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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

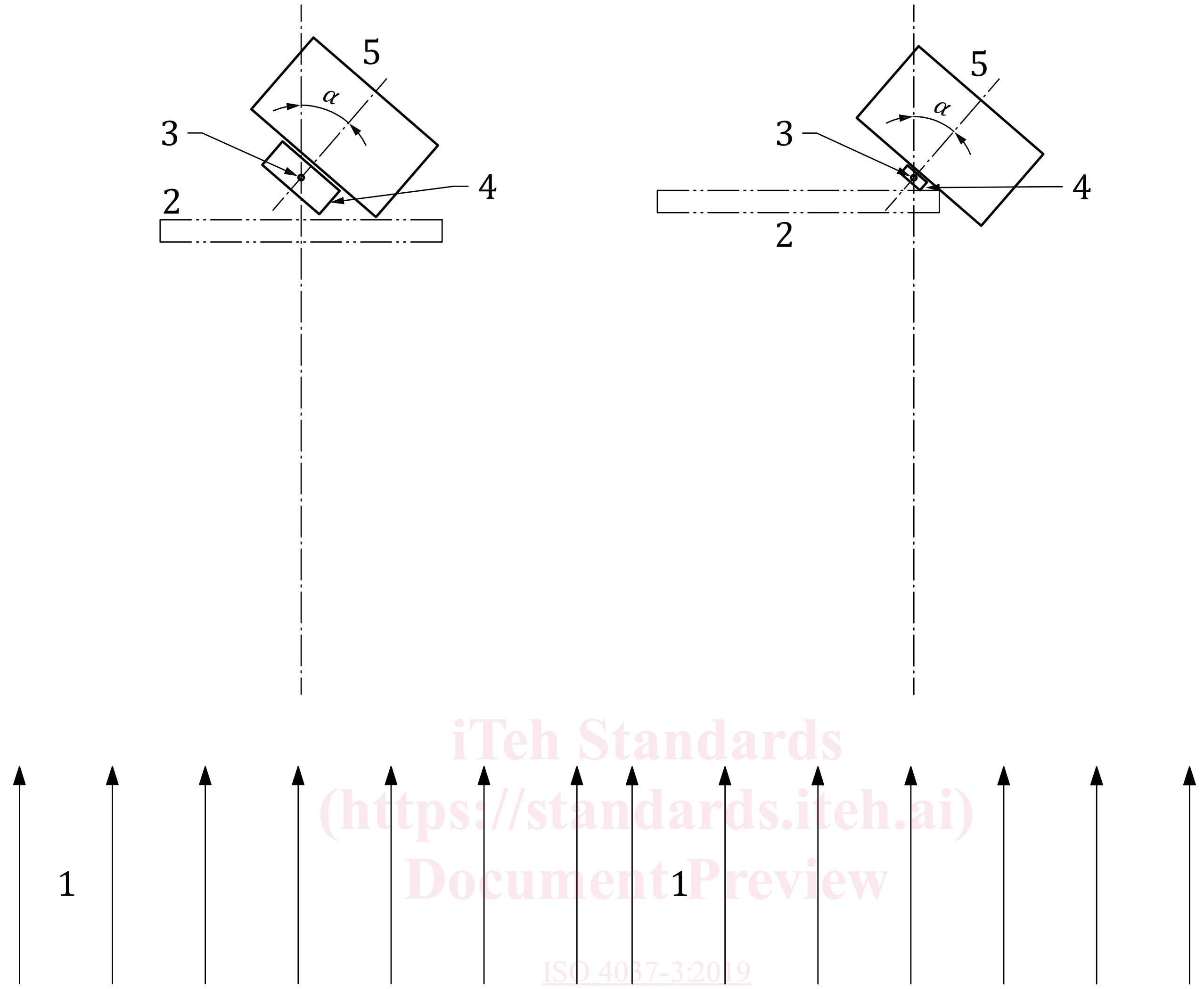
Electrons with energies above 65 keV, 0,75 MeV and 2,1 MeV can just penetrate 0,07 mm, 3 mm and 10 mm of ICRU tissue, respectively, see ICRU Report 56[5]. In photon reference radiation fields capable of producing secondary electrons of these or higher energies, the quantity value and the indication of 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