters.

The procedures to be followed for the different types of dosemeters are described. Recommendations are given on the phantom to be used and on the conversion coefficients to be applied. Recommended conversion coefficients are only given for matched reference radiation fields, which are specified in ISO 4037-1:2019, Clauses 4 to 6. ISO 4037-1:2019, Annexes A and B, both informative, include fluorescent radiations, the gamma radiation of the radionuclide ^{241}Am, S-Am, for which detailed published information is not available. ISO 4037-1:2019, Annex C, gives additional X radiation fields, which are specified by the quality index. For all these radiation qualities, conversion coefficients are given in Annexes A to C, but only as a rough estimate as the overall uncertainty of these conversion coefficients in practical reference radiation fields is not known.

NOTE The term dosemeter is used as a generic term denoting any dose or doserate meter for individual or area monitoring.

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 4037-1, *Radiological protection — X and gamma reference radiations for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy — Part 1: Radiation characteristics and production methods*

ISO 4037-2:2019, *Radiological protection — X and gamma reference radiations for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy — Part 2: Dosimetry for radiation protection over the energy ranges from 8 keV to 1,3 MeV and 4 MeV to 9 MeV*

ISO 4037-4:2019, *Radiological protection — X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy — Part 4: Calibration of area and personal dosemeters in low energy X reference radiation fields*

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

ISO 80000-10, *Quantities and units — Part 10: Atomic and nuclear physics*[1)]

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 4037-1, ISO 4037-2, ISO 29661, ISO 80000-10, 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 http://www.electropedia.org/

3.1
back-scatter factor
ratio of air kerma in front of a phantom to the air kerma at the same position free-in-air without the phantom. The field is considered to be unidirectional with a direction of incidence perpendicular to the phantom surface

Note 1 to entry: The value of the back-scatter factor depends on the point of test (distance from the surface and from the beam axis), beam diameter, phantom size and material and radiation energy.

4 Procedures applicable to all area and personal dosemeters

4.1 General principles

4.1.1 Radiation qualities

All radiation qualities shall be chosen from, and produced in accordance to, ISO 4037-1. In general, it is useful to select an appropriate validated radiation quality taking into account the specified energy and dose or dose rate range of the dosemeter to be tested.

1) Under preparation. Stage at the time of publication ISO/Guide 80000-10:2019.

4.1.2 Recommended conversion coefficients

If only a standard instrument for the air kerma, K_a, free-in-air is used for dosimetric measurements, then for all the other phantom related operational quantities $H^*(10)$, $H_p(10)$, $H'(3)$, $H_p(3)$, $H'(0{,}07)$ and $H_p(0{,}07)$, appropriate conversion coefficients shall be applied to the measured air kerma values. These conversion coefficients shall, in principle, be determined by spectrometry for any reference field, any measuring quantity and, if applicable, for any phantom and angle of radiation incidence.

The air kerma is given by the sum of the air collision kerma, $K_{a,coll}$, and the air radiative kerma, $K_{a,rad}$: $K_a = K_{a,coll} + K_{a,rad}$. The air collision kerma, $K_{a,coll}$, is related to the air kerma by the equation $K_{a,coll} = K_a \cdot (1 - g_a)$, where g_a is the fraction of the energy of the electrons liberated by photons that is lost by radiative processes (bremsstrahlung, fluorescence radiation or annihilation radiation of positrons). Values of $(1–g_a)$ for mono-energetic radiation are given in ISO 4037-2, upper part of Table 2. In the lower part of that Table 2, values for the reference radiations S-Cs, S-Co, R-C and R-F are given. Values are interpolated for S-Cs or taken from Roos and Grosswendt[8] for S-Co and from PTB-Dos-32 for R-C and R-F. For water or air and for energies lower than 1,3 MeV, g_a is less than 0,003 and below 1,5 MeV the values of $(1–g_a)$ can be considered to be unity, see ICRU Report 47[9], A.2.1.

The air collision kerma is the part that leads to the production of electrons that dissipate their energy as ionization in or near the electron tracks in the medium – and is obtained in some Monte Carlo calculations as the energy deposited. The interpretation that was made in ISO 29661 was that the original conversion coefficients which were derived from ICRU Report 57 actually refer to air collision kerma. This approach is adopted in ISO 4037 in the following way: for energies up to and including that of the S-Co reference field the original values are used, as the application of the factor $(1 – g_a)$ does not change numerical values truncated to three significant digits. Conversion coefficients for the R-C and R-F given in ISO 4037-3 differ from those given in ICRU and the previous edition of 4037-3 (1999) by the factor $(1 - g_a) = 0{,}987$ and $(1 - g_a) = 0{,}978$, respectively.

For the tables in Clauses 6 and 8, the irradiation distance is measured from the focal spot of the X-ray tube (or from the geometrical centre of the radio nuclide source) to the point of test, at which the reference point of the dosemeter shall be located. For the R-C and R-F radiations, the irradiation distance shall be measured from the centre of the target surface from which the radiation emerges to the point of test. For the X-radiation qualities, recommended conversion coefficients are given, if available, for two distances of 1,0 m and 2,5 m in separate columns, even if they differ only by the last digit. This shall avoid the introduction of additional uncertainties. If these recommended conversion coefficients are identical for both distances, then the two table cells are merged and only one recommended conversion coefficient is given. This indicates that the recommended conversion coefficient can be used at least for distances from 1 m to 2,5 m. If the recommended conversion coefficients are different for the distances of 1 m and 2,5 m and a recommended conversion coefficient is required for other distances, then the given values of the recommended conversion coefficients shall be interpolated or extrapolated accordingly. If both values are very similar, e.g., only different by 2 % or less, then a linear interpolation may be used. If a range is given for the distance, then the values of the recommended conversion coefficients may be used without modification over this range of distances. From the available data in the Tables, it can be concluded that for collimated beams with mean energies above about 40 keV there is no difference in the recommended conversion coefficients for both distances. The difference increases with decreasing photon energy, increasing definition depth, increasing width of the spectra and increasing angle of radiation incidence.

In Clauses 6 and 8 and in Annexes A to C, a notation is used for the presentation of recommended conversion coefficients which is explained in the following: The example of $h'_K(0{,}07; E, \alpha)$ refers to the conversion coefficient from air kerma K_a to directional dose equivalent in a depth of 0,07 mm for mono-energetic and unidirectional photon radiation of energy E, with an angle α between the reference direction of the dosemeter and the direction of radiation incidence. The prime is replaced by an asterisk for ambient dose equivalent or by the letter p as a subscript for personal dose equivalent. For personal dose equivalent, the type of the phantom is indicated by a subscript at the end. The subscripts rod, pill, cyl and slab stand for rod phantom, pillar phantom, cylinder phantom and slab phantom, respectively. Similar to the above example this would be for the rod phantom $h_{pK}(0{,}07; E, \alpha)_{rod}$. For radiation qualities, U, of finite spectral width the symbol E is replaced by the letter U to represent any radiation quality or by the specific letter according to ISO 4037-1:2019, Table 1, denoting a particular series of reference radiation, i.e. L, N, W, H, S or R.

Numerical values of conversion coefficients for mono-energetic and unidirectional radiation given in Tables 1, 7, 14, 21, 27, 33, 39 and 46 shall be treated as having no uncertainty. Unless otherwise stated, the recommended conversion coefficients in the remaining tables of Clauses 6 and 8 shall be considered as being associated with a standard uncertainty (k = 1) of 2 %. This uncertainty takes account of differences between the spectrum used for the calculation of the conversion coefficient and that prevailing at the point of test, see References [1] and [3].

For tube potentials of and below 30 kV, and especially for the wide and high air kerma rate series, the numerical values of the recommended conversion coefficients $h^*_K(10; \mathrm{U})$ and $h_{\mathrm{p}K}(10, \mathrm{U}, \alpha)$ depend strongly on the air density, i.e., the air temperature, pressure and humidity. The stated values of the recommended conversion coefficients are valid for reference conditions only. Any deviation shall be corrected in accordance with ISO 4037-4:2019, Annex A. For these radiation qualities, detailed information and additional requirements are given in ISO 4037-4. If a radiation quality listed in ISO 4037-1:2019, Table 1, is not contained in one of the tables for the recommended conversion coefficients $h^*_K(10; \mathrm{U})$ and $h_{\mathrm{p}K}(10, \mathrm{U}, \alpha)$ this means that no reliable values may be given.

NOTE For low photon energies small differences in the energy distribution can result in significant changes in the numerical values of these conversion coefficients as the major contribution to the air kerma originates from the low energy part of the spectrum, while the major contribution to $H^*(10)$ and $H_{\mathrm{p}}(10)$ originates from the high energy part of the spectrum, see Reference [4]. Differences in energy distribution from one experimental arrangement to another can occur due to a variety of factors, e.g., anode angle, anode roughening, tungsten evaporated on the tube window, presence of a transmission monitor chamber in the beam, deviation of the thickness of filters from nominal values, length of the air path between focal spot and point of test and atmospheric pressure at the time of measurement. All these points are considered in ISO 4037-4.

4.1.3 Point of test and reference point

Measurements shall be carried out by positioning the reference point of the dosemeter at the point of test. The reference point and the reference direction of the dosemeter to be tested should be stated by the manufacturer in accordance to ISO 29661 or fixed by agreement between manufacturer and testing laboratory. The reference point should be marked on the outside of the dosemeter. If this proves impossible the reference point should be indicated in the accompanying documents supplied with the instrument. All stated distances between the radiation source and the dosemeter shall be taken as the distance between the radiation source and the dosemeter's reference point.

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 clearly stated in the test certificate.

NOTE In the case of point sources and in the absence of scattered radiation and photon absorption, the dose rate changes with the inverse square of the distance R. A misplacement of the dosemeter's reference point in the beam by the amount of ΔR in the direction of the beam leads to a relative error in the calibration factor of $2\Delta R/R$ at the distance R. Misalignment perpendicular to the beam axis by Δr causes a relative error of $(\Delta r/R)^2$. In the presence of scattered radiation and for sources of finite dimensions the above approximations are limited to values of ΔR or Δr small in comparison to R.

4.1.4 Axes of rotation

For examining the effect of the direction of radiation incidence, a rotation of the area dosemeter or of the combination of personal dosemeter and phantom may be required. The variation of response with direction of radiation incidence shall be examined by a rotation around at least two dosemeter axes. The direction of the axes shall be mutually perpendicular, if two axes are used. The axes of rotation shall pass through the reference point of the dosemeter. For an illustration of the geometry, see Figure 1.

4.1.5 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 of radioactive contamination. The set-up procedure and the mode of operation of the dosemeter shall be in accordance with its instruction manual.

4.1.6 Effects associated with electron ranges

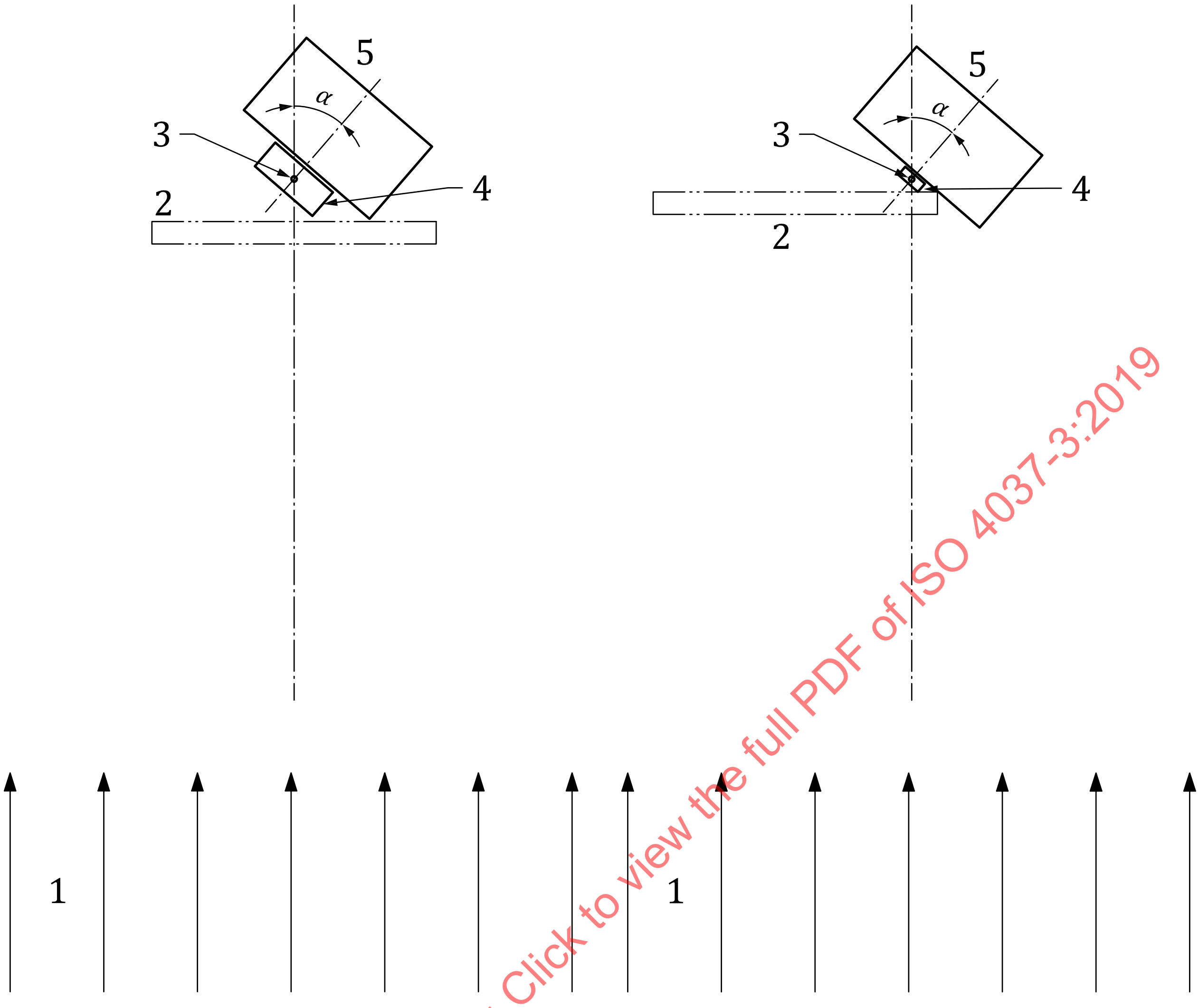
Electrons with energies above 65 keV, 0,75 MeV and 2,1 MeV can just penetrate 0,07 mm, 3 mm and 10 mm of ICRU tissue, respectively, see ICRU Report 56[5]. In photon reference radiation fields capable of producing secondary electrons of these or higher energies, the quantity value and the indication of the dosemeter depends on effects associated with electron ranges and this needs to be considered. In addition, the beam diameter is also of importance for the establishment of electron equilibrium. For a more detailed discussion of this subject, see D.2. The procedure to be followed in such cases is described in the following.

For all phantom related quantities, $H'(0{,}07)$ and $H_p(0{,}07)$, $H'(3)$ and $H_p(3)$ as well as $H^*(10)$ and $H_p(10)$, and for the reference radiation fields generated by X-rays, no special precautions are required. Due to the presence of air and of other materials, e.g. monitor chamber, build-up is completed in the reference depth in practically all situations where the photon energy is below about 250 keV, see Reference [4].

In the case of photon fields with energies from that of S-Cs up to 9 MeV and for all phantom related quantities, first the quantity value shall be determined at the point of test as described in ISO 4037-2 for matched or characterized reference fields. For matched reference fields, the recommended conversion coefficients listed in this document shall be used. Then the reference point of the dosemeter shall be brought to the point of test and a plate of polymethyl-methacrylate (PMMA) of a thickness sufficient to secure completed build-up shall be positioned in front of the dosemeter (for area dosemeters) or in front of the combination of dosemeter and phantom (for personal dosemeters). The required thickness is specified in the Tables of the conversion coefficients in Clauses 6 and 8. The modification of the radiation field by introducing the PMMA plate should be taken into account by multiplying the conversion coefficient with the correction factor k_{PMMA} given in the Tables in Clauses 6 and 8. The cross-sectional area of the plate shall be at least 30 cm × 30 cm and, for area dosemeters, overlapping the dosemeter under test at minimum one time the distance from the plate to the centre of the detector (the reference point of the dosemeter). The thickness of the plate shall be as given in the Tables. The plate shall be positioned as close as possible to the dosemeter and perpendicular to the beam direction, see example in Figure 1.

NOTE 1 For the S-Cs and S-Co reference fields a PMMA plate of 3 mm thickness is sufficient to establish secondary electron equilibrium[6].

NOTE 2 As an example, for a spherical area dosemeter with 30 cm diameter and the reference point of the dosemeter in its centre, the size of the build-up plate shall be at least 60 cm × 60 cm if positioned as close as possible to the dosemeter.



Key

1 near-parallel beam
2 build-up layer, if required
3 reference point
4 dosemeter
5 slab phantom

Figure 1 — Arrangement for the calibration of personal dosemeters at angle α, Left: large dosemeter, right: small dosemeter

4.2 Methods for the determination of the calibration factor and of the response

4.2.1 Operation of the standard instrument

The mode of operation of the standard instrument shall be in accordance with its calibration certificate, the instrument instruction manual and of ISO 4037-2:2019, Annex A, e. g., set zero control, warm up time, application of range or scale correction factors. The time interval between periodic calibrations of the standard instrument shall be within the period defined by national regulations. Where no such regulations exist, the time interval should not exceed two years.

Measurements shall be made regularly, using either a radioactive check source or a calibrated radiation field, to determine that the reproducibility of the standard instrument is within ±1 % of the certificate value. Corrections shall be applied for the radioactive decay of the source and for deviations in air density from its reference value, when necessary.

In the case of a sequential irradiation of the standard instrument and of the dosemeter under test, see ISO 29661:2012, 6.4.2, a decision shall be made whether a monitor has to be used or not (see 4.2.2). This decision shall be based on the stability of the output of the radiation source.

There are two types of standard instruments: those that measure a more basic dosimetric quantity, e.g., air kerma and others that measure directly the phantom related quantities in which the calibration is to be performed. For the first kind of instruments, the suitable conversion coefficient h shall be used, while no conversion coefficient is required for the second kind of instruments. The recommended suitable conversion coefficient h, as listed in the following Tables for all radiation qualities, shall only be used if the corresponding matched radiation quality of the reference field is validated. Otherwise, the method given in ISO 4037-2:2019, 5.2 or Clause 6, shall be used.

4.2.2 Measurements without a monitor for the source output

In general, a monitor, see ISO 4037-1:2019, 3.5, is not needed in reference radiation fields produced by radioactive sources. For X-radiation reference fields, the use of a monitor is usually recommended.

5 Particular procedures for area dosemeters

5.1 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. They do not apply to *in-situ* calibrations of installed area dosemeters. Dosemeters for area monitoring shall be irradiated free-in-air (without any phantom). Measurements of the response may be necessary in the photon energy range from 8 keV to 9 MeV, and, depending on the equipment for the irradiation, at various irradiation distances. Clause 6 contains, for matched ISO reference radiations, conversion coefficients h to convert air kerma, K_a, to the operational quantities $H'(0{,}07)$, $H'(3)$ and $H^*(10)$. Conversion coefficients for mono-energetic photons for a broad parallel beam and in the absence of scattered radiation are also given.

In practice, calibrations are always performed in divergent beams. This is taken account of by referring the recommended conversion coefficients to a reference distance between radiation source and point of test. In case of a divergent beam, the beam axis is considered as the direction of the beam. In cases where a reference distance is given together with an angle α of the direction of radiation incidence, α is the angle between the reference orientation of the dosemeter and the actual direction of the beam. All conversion coefficients are determined for unidirectional radiation incidence.

5.2 Quantities to be measured

For area dosemeters the quantities to be measured shall be the directional dose equivalents, $H'(0{,}07)$ and $H'(3)$, and the ambient dose equivalent, $H^*(10)$. For area dosemeters, calibration procedures for any angle up to 180° make sense, as the calibration is performed without a phantom.

6 Conversion coefficients for area dosimetry

6.1 Conversion coefficients from air kerma, K_a, to $H'(0{,}07)$

6.1.1 Mono-energetic radiation

See Table 1.

NOTE Data were taken from ICRU 57[7] (bold) and interpolated values either from Ankerhold[1] or from Ankerhold[8].

6.1.2 Low air kerma rate series

See Table 2.

NOTE Data were taken from Ankerhold[1].

6.1.3 Narrow series

See Table 3.

NOTE Data were taken from Ankerhold[1] and, for N-350 and N-400, from Ankerhold[8].

6.1.4 Wide series

See Table 4.

NOTE Data were taken from Ankerhold[1].

6.1.5 High air kerma rate series

See Table 5.

NOTE Data were taken from Ankerhold[1] and, for H-350 and H-400, from Ankerhold[8].

6.1.6 Radionuclides

See Table 6.

NOTE Data were taken from DIN 6818-1:2004[10].

Table 1 — Conversion coefficient $h'_K(0{,}07; E, \alpha)$ from air kerma, K_a, to the directional dose equivalent $H'(0{,}07)$ for mono-energetic and parallel photon radiation (expanded field)

Photon energy, E	$h'_K(0{,}07; E, \alpha)$ **in Sv/Gy for angle of incidence**, α, **of**							
keV	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**	**90°**	**180°**
3	0,287	0,266	0,214	0,151	0,044	0,000	0,000	0,000
4	0,586	0,557	0,490	0,416	0,185	0,000	0,000	0,000
5	**0,76**	**0,73**	**0,66**	**0,60**	**0,31**	**0,00**	**0,00**	**0,00**
6	0,798	0,772	0,715	0,667	0,432	0,169	0,036	0,000
8	0,874	0,856	0,823	0,799	0,672	0,507	0,108	0,000
10	**0,95**	**0,94**	**0,93**	**0,93**	**0,91**	**0,85**	**0,18**	**0,00**
12	0,966	0,958	0,949	0,951	0,935	0,878	0,253	0,000
14	0,982	0,976	0,966	0,970	0,959	0,910	0,325	0,000
15	**0,99**	0,985	0,975	0,980	0,970	0,926	0,361	0,000
20	**1,05**	**1,05**	**1,04**	**1,05**	**1,05**	**1,03**	**0,57**	**0,00**
30	**1,22**	**1,21**	**1,21**	**1,21**	**1,20**	**1,15**	**0,76**	**0,00**
40	**1,41**	1,40	1,39	1,39	1,37	1,31	0,924	0,014
50	**1,53**	**1,51**	**1,50**	**1,50**	**1,48**	**1,41**	**1,06**	**0,03**
60	**1,59**	1,57	1,56	1,56	1,55	1,47	1,12	0,041
70	1,61	1,60	1,59	1,59	1,57	1,50	1,16	0,051
80	**1,61**	1,59	1,59	1,59	1,57	1,50	1,19	0,061
100	**1,55**	**1,53**	**1,53**	**1,53**	**1,52**	**1,46**	**1,19**	**0,08**
125	1,49	1,47	1,47	1,47	1,46	1,42	1,21	0,09

Table 1 *(continued)*

Photon energy, E keV	$h'_K(0{,}07; E, \alpha)$ **in Sv/Gy for angle of incidence,** α**, of**							
	0°	**15°**	**30°**	**45°**	**60°**	**75°**	**90°**	**180°**
150	**1,42**	**1,41**	**1,41**	**1,41**	**1,41**	**1,38**	**1,24**	**0,10**
200	**1,34**	1,33	1,33	1,33	1,34	1,31	1,17	0,11
300	**1,31**	**1,31**	**1,31**	**1,31**	**1,34**	**1,31**	**1,17**	**0,13**
662	**1,20**	**1,20**	**1,20**	**1,20**	**1,20**	**1,18**	**1,07**	**0,22**
1 250	**1,16**	**1,16**	**1,16**	**1,16**	**1,16**	**1,14**	**1,04**	**0,35**

Table 2 — Recommended conversion coefficient $h'_K(0{,}07; \mathrm{L}, \alpha)$ from air kerma, K_a, to the directional dose equivalent $H'(0{,}07)$

Radiation quality	$h'_K(0{,}07; \mathrm{L}, \alpha)$ in Sv/Gy for the angle of incidence, α, and distance of															
	0°		15°		30°		45°		60°		75°		90°		180°	
	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m
L-10	0,908	0,915	0,893	0,902	0,871	0,882	0,857	0,871	0,778	0,802	0,656	0,691	0,140	0,148	0,000	
L-20	1,01		1,01		1,00		1,01		1,00		0,965	0,962	0,441		0,000	
L-30	1,16		1,15		1,15		1,15		1,14		1,10		0,686		0,000	
L-35	1,22		1,21		1,21		1,21		1,20		1,15		0,752		0,002	
L-55	1,49		1,48		1,47		1,47		1,45		1,38		1,02		0,026	
L-70	1,59		1,57		1,56		1,56		1,54		1,47		1,12		0,042	
L-100	1,59		1,57		1,57		1,57		1,55		1,48		1,19		0,067	
L-125	1,52		1,51		1,51		1,51		1,50		1,44		1,20		0,082	
L-170	1,42		1,41		1,41		1,41		1,41		1,38		1,23		0,098	
L-210	1,36		1,35		1,35		1,35		1,36		1,33		1,19		0,105	
L-240	1,34		1,33		1,33		1,33		1,34		1,32		1,18		0,110	

Table 3 — Recommended conversion coefficient $h'_K(0{,}07; \text{N}, \alpha)$ from air kerma, K_a, to the directional dose equivalent $H'(0{,}07)$

Radiation quality	$h'_K(0{,}07; \text{N}, \alpha)$ in Sv/Gy for the angle of incidence, α, and distance of															
	0°		15°		30°		45°		60°		75°		90°		180°	
	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m
N-10	0,885	0,902	0,868	0,887	0,839	0,863	0,818	0,847	0,706	0,760	0,556	0,632	0,119	0,135	0,000	
N-15	0,963	0,967	0,955	0,959	0,944	0,949	0,945	0,951	0,924	0,933	0,862	0,875	0,250	0,264	0,000	
N-20	0,999	1,00	0,995	0,998	0,984	0,987	0,990	0,993	0,980	0,983	0,937	0,942	0,389	0,399	0,000	
N-25	1,05		1,05		1,04		1,05		1,04		1,01		0,529	0,534	0,000	
N-30	1,12		1,11		1,10	1,11	1,11		1,11		1,07		0,635	0,636	0,000	
N-40	1,27		1,26		1,25		1,25		1,24		1,19		0,795	0,796	0,004	
N-60	1,48		1,47		1,45	1,46	1,45	1,46	1,44		1,37		1,00		0,025	
N-80	1,60		1,58		1,57		1,57		1,55		1,48		1,13		0,046	
N-100	1,59		1,58		1,57		1,57		1,56		1,49		1,18		0,064	
N-120	1,55		1,53		1,53		1,53		1,52		1,46		1,20		0,077	
N-150	1,50		1,48		1,48		1,48		1,47		1,42		1,21		0,086	
N-200	1,39		1,38		1,38		1,38		1,38		1,36		1,21		0,102	0,101
N-250	1,34		1,34		1,34		1,34		1,35		1,32		1,18		0,110	
N-300	1,33		1,32		1,32		1,32		1,34		1,31		1,17		0,120	
N-350	1,31		1,31		1,31		1,31		1,33		1,31		1,16		0,129	
N-400	1,29		1,29		1,29		1,29		1,32		1,29		1,15		0,138	

Table 4 — Recommended conversion coefficient $h'_K(0{,}07; \text{W}, \alpha)$ from air kerma, K_a, to the directional dose equivalent $H'(0{,}07)$

Radiation quality	$h'_K(0{,}07; \text{W}, \alpha)$ in Sv/Gy for the angle of incidence, α, and distance of															
	0°		15°		30°		45°		60°		75°		90°		180°	
	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m
W-30	1,08	1,09	1,08		1,07		1,08		1,07	1,08	1,04		0,581	0,585	0,000	
W-40	1,19		1,18		1,18		1,18		1,17		1,13		0,713	0,717	0,002	
W-60	1,43		1,41	1,42	1,41		1,41		1,39		1,32	1,33	0,951	0,952	0,019	
W-80	1,54		1,52		1,51		1,51		1,49		1,42		1,06		0,035	
W-110	1,59		1,57		1,57		1,57		1,55		1,48		1,17		0,060	
W-150	1,53		1,51		1,51		1,51		1,50		1,44		1,20		0,079	
W-200	1,44		1,43		1,43		1,43		1,43		1,39		1,21		0,094	
W-250	1,38		1,37		1,37		1,37		1,38		1,35		1,20		0,104	
W-300	1,35		1,34		1,34		1,34		1,35		1,33		1,18		0,111	

Table 5 — Recommended conversion coefficient $h'_K(0{,}07; \mathrm{H}, \alpha)$ from air kerma, K_a, to the directional dose equivalent $H'(0{,}07)$

Radiation quality	$h'_K(0{,}07; \mathrm{H}, \alpha)$ in Sv/Gy for the angle of incidence, α, and distance of															
	0°		15°		30°		45°		60°		75°		90°		180°	
	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m
H-10	0,863	0,892	0,844	0,876	0,808	0,848	0,781	0,829	0,639	0,727	0,462	0,585	0,0985	0,125	0,000	
H-20	0,950	0,966	0,941	0,958	0,926	0,946	0,923	0,946	0,886	0,920	0,808	0,856	0,237	0,276	0,000	
H-30	1,02	1,03	1,01	1,02	1,00	1,01	1,00	1,02	0,992	1,01	0,946	0,970	0,418	0,452	0,000	
H-40	1,09	1,10	1,09	1,10	1,08	1,09	1,08	1,09	1,08	1,09	1,04	1,05	0,572	0,588	0,001	
H-60	1,28	1,29	1,27	1,28	1,26	1,27	1,27		1,25	1,26	1,20	1,21	0,803	0,812	0,008	0,009
H-80	1,42		1,41		1,40		1,40		1,38	1,39	1,32		0,943	0,951	0,021	
H-100	1,49	1,50	1,48		1,47		1,47		1,45	1,46	1,38	1,39	1,03		0,032	
H-150	1,55		1,54		1,53		1,53		1,52		1,45		1,15		0,058	
H-200	1,51		1,50		1,49		1,49		1,48		1,43		1,18	1,19	0,076	
H-250	1,46		1,45		1,45		1,45		1,44		1,40		1,19		0,088	
H-280	1,42		1,41		1,41		1,41		1,41		1,37		1,20		0,097	
H-300	1,42		1,41		1,41		1,41		1,41		1,37		1,19		0,097	
H-350	1,39		1,38		1,38		1,38		1,39		1,35		1,19		0,105	
H-400	1,37		1,36		1,36		1,36		1,37		1,34		1,18		0,112	

Table 6 — Recommended conversion coefficient $h'_K(0{,}07; S, \alpha)$ from air kerma, K_a, to the directional dose equivalent $H'(0{,}07)$

<table>
<tr><th rowspan="3">Radiation quality</th><th colspan="2">PMMA build-up layer</th><th colspan="14">$h'_K(0{,}07; S, \alpha)$ in Sv/Gy for the angle of incidence, α, and distance of</th></tr>
<tr><th rowspan="2">d_{PMMA}
mm</th><th rowspan="2">k_{PMMA}</th><th colspan="2">0°</th><th colspan="2">15°</th><th colspan="2">30°</th><th colspan="2">45°</th><th colspan="2">60°</th><th colspan="2">75°</th><th colspan="2">90°</th><th colspan="2">180°</th></tr>
<tr><th>1,0 m</th><th>2,5 m</th><th>1,0 m</th><th>2,5 m</th><th>1,0 m</th><th>2,5 m</th><th>1,0 m</th><th>2,5 m</th><th>1,0 m</th><th>2,5 m</th><th>1,0 m</th><th>2,5 m</th><th>1,0 m</th><th>2,5 m</th><th>1,0 m</th><th>2,5 m</th></tr>
<tr><td>S-Cs</td><td>3</td><td>1,00</td><td colspan="2">1,20</td><td colspan="2">1,20</td><td colspan="2">1,20</td><td colspan="2">1,20</td><td colspan="2">1,20</td><td colspan="2">1,18</td><td colspan="2">1,07</td><td colspan="2">0,21</td></tr>
<tr><td>S-Co</td><td>3</td><td>1,00</td><td colspan="2">1,16</td><td colspan="2">1,16</td><td colspan="2">1,16</td><td colspan="2">1,16</td><td colspan="2">1,16</td><td colspan="2">1,14</td><td colspan="2">1,04</td><td colspan="2">0,34</td></tr>
</table>

6.2 Conversion coefficients from air kerma, K_a, to $H'(3)$

6.2.1 Mono-energetic radiation

See Table 7.

NOTE Data were taken from Behrens[11]. For energies above 1,5 MeV the bremsstrahlung correction according to 4.1.2 was applied. For the monoenergetic $(1 - g_a)$ values, see ISO 4037-2:2019, Table 2.

6.2.2 Low air kerma rate series

See Table 8.

NOTE Data were taken from Behrens[11].

6.2.3 Narrow series

See Table 9.

NOTE Data were taken from Behrens[11].

6.2.4 Wide series

See Table 10.

NOTE Data were taken from Behrens[11].

6.2.5 High air kerma rate series

See Table 11.

NOTE Data were taken from Behrens[11].

6.2.6 Radionuclides

See Table 12.

NOTE Data were taken from Behrens[11].

6.2.7 High energy photon radiations

See Table 13.

NOTE Data were taken from Behrens[11]. The “bremsstrahlung” correction according to 4.1.2 was applied.

Table 7 — Conversion coefficient $h'_K(3; E, \alpha)$ from air kerma, K_a, to the directional dose equivalent $H'(3)$ for mono-energetic and parallel photon radiation (expanded field)

Photon energy	$h'_K(3; E, \alpha)$ in Sv/Gy for angle of incidence, α, of							
keV	0°	15°	30°	45°	60°	75°	90°	180°
5	<0,000 1	<0,000 1	<0,000 1	<0,000 1	<0,000 1	<0,000 1	0	0
6	0,001 1	0,000 9	0,000 4	<0,000 1	<0,000 1	<0,000 1	<0,000 1	0
7	0,014 3	0,012 3	0,007 5	0,002 7	0,000 3	<0,000 1	<0,000 1	0
8	0,059 2	0,053 6	0,038 6	0,019 2	0,004 4	0,000 21	<0,000 1	0
9	0,140	0,130	0,104	0,063 3	0,022 1	0,001 71	<0,000 1	0
10	0,240	0,229	0,194	0,135	0,062 3	0,00845	<0,000 1	0

Table 7 *(continued)*

Photon energy keV	$h'_K(3; E, \alpha)$ in Sv/Gy for angle of incidence, α, of							
	0°	**15°**	**30°**	**45°**	**60°**	**75°**	**90°**	**180°**
11	0,347	0,334	0,295	0,225	0,125	0,0266	0,000 3	0
13	0,536	0,524	0,486	0,412	0,287	0,108	0,002 7	0
15	0,682	0,671	0,638	0,571	0,449	0,231	0,015 5	0
17	0,791	0,784	0,756	0,699	0,588	0,364	0,048 7	0
20	0,917	0,912	0,890	0,844	0,750	0,541	0,136	0
24	1,04	1,04	1,02	0,982	0,903	0,719	0,278	<0,000 1
30	1,22	1,21	1,20	1,16	1,09	0,921	0,478	0,000 4
40	1,45	1,44	1,43	1,39	1,31	1,15	0,715	0,005 9
50	1,61	1,60	1,58	1,54	1,46	1,30	0,875	0,023 9
60	1,68	1,68	1,66	1,62	1,54	1,38	0,971	0,041 7
70	1,70	1,70	1,68	1,64	1,57	1,42	1,03	0,057 2
80	1,68	1,67	1,66	1,63	1,56	1,43	1,05	0,067 9
100	1,61	1,61	1,60	1,57	1,52	1,41	1,06	0,078 9
120	1,52	1,52	1,52	1,50	1,47	1,37	1,05	0,084 0
150	1,47	1,47	1,46	1,46	1,43	1,35	1,06	0,091 3
200	1,39	1,39	1,39	1,38	1,37	1,31	1,06	0,110
300	1,30	1,30	1,30	1,31	1,31	1,27	1,07	0,139
400	1,26	1,25	1,25	1,26	1,26	1,24	1,07	0,166
500	1,22	1,22	1,22	1,23	1,24	1,22	1,07	0,196
662	1,18	1,19	1,20	1,20	1,21	1,20	1,08	0,236
800	1,17	1,17	1,18	1,18	1,19	1,19	1,07	0,263
1 000	1,15	1,16	1,16	1,17	1,17	1,17	1,07	0,304
1 300	1,15	1,15	1,15	1,15	1,16	1,16	1,08	0,356
1 500	1,14	1,14	1,14	1,14	1,15	1,15	1,08	0,383
2 000	1,12	1,12	1,12	1,13	1,13	1,13	1,07	0,444
3 000	1,11	1,11	1,11	1,11	1,12	1,12	1,07	0,515
5 000	1,10	1,09	1,09	1,10	1,10	1,09	1,06	0,602
8 000	1,08	1,08	1,07	1,08	1,08	1,07	1,04	0,645
10 000	1,07	1,07	1,07	1,07	1,07	1,06	1,03	0,673

Table 8 — Recommended conversion coefficient $h'_K(3; \text{L}, \alpha)$ from air kerma, K_a, to the directional dose equivalent $H'(3)$

Radiation quality	$h'_K(3; \text{L}, \alpha)$ in Sv/Gy for the angle of incidence, α, and distance of															
	0°		15°		30°		45°		60°		75°		90°		180°	
	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m
L-10	0,137	0,154	0,128	0,144	0,103	0,118	0,065 7	0,076 1	0,025 7	0,030 7	0,002 8	0,003 4	<0,000 1	<0,000 1	0	0
L-20	0,773		0,765		0,736		0,679		0,570		0,356	0,358	0,058 1	0,059 2	0	0
L-30	1,11		1,10		1,09		1,05		0,972		0,793	0,794	0,354		0,000 2	0,000 2
L-35	1,21		1,20		1,19		1,15		1,08		0,905		0,464		0,000 9	0,001 0
L-55	1,56		1,55		1,54		1,5		1,42		1,25		0,827		0,019 2	0,019 3
L-70	1,68		1,67		1,65		1,61		1,54		1,38		0,964		0,041 9	0,042 0
L-100	1,65		1,65		1,63		1,61		1,55		1,42		1,05		0,071 4	
L-125	1,57		1,56		1,56		1,54		1,50		1,39		1,06		0,081 2	
L-170	1,47		1,47		1,47		1,46		1,43		1,35		1,06		0,091 9	
L-210	1,41		1,41		1,41		1,40		1,39		1,32		1,06		0,105	
L-240	1,37		1,38		1,38		1,38		1,37		1,31		1,06		0,114	

Table 9 — Recommended conversion coefficient $h'_K(3; \mathrm{N}, \alpha)$ from air kerma, K_a, to the directional dose equivalent $H'(3)$

Radiation quality	$h'_K(3; \mathrm{N}, \alpha)$ in Sv/Gy for the angle of incidence, α, and distance of															
	0°		15°		30°		45°		60°		75°		90°		180°	
	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m
N-10	0,095 6	0,126	0,088 9	0,117	0,070 2	0,094 2	0,042 9	0,059 4	0,015 7	0,022 8	0,001 6	0,002 4	<0,000 1	<0,000 1	0	0
N-15	0,427	0,461	0,415	0,449	0,379	0,412	0,312	0,344	0,209	0,235	0,077 5	0,090 5	0,003 0	0,003 6	0	0
N-20	0,693	0,710	0,684	0,701	0,653	0,670	0,592	0,609	0,479	0,497	0,277	0,292	0,037 8	0,041 3	0	0
N-25	0,884	0,889	0,877	0,883	0,853	0,859	0,804	0,810	0,706	0,714	0,500	0,508	0,133	0,137	<0,000 1	<0,000 1
N-30	1,03		1,03		1,01		0,967	0,969	0,883	0,886	0,694	0,698	0,270	0,273	<0,000 1	<0,000 1
N-40	1,27		1,26		1,25		1,21		1,14		0,967		0,528	0,530	0,002 1	0,002 1
N-60	1,54		1,54		1,52		1,48		1,40		1,24		0,811	0,812	0,018 8	0,018 9
N-80	1,68		1,68		1,66		1,62		1,55		1,40		0,989	0,990	0,048 8	0,048 9
N-100	1,66		1,66		1,64		1,61		1,55		1,42		1,05		0,068 6	0,068 7
N-120	1,60		1,60		1,59		1,56		1,52		1,40		1,06		0,078 1	
N-150	1,54		1,54		1,53		1,51		1,48		1,38		1,06		0,083 7	
N-200	1,44		1,44		1,44		1,43		1,41		1,34		1,06		0,098 1	
N-250	1,38		1,38		1,38		1,38		1,37		1,31		1,06		0,113	
N-300	1,34		1,34		1,34		1,34		1,34		1,29		1,07		0,125	
N-350	1,31		1,31		1,31		1,31		1,31		1,28		1,07		0,136	
N-400	1,29		1,28		1,29		1,29		1,29		1,26		1,07		0,147	

Table 10 — Recommended conversion coefficient $h'_K(3;\text{W},\alpha)$ from air kerma, K_a, to the directional dose equivalent $H'(3)$

Radiation quality	$h'_K(3;\text{W},\alpha)$ in Sv/Gy for the angle of incidence, α, and distance of															
	0°		15°		30°		45°		60°		75°		90°		180°	
	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m
W-30	0,957	0,963	0,950	0,957	0,929	0,935	0,884	0,891	0,793	0,801	0,596	0,605	0,202	0,207	<0,000 1	<0,000 1
W-40	1,15	1,16	1,14	1,15	1,13	1,13	1,09	1,09	1,01	1,01	0,830	0,837	0,397	0,403	0,000 9	0,001 0
W-60	1,48		1,47		1,45	1,46	1,41	1,42	1,34		1,17		0,742	0,743	0,013 6	0,013 7
W-80	1,61		1,60	1,61	1,59		1,55		1,47		1,31		0,893	0,894	0,032 6	0,032 7
W-110	1,66		1,66		1,64		1,61		1,55		1,41		1,03		0,063 6	0,063 7
W-150	1,57		1,57		1,56		1,54		1,50		1,39		1,05		0,078 4	0,078 6
W-200	1,49		1,49		1,48		1,47		1,44		1,36		1,06		0,090 6	0,090 7
W-250	1,42		1,43		1,42		1,42		1,40		1,33		1,06		0,103	
W-300	1,38		1,38		1,38		1,38		1,37		1,31		1,06		0,113	

Table 11 — Recommended conversion coefficient $h'_K(3;\text{H},\alpha)$ from air kerma, K_a, to the directional dose equivalent $H'(3)$

Radiation quality	$h'_K(3;\text{H},\alpha)$ in Sv/Gy for the angle of incidence, α, and distance of															
	0°		15°		30°		45°		60°		75°		90°		180°	
	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m
H-10	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]
H-20	0,374	0,463	0,363	0,452	0,332	0,419	0,276	0,359	0,193	0,263	0,087 9	0,129	0,008 5	0,013 5	0	0
H-30	0,708	0,766	0,7	0,757	0,671	0,73	0,616	0,675	0,516	0,574	0,338	0,386	0,085 5	0,102	<0,000 1	<0,000 1
H-40	0,946	0,971	0,938	0,963	0,916	0,942	0,869	0,895	0,778	0,805	0,586	0,612	0,218	0,234	0,000 3	0,000 3
H-60	1,27	1,29	1,26	1,28	1,25	1,26	1,21	1,22	1,13	1,15	0,962	0,975	0,534	0,544	0,005 5	0,005 7
H-80	1,46	1,47	1,45	1,46	1,43	1,45	1,40	1,41	1,32	1,33	1,16	1,17	0,731	0,740	0,018 0	0,018 4
H-100	1,55	1,56	1,54	1,55	1,53		1,49		1,41	1,42	1,26	1,26	0,841	0,846	0,030 7	0,031 0
H-150	1,62		1,61	1,62	1,60		1,57		1,51		1,37		0,993	0,994	0,058 2	0,058 3
H-200	1,57		1,57		1,56		1,53		1,49		1,38		1,03		0,074 7	0,074 8
H-250	1,51		1,51		1,50		1,49		1,45		1,36		1,05		0,087 1	0,087 0
H-280	1,46		1,47		1,46		1,45		1,43		1,35		1,06		0,096 4	0,096 5
H-300	1,46		1,46		1,46		1,45		1,42		1,35		1,06		0,096 8	
H-350	1,42		1,42		1,42		1,41		1,4		1,33		1,06		0,106	
H-400	1,39		1,39		1,39		1,39		1,37		1,31		1,06		0,114	

[a] A matched field is not possible for this irradiation condition, see ISO 4037-1:2019, 4.2.4.

Table 12 — Recommended conversion coefficient $h'_K(3; \mathrm{S}, \alpha)$ from air kerma, K_a, to the directional dose equivalent $H'(3)$

Radiation quality	PMMA build-up layer		$h'_K(3; \mathrm{S}, \alpha)$ in Sv/Gy for the angle of incidence, α, and distance of 1 m to 2,5 m							
	d_{PMMA} mm	k_{PMMA}	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**	**90°**	**180°**
S-Cs	3	1,00	1,19	1,19	1,20	1,21	1,21	1,20	1,08	0,232
S-Co	3	1,00	1,15	1,15	1,15	1,16	1,17	1,17	1,08	0,345

Table 13 — Recommended conversion coefficient $h'_K(3;\mathrm{R},\alpha)$ from air kerma, K_a, to the directional dose equivalent $H'(3)$

Radiation quality	PMMA build-up layer		$h'_K(3;\mathrm{R},\alpha)$ in Sv/Gy for the angle of incidence, α, and distance of 1 m to 2,5 m							
	d_{PMMA} mm	k_{PMMA}	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**	**90°**	**180°**
R-C	25	0,95	1,10	1,10	1,10	1,10	1,10	1,10	1,06	0,583
R-F	25	0,95	1,09	1,09	1,09	1,09	1,09	1,09	1,05	0,621

6.3 Conversion coefficient from air kerma, K_a, to $H^*(10)$

6.3.1 Mono-energetic radiation

See Table 14.

NOTE Data were taken from ICRU 57[7] (bold) and extrapolated values below 10 keV and interpolated values from Ankerhold[1]. For energies above 1,5 MeV the bremsstrahlung correction according to 4.1.2 was applied. For the monoenergetic $(1 - g_a)$ values, see ISO 4037-2:2019, Table 2.

6.3.2 Low air kerma rate series

See Table 15.

NOTE Data were taken from Ankerhold[1].

6.3.3 Narrow series

See Table 16.

NOTE Data were taken from Ankerhold[1] and, for N-350 and N-400, from Ankerhold[8].

6.3.4 Wide series

See Table 17.

NOTE Data were taken from Ankerhold[1].

6.3.5 High air kerma rate series

See Table 18.

NOTE Data were taken from Ankerhold[1] and, for H-350 and H-400, from Ankerhold[8].

6.3.6 Radionuclides

See Table 19.

NOTE Data were taken from DIN 6818-1:2004[10] for Co-60 and Dos 23e[4] for Cs-137.

6.3.7 High energy photon radiations

See Table 20.

NOTE Data were taken from Behrens et al.[12] The bremsstrahlung correction according to 4.1.2 was applied.

Table 14 — Conversion coefficient $h^*_K(10; E)$ from air kerma, K_a, to the ambient dose equivalent $H^*(10)$ for mono-energetic and parallel photon radiation (expanded field)

Photon energy, E keV	$h^*_K(10; E)$ Sv/Gy
7	0,000 012
8	0,000 095
9	0,001 45
10	**0,008**
11	0,033 1
12	0,073 7

Table 14 *(continued)*

Photon energy, E keV	$h^*_K(10; E)$ Sv/Gy
13	0,127
14	0,190
15	**0,26**
16	0,326
17	0,395
18	0,466
19	0,538
20	**0,61**
30	**1,10**
40	**1,47**
50	**1,67**
60	**1,74**
80	**1,72**
100	**1,65**
150	**1,49**
200	**1,40**
300	**1,31**
400	**1,26**
500	**1,23**
600	**1,21**
800	**1,19**
1 000	**1,17**
1 500	**1,15**
2 000	**1,13**
3 000	**1,12**
4 000	**1,11**
5 000	**1,09**
6 000	**1,09**
8 000	**1,08**
10 000	**1,06**

Table 15 — Recommended conversion coefficient $h^*_K(10; \mathrm{L})$ from air kerma, K_a, to the ambient dose equivalent $H^*(10)$

Radiation quality	$h^*_K(10; \mathrm{L})$ **in Sv/Gy for the distance of**	
	1,0 m	**2,5 m**
L-10	—[a]	—[a]
L-20	0,393	0,396
L-30	0,937	0,938
L-35	1,09	1,10
L-55	1,62	
L-70	1,73	

[a] A matched field is not possible for this irradiation condition, see ISO 4037-1:2019, 4.2.4.

Table 15 *(continued)*

Radiation quality	$h^*_K(10; L)$ in Sv/Gy for the distance of	
	1,0 m	2,5 m
L-100	1,70	
L-125	1,61	
L-170	1,49	
L-210	1,42	
L-240	1,38	

[a] A matched field is not possible for this irradiation condition, see ISO 4037-1:2019, 4.2.4.

Table 16 — Recommended conversion coefficient $h^*_K(10; N)$ from air kerma, K_a, to the ambient dose equivalent $H^*(10)$

Radiation quality	$h^*_K(10; N)$ in Sv/Gy for the distance of	
	1,0 m	2,5 m
N-10	—[a]	—[a]
N-15	—[a]	—[a]
N-20	0,307	0,323
N-25	0,566	0,576
N-30	0,810	0,814
N-40	1,19	1,20
N-60	1,59	
N-80	1,74	
N-100	1,71	
N-120	1,65	
N-150	1,58	
N-200	1,46	
N-250	1,39	
N-300	1,35	
N-350	1,32	
N-400	1,29	

[a] A matched field is not possible for this irradiation condition, see ISO 4037-1:2019, 4.2.4.

Table 17 — Recommended conversion coefficient $h^*_K(10; W)$ from air kerma, K_a, to the ambient dose equivalent $H^*(10)$

Radiation quality	$h^*_K(10; W)$ in Sv/Gy for the distance of	
	1,0 m	2,5 m
W-30	0,687	0,697
W-40	0,998	1,01
W-60	1,50	
W-80	1,66	
W-110	1,71	
W-150	1,62	

Table 17 *(continued)*

Radiation quality	$h^*_K(10; \mathrm{W})$ **in Sv/Gy for the distance of**	
	1,0 m	**2,5 m**
W-200	1,52	
W-250	1,44	
W-300	1,39	

Table 18 — Recommended conversion coefficient $h^*_K(10; \mathrm{H})$ from air kerma, K_a, to the ambient dose equivalent $H^*(10)$

Radiation quality	$h^*_K(10; \mathrm{H})$ **in Sv/Gy for the distance of**	
H-10	—[a]	—[a]
H-20	—[a]	—[a]
H-30	—[a]	—[a]
H-40	0,684	0,717
H-60	1,19	1,21
H-80	1,46	1,47
H-100	1,57	1,58
H-150	1,67	
H-200	1,61	
H-250	1,54	
H-280	1,49	
H-300	1,49	
H-350	1,44	
H-400	1,41	

[a] A matched field is not possible for this irradiation condition, see ISO 4037-1:2019, 4.2.4.

Table 19 — Recommended conversion coefficient $h^*_K(10; \mathrm{S})$ from air kerma, K_a, to the ambient dose equivalent $H^*(10)$

Radiation quality	**PMMA build-up layer**		**Irradiation distance**	$h^*_K(10; \mathrm{S})$
	d_{PMMA} mm	k_{PMMA}	m	Sv/Gy
S-Cs	3	1,00	1,0 – 3,0	1,21
S-Co	3	1,00	1,0 – 3,0	1,16

Table 20 — Recommended conversion coefficient $h^*_K(10; \mathrm{R})$ from air kerma, K_a, to the ambient dose equivalent $H^*(10)$

Radiation quality	**PMMA build-up layer**		**Irradiation distance**	$h^*_K(10; \mathrm{R})$
	d_{PMMA} mm	k_{PMMA}	m	Sv/Gy
R-C	25	0,95	1,0	1,11
R-F	25	0,95	1,0	1,10

7 Particular procedures for personal dosemeters

7.1 General principles

These principles apply to the calibration of all personal dosemeters, i. e., whole body and extremity dosemeters. The irradiation shall be performed on a phantom made of PMMA or a combination of PMMA and water, see 7.3.1. Measurements of the response may be necessary in the photon energy range from 8 keV to 9 MeV, at angles of radiation incidence from 0° up to 75° or 90° and at various irradiation distances.

Clause 8 contains recommended conversion coefficients $h_{pK}(d)$ to convert air kerma free-in-air to the phantom related operational quantities $H_p(0{,}07)$, $H_p(3)$, and $H_p(10)$ defined by ICRU in phantoms made of ICRU tissue. These recommended conversion coefficients pertain only to validated matched reference radiation qualities, see ISO 4037-1. The difference in material from ICRU tissue, used for the definition of the quantity, to the recommended ISO phantoms according to 7.3.1, used for the calibration of the dosemeters, shall be ignored. This is because the ISO phantoms are designed to provide the same backscatter as phantoms made of ICRU tissue. However, as they are not made of tissue equivalent material, the permeability/absorption is not the same as for phantoms made of ICRU tissue. Therefore, for personal dosemeters, any calibration procedure on the slab phantom for angles larger than 75° and on the other phantoms for angles larger than 90° makes no sense, as the radiation then penetrates the phantom. For these irradiation conditions, no conversion coefficients are given.

Initial "reference" data of the conversion coefficients for mono-energetic photons for a broad parallel beam and in the absence of scattered radiation are given in Tables 21, 27, 33, 39 and 46.

7.2 Quantities to be measured

The quantities to be measured for individual monitoring are the personal dose equivalents, $H_p(0{,}07)$, $H_p(3)$, and $H_p(10)$. The phantom definition depth shall be chosen in agreement with the properties of the dosemeter under test. Tables 21 to 52 contain recommended conversion coefficients converting the air kerma, K_a to the personal dose equivalent $H_p(d)$. Depending on the value of d the recommended conversion coefficients pertain to different phantoms, all made of ICRU tissue. For d = 0,07 mm conversion coefficients are provided for the rod, the pillar and the slab phantom. For d = 3 mm recommended conversion coefficients are provided for the cylinder phantom defined in Reference [13] as a cylinder of 20 cm length and 20 cm diameter, which is not (yet) included in the set of phantoms recommended by ICRU. The recommended conversion coefficients for a depth d = 10 mm are provided for the slab phantom. All recommended conversion coefficients pertain only to validated matched reference radiations as given in ISO 4037-1.

7.3 Experimental conditions

7.3.1 Use of phantoms

Measurements of the response as a function of radiation energy and direction of radiation incidence and calibrations of personal dosemeters shall be performed on a phantom suitable in view of the depth of measurement and of the type of dosemeter. For whole body dosemeters worn on the body, the ISO slab phantom shall be used. For eye dosemeters, the cylinder phantom[13] shall be used, which is not (yet) included in the set of phantoms recommended by ICRU. For dosemeters worn on the fingers, the ISO rod phantom shall be used. For those worn on the wrist or the ankle, the ISO pillar phantom shall be used.

The ISO slab phantom is a water filled hollow slab with PMMA walls (front wall 2,5 mm thick, other walls 10 mm thick) and of outer dimensions 30 cm × 30 cm × 15 cm. The ISO rod phantom is a PMMA cylinder of 19 mm diameter and a length of 300 mm. The ISO pillar phantom is a water filled hollow cylinder with PMMA walls and an outer diameter of 73 mm and a length of 300 mm. The cylinder walls have a thickness of 2,5 mm and the end faces of 10 mm. The cylinder phantom[13] is a water filled hollow cylinder with PMMA walls and an outer diameter of 200 mm and a length of 200 mm. The cylinder walls and the end faces have a thickness of 5 mm.

When using reference radiations with a mean energy equal to or above that of the radionuclide ^{137}Cs, also a solid PMMA slab of the same outer dimensions may be used.

When these phantoms are employed as described above, no correction factors shall be applied to the reading of the instrument under test due to possible differences in back-scatter factor or properties between these phantoms and those made of ICRU tissue.

NOTE In low energy radiation fields, where $H_p(0,07)$ could be relevant for the exposure of the trunk, care should be taken in the interpretation of the indicated values of dosemeters designed to measure $H_p(0,07)$ when worn on the trunk. Due to the absorption of radiation in the clothing the actual value of $H_p(0,07)$ may significantly differ from the value indicated.

7.3.2 Geometrical considerations in divergent beams

In case of a divergent beam, the beam axis is considered as the direction of the beam. The point of test shall be chosen at a distance from the source such that the field size in the plane of measurement is sufficiently large to allow the irradiation of the entire phantom front face. The quantity to be measured shall be determined by positioning the reference point of the standard instrument at the point of test. Then the reference point of the dosemeter under test shall be positioned at the point of test with its reference direction oriented parallel to the direction of the beam. Extremity dosemeters should be attached to the phantom in the way they are attached to the body during normal use. The slab phantom shall be positioned in such a way that its front surface is in contact with the rear side of the dosemeter and that its front surface is perpendicular to the beam axis. The irradiation of the device under test shall be made under conditions identical to those prevailing during the irradiation of the standard instrument, but now with the phantom present. For a test of the influence of the direction of radiation incidence, the assembly consisting of dosemeter and phantom shall be rotated around the point of test as illustrated in Figure 1.

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 as stated by the manufacturer. The value of the quantity to be measured pertains to the value of the dose equivalent in depth, d, inside the reference phantom in absence of the dosemeter in broad parallel fields.

NOTE 2 For an irradiation on the slab phantom, it may be practical to rotate the phantom only around 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

When several personal dosemeters are irradiated simultaneously on the front face of the slab phantom they shall not cover any phantom surface outside a circle with a diameter, d_F, given by the approximate locus of the 98 % isodose contour with respect to the dose in the centre of the phantom front face. The values of d_F depend on the radiation quality and they are given for every reference radiation in Tables 47 to 52. If smaller irradiation distances than those given in the following tables are used, the diameter, d_F becomes smaller. Different distances between the reference points of the dosemeters and the radiation source shall be taken account of according to 4.1.3.

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.

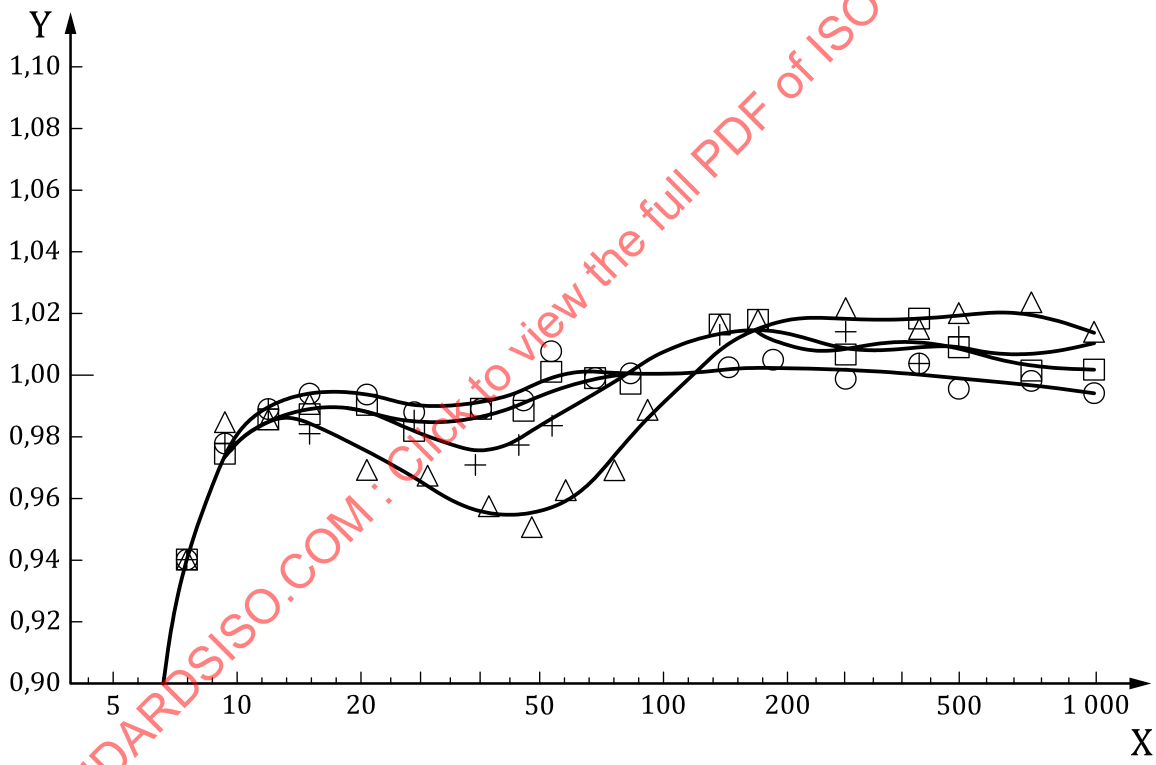
Two effects associated with this (simplified) procedure require additional attention: i) by positioning several dosemeters on the phantom surface the back-scatter may be reduced due to the attenuation of the primary radiation passing through the dosemeters and ii) possibly different distances of the reference points from the radiation source have to be considered. Such differences in distance should be taken account of. Before such a practice is adopted, it shall be verified that it leads to results identical to within 2 % of those obtained when only one dosemeter is irradiated in the centred position.

NOTE There may be certain types of dosemeters, which respond very sensitively to small changes in the properties of the back-scattered photon field. This may be due to the usage of strongly energy dependent detectors or possibly, by the properties of the algorithms used to arrive at the value of the dose equivalent from the detector signal. In such cases, it may be advisable to have only one dosemeter mounted on the phantom surface for any calibration.

7.3.4 Influence of the orientation on the values of $H_p(0,07)$

In a given radiation field the value of $H_p(0,07)$ depends on the direction of radiation incidence ↑. For the pillar and the rod phantom there are two, mutually perpendicular, axes of rotation, both of which intersect the reference point of the dosemeter. One is parallel to the cylinder axis while the other one is perpendicular to both the cylinder axis and to the direction of radiation incidence. Figure 2 shows, as a function of photon energy, that for an angle of rotation of 60° around either of the two axes, the value of $h_{pK}(0,07; E, \alpha)_{rod}$ and $h_{pK}0,07; E, \alpha)_{pill}$ remains between 0,95 and 1,05 of the value of normal incidence. The data for Figure 2 are taken from references [14] and [15]. For smaller angles of rotation, these variations are always smaller. Due to the small magnitude of the angular variation of the conventional quantity value of $H_p(0,07)$, it is assumed in this document that $H_p(0,07)$ for the pillar and the rod phantom is independent of the direction of radiation incidence for angles up to 60°. Rotations over larger angles than 60° are not considered in this document.

NOTE 1 The variation of ±5 % of the value of $h_{pK}(0,07; E, \alpha)$ over the range of α considered here is larger than the general figure on uncertainties of ±2 % proposed in 4.1.2. Nevertheless, these variations are disregarded in this document. This does not jeopardise the objective of this document of providing reliable and accurate calibration procedures, but rather reduces the size and number of the tables.



Key

X energy, keV

Y $H_p(0,07\,; E; 60°)\,/\,H_p(0,07; E; 0°)$

○ 19 mm rod direction 1

□ 19 mm rod direction 2

\+ 73 mm pillar direction 1

Δ 73 mm pillar direction 2

NOTE 2 Direction 1 represents a rotation around the cylinder axis and direction 2 around the axis perpendicular to the cylinder axis and to the direction of radiation incidence

Figure 2 — Variation of $H_p(0,07\,; E; 60°)/H_p(0,07; E; 0°)$ for the rod (19 mm) and the pillar phantom (73 mm) as a function of photon energy in the same radiation field

7.3.5 Length of the rod phantom

The nominal length of the rod phantom is 30 cm, but for the middle point of the phantom at half of its length, the amount of backscattered radiation is not changed if the total length is reduced to 10 cm, i.e., 5 cm phantom length to each side, see Brunzendorf[16]. Therefore, for irradiation of a single dosemeter in the middle of the phantom a length of 10 cm is sufficient.

8 Conversion coefficients for personal dosimetry

8.1 General

The recommended conversion coefficients refer to the rod, the pillar, the cylinder and the slab phantom, all made of ICRU tissue. The cylinder phantom is defined in Reference [13] as a cylinder of 20 cm length and 20 cm diameter. Calibrations of individual dosemeters shall be performed on the phantom described in 7.3 which suites the kind of instrument under test. These phantoms shall be considered as being made of ICRU tissue. No corrections shall be made for possible differences in backscatter properties of the actual phantom used and the equivalent phantom of ICRU tissue with identical shape.

In practice, calibrations are always performed in divergent beams. This is taken account of by referring the recommended conversion coefficients to a reference distance between radiation source and point of test. In case of a divergent beam the beam axis is considered as the direction of the beam. In cases where a reference distance is given together with an angle α of the direction of radiation incidence, α is the angle between the reference orientation of the dosemeter and the actual direction of the beam. All conversion coefficients are determined for unidirectional radiation incidence.

8.2 Conversion coefficients from air kerma, K_a, to $H_p(0,07)$ in the rod phantom

8.2.1 Mono-energetic radiations

See Table 21.

NOTE Data were taken for 3 keV extrapolated from Ankerhold[1], for energies between 4 keV and 1250 keV from Grosswendt[14] (bold) and interpolated values from Ankerhold[1].

8.2.2 Low air kerma rate series

See Table 22.

NOTE Data were taken from Ankerhold[1].

8.2.3 Narrow series

See Table 23.

NOTE Data were taken from Ankerhold[1] and, for N-350 and N-400, from Ankerhold[8].

8.2.4 Wide series

See Table 24.

NOTE Data were taken from Ankerhold[1].

8.2.5 High air kerma rate series

See Table 25.

NOTE Data were taken from Ankerhold[1] and, for H-350 and H-400, from Ankerhold[8].

8.2.6 Radionuclides

See Table 26.

NOTE Data were taken from DIN 6818-1:2004[10].

Table 21 — Conversion coefficient $h_{pK}(0,07;\,E)_{rod}$ from air kerma, K_a, to the dose equivalent $H_p(0,07)$ for mono-energetic and parallel photon radiation (expanded field) and the rod phantom at angle of radiation incidence of 0°

Energy keV	$h_{pK}(0,07;\,E)_{rod}$ Sv/Gy
3,0	0,306
4,0	**0,587**
5,0	**0,755**
6,0	**0,841**
7,0	0,891
8,0	**0,922**
9,0	0,940
10,0	**0,948**
11,0	0,956
12,0	0,959
12,5	**0,960**
13,0	0,964
14,0	0,971
15,0	**0,976**
16,0	0,987
17,0	0,993
17,5	**0,995**
18,0	0,999
19,0	1,00
20	**1,01**
25	**1,04**
30	**1,06**
35	**1,08**
40	**1,09**
45	**1,11**
50	**1,12**
55	**1,13**
60	**1,14**
70	**1,15**
80	**1,16**
90	**1,17**
100	**1,17**
125	**1,16**
150	**1,16**
200	**1,15**
300	**1,14**
400	**1,12**

Table 21 *(continued)*

Energy keV	$h_{pK}(0{,}07; E)_{rod}$ Sv/Gy
500	**1,12**
700	**1,11**
1 000	**1,11**
1 250	**1,11**

Table 22 — Recommended conversion coefficient $h_{pK}(0{,}07; \mathrm{L})_{rod}$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for the rod phantom at angle of radiation incidence from 0° up to 60°

Radiation quality	$h_{pK}(0{,}07; \mathrm{L})_{rod}$ **in Sv/Gy for the distance of**	
	1,0 m	**2,5 m**
L-10	0,936	0,939
L-20	0,992	
L-30	1,04	
L-35	1,06	
L-55	1,11	
L-70	1,14	
L-100	1,16	
L-125	1,17	
L-170	1,16	
L-210	1,15	
L-240	1,15	

Table 23 — Recommended conversion coefficient $h_{pK}(0{,}07; \mathrm{N})_{rod}$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for the rod phantom at angle of radiation incidence from 0° up to 60°

Radiation quality	$h_{pK}(0{,}07; \mathrm{N})_{rod}$ **in Sv/Gy for the distance of**	
	1,0 m	**2,5 m**
N-10	0,922	0,933
N-15	0,959	0,962
N-20	0,983	0,985
N-25	1,01	
N-30	1,03	
N-40	1,07	
N-60	1,11	
N-80	1,15	
N-100	1,16	
N-120	1,17	
N-150	1,16	
N-200	1,16	
N-250	1,15	
N-300	1,14	
N-350	1,14	
N-400	1,13	

Table 24 — Recommended conversion coefficient $h_{pK}(0{,}07; \mathrm{W})_{rod}$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for the rod phantom at angle of radiation incidence from 0° up to 60°

Radiation quality	$h_{pK}(0{,}07; \mathrm{W})_{rod}$ in Sv/Gy for the distance of	
	1,0 m	2,5 m
W-30	1,02	
W-40	1,05	
W-60	1,10	
W-80	1,13	
W-110	1,16	
W-150	1,16	
W-200	1,16	
W-250	1,15	
W-300	1,15	

Table 25 — Recommended conversion coefficient $h_{pK}(0{,}07; \mathrm{H})_{rod}$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for the rod phantom at angle of radiation incidence from 0° up to 60°

Radiation quality	$h_{pK}(0{,}07; \mathrm{H})_{rod}$ in Sv/Gy for the distance of	
	1,0 m	2,5 m
H-10	0,905	0,927
H-20	0,954	0,963
H-30	0,988	0,995
H-40	1,02	
H-60	1,07	
H-80	1,10	
H-100	1,12	
H-150	1,15	
H-200	1,16	
H-250	1,16	
H-280	1,16	
H-300	1,15	
H-350	1,15	
H-400	1,15	

Table 26 — Recommended conversion coefficient $h_{pK}(0{,}07; \mathrm{S})_{rod}$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for the rod phantom at angle of radiation incidence from 0° up to 60°

Radiation quality	PMMA build-up layer		Irradiation distance	$h_{pK}(0{,}07; \mathrm{S})_{rod}$
	d_{PMMA} mm	k_{PMMA}	m	Sv/Gy
S-Cs	3	1,00	1,0 – 3,0	1,13
S-Co	3	1,00	1,0 – 3,0	1,12

8.3 Conversion coefficients from air kerma, K_a, to $H_p(0,07)$ in the pillar phantom

8.3.1 Mono-energetic radiations

See Table 27.

NOTE Data were taken from Grosswendt[14] for a phantom of 7,3 cm diameter.

8.3.2 Low air kerma rate series

See Table 28.

NOTE Data were taken from Behrens[17].

8.3.3 Narrow series

See Table 29.

NOTE Data were taken Behrens[17].

8.3.4 Wide series

See Table 30.

NOTE Data were taken from Behrens[17].

8.3.5 High air kerma rate series

See Table 31.

NOTE Data were taken from Behrens[17].

8.3.6 Radionuclides

See Table 32.

NOTE Data were taken from Behrens[17].

Table 27 — Conversion coefficient $h_{pK}(0,07; E)_{pill}$ from air kerma, K_a, to the dose equivalent $H_p(0,07)$ for mono-energetic and parallel photon radiation (expanded field) and the pillar phantom at angle of radiation incidence of 0°

Energy keV	$h_{pK}(0,07; E)_{pill}$ Sv/Gy
4,0	**0,588**
5,0	**0,755**
6,0	**0,843**
8,0	**0,921**
10,0	**0,949**
12,5	**0,964**
15,0	**0,983**
20	**1,04**
25	1,10[a]
30	**1,18**

[a] By error given in Reference [14] as 0,098.

Table 27 *(continued)*

Energy keV	$h_{pK}(0{,}07; E)_{pill}$ Sv/Gy
35	**1,24**
40	**1,29**
45	**1,33**
50	**1,37**
55	**1,37**
60	**1,39**
70	**1,39**
80	**1,38**
90	**1,37**
100	**1,35**
125	**1,32**
150	**1,28**
200	**1,25**
300	**1,21**
400	**1,18**
500	**1,16**
700	**1,14**
1 000	**1,13**
1 250	**1,12**

[a] By error given in Reference [14] as 0,098.

Table 28 — Recommended conversion coefficient $h_{pK}(0{,}07; \mathrm{L})_{pill}$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for the pillar phantom at angle of radiation incidence from 0° up to 60°

Radiation quality	$h_{pK}(0{,}07; \mathrm{L})_{pill}$ **for the distance of 2,5 m** Sv/Gy
L-10	0,94
L-20	1,00
L-30	1,12
L-35	1,17
L-55	1,34
L-70	1,39
L-100	1,37
L-125	1,34
L-170	1,29
L-210	1,26
L-240	1,24

Table 29 — Recommended conversion coefficient $h_{pK}(0{,}07;\,\mathrm{N})_{\mathrm{pill}}$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for the pillar phantom at angle of radiation incidence from 0° up to 60°

Radiation quality	$h_{pK}(0{,}07;\,\mathrm{N})_{\mathrm{pill}}$ for the distance of 2,5 m Sv/Gy
N-10	0,93
N-15	0,96
N-20	0,99
N-25	1,03
N-30	1,09
N-40	1,20
N-60	1,33
N-80	1,39
N-100	1,37
N-120	1,35
N-150	1,32
N-200	1,27
N-250	1,24
N-300	1,22
N-350	1,21
N-400	1,20

Table 30 — Recommended conversion coefficient $h_{pK}(0{,}07;\,\mathrm{W})_{\mathrm{pill}}$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for the pillar phantom at angle of radiation incidence from 0° up to 60°

Radiation quality	$h_{pK}(0{,}07;\,\mathrm{W})_{\mathrm{pill}}$ for the distance of 2,5 m Sv/Gy
W-30	1,06
W-40	1,15
W-60	1,30
W-80	1,36
W-110	1,38
W-150	1,34
W-200	1,30
W-250	1,26
W-300	1,24

Table 31 — Recommended conversion coefficient $h_{pK}(0{,}07;\,\mathrm{H})_{\mathrm{pill}}$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for the pillar phantom at angle of radiation incidence from 0° up to 60°

Radiation quality	$h_{pK}(0{,}07;\,\mathrm{H})_{\mathrm{pill}}$ for the distance of 2,5 m Sv/Gy
H-10	0,93
H-20	0,97
H-30	1,01
H-40	1,07

Table 31 *(continued)*

Radiation quality	$h_{pK}(0{,}07;\mathrm{H})_{pill}$ for the distance of 2,5 m Sv/Gy
H-60	1,21
H-80	1,29
H-100	1,33
H-150	1,36
H-200	1,33
H-250	1,31
H-280	1,28
H-300	1,28
H-350	1,26
H-400	1,25

Table 32 — Recommended conversion coefficient $h_{pK}(0{,}07;\mathrm{S})_{pill}$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for the pillar phantom at angle of radiation incidence from 0° up to 60°

Radiation quality	PMMA build-up layer		Irradiation distance	$h_{pK}(0{,}07;\mathrm{S})_{pill}$
	d_{PMMA} mm	PMMA	m	Sv/Gy
S-Cs	3	1,00	2,5	1,14
S-Co	3	1,00	2,5	1,13

8.4 Conversion coefficients from air kerma, K_a, to $H_p(0{,}07)$ in the ICRU slab phantom

8.4.1 Mono-energetic radiations

See Table 33.

NOTE Data were taken for energies below 10 keV from Grosswendt[18] and, for energies including and above 10 keV from Till et al[19]. For energies above 1,5 MeV the bremsstrahlung correction according to 4.1.2 was applied. For the mono-energetic $(1 - g_a)$ values, see ISO 4037-2:2019, Table 2.

8.4.2 Low air kerma rate series

See Table 34.

NOTE Data were taken from Behrens[17].

8.4.3 Narrow series

See Table 35.

NOTE Data were taken from Behrens[17].

8.4.4 Wide series

See Table 36.

NOTE Data were taken from Behrens[17].

8.4.5 High air kerma rate series

See Table 37.

NOTE Data were taken from Behrens[17]].

8.4.6 Radionuclides

See Table 38.

NOTE Data were taken from Behrens[17].

Table 33 — Conversion coefficient $h_{pK}(0{,}07; E, \alpha)_{slab}$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for mono-energetic and parallel photon radiation (expanded field) and the ICRU slab phantom

Photon energy, E keV	$h_{pK}(0{,}07; E, \alpha)_{slab}$ in Sv/Gy for angle of incidence, α, of					
	0°	15°	30°	45°	60°	75°
3	0,320	0,309	0,268	0,192	0,096	0,010
4	0,587	0,578	0,542	0,467	0,345	0,130
5	0,755	0,749	0,723	0,675	0,578	0,347
6	0,842	0,838	0,829	0,790	0,722	0,544
8	0,920	0,918	0,905	0,897	0,858	0,765
10	0,970	0,974	0,976	0,972	0,967	0,972
20	1,05	1,05	1,03	1,04	1,01	0,985
30	1,22	1,22	1,20	1,16	1,11	1,05
40	1,44	1,43	1,40	1,33	1,23	1,16
50	1,62	1,60	1,55	1,48	1,35	1,25
60	1,71	1,68	1,64	1,56	1,43	1,32
70	1,71	1,70	1,66	1,58	1,46	1,40
80	1,73	1,71	1,67	1,61	1,49	1,39
100	1,66	1,65	1,63	1,58	1,48	1,40
150	1,53	1,52	1,51	1,49	1,44	1,39
200	1,43	1,43	1,44	1,43	1,40	1,36
300	1,34	1,34	1,35	1,36	1,36	1,35
500	1,25	1,25	1,27	1,29	1,30	1,31
1 000	1,17	1,18	1,19	1,21	1,25	1,25
3 000	1,12	1,13	1,13	1,15	1,18	1,18
6 000	1,09	1,09	1,09	1,10	1,13	1,16
10 000	1,08	1,08	1,07	1,08	1,09	1,10

Table 34 — Recommended conversion coefficient $h_{pK}(0{,}07; \mathrm{L}, \alpha)_{slab}$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for the ICRU slab phantom

Radiation quality	Diameter d_F cm	$h_{pK}(0{,}07; \mathrm{L}, \alpha)_{slab}$ in Sv/Gy for a distance of 2,5 m and the angle of incidence, α, of					
		0°	15°	30°	45°	60°	75°
L-10	25	0,92	0,92	0,91	0,90	0,87	0,79
L-20	25	1,00	1,00	1,00	0,99	0,99	0,95
L-30	18	1,16	1,15	1,15	1,13	1,11	1,06

Table 34 *(continued)*

Radiation quality	Diameter d_F	$h_{pK}(0,07; L, \alpha)_{slab}$ in Sv/Gy for a distance of 2,5 m and the angle of incidence, α, of					
	cm	0°	15°	30°	45°	60°	75°
L-35	16	1,23	1,22	1,22	1,20	1,16	1,10
L-55	11	1,58	1,57	1,55	1,51	1,44	1,32
L-70	11	1,71	1,70	1,68	1,64	1,56	1,43
L-100	11	1,71	1,70	1,69	1,66	1,60	1,48
L-125	11	1,63	1,62	1,62	1,60	1,56	1,47
L-170	12	1,52	1,52	1,53	1,51	1,48	1,44
L-210	12	1,45	1,46	1,46	1,46	1,44	1,41
L-240	13	1,42	1,42	1,42	1,42	1,42	1,40

Table 35 — Recommended conversion coefficient $h_{pK}(0,07; N, \alpha)_{slab}$ from air kerma, K_a, to the dose equivalent $H_p(0,07)$ for the ICRU slab phantom

Radiation quality	Diameter d_F	$h_{pK}(0,07; N, \alpha)_{slab}$ in Sv/Gy for a distance of 2,5 m and the angle of incidence, α, of					
	cm	0°	15°	30°	45°	60°	75°
N-10	25	0,91	0,91	0,90	0,88	0,85	0,76
N-15	25	0,97	0,97	0,97	0,96	0,95	0,91
N-20	25	0,99	0,99	0,98	0,98	0,94	0,94
N-25	23	1,04	1,04	1,03	1,02	0,99	0,99
N-30	20	1,11	1,11	1,09	1,08	1,04	1,04
N-40	16	1,28	1,27	1,25	1,21	1,14	1,14
N-60	11	1,56	1,55	1,50	1,43	1,31	1,31
N-80	11	1,72	1,71	1,66	1,58	1,45	1,45
N-100	11	1,72	1,71	1,66	1,60	1,48	1,48
N-120	11	1,66	1,65	1,62	1,57	1,48	1,48
N-150	11	1,60	1,59	1,57	1,54	1,47	1,47
N-200	12	1,49	1,49	1,48	1,46	1,43	1,43
N-250	13	1,42	1,42	1,43	1,42	1,40	1,40
N-300	15	1,38	1,38	1,39	1,39	1,38	1,38
N-350	—[a]	1,34	1,35	1,36	1,37	1,36	1,36
N-400	—[a]	1,32	1,32	1,33	1,35	1,34	1,34

[a] No data available.

Table 36 — Recommended conversion coefficient $h_{pK}(0,07; W, \alpha)_{slab}$ from air kerma, K_a, to the dose equivalent $H_p(0,07)$ for the ICRU slab phantom

Radiation quality	Diameter d_F	$h_{pK}(0,07; W, \alpha)_{slab}$ in Sv/Gy for a distance of 2,5 m and the angle of incidence, α, of					
	cm	0°	15°	30°	45°	60°	75°
W-30	—[a]	1,08	1,07	1,07	1,06	1,05	1,01
W-40	—[a]	1,20	1,19	1,19	1,17	0,14	1,09
W-60	11	1,49	1,48	1,47	1,43	1,37	1,27
W-80	11	1,64	1,63	1,61	1,57	1,50	1,38
W-110	11	1,71	1,70	1,69	1,65	1,59	1,47

[a] No data available.

Table 36 *(continued)*

Radiation quality	Diameter d_F	$h_{pK}(0,07; W, \alpha)_{slab}$ in Sv/Gy for a distance of 2,5 m and the angle of incidence, α, of					
	cm	0°	15°	30°	45°	60°	75°
W-150	11	1,64	1,63	1,62	1,60	1,55	1,47
W-200	12	1,54	1,54	1,54	1,53	1,50	1,45
W-250	13	1,47	1,47	1,47	1,47	1,45	1,42
W-300	14	1,42	1,42	1,42	1,43	1,42	1,40

[a] No data available.

Table 37 — Recommended conversion coefficient $h_{pK}(0,07; H, \alpha)_{slab}$ from air kerma, K_a, to the dose equivalent $H_p(0,07)$ for the ICRU slab phantom

Radiation quality	Diameter d_F	$h_{pK}(0,07; H, \alpha)_{slab}$ in Sv/Gy for a distance of 2,5 m and the angle of incidence, α, of					
	cm	0°	15°	30°	45°	60°	75°
H-10	25	0,90	0,89	0,89	0,87	0,83	0,73
H-20	25	0,96	0,96	0,96	0,95	0,94	0,89
H-30	20	1,02	1,02	1,02	1,01	1,00	0,96
H-40	—[a]	1,10	1,09	1,09	1,08	1,07	1,02
H-60	12	1,32	1,31	1,30	1,28	1,23	1,16
H-80	—[a]	1,49	1,48	1,47	1,44	1,38	1,27
H-100	12	1,58	1,57	1,56	1,52	1,46	1,35
H-150	—[a]	1,67	1,66	1,65	1,61	1,55	1,44
H-200	12	1,62	1,62	1,61	1,59	1,54	1,45
H-250	14	1,56	1,56	1,56	1,54	1,51	1,44
H-280	14	1,51	1,51	1,51	1,50	1,48	1,43
H-300	15	1,51	1,51	1,51	1,50	1,48	1,43
H-350	—[a]	1,47	1,47	1,47	1,46	1,45	1,41
H-400	—[a]	1,43	1,43	1,44	1,43	1,43	1,40

[a] No data available.

Table 38 — Recommended conversion coefficient $h_{pK}(0,07; S, \alpha)_{slab}$ from air kerma, K_a, to the dose equivalent $H_p(0,07)$ for the ICRU slab phantom

Radiation quality	PMMA build-up layer		Diameter	$h_{pK}(0,07; S, \alpha)_{slab}$ in Sv/Gy for a distance of 2,5 m and the angle of incidence, α, of					
	d_{PMMA}	k_{PMMA}	d_F						
	mm		cm	0°	15°	30°	45°	60°	75°
S-Cs	3	1,00	—[a]	1,21	1,22	1,22	1,23	1,26	1,28
S-Co	3	1,00	—[a]	1,17	1,17	1,17	1,18	1,21	1,23

[a] No data available.

8.5 Conversion coefficients from air kerma, K_a, to $H_p(3)$ in the cylinder phantom

8.5.1 Mono-energetic radiations

See Table 39.

NOTE Data were taken for energies below 10 keV from Behrens[20] using exponential attenuation law and, for energies including and above 10 keV, from Table 2.2 of Vanhavere et al[21]. For energies above 1,5 MeV no bremsstrahlung correction according to 4.1.2 was necessary, as the data of Behrens[20] and Vanhavere et al.[21] include this correction.

8.5.2 Low air kerma rate series

See Table 40.

NOTE Data were taken from Behrens[20].

8.5.3 Narrow series

See Table 41.

NOTE Data were taken from Behrens[20].

8.5.4 Wide series

See Table 42.

NOTE Data were taken from Behrens[20].

8.5.5 High air kerma rate series

See Table 43.

NOTE Data were taken from Behrens[20].

8.5.6 Radionuclides

See Table 44.

NOTE Data were taken from Behrens[20].

8.5.7 High energy photon radiations

See Table 45.

NOTE Data were taken from Behrens[20]. No bremsstrahlung correction according to 4.1.2 was necessary, as the data of Behrens[20] include this correction.

Table 39 — Conversion coefficient $h_{pK}(3; E, \alpha)_{cyl}$ from air kerma, K_a, to the dose equivalent $H_p(3)$ for mono-energetic and parallel photon radiation (expanded field) and the cylinder phantom consisting of ICRU tissue

Photon energy, E	$h_{pK}(3; E, \alpha)_{cyl}$ in Sv/Gy for angle of incidence, α, of						
keV	0°	15°	30°	45°	60°	75°	90°
5	$8{,}45 \cdot 10^{-6}$	—	—	—	—	—	—
6	0,001 21	0,000 9	0,000 443	—	—	—	—
8	0,061 4	0,055 7	0,040 4	0,020 4	0,004 75	0,000 116	—

Table 39 *(continued)*

Photon energy, E keV	$h_{pK}(3; E, \alpha)_{cyl}$ in Sv/Gy for angle of incidence, α, of						
	0°	15°	30°	45°	60°	75°	90°
10	0,244	0,232	0,197	0,139	0,066 9	0,010 7	0,000 244
20	0,919	0,912	0,891	0,845	0,755	0,562	0,202
30	1,22	1,21	1,20	1,17	1,10	0,945	0,588
40	1,45	1,44	1,42	1,39	1,32	1,18	0,846
50	1,60	1,59	1,57	1,54	1,47	1,33	1,01
60	1,67	1,66	1,64	1,61	1,54	1,41	1,11
70	1,67	1,67	1,65	1,62	1,57	1,44	1,15
80	1,65	1,65	1,63	1,61	1,56	1,45	1,17
90	1,61	1,61	1,60	1,58	1,54	1,44	1,18
100	1,58	1,58	1,57	1,55	1,51	1,42	1,17
110	1,55	1,55	1,54	1,53	1,49	1,41	1,17
150	1,45	1,45	1,44	1,44	1,42	1,36	1,15
200	1,37	1,37	1,37	1,37	1,36	1,32	1,14
300	1,29	1,29	1,29	1,29	1,29	1,27	1,13
400	1,24	1,24	1,24	1,25	1,25	1,24	1,12
500	1,21	1,21	1,21	1,22	1,23	1,21	1,11
600	1,19	1,19	1,20	1,20	1,21	1,20	1,11
700	1,18	1,18	1,18	1,19	1,19	1,19	1,11
800	1,17	1,17	1,17	1,18	1,18	1,18	1,10
900	1,16	1,16	1,16	1,17	1,17	1,17	1,10
1 000	1,15	1,15	1,15	1,16	1,16	1,16	1,10
1 100	1,14	1,14	1,15	1,15	1,16	1,16	1,10
1 500	1,13	1,13	1,13	1,14	1,14	1,14	1,09
2 000	1,12	1,12	1,12	1,13	1,13	1,13	1,09
3 000	1,11	1,11	1,11	1,11	1,12	1,11	1,08
4 000	1,10	1,10	1,10	1,10	1,10	1,10	1,08
5 000	1,10	1,10	1,10	1,10	1,10	1,09	1,07
6 000	1,09	1,09	1,09	1,09	1,09	1,08	1,06
7 000	1,09	1,08	1,08	1,09	1,08	1,08	1,06
8 000	1,08	1,08	1,08	1,08	1,07	1,07	1,05
10 000	1,07	1,07	1,07	1,07	1,07	1,06	1,04

Table 40 — Recommended conversion coefficient $h_{pK}(3; \mathrm{L}, \alpha)_{cyl}$ from air kerma, K_a, to the dose equivalent $H_p(3)$ for the cylinder phantom consisting of ICRU tissue

Radiation quality	$h_{pK}(3; \mathrm{L}, \alpha)_{cyl}$ in Sv/Gy for a distance of 2,5 m and the angle of incidence, α, of						
	0°	15°	30°	45°	60°	75°	90°
L-10	0,158	0,148	0,121	0,078	0,032	0,003 7	0,000 050
L-20	0,74	0,73	0,71	0,66	0,57	0,40	0,124
L-30	1,12	1,11	1,09	1,06	0,98	0,82	0,46
L-35	1,22	1,21	1,19	1,16	1,09	0,93	0,58
L-55	1,55	1,55	1,53	1,49	1,43	1,29	0,96

Table 40 *(continued)*

Radiation quality	$h_{pK}(3; \text{L}, \alpha)_{cyl}$ in Sv/Gy for a distance of 2,5 m and the angle of incidence, α, of						
	0°	15°	30°	45°	60°	75°	90°
L-70	1,65	1,65	1,63	1,60	1,53	1,40	1,10
L-100	1,62	1,62	1,61	1,59	1,54	1,44	1,17
L-125	1,55	1,55	1,54	1,53	1,49	1,41	1,17
L-170	1,45	1,45	1,45	1,44	1,42	1,36	1,15
L-210	1,39	1,39	1,39	1,39	1,38	1,33	1,14
L-240	1,36	1,36	1,36	1,36	1,35	1,31	1,14

Table 41 — Recommended conversion coefficient $h_{pK}(3; \text{N}, \alpha)_{cyl}$ from air kerma, K_a, to the dose equivalent $H_p(3)$ for the cylinder phantom consisting of ICRU tissue

Radiation quality	$h_{pK}(3; \text{N}, \alpha)_{cyl}$ in Sv/Gy for a distance of 2,5 m and the angle of incidence, α, of						
	0°	15°	30°	45°	60°	75°	90°
N-10	0,129	0,121	0,097	0,061	0,023 7	0,002 45	0,000 024 1
N-15	0,42	0,41	0,38	0,32	0,244	0,147	0,036
N-20	0,67	0,66	0,63	0,58	0,50	0,35	0,102
N-25	0,88	0,87	0,85	0,80	0,72	0,54	0,212
N-30	1,04	1,03	1,01	0,97	0,89	0,72	0,37
N-40	1,28	1,27	1,25	1,22	1,15	1,00	0,65
N-60	1,54	1,53	1,51	1,48	1,41	1,27	0,95
N-80	1,66	1,65	1,64	1,60	1,54	1,42	1,12
N-100	1,63	1,63	1,62	1,59	1,54	1,44	1,17
N-120	1,58	1,58	1,57	1,55	1,51	1,42	1,17
N-150	1,52	1,52	1,51	1,50	1,47	1,40	1,16
N-200	1,42	1,42	1,42	1,42	1,40	1,34	1,15
N-250	1,36	1,36	1,36	1,36	1,36	1,31	1,14
N-300	1,32	1,33	1,33	1,33	1,32	1,29	1,13
N-350	1,29	1,30	1,30	1,30	1,30	1,27	1,13
N-400	1,27	1,27	1,27	1,28	1,28	1,26	1,12

Table 42 — Recommended conversion coefficient $h_{pK}(3; \text{W}, \alpha)_{cyl}$ from air kerma, K_a, to the dose equivalent $H_p(3)$ for the cylinder phantom consisting of ICRU tissue

Radiation quality	$h_{pK}(3; \text{W}, \alpha)_{cyl}$ in Sv/Gy for a distance of 2,5 m and the angle of incidence, α, of						
	0°	15°	30°	45°	60°	75°	90°
W-30	0,96	0,95	0,93	0,89	0,81	0,63	0,292
W-40	1,16	1,15	1,14	1,10	1,02	0,86	0,51
W-60	1,48	1,47	1,45	1,42	1,35	1,21	0,88
W-80	1,60	1,59	1,57	1,54	1,47	1,34	1,03
W-110	1,63	1,63	1,62	1,59	1,54	1,43	1,15
W-150	1,55	1,55	1,54	1,53	1,49	1,41	1,16
W-200	1,47	1,47	1,47	1,46	1,43	1,37	1,15
W-250	1,41	1,41	1,41	1,40	1,39	1,34	1,14
W-300	1,36	1,36	1,36	1,36	1,36	1,31	1,14

Table 43 — Recommended conversion coefficient $h_{pK}(3; \mathrm{H}, \alpha)_{cyl}$ from air kerma, K_a, to the dose equivalent $H_p(3)$ for the cylinder phantom consisting of ICRU tissue

Radiation quality	$h_{pK}(3; \mathrm{H}, \alpha)_{cyl}$ in Sv/Gy for a distance of 2,5 m and the angle of incidence, α, of						
	0°	15°	30°	45°	60°	75°	90°
H-10	0,110	0,102	0,081	0,050	0,018 8	0,001 86	0,000 019 2
H-20	0,43	0,42	0,39	0,34	0,268	0,170	0,046
H-30	0,74	0,73	0,71	0,66	0,58	0,43	0,166
H-40	0,96	0,96	0,93	0,89	0,81	0,64	0,32
H-60	1,29	1,28	1,26	1,23	1,16	1,00	0,66
H-80	1,46	1,46	1,44	1,41	1,34	1,20	0,87
H-100	1,54	1,54	1,52	1,49	1,42	1,29	0,98
H-150	1,60	1,59	1,58	1,56	1,51	1,40	1,12
H-200	1,55	1,55	1,54	1,52	1,48	1,39	1,15
H-250	1,49	1,49	1,49	1,47	1,45	1,37	1,15
H-280	1,45	1,45	1,44	1,44	1,42	1,35	1,15
H-300	1,45	1,45	1,44	1,44	1,41	1,35	1,15
H-350	1,41	1,41	1,40	1,40	1,39	1,33	1,14
H-400	1,38	1,38	1,37	1,37	1,36	1,32	1,14

Table 44 — Recommended conversion coefficient $h_{pK}(3; \mathrm{S}, \alpha)_{cyl}$ from air kerma, K_a, to the dose equivalent $H_p(3)$ for the cylinder phantom consisting of ICRU tissue

Radiation quality	PMMA build-up layer		$h_{pK}(3; \mathrm{S}, \alpha)_{cyl}$ in Sv/Gy for a distance of 2,5 m and the angle of incidence, α, of						
	d_{PMMA} mm	k_{PMMA}	0°	15°	30°	45°	60°	75°	90°
S-Cs	3	1,00	1,18	1,19	1,19	1,20	1,20	1,19	1,11
S-Co	3	1,00	1,14	1,14	1,14	1,15	1,16	1,15	1,10

Table 45 — Recommended conversion coefficient $h_{pK}(3; \mathrm{R}, \alpha)_{cyl}$ from air kerma, K_a, to the dose equivalent $H_p(3)$ for the cylinder phantom consisting of ICRU tissue

Radiation quality	PMMA build-up layer		$h_{pK}(3; \mathrm{R}, \alpha)_{cyl}$ in Sv/Gy for a distance of 2,5 m and the angle of incidence, α, of						
	d_{PMMA} mm	k_{PMMA}	0°	15°	30°	45°	60°	75°	90°
R-C	25	0,95	1,10	1,10	1,10	1,10	1,10	1,10	1,07
R-F	25	0,95	1,09	1,09	1,09	1,09	1,09	1,09	1,06

8.6 Conversion coefficients from air kerma, K_a, to $H_p(10)$ in the ICRU slab phantom

8.6.1 Mono-energetic radiations

See Table 46.

NOTE Data were taken from ICRU 57[7] (bold) and interpolated values from Ankerhold[1]. For energies above 1,5 MeV the bremsstrahlung correction according to 4.1.2 was applied. For the monoenergetic $(1–g_a)$ values, see ISO 4037-2:2019, Table 2.

8.6.2 Low air kerma rate series

See Table 47.

NOTE Data were taken from Ankerhold[1].

8.6.3 Narrow series

See Table 48.

NOTE Data were taken from Ankerhold[1] and, for N-350 and N-400, from Ankerhold[8].

8.6.4 Wide series

See Table 49.

NOTE Data were taken from Ankerhold[1].

8.6.5 High air kerma rate series

See Table 50.

NOTE Data were taken from Ankerhold[1] and, for H-350 and H-400, from Ankerhold[8].

8.6.6 Radionuclides

See Table 51.

NOTE Data were taken from DIN 6818-1:2004[10].

8.6.7 High energy photon radiations

See Table 52.

NOTE Data were taken from Behrens et al[12]. The bremsstrahlung correction according to 4.1.2 was applied.

Table 46 — Conversion coefficient $h_{pK}(10; E, \alpha)_{slab}$ from air kerma, K_a, to the dose equivalent $H_p(10)$ for mono-energetic and parallel photon radiation (expanded field) and the ICRU slab phantom

Photon energy E keV	$h_{pK}(10; E, \alpha)_{slab}$ in Sv/Gy for angle of incidence, α, of					
	0°	**15°**	**30°**	**45°**	**60°**	**75°**
7	$1{,}3\cdot 10^{-6}$	$<1\cdot 10^{-6}$	$<1\cdot 10^{-6}$	$<1\cdot 10^{-6}$	$<1\cdot 10^{-6}$	$<1\cdot 10^{-6}$
8	$1{,}07\cdot 10^{-4}$	$8{,}13\cdot 10^{-5}$	$2{,}99\cdot 10^{-5}$	$0{,}38\cdot 10^{-5}$	$<1\cdot 10^{-6}$	$<1\cdot 10^{-6}$
9	0,001 63	0,001 36	$6{,}94\cdot 10^{-4}$	$1{,}78\cdot 10^{-4}$	$0{,}38\cdot 10^{-5}$	$<1\cdot 10^{-6}$
10	**0,009**	**0,008**	**0,005**	**0,002**	0,000 12	$<1\cdot 10^{-6}$
11	0,030 7	0,028 1	0,019 5	0,009 23	0,001 16	$<1\cdot 10^{-5}$
12	0,071 6	0,066 3	0,049 1	0,025 8	0,005 52	0,000 066
12,5	**0,098**	**0,091**	**0,069**	**0,038**	**0,010**	0,000 21
13	0,130	0,122	0,094 8	0,005 53	0,016 9	0,000 55
14	0,198	0,189	0,154	0,099 7	0,038 3	0,002 55
15	**0,264**	**0,255**	**0,217**	**0,152**	**0,069**	**0,008**
16	0,339	0,329	0,288	0,215	0,111	0,017 6
17	0,411	0,399	0,358	0,280	0,159	0,032 0
17,5	**0,445**	**0,432**	**0,391**	**0,312**	**0,185**	**0,041**

Table 46 *(continued)*

Photon energy E keV	$h_{pK}(10; E, \alpha)_{slab}$ **in Sv/Gy for angle of incidence,** α**, of**					
	0°	**15°**	**30°**	**45°**	**60°**	**75°**
18	0,481	0,468	0,427	0,345	0,212	0,051 1
19	0,549	0,536	0,495	0,408	0,265	0,074 6
20	**0,611**	**0,600**	**0,558**	**0,466**	**0,318**	**0,102**
25	**0,883**	**0,865**	**0,827**	**0,735**	**0,574**	**0,282**
30	**1,11**	**1,09**	**1,06**	**0,965**	**0,796**	**0,457**
40	**1,49**	**1,45**	**1,43**	**1,33**	**1,13**	**0,736**
50	**1,77**	**1,74**	**1,70**	**1,57**	**1,38**	**0,929**
60	**1,89**	**1,87**	**1,83**	**1,72**	**1,50**	**1,06**
80	**1,90**	**1,86**	**1,85**	**1,75**	**1,54**	**1,13**
100	**1,81**	**1,80**	**1,76**	**1,68**	**1,51**	**1,11**
125	**1,70**	**1,69**	**1,66**	**1,59**	**1,45**	**1,10**
150	**1,61**	**1,60**	**1,58**	**1,52**	**1,40**	**1,09**
200	**1,49**	**1,49**	**1,48**	**1,43**	**1,34**	**1,08**
300	**1,37**	**1,37**	**1,36**	**1,35**	**1,27**	**1,06**
400	**1,30**	**1,31**	**1,30**	**1,29**	**1,24**	**1,06**
500	**1,26**	**1,26**	**1,26**	**1,26**	**1,22**	**1,06**
600	**1,23**	**1,23**	**1,23**	**1,23**	**1,20**	**1,06**
800	**1,19**	**1,19**	**1,19**	**1,20**	**1,17**	**1,06**
1 000	**1,17**	**1,17**	**1,16**	**1,18**	**1,16**	**1,06**
1 500	**1,14**	**1,14**	**1,14**	**1,15**	**1,14**	**1,06**
3 000	**1,11**	**1,11**	**1,12**	**1,11**	**1,11**	**1,06**
6 000	**1,09**	**1,09**	**1,09**	**1,08**	**1,08**	**1,08**
10 000	**1,07**	**1,07**	**1,06**	**1,06**	**1,06**	**1,03**

Table 47 — Recommended conversion coefficient $h_{pK}(10; \text{L}, \alpha)_{slab}$ from air kerma, K_a, to the dose equivalent $H_p(10)$ for the ICRU slab phantom

Radiation quality	Diameter d_F cm	$h_{pK}(10; \text{L}, \alpha)_{slab}$ in Sv/Gy for the angle of incidence, α, and distance of 0° 1,0 m	0° 2,5 m	15° 1,0 m	15° 2,5 m	30° 1,0 m	30° 2,5 m	45° 1,0 m	45° 2,5 m	60° 1,0 m	60° 2,5 m	75° 1,0 m	75° 2,5 m
L-10	—[a,b]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]
L-20	25	0,405	0,407	0,394	0,396	0,354	0,356	0,279	0,281	0,164	0,167	0,038 2	0,039 0
L-30	18	0,944		0,926	0,227	0,888	0,889	0,769	0,797	0,633	0,634	0,328	0,328
L-35	16	1,11		1,09		1,05		0,958	0,959	0,788	0,789	0,451	0,452
L-55	11	1,69		1,67		1,63		1,51		1,31		0,877	0,878
L-70	11	1,88		1,85		1,82		1,70		1,49		1,05	
L-100	11	1,87		1,86		1,81		1,72		1,53		1,13	
L-125	11	1,76		1,75		1,72		1,64		1,49		1,10	
L-170	12	1,61		1,60		1,58		1,52		1,40		1,09	
L-210	12	1,52		1,52		1,50		1,45		1,36		1,08	
L-240	13	1,47		1,47		1,46		1,42		1,33		1,08	

a A matched field is not possible for this irradiation condition, see ISO 4037-1:2019, 4.2.4.

b No data available.

Table 48 — Recommended conversion coefficient $h_{pK}(10; \mathrm{N}, \alpha)_{slab}$ from air kerma, K_a, to the dose equivalent $H_p(10)$ for the ICRU slab phantom

Radiation quality	Diameter d_F	$h_{pK}(10; \mathrm{N}, \alpha)_{slab}$ in Sv/Gy for the angle of incidence, α, and distance of											
		0°		15°		30°		45°		60°		75°	
	cm	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m
N-10	—[ab]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]
N-15	—[ab]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]
N-20	25	0,316	0,333	0,306	0,323	0,270	0,286	0,206	0,219	0,114	0,123	0,023 7	0,026 1
N-25	23	0,574	0,583	0,562	0,571	0,521	0,531	0,436	0,444	0,298	0,305	0,103	0,107
N-30	20	0,815	0,819	0,800	0,804	0,761	0,765	0,668	0,673	0,512	0,516	0,239	0,243
N-40	16	1,21		1,19		1,15		1,06		0,880	0,883	0,527	0,530
N-60	11	1,66		1,64		1,60		1,49		1,29		0,861	0,862
N-80	11	1,89		1,87		1,83		1,72		1,51		1,07	
N-100	11	1,88		1,87		1,82		1,73		1,53		1,12	
N-120	11	1,80		1,79		1,75		1,67		1,51		1,11	
N-150	11	1,72		1,71		1,68		1,61		1,46		1,10	
N-200	12	1,56		1,56		1,54		1,49		1,38		1,08	
N-250	13	1,48		1,47		1,46		1,42		1,33		1,08	
N-300	15	1,42		1,42		1,41		1,38		1,30		1,07	
N-350	—[b]	1,38		1,38		1,37		1,35		1,28		1,06	
N-400	—[b]	1,35		1,35		1,34		1,33		1,26		1,06	

[a] A matched field is not possible for this irradiation condition, see ISO 4037-1:2019, 4.2.4.

[b] No data available.

Table 49 — Recommended conversion coefficient $h_{pK}(10; \text{W}, \alpha)_{slab}$ from air kerma, K_a, to the dose equivalent $H_p(10)$ for the ICRU slab phantom

Radiation quality	Diameter d_F cm	$h_{pK}(10; \text{W}, \alpha)_{slab}$ in Sv/Gy for the angle of incidence, α, and distance of											
		0°		15°		30°		45°		60°		75°	
		1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m
W-30	—[a]	0,693	0,704	0,679	0,690	0,640	0,650	0,551	0,562	0,404	0,414	0,172	0,178
W-40	—[a]	1,01	1,02	0,990	0,999	0,951	0,960	0,860	0,868	0,693	0,701	0,380	0,386
W-60	11	1,55	1,55	1,53	1,53	1,49	1,49	1,38	1,38	1,19	1,19	0,778	0,780
W-80	11	1,77	1,77	1,75	1,75	1,71	1,71	1,60	1,60	1,39	1,39	0,960	0,960
W-110	11	1,87	1,87	1,86	1,86	1,82	1,82	1,72	1,72	1,52	1,52	1,10	1,10
W-150	11	1,77	1,76	1,76	1,76	1,72	1,72	1,64	1,64	1,48	1,48	1,10	1,10
W-200	12	1,64	1,64	1,63	1,63	1,61	1,61	1,55	1,55	1,42	1,42	1,09	1,09
W-250	13	1,54	1,54	1,54	1,54	1,52	1,52	1,47	1,47	1,37	1,37	1,08	1,08
W-300	14	1,48	1,48	1,47	1,47	1,46	1,46	1,42	1,42	1,33	1,33	1,08	1,08

[a] No data available.

Table 50 — Recommended conversion coefficient $h_{pK}(10; \mathrm{H}, \alpha)_{slab}$ from air kerma, K_a, to the dose equivalent $H_p(10)$ for the ICRU slab phantom

Radiation quality	Diameter d_F cm	$h_{pK}(10; \mathrm{H}, \alpha)_{slab}$ in Sv/Gy for the angle of incidence, α, and distance of											
		0°		15°		30°		45°		60°		75°	
		1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m	1,0 m	2,5 m
H-10	—[a][b]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]
H-20	—[a][b]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]
H-30	—[a][b]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]	—[a]
H-40	—[b]	0,692	0,724	0,678	0,710	0,640	0,672	0,556	0,586	0,417	0,443	0,196	0,211
H-60	12	1,22	1,24	1,20	1,22	1,16	1,18	1,06	1,08	0,887	0,902	0,539	0,549
H-80	—[b]	1,52	1,54	1,50	1,52	1,46	1,48	1,36	1,37	1,16	1,18	0,768	0,777
H-100	12	1,67	1,68	1,65	1,66	1,61	1,62	1,51	1,52	1,31	1,32	0,896	0,902
H-150	—[b]	1,81		1,79		1,76		1,66		1,47		1,06	
H-200	12	1,75		1,74		1,71		1,62		1,46		1,09	
H-250	14	1,67		1,66		1,64	1,63	1,57		1,43		1,09	
H-280	14	1,60		1,60		1,58		1,52		1,40		1,09	
H-300	15	1,60		1,59	1,60	1,58		1,52		1,40		1,09	
H-350	—[b]	1,54		1,54		1,52		1,47		1,37		1,08	
H-400	—[b]	1,50		1,49		1,48		1,44		1,34		1,08	

[a] A matched field is not possible for this irradiation condition, see ISO 4037-1:2019, 4.2.4.

[b] No data available.

Table 51 — Recommended conversion coefficient $h_{pK}(10; \mathrm{S}, \alpha)_{slab}$ from air kerma, K_a, to the dose equivalent $H_p(10)$ for the ICRU slab phantom

Radiation quality	PMMA build-up layer		Diameter	Irradiation distance	$h_{pK}(10; \mathrm{S}, \alpha)_{slab}$ in Sv/Gy for the angle of incidence, α, of					
	d_{PMMA}	k_{PMMA}	d_F							
	mm		cm	m	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**
S-Cs	3	1,00	15	1,0 – 4,0	1,21	1,22	1,22	1,22	1,19	1,06
S-Co	3	1,00	15	1,0 – 4,0	1,15	1,15	1,15	1,16	1,14	1,10

Table 52 — Recommended conversion coefficient $h_{pK}(10; \mathrm{R}, \alpha)_{slab}$ from air kerma, K_a, to the dose equivalent $H_p(10)$ for the ICRU slab phantom

Radiation quality	PMMA build-up layer		Diameter	Irradiation distance	$h_{pK}(10; \mathrm{R}, \alpha)_{slab}$ in Sv/Gy for the angle of incidence, α, of					
	d_{PMMA}	k_{PMMA}	d_F							
	mm		cm	m	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**
R-C	25	0,95	15	0,3 – 5,0	1,11	1,11	1,11	1,10	1,10	1,10
R-F	25	0,95	15	0,3 – 5,0	1,10	1,10	1,09	1,09	1,10	1,09

9 Uncertainties

9.1 Statement of uncertainties

ISO/IEC Guide 98-3 shall be used for the determination of uncertainties and the statement of uncertainty shall be consistent with the approaches recommended in ISO 29661.

The following component uncertainties shall be taken into account. The listed numerical values refer to a confidence level of 95 % (two standard deviations, $k = 2$) and serve only as a guideline. For further information, see also ISO 4037-2.

a) Uncertainty of the conventional quantity value; as taken from the calibration certificate of the standard instrument or provided for the reference field.

b) Uncertainty in the exact positioning of standard and test instrument (see 4.1.3); to be assessed by the test laboratory.

c) Uncertainty resulting from different irradiation distances; 2 % for irradiation distances greater than 2 m, otherwise to be assessed by the test laboratory.

d) Uncertainty of the conversion coefficient; usually 4 % for matched reference fields, for characterized reference fields the test laboratory shall assess the uncertainty on the basis of the conditions prevailing.

e) Uncertainty due to field inhomogeneity over the cross-sectional area of the beam in the plane of measurement owing to beam divergence and, in the case of X radiation, to the 'heel effect'; 4 % for matched reference fields and for distances between source and point of test greater than 2 m, for characterized reference fields the test laboratory shall assess the uncertainty on the basis of the conditions prevailing.

f) Uncertainty due to the simultaneous irradiation of several dosemeters (see 6.3.3); an estimate on the effect of absorption of the primary radiation by the dosemeters shall be made and added to the component uncertainties, where applicable, upper limit 4 %.

g) Uncertainties due to simplified procedures (see 6.3.1); where applicable, to be assessed by the test laboratory, upper limit 4 %.

h) Uncertainty introduced by using a build-up plate; where applicable 2 %.

i) Uncertainty due to long-term variation of response of standard instrument, upper limit 4 % (see 4.2.1)

Annex A
(informative)

Estimated conversion coefficients for fluorescence X radiation

A.1 Principle

The calibration of dosemeters and doserate meters by means of fluorescence radiation makes use of the K fluorescence lines of certain materials having energies between 8,6 keV and 100 keV and which are given, as a first approximation, by that of their $K_{\alpha 1}$ line (see ISO 4037-1:2019, Figure A.1). The contribution of the K_{β} lines is made negligible with the aid of secondary filters whose K-absorption edges lie between the K_{α} and K_{β} lines (see ISO 4037-1:2019, Table A.1).

A.2 General

For the reference fluorescence radiation fields sufficient information on the fluence spectra and on the requirements for all relevant parameters of the matched or characterized reference fields is not available to achieve the targeted overall uncertainty of about 6 % to 10 % for the phantom related operational quantities. There is a paper of Behrens et al.[22] on fluorescence radiation fields, which shows some deficiencies of the fields specified by ISO 4037-1:2019, Table A.1, but there is no practical experience with these modified fields. Therefore, the conversion coefficients are provided here as estimated values. For any reference fluorescence radiation field, the conversion coefficients and the achieved overall uncertainty need individual determination.

A.3 Estimated conversion coefficients for area dosimetry

A.3.1 Estimated conversion coefficients from air kerma, K_a, to $H'(0{,}07)$

See Table A.1.

A.3.2 Estimated conversion coefficient from air kerma, K_a, to $H^*(10)$

See Table A.2.