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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

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 (ou d'ambiance) et individuels et mesurage de leur réponse en fonction de l'énergie et de l'angle d'incidence

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Contents

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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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 4037-3 was prepared by Technical Committee ISO/TC 85 *Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

ISO 4037 consists of the following parts, under the general title *X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy* :

— *Part 1: Radiation characteristics and production methods*

— *Part 2: Dosimetry for radiation protection over the energy ranges 8 keV to 1,3 MeV and 4 MeV to 9 MeV*

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

Introduction

This part of ISO 4037 is closely related to two other International Standards. The first, ISO 4037-1, describes the methods of production and characterization of the photon reference radiations. The second, ISO 4037-2, describes the dosimetry of the reference radiations.

This part of ISO 4037 is the third part of the series, and it describes procedures for calibrating and determining the response of dosemeters and doserate meters in terms of the International Commission on Radiation Units and Measurements (ICRU) operational quantities [1,2,3,4] for radiation protection purposes [5]. The rationale for using the operational quantities is based on the fact that the effective dose as defined in ICRP 60 [6] cannot be measured directly. The operational quantities provide a reasonable and conservative approximation to the effective dose for most photon radiations.

The determination of the response of dosemeters and doserate meters is essentially a three-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. Finally the device under test is placed at the same point 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 part of ISO 4037 describes the methods and the conversion coefficients to be used for the determination of the response of dosemeters and doserate meters in terms of the ICRU operational quantities for photons.

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 part of ISO 4037 specifies the calibration of dosemeters and doserate meters used for individual and for area monitoring in photon reference radiation fields with mean energies between 8 keV and 9 MeV (see ISO 4037-1). For individual monitoring, both whole body and extremity dosemeters are covered and for area monitoring both portable and installed dosemeters are covered. This part of ISO 4037 also deals with the determination of the response as a function of photon energy and angle of radiation incidence. Such measurements may represent part of a type test in the course of which the effect of further influence quantities on the response is examined.

This part of ISO 4037 does not cover the *in-situ* calibration of fixed installed area dosemeters which will be covered in a future standard.

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. In addition, this International Standard gives guidance on the statement of uncertainties and on the preparation of calibration records and certificates.

NOTE 1 The term dosemeter is used as a generic term denoting any dose or doserate meter for individual or area monitoring.

NOTE 2 Throughout this part of ISO 4037, unless otherwise stated, the term kerma is used to denote air kerma free in air.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 4037. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 4037 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 4037-1:1996, *X and gamma reference radiation 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 4037-2:1997, *X and gamma reference radiation 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 8 keV to 1,3 MeV and 4 MeV to 9 MeV.*

ISO Guide to the Expression of Uncertainty in Measurement, 1993.

3 Definitions

For the purposes of this part of ISO 4037, the following definitions apply.

3.1 Quantities and units

3.1.1
dose equivalent
H
product of Q and D at a point in tissue, where D is the absorbed dose at that point and Q the quality factor (ICRU 51 [7]):

$$H = QD \tag{1}$$

NOTE 1 The unit of the dose equivalent is joules per kilogram ($J \cdot kg^{-1}$) with the special name sievert (Sv).

NOTE 2 For the purpose of this part of ISO 4037, for photon and electron radiation, the quality factor has the value unity.

3.1.2
operational quantities

3.1.2.1
ambient dose equivalent
$H^*(10)$
dose equivalent that, at a point in a radiation field, would be produced by the corresponding expanded and aligned field, in the ICRU sphere, at a depth of 10 mm on the radius opposing the direction of the aligned field

NOTE 1 The unit of the ambient dose equivalent is joules per kilogram ($J \cdot kg^{-1}$) with the special name sievert (Sv).

NOTE 2 In the expanded and aligned field, the fluence and its energy distribution have the same value throughout the volume of interest as at the point of test; the field is unidirectional.

3.1.2.2
directional dose equivalent
$H'(0{,}07;\Omega)$
dose equivalent that, at a point in a radiation field, would be produced by the corresponding expanded field in the ICRU sphere at a depth of 0,07 mm on a radius in a specified direction Ω

NOTE 1 The unit of the directional dose equivalent is joules per kilogram ($J \cdot kg^{-1}$) with the special name sievert (Sv).

NOTE 2 In a unidirectional field, the direction can be specified in terms of the angle, α, between the radius opposing the incident field and a specified radius. When $\alpha = 0$, the quantity $H'(0{,}07;0)$ may be written as $H'(0{,}07)$.

NOTE 3 In the expanded field, the fluence and its angular and energy distributions have the same value over the volume of interest as in the actual field at the point of measurement.

3.1.2.3
personal dose equivalent
$H_p(d)$
dose equivalent in soft tissue as defined in ICRU 51 [7] below a specified point on the body at an appropriate depth d

NOTE 1 The unit of the personal dose equivalent is joules per kilogram ($J \cdot kg^{-1}$) with the special name sievert (Sv).

NOTE 2 Any statement of personal dose equivalent should include a specification of the depth, d, expressed in millimetres.

For weakly penetrating radiation, a depth of 0,07 mm for the skin is employed. The personal dose equivalent for this depth is then denoted by $H_p(0{,}07)$. For strongly penetrating radiation, a depth of 10 mm is frequently employed with analogous notation.

NOTE 3 In Report 47 [4], the ICRU has considered the definition of the personal dose equivalent to include the dose equivalent at a depth d in a phantom having the composition of the ICRU tissue. Then $H_p(d)$, for the calibration of personal dosemeters, is the dose equivalent at a depth d in a phantom composed of ICRU tissue (see 6.2), but of the size and shape of the phantom used for the calibration (see 6.3.1).

3.2 Calibration factor and response determination

3.2.1
influence quantity
influence parameter
quantity which may have a bearing on the result of a measurement without being the subject of the measurement

EXAMPLE The reading of a dosemeter with an unsealed ionization chamber is influenced by the temperature and pressure of the surrounding atmosphere. Although needed for determining the value of the dose, the measurement of these two quantities is not the primary objective.

3.2.2
reference conditions
reference conditions represent the set of influence quantities for which the calibration factor is valid without any correction
(See also note to 3.2.3.)

NOTE The value for the quantity to be measured may be chosen freely in agreement with the properties of the instrument to be calibrated. The quantity to be measured is not an influence quantity (3.2.1).

3.2.3
standard test conditions
standard test conditions represent the range of values of a set of influence quantities under which a calibration or a determination of response is carried out

NOTE Ideally, calibrations should be carried out under reference conditions. As this is not always achievable (e.g. for ambient air pressure) or convenient (e.g. for ambient temperature), a (small) interval around the reference values may be used. The deviations of the calibration factor from its value under reference conditions caused by these deviations should in principle be corrected for. In practice, the uncertainty aimed at serves as a criterion as to which influence quantity has to be taken into account by an explicit correction or whether its effect may be incorporated into the uncertainty. During type tests, all values of influence quantities which are not the subject of the test are fixed within the interval of the standard test conditions. The standard test conditions together with the reference conditions applicable to this part of ISO 4037 are given in Tables A.1 and A.2 of annex A.

3.2.4
calibration conditions
conditions within the range of standard test conditions actually prevailing during the calibration

3.2.5
reference point
⟨dosemeter⟩ point which is placed at the point of test for calibrating or testing purposes

NOTE The distance of measurement refers to the distance between the radiation source and the reference point of the dosemeter.

3.2.6
point of test
point in the radiation field at which the reference point of a dosemeter is placed for calibrating or testing purposes and at which the conventional true value (see 3.2.9) of the quantity to be measured is known

3.2.7
reference direction
direction, in the coordinate system of a dosemeter, with respect to which the angle to the direction of radiation incidence is measured in unidirectional fields

3.2.8
reference orientation
⟨dosemeter⟩ orientation for which the direction of incident radiation coincides with the reference direction of the dosemeter

3.2.9
conventional true value of a quantity
best estimate of the value of the quantity to be measured, determined by a primary or secondary standard or by a reference instrument that has been calibrated against a primary or secondary standard

NOTE A conventional true value is, in general, regarded as being sufficiently close to the true value for the difference to be insignificant for the given purpose.

EXAMPLE Within an organization, the result of a measurement obtained with a secondary standard instrument may be taken as the conventional true value of the quantity to be measured.

3.2.10
response
R
⟨dosemeter⟩ quotient of its reading *M* and the conventional true value of the measured quantity; the type of response should be specified

EXAMPLE The response with respect to ambient dose equivalent $H^*(10)$:

$$R = M / H^*(10) \quad (2)$$

NOTE 1 The value of the response may vary with the magnitude of the quantity to be measured. In such cases, a dosemeter is said to be non-linear.

NOTE 2 The response usually varies with the energy and directional distribution of the incident radiation. It is, therefore, useful to consider the response as a function $R(E,\Omega)$ of the energy E of the incident mono-energetic radiation and of the direction Ω of the incident monodirectional radiation. $R(E)$ describes the “energy dependence” and $R(\Omega)$ the “angular dependence” of response; for the latter Ω may be expressed by the angle α between the reference direction of the device and the direction of an external monodirectional field.

NOTE 3 Some evaluation algorithms of multi-element detectors may not be additive, if the dosemeter is irradiated by a combination of radiations of various energies and angles of incidence. For example, if there are two such contributions to the dose equivalent, H_1 and H_2, the sum of the two corresponding readings may differ from the reading caused by a single irradiation with $H_1 + H_2$, i.e. $M_{H1} + M_{H2} \neq M_{H1+H2}$. In such cases, the function $R(E,\Omega)$ dealt with in the previous note is not sufficient to characterize the dosemeter in all radiation fields.

3.2.11
calibration
quantitative determination, under a controlled set of standard test conditions, of the reading given by a dosemeter as a function of the value of the quantity to be measured

(See also note 2 to 3.2.12.)

NOTE Normally, the calibration conditions are the full set of standard test conditions (A.1). A routine calibration can be performed, under simplified conditions, either to check the calibration carried out by the manufacturer or to check whether the calibration factor is sufficiently stable during a continued long-term use of the dosemeter. In general, the methods of a routine calibration will be worked out on the basis of the results of a type test. One of the objectives of a type test may be to establish the procedures for a routine calibration in a way that the result of a routine calibration approximates that of a calibration under standard test conditions as closely as possible (see also 6.3.1). A routine calibration is often used to provide batch or individual calibration factors.

3.2.12
calibration factor
N
conventional true value of the quantity the dosemeter is intended to measure, *H*, divided by the dosemeter’s reading, *M*, (corrected if necessary)

EXAMPLE The calibration factor with respect to personal dose equivalent is given by

$$N = H_p / M \quad (3)$$

NOTE 1 The calibration factor *N* is dimensionless when the instrument indicates the quantity to be measured. A dosemeter indicating the conventional true value correctly has a calibration factor of unity.

NOTE 2 The reciprocal of the calibration factor is equal to the response under reference conditions. In contrast to the calibration factor, which refers to the reference conditions only, the response refers to any conditions prevailing at the time of measurement.

NOTE 3 The value of the calibration factor may vary with the magnitude of the quantity to be measured. In such cases, a dosemeter is said to have a non-linear response.

3.2.13
normalization
procedure in which the calibration factor is multiplied by a factor in order to achieve, over a certain range of influence quantities, a better estimate of the quantity to be measured

NOTE A normalization may be practical when a dosemeter will be used mostly under conditions differing from the reference conditions. In this case, the normalization takes account of differences in response under reference conditions and under conditions of normal operation.

3.2.14
kerma-to-dose-equivalent conversion coefficient
h_K
quotient of the dose equivalent, H, and the air kerma, K_a, at a point in the radiation field:

$$h_K = H / K_a \tag{4}$$

NOTE 1 The conversion coefficients of clauses 5 and 6 averaged over spectral distributions are based on the mono-energetic data of ICRP 74 [17].

NOTE 2 Any statement of a kerma-to-dose-equivalent conversion coefficient requires the statement of the type of dose equivalent, e.g. ambient, directional or personal dose equivalent. The conversion coefficient h_K depends on the energy and, for $H_p(10;\alpha)$ and $H'(0,07;\alpha)$, also directional distribution of the incident radiation. It is, therefore, useful to consider the conversion coefficient as a function $h_K(E)$ of the energy E of mono-energetic photons at several angles of incidence. This set of basic data is frequently called the conversion function.

3.2.15
back-scatter factor
ratio of air kerma in front of a phantom to the air kerma at the same position free in air

NOTE 1 The field is considered to be unidirectional with a direction of incidence perpendicular to the phantom surface.

NOTE 2 The value of the back-scatter factor depends on the point of test (distance from the surface and from the beam axis), on the beam diameter, on the phantom size, on the material and on the 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 will be useful to select an appropriate radiation quality taking into account the specified energy and dose or dose rate range of the dosemeter to be tested. For reasons of brevity, short names are introduced in this part of ISO 4037 for the radiation qualities of ISO 4037- 1.

For X-radiation, the letters F, L, N, W or H denote the radiation quality, i.e. the fluorescence, the low air kerma rate, the narrow, the wide, the high air kerma rate series, respectively followed by the chemical symbol of the radiator for the fluorescence radiation and the generating potential for filtered X-radiation.

Reference radiations produced by radioactive sources are denoted by the letter S combined with the chemical symbol of the radionuclide ; reference radiations produced by nuclear reactions are denoted by the letter R followed by the chemical symbol of the element of the target responsible for the emission of the radiation.

Table 1 contains all radiation qualities covered in this part of ISO 4037 together with their mean energies $\bar{E}$ averaged over the fluence spectrum. The dosimetry in these radiation fields shall be conducted in accordance with ISO 4037-2.

Table 1 — Radiation qualities covered in this part of ISO 4037

Radiation quality	**Energy** keV	**Radiation quality**	$\bar{E}$ keV	**Radiation quality**	$\bar{E}$ keV	**Radiation quality**	$\bar{E}$ keV	**Radiation quality**	$\bar{E}$ keV
F-Zn	8,6	L-10	8,5	N-10	8	W-60	45	H-10	7,5
F-Ge	9,9	L-20	17	N-15	12	W-80	57	H-20	12,9
F-Zr	15,8	L-30	26	N-20	16	W-110	79	H-30	19,7
F-Mo	17,5	L-35	30	N-25	20	W-150	104	H-60	37,3
F-Cd	23,2	L-55	48	N-30	24	W-200	137	H-100	57,4
F-Sn	25,3	L-70	60	N-40	33	W-250	173	H-200	102
F-Cs	31,0	L-100	87	N-60	48	W-300	208	H-250	122
F-Nd	37,4	L-125	109	N-80	65			H-280	146
F-Sm	40,1	L-170	149	N-100	83			H-300	147
F-Er	49,1	L-210	185	N-120	100				
F-W	59,3	L-240	211	N-150	118				
F-Au	68,8			N-200	164				
F-Pb	75,0			N-250	208				
F-U	98,4			N-300	250				

Radionuclides		
radiation quality	radio-nuclide	$\bar{E}$ keV
S-Am	^{241}Am	59,5
S-Cs	^{137}Cs	662
S-Co	^{60}Co	1 250

High energy photon radiations		
radiation quality	reaction	$\bar{E}$ MeV
R-C	^{12}C (p,p'γ) ^{12}C	4,36[a]
R-F	^{19}F (p,αγ) ^{16}O	6,61[a]
R-Ti	(n,γ) capture in Ti	5,14[a]
R-Ni	(n,γ) capture in Ni	6,26[a]
R-O	^{16}O (n,p) ^{16}N	6,61[a]

a Average taken over the spectral fluence.

4.1.2 Conversion coefficients

For the Tables in clauses 5 and 6 and in annex A.2, the irradiation distance is measured from the focal spot of the X-ray tube (or from the geometrical centre of the radionuclide source) to the point of test, at which the reference point of the dosemeter shall be located. For the fluorescence X-radiation, and the R-C, R-F or the R-O radiations, the irradiation distance shall be measured from the centre of the radiator or target surface from which the radiation emerges to the point of test. If a range is given for the distance, the values of the conversion coefficients may be used without modification over this range of distances.

In clauses 5 and 6 and in annex A.2, a notation will be used for the presentation of 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 photon radiation of energy E, with an angle α between the reference direction of the dosemeter and the direction of radiation incidence. In other examples, the prime could be replaced by an asterisk for ambient dose equivalent or by the letter p for personal dose equivalent. For radiation qualities of finite spectral width, the symbol E is replaced by the letter according to Table 1 denoting a particular series of reference radiation, i.e. F, L, N, W, H, S or R.

Numerical values of conversion coefficients for mono-energetic radiation [16] given in the Tables 2, 8, 15, 21, 27 and A.3 shall be treated as having no uncertainty. Unless otherwise stated, the conversion coefficients in the remaining tables of clauses 5 and 6 shall be considered as being associated with a standard uncertainty of ± 2 %. This uncertainty takes account of differences between the spectrum used for the calculation of the conversion coefficients [8] and that prevailing at the point of test.

For tube voltages below about 30 kV, and especially for the high air kerma rate series, the numerical values of the conversion coefficients $h_K^*(10;E)$ and $h_{pK}(10;E,\alpha)$ actually applicable to a given experimental set-up may differ by substantially more than 2 % from the nominal value given in the Tables of clauses 5 and 6. Combinations of radiation qualities and conversion coefficients which are sensitive to small variations in energy distribution are marked in the corresponding tables with an exclamation mark. In this case, the 2 % uncertainty may not be sufficient and a proper estimate of the uncertainty or a more reliable value of the conversion coefficient may be required. If a radiation quality listed in Table 1 is not contained in one of the tables for the conversion coefficients $h_K^*(10;E)$ and $h_{pK}(10;E,\alpha)$, 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 majority contribution to the air kerma originates from the low energy part of the spectrum, while the majority contribution to $H^*(10)$ and $H_p(10)$ originates from the high energy part of the spectrum [9]. Differences in energy distribution from one experimental arrangement to another can occur due to a great number 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. For fluorescence radiations, it may be necessary to carry out an optimization in view of bringing the contribution from scattered radiation down to an acceptable level. This may be achieved by using a thinner radiator and/or by lowering the tube voltage.

4.1.3 Standard test conditions

Calibrations and the determination of response (see also 4.1.4) shall be conducted under standard test conditions. The range of values of influence quantities within the standard test conditions are given in Tables A.1 and A.2 for radiation-related and other parameters, respectively.

4.1.4 Variation of influence quantities

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

NOTE There may be cases in which it is important that an influence quantity is varied in a way that the response of the instrument under test is constant. For example, if the energy dependence of a dosemeter with a counter tube is to be examined in a dose rate range where there is a substantial dead time, it may be desirable that the measurements with the various radiation qualities be carried out at constant indication and not at constant dose rate. The same holds true for thermoluminescence dosemeters exhibiting a so-called supra-linearity. However, it should be added that it is usually advisable to carry out the examination of an instrument under conditions in which the response to dose or to dose rate is essentially linear.

4.1.5 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. The reference point should be marked on the outside of a dosemeter. If this proves impossible, the reference point should be indicated in the accompanying documents supplied with the instrument. All 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 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 l. A misplacement of the dosemeter's reference point in the beam by the amount of Δl in the direction of the beam will lead to a relative error in the calibration factor of $2\Delta l/l$ at the distance l. Misalignment perpendicular to the beam axis by $\Delta\lambda$ causes a relative error of $(\Delta\lambda/l)^2$. In the presence of scattered radiation and for sources of finite dimensions, the above approximations are limited to values of Δl or $\Delta\lambda$ that are small in comparison to l.

4.1.6 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 A.1.

4.1.7 Condition of the dosemeter to be calibrated

Before any calibration is made, the dosemeter shall be examined to confirm that it is in 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.

4.1.8 Effects associated with electron ranges

Electrons with energies above 65 keV and 2 MeV can penetrate 0,07 mm and 10 mm of ICRU tissue, respectively. In photon reference radiation fields capable of producing electrons of such energies, or higher effects associated with electron ranges need to be considered. For a more detailed discussion of this subject, see A.3. The procedure to be followed in such cases is described as follows.

For the quantities $H'(0,07)$ and $H_p(0,07)$ and for the energies covered in Tables 2 to 7, 15 to 26 and A.3 to A.8, 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 [10]. For a determination of response at higher energies, a calibration under equilibrium conditions in photon fields becomes progressively more meaningless. Instead, a calibration in suitable electron reference radiation fields [19] should be conducted. For further explanations, see A.3.

In the case of photon fields with energies from that of S-Cs to 9 MeV and for the quantities $H^*(10)$ and H_p (10), first the conventional true value of the air kerma shall be determined at the point of test as described in ISO 4037-2. 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 should be positioned in front of the dosemeter (for area dosemeters) or in front of the combination of dosemeter and phantom (for personal dosemeters). 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 Tables 14 and 33. The cross-sectional area of the plate shall be 30 cm × 30 cm and the thickness of the plate shall be as given in Tables 14 and 33.

NOTE For irradiations on a phantom and for some area dosemeters, it may be practical to position the PMMA plate a certain distance away from the dosemeter or dosemeter phantom combination so that it is not necessary to also rotate the plate when the variation of response with the direction of radiation incidence is examined (see Figure A.1).

4.2 Methods for the determination of the calibration factor and 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 and the instrument instruction manual, e.g. set zero control, warm-up time, battery check, 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 three 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 ± 2 % 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, a decision shall be made as to whether a monitor has to be used (see 4.2.3.1 and 4.2.3.2) or not (see 4.2.2.1 and 4.2.2.2). This decision shall be based on the stability of the output of the radiation source.

There may be two types of standard instruments: ones which measure a more basic dosimetric quantity like, for example, air kerma and others which **directly** measure the quantity in which the calibration is to be performed. For the first kind of instruments, the suitable conversion coefficient h shall be used in the formulas of subclauses 4.2.2 to 4.2.5 while h is equal to unity for the second kind of instruments.

4.2.2 Measurements without a monitor for the source output

In general, a monitor is not needed in reference radiation fields produced by radioactive sources. For X-radiation reference fields, the use of a monitor is usually recommended.

4.2.2.1 Calibration

This procedure may be adopted, if the air kerma rate in the radiation field is stable over a time span corresponding to the duration of the calibration to the extent necessary to achieve results of the desired accuracy. The calibration factor, N_B, of a dosemeter whose detector is **subsequently positioned** at the point of test for the same time as the detector of the standard instrument shall be obtained by

$$N_B = \frac{hN_A M_A}{M_B} \quad (5)$$

h kerma-to-dose-equivalent conversion coefficient;

N_A calibration factor of the standard instrument;

N_B calibration factor of the dosemeter under calibration;

M_A measured value of the standard instrument, i.e. reading multiplied by the correction factor for differences in air density, where applicable;

M_B measured value of the dosemeter under calibration, i.e. reading multiplied by the correction factor for differences in air density, where applicable.

4.2.2.2 Determination of the response as a function of energy and angle of incidence

Under conditions not necessarily identical to the reference conditions, the response of a dosemeter is determined by

$$R(E,\alpha) = \frac{M_B(E,\alpha)}{h(E,\alpha) N_A M_A k_E k_\alpha} \quad (6)$$

where the symbols are defined as in 4.2.2.1 and k_E and k_α are the correction factors to be applied to the reading of the standard instrument to take into account the differences in radiation quality and direction of radiation incidence between the reference conditions and those prevailing at the time of measurement.

Often, the response of the dosemeter is given as its relative response, *r*, with respect to its response under reference conditions.

$$r = \frac{R}{R_r} \quad (7)$$

where

R_r is the response under reference conditions.

NOTE The relative response can be a useful quantity for describing the variation of response as a function of photon energy or angle of incidence (see also 3.2.10).

4.2.3 Measurements with a monitor for the source output

4.2.3.1 Calibration

Moderate variations in the air kerma rate with time can be corrected for by using a monitor and by irradiating the standard instrument and dosemeter **sequentially**. This technique is often employed with X-ray units in order to correct for variations in air kerma rate when the standard and dosemeter are placed alternately at the point of test. The measured values M_A and M_B for the standard instrument and the dosemeter whose detectors are located one after the other at the point of test shall be related to the values for the monitor. The calibration factor N_B shall be obtained by

$$N_B = h N_A \left(\frac{M_A}{m_A}\right)\left(\frac{m_B}{M_B}\right) \quad (8)$$

where

m_A is the measured value of the monitor for the irradiation of the standard instrument;

m_B is the measured value of the monitor for the irradiation of the dosemeter to be calibrated.

h and N_A are defined as in 4.2.2.1.

NOTE 1 In practice, if the irradiations of the standard instrument and the dosemeter to be calibrated are performed shortly one after another, the ambient conditions of the monitor remain the same and corrections of the indicated value of the monitor to reference conditions are unnecessary.

NOTE 2 In cases where the monitor has a good long-term stability (see also 4037-2:1997, subclause 8.2) it may serve as the reference instrument after having been calibrated by the standard instrument.

4.2.3.2 Determination of the response as a function of energy and angle of incidence (see 4.2.2.2)

Under conditions not necessarily identical to the reference conditions, the response of a dosemeter is determined by

$$R(E,\alpha) = \frac{m_A M_B(E,\alpha)}{h(E,\alpha) N_A m_B M_A k_E k_\alpha} \qquad (9)$$

The relative response is obtained using equation (7).

4.2.4 Measurements by simultaneous irradiation of standard instrument and dosemeter

4.2.4.1 Calibration

In some circumstances (see note below) calibrations may also be performed by **simultaneous** irradiation of the standard instrument and the dosemeter under test in a field by locating them symmetrically to the axis of the radiation field at the same distance from the source. The distance between the two detectors shall be sufficiently large so that the reading of either instrument is not influenced by the presence of the other to an extent exceeding 2 %.

To eliminate the influence of asymmetry of the radiation field, the measurements shall be repeated after exchanging the positions of the two instruments and the geometrical mean of the readings shall be determined. The calibration factor N_B shall be obtained by

$$N_B = h N_A \sqrt{\left(\frac{M_A}{M_B}\right)_1 \left(\frac{M_A}{M_B}\right)_2} \qquad (10)$$

where the symbols are as defined in 4.2.2.1 and the indices 1 and 2 refer to the two irradiations.

NOTE Primarily, this procedure will be applicable to those cases in which no phantom is required, i.e. for area dosemeters. This technique is used particularly in reference radiations produced by accelerators or when using uncollimated sources (see ISO 4037-1).

4.2.4.2 Determination of the response as a function of energy and angle of incidence

Under conditions not necessarily identical to the reference conditions, the response of a dosemeter is determined by

$$R(E,\alpha) = \frac{1}{h(E,\alpha) N_A k_E k_\alpha} \sqrt{\left(\frac{M_B(E,\alpha)}{M_A}\right)_1 \left(\frac{M_B(E,\alpha)}{M_A}\right)_2} \qquad (11)$$

where the symbols are as defined in 4.2.2.1 and 4.2.2.2 and the indices 1 and 2 refer to the two irradiations.

The relative response is obtained by using equation (7).

4.2.5 Determination of the calibration factor and the response in a known gamma radiation field

For a gamma radiation field in which the air kerma rate at the point of test is known, the calibration factor of a dosemeter under calibration, N_B, is obtained by

$$N_B = \frac{h K_a}{M_B} \qquad (12)$$

K_a is the air kerma;

M_B measured value (under reference conditions) of the dosemeter under calibration;

h is as defined in 4.2.2.1.

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 in free air (without a phantom). Measurements of the response may be necessary in the photon energy range 8 keV to 9 MeV, and, depending on the equipment for the irradiation, at various irradiation distances. Subclauses 5.3.1 and 5.3.2 contain, for the ISO reference radiations, conversion coefficients *h* to convert air kerma to the operational quantities $H^*(10)$ and $H'(0{,}07)$ defined in clause 3. Conversion coefficients for mono-energetic photons for a broad parallel beam and in the absence of scattered radiation are given in 5.3.1.1 and 5.3.2.1.

In practice, calibrations are always performed in divergent beams. This is taken account of by referring the conversion coefficients to a reference distance between the radiation source and point of test. 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 and actual orientation of the dosemeter in the field.

5.2 Quantities to be measured

For area dosemeters, the quantities to be measured shall be the ambient dose equivalent, $H^*(10)$, and directional dose equivalent, $H'(0{,}07)$.

5.3 Conversion coefficients

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

5.3.1.1 Mono-energetic radiation

See Table 2.

5.3.1.2 Fluorescence radiations and ^{241}Am

See Table 3.

5.3.1.3 Low air kerma rate series

See Table 4.

5.3.1.4 Narrow series

See Table 5.

5.3.1.5 Wide series

See Table 6.

5.3.1.6 High air kerma rate series

See Table 7.

Table 2 — Conversion coefficient $h'_K(0{,}07;E,\alpha)$ from air kerma, K_a, to the dose equivalent $H'(0{,}07)$ for mono-energetic and parallel photon radiation (expanded field) and the ICRU sphere

Photon energy	$h'_K(0{,}07;E,\alpha)$ in Sv/Gy for angle of incidence of																
keV	0°	10°	20°	30°	40°	45°	50°	60°	70°	80°	90°	100°	120°	135°	150°	180°	rot.
5	0,76	0,74	0,71	0,66	0,64	0,61	0,63	0,31	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,26
6	0,84	0,83	0,81	0,77	0,76	0,74	0,73	0,55	0,35	0,16	0,00	0,00	0,00	0,00	0,00	0,00	0,33
8	0,92	0,92	0,91	0,89	0,89	0,87	0,87	0,81	0,72	0,57	0,00	0,00	0,00	0,00	0,00	0,00	0,41
10	0,95	0,95	0,94	0,93	0,94	0,93	0,93	0,91	0,87	0,75	0,18	0,00	0,00	0,00	0,00	0,00	0,44
12,5	0,97	0,97	0,97	0,96	0,97	0,97	0,97	0,97	0,95	0,86	0,35	0,00	0,00	0,00	0,00	0,00	0,46
15	0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,98	0,91	0,44	0,05	0,00	0,00	0,00	0,00	0,48
20	1,05	1,04	1,04	1,04	1,04	1,04	1,04	1,04	1,03	0,97	0,57	0,13	0,00	0,00	0,00	0,00	0,52
25	1,13	1,12	1,12	1,12	1,12	1,12	1,12	1,11	1,10	1,03	0,67	0,21	0,00	0,00	0,00	0,00	0,57
30	1,22	1,21	1,21	1,21	1,21	1,21	1,21	1,20	1,18	1,10	0,63	0,29	0,01	0,00	0,00	0,00	0,63
40	1,41	1,39	1,39	1,39	1,39	1,39	1,38	1,37	1,33	1,24	0,76	0,44	0,06	0,02	0,02	0,00	0,74
50	1,53	1,52	1,51	1,51	1,51	1,51	1,50	1,48	1,45	1,34	0,93	0,56	0,10	0,05	0,04	0,01	0,82
60	1,60	1,58	1,58	1,57	1,57	1,57	1,56	1,54	1,51	1,40	1,06	0,65	0,14	0,07	0,06	0,03	0,87
80	1,61	1,59	1,59	1,58	1,58	1,58	1,58	1,56	1,53	1,43	1,13	0,74	0,19	0,10	0,08	0,05	0,90
100	1,55	1,54	1,54	1,54	1,53	1,53	1,53	1,52	1,50	1,42	1,19	0,78	0,22	0,12	0,09	0,07	0,89
125	1,48	1,47	1,46	1,46	1,46	1,46	1,46	1,46	1,44	1,38	1,19	0,79	0,24	0,13	0,10	0,09	0,87
150	1,42	1,41	1,41	1,41	1,41	1,41	1,41	1,41	1,39	1,34	1,17	0,79	0,26	0,14	0,11	0,10	0,84
200	1,34	1,34	1,34	1,34	1,34	1,34	1,35	1,35	1,34	1,30	1,15	0,79	0,30	0,16	0,13	0,10	0,83
300	1,28	1,28	1,28	1,28	1,28	1,28	1,29	1,30	1,30	1,24	1,16	0,83	0,37	0,21	0,16	0,13	0,82

NOTE The energy range in tables 2 to 14 is restricted to approximately the range in which electronic build-up is secured for the depth of 0,07 mm. For higher energies, the quantity H' loses importance, as in this range H^* is the limiting quantity.

Table 3 — Conversion coefficient $h'_K(0,07;F,\alpha)$ and $h'_K(0,07;S,\alpha)$ from air kerma, K_a, to the dose equivalent $H'(0,07)$ for radiation qualities given in ISO 4037-1 (expanded field) and the ICRU sphere, reference distance 2 m

Radiation quality	Irradiation distance	$h'_K(0,07;F,\alpha)$ and $h'_K(0,07;S,\alpha)$ in Sv/Gy for angle of incidence of																
	m	0°	10°	20°	30°	40°	45	50°	60°	70°	80°	90°	100°	120°	135°	150°	180°	rot.
F-Zn	1,0 - 2,0	0,94	0,93	0,92	0,91	0,91	0,90	0,89	0,85	0,78	0,64	0,04	0,00	0,00	0,00	0,00	0,00	0,42
F-Ge	1,0 - 2,0	0,95	0,95	0,94	0,93	0,93	0,93	0,93	0,91	0,87	0,75	0,17	0,00	0,00	0,00	0,00	0,00	0,44
F-Zr	1,0 - 2,0	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,99	0,92	0,47	0,06	0,00	0,00	0,00	0,00	0,49
F-Mo	1,0 - 2,0	1,02	1,01	1,01	1,01	1,01	1,01	1,02	1,02	1,01	0,94	0,51	0,09	0,00	0,00	0,00	0,00	0,50
F-Cd	1,0 - 3,0	1,09	1,09	1,09	1,08	1,09	1,09	1,09	1,08	1,07	1,00	0,63	0,18	0,00	0,00	0,00	0,00	0,55
F-Sn	1,0 - 3,0	1,13	1,13	1,12	1,12	1,12	1,12	1,12	1,12	1,10	1,03	0,67	0,22	0,00	0,00	0,00	0,00	0,57
F-Cs	1,0 - 3,0	1,24	1,23	1,23	1,23	1,23	1,23	1,22	1,22	1,22	1,11	0,78	0,31	0,01	0,00	0,00	0,00	0,64
F-Nd	1,0 - 3,0	1,36	1,35	1,35	1,34	1,35	1,34	1,34	1,33	1,30	1,20	0,89	0,41	0,05	0,02	0,01	0,01	0,71
F-Sm	1,0 - 3,0	1,41	1,40	1,39	1,39	1,39	1,39	1,38	1,37	1,34	1,24	0,94	0,44	0,06	0,02	0,02	0,01	0,74
F-Er	1,0 - 3,0	1,52	1,51	1,51	1,50	1,50	1,50	1,49	1,47	1,44	1,33	1,05	0,55	0,10	0,05	0,04	0,03	0,82
F-W	1,0 - 3,0	1,59	1,58	1,57	1,57	1,57	1,56	1,56	1,54	1,50	1,40	1,13	0,64	0,14	0,07	0,06	0,05	0,86
F-Au	1,0 - 3,0	1,61	1,60	1,59	1,59	1,59	1,59	1,58	1,57	1,53	1,42	1,17	0,70	0,16	0,09	0,07	0,06	0,89
F-Pb	1,0 - 3,0	1,61	1,60	1,59	1,59	1,59	1,59	1,58	1,57	1,53	1,43	1,19	0,73	0,18	0,10	0,08	0,07	0,90
F-U	1,0 - 3,0	1,56	1,54	1,54	1,54	1,54	1,54	1,54	1,53	1,50	1,42	1,19	0,77	0,21	0,12	0,09	0,08	0,89
S-Am	1,0 - 3,0	1,59	1,58	1,57	1,57	1,57	1,57	1,56	1,54	1,51	1,40	1,13	0,65	0,14	0,07	0,06	0,05	0,87

Table 4 — Conversion coefficient $h'_K(0{,}07;L,\alpha)$ from air kerma, K_a, to the dose equivalent $H'(0{,}07)$ for radiation qualities given in ISO 4037-1 (expanded field) and the ICRU sphere, reference distance 2 m

Radiation quality	Irradiation distance	$h'_K(0{,}07;L,\alpha)$ in Sv/Gy for angle of incidence of																
	m	0°	10°	20°	30°	40°	45	50°	60°	70°	80°	90°	100°	120°	135°	150°	180°	rot.
L-10	1,0 - 2,0	0,93	0,92	0,91	0,89	0,89	0,88	0,87	0,82	0,74	0,59	0,04	0,00	0,00	0,00	0,00	0,00	0,41
L-20	1,0 - 2,0	1,01	1,01	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,93	0,48	0,07	0,00	0,00	0,00	0,00	0,49
L-30	1,0 - 2,0	1,13	1,13	1,13	1,12	1,13	1,13	1,12	1,12	1,10	1,03	0,67	0,22	0,00	0,00	0,00	0,00	0,58
L-35	1,0 - 2,0	1,22	1,21	1,21	1,20	1,20	1,20	1,20	1,19	1,17	1,09	0,75	0,28	0,01	0,00	0,00	0,00	0,62
L-55	1,0 - 3,0	1,50	1,48	1,48	1,47	1,47	1,47	1,46	1,45	1,41	1,31	1,02	0,53	0,09	0,04	0,03	0,02	0,80
L-70	1,0 - 3,0	1,59	1,57	1,57	1,57	1,57	1,56	1,56	1,54	1,50	1,40	1,13	0,65	0,14	0,07	0,06	0,05	0,87
L-100	1,0 - 3,0	1,59	1,57	1,57	1,57	1,57	1,56	1,56	1,55	1,52	1,43	1,19	0,75	0,20	0,11	0,09	0,08	0,90
L-125	1,0 – 3,0	1,52	1,51	1,51	1,51	1,51	1,51	1,50	1,50	1,47	1,40	1,19	0,78	0,23	0,12	0,10	0,09	0,88
L-170	1,0 - 3,0	1,42	1,41	1,41	1,41	1,41	1,41	1,41	1,41	1,40	1,35	1,15	0,78	0,26	0,14	0,11	0,10	0,86
L-210	1,0 - 3,0	1,36	1,36	1,36	1,36	1,36	1,36	1,36	1,37	1,36	1,31	1,14	0,79	0,29	0,16	0,12	0,11	0,83
L-240	1,0 - 3,0	1,33	1,33	1,33	1,33	1,33	1,34	1,34	1,34	1,35	1,30	1,14	0,80	0,30	0,17	0,13	0,11	0,83

Table 5 — Conversion coefficient $h'_K(0,07;N,\alpha)$ from air kerma, K_a, to the dose equivalent $H'(0,07)$ for radiation qualities given in ISO 4037-1 (expanded field) and the ICRU sphere, reference distance 2 m

Radiation quality	Irradiation distance	$h'_K(0,07;N,\alpha)$ in Sv/Gy for angle of incidence of																
	m	0°	10°	20°	30°	40°	45	50°	60°	70°	80°	90°	100°	120°	135°	150°	180°	rot.
N-10	1,0 - 2,0	0,91	0,91	0,89	0,87	0,87	0,86	0,85	0,77	0,67	0,51	0,02	0,00	0,00	0,00	0,00	0,00	0,40
N-15	1,0 - 2,0	0,96	0,96	0,96	0,95	0,95	0,95	0,95	0,94	0,91	0,81	0,27	0,01	0,00	0,00	0,00	0,00	0,45
N-20	1,0 - 2,0	1,00	0,99	0,99	0,99	0,99	0,99	0,99	0,99	0,98	0,90	0,44	0,06	0,00	0,00	0,00	0,00	0,48
N-25	1,0 - 2,0	1,03	1,03	1,03	1,03	1,03	1,03	1,03	1,03	1,02	0,95	0,53	0,11	0,00	0,00	0,00	0,00	0,51
N-30	1,0 - 2,0	1,10	1,10	1,09	1,09	1,09	1,09	1,09	1,09	1,08	1,01	0,64	0,18	0,00	0,00	0,00	0,00	0,56
N-40	1,0 - 2,0	1,25	1,25	1,25	1,24	1,24	1,24	1,24	1,23	1,21	1,13	0,80	0,32	0,02	0,01	0,01	0,00	0,65
N-60	1,0 - 3,0	1,48	1,47	1,47	1,46	1,46	1,46	1,45	1,44	1,40	1,30	1,01	0,52	0,09	0,04	0,03	0,02	0,79
N-80	1,0 - 3,0	1,60	1,58	1,58	1,57	1,57	1,57	1,56	1,55	1,51	1,41	1,15	0,67	0,15	0,08	0,06	0,05	0,88
N-100	1,0 - 3,0	1,60	1,58	1,58	1,57	1,57	1,57	1,56	1,55	1,52	1,43	1,19	0,75	0,19	0,10	0,08	0,07	0,90
N-120	1,0 - 3,0	1,55	1,54	1,53	1,53	1,53	1,53	1,53	1,52	1,49	1,41	1,19	0,77	0,22	0,12	0,09	0,09	0,89
N-150	1,0 - 3,0	1,50	1,48	1,48	1,48	1,48	1,48	1,48	1,47	1,45	1,39	1,18	0,78	0,23	0,13	0,10	0,09	0,87
N-200	1,0 - 3,0	1,39	1,38	1,38	1,38	1,38	1,38	1,39	1,39	1,37	1,33	1,15	0,79	0,27	0,15	0,12	0,10	0,84
N-250	1,0 - 3,0	1,34	1,34	1,34	1,34	1,34	1,34	1,34	1,35	1,34	1,30	1,14	0,80	0,30	0,17	0,13	0,11	0,83
N-300	1,0 - 3,0	1,31	1,31	1,31	1,31	1,31	1,31	1,32	1,33	1,32	1,27	1,14	0,81	0,33	0,19	0,14	0,12	0,83

Table 6 — Conversion coefficient $h'_K(0{,}07;\mathrm{W},\alpha)$ from air kerma, K_a, to the dose equivalent $H'(0{,}07)$ for radiation qualities given in ISO 4037-1 (expanded field) and the ICRU sphere, reference distance 2 m

Radiation quality	Irradiation distance	$h'_K(0{,}07;\mathrm{W},\alpha)$ in Sv/Gy for angle of incidence of																
	m	0°	10°	20°	30°	40°	45	50°	60°	70°	80°	90°	100°	120°	135°	150°	180°	rot.
W-60	1,0 - 3,0	1,43	1,42	1,42	1,41	1,41	1,41	1,40	1,39	1,36	1,26	0,96	0,47	0,07	0,03	0,03	0,02	0,76
W-80	1,0 - 3,0	1,54	1,52	1,52	1,52	1,52	1,51	1,51	1,49	1,46	1,35	1,08	0,59	0,12	0,06	0,05	0,04	0,83
W-110	1,0 - 3,0	1,59	1,57	1,57	1,57	1,57	1,56	1,56	1,55	1,51	1,42	1,18	0,73	0,18	0,09	0,08	0,07	0,89
W-150	1,0 - 3,0	1,53	1,51	1,51	1,51	1,51	1,51	1,50	1,50	1,47	1,40	1,18	0,77	0,22	0,12	0,10	0,09	0,88
W-200	1,0 - 3,0	1,44	1,43	1,43	1,43	1,43	1,43	1,43	1,43	1,41	1,36	1,16	0,79	0,25	0,14	0,11	0,10	0,85
W-250	1,0 - 3,0	1,37	1,37	1,37	1,37	1,37	1,37	1,37	1,38	1,37	1,32	1,14	0,79	0,28	0,16	0,12	0,11	0,84
W-300	1,0 - 3,0	1,34	1,34	1,34	1,34	1,34	1,34	1,34	1,35	1,34	1,30	1,14	0,80	0,31	0,17	0,13	0,11	0,83

Table 7 — Conversion coefficient $h'_K(0{,}07;H,\alpha)$ from air kerma, K_a, to the dose equivalent $H'(0{,}07)$ for radiation qualities given in ISO 4037-1 (expanded field) and the ICRU sphere, reference distance 2 m

Radiation quality	Irradiation distance	$h'_K(0{,}07;H,\alpha)$ in Sv/Gy for angle of incidence of																
	m	0°	10°	20°	30°	40°	45	50°	60°	70°	80°	90°	100°	120°	135°	150°	180°	rot.
H-10	1,0 - 2,0	0,89	0,88	0,86	0,84	0,83	0,81	0,81	0,70	0,57	0,41	0,01	0,00	0,00	0,00	0,00	0,00	0,37
H-20	1,0 - 2,0	0,96	0,96	0,95	0,94	0,95	0,94	0,94	0,92	0,88	0,78	0,24	0,02	0,00	0,00	0,00	0,00	0,45
H-30	1,0 - 2,0	1,02	1,01	1,01	1,00	1,01	1,00	1,01	1,00	0,99	0,91	0,46	0,08	0,00	0,00	0,00	0,00	0,50
H-60	1,0 - 2,0	1,26	1,25	1,25	1,25	1,25	1,25	1,24	1,23	1,21	1,13	0,80	0,32	0,03	0,01	0,01	0,01	0,65
H-100	1,0 - 3,0	1,49	1,48	1,48	1,47	1,47	1,47	1,46	1,45	1,42	1,32	1,04	0,56	0,11	0,05	0,04	0,03	0,81
H-200	1,0 - 3,0	1,51	1,50	1,49	1,50	1,49	1,49	1,49	1,48	1,46	1,38	1,16	0,75	0,22	0,12	0,09	0,08	0,87
H-250	1,0 - 3,0	1,45	1,45	1,45	1,45	1,45	1,45	1,45	1,44	1,42	1,36	1,16	0,77	0,24	0,13	0,10	0,09	0,86
H-280	1,0 - 3,0	1,41	1,41	1,41	1,41	1,41	1,41	1,41	1,41	1,40	1,34	1,16	0,79	0,27	0,15	0,11	0,10	0,85
H-300	1,0 - 3,0	1,40	1,40	1,40	1,40	1,40	1,40	1,41	1,41	1,39	1,33	1,15	0,79	0,27	0,15	0,12	0,10	0,85

5.3.2 Conversion coefficient from air kerma to *H**(10)

5.3.2.1 Mono-energetic radiations

See Table 8.

Table 8 — Conversion coefficient $h^*_K(10)$ from air kerma, K_a, to ambient dose equivalent $H^*(10)$ for mono-energetic and parallel photon radiation (expanded and aligned field) and the ICRU sphere

Photon energy keV	$h^*_K(10)$ Sv/Gy
10	0,008
15	0,26
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	1,14
3 000	1,13
4 000	1,12
5 000	1,11
6 000	1,11
8 000	1,11
10 000	1,10

5.3.2.2 Fluorescence radiations

See Table 9.

Table 9 — Conversion coefficient $h^*_K(10;F)$ from air kerma, K_a, to ambient dose equivalent $H^*(10)$ for radiation qualities given in ISO 4037-1 (expanded and aligned field) and the ICRU sphere, reference distance 2 m.

Radiation quality	**Irradiation distance** m	$h^*_K(10;F)$ Sv/Gy
F-Zr [a]	1,0 - 2,0	0,32
F-Mo [a]	1,0 - 2,0	0,44
F-Cd	1,0 - 2,0	0,80
F-Sn	1,0 - 3,0	0,91
F-Cs	1,0 - 3,0	1,14
F-Nd	1,0 - 3,0	1,39
F-Sm	1,0 - 3,0	1,47
F-Er	1,0 - 3,0	1,65
F-W	1,0 - 3,0	1,74
F-Au	1,0 - 3,0	1,75
F-Pb	1,0 - 3,0	1,74
F-U	1,0 - 3,0	1,65

[a] With these radiation qualities, care needs to be taken as energy impurities may have a substantial influence on the numerical values of conversion coefficients (see 4.1.2).

5.3.2.3 Low air kerma rate series

See Table 10.

Table 10 — Conversion coefficient $h^*_K(10;L)$ from air kerma, K_a, to ambient dose equivalent $H^*(10)$ for radiation qualities given in ISO 4037-1 (expanded and aligned field) and the ICRU sphere, reference distance 2 m

Radiation quality	**Irradiation distance** m	$h^*_K(10;L)$ Sv/Gy
L-20 [a]	1,0 - 2,0	0,37
L-30 [a]	1,0 - 2,0	0,90
L-35	1,0 - 2,0	1,08
L-55	1,0 - 3,0	1,61
L-70	1,0 - 3,0	1,73
L-100	1,0 - 3,0	1,69
L-125	1,0 - 3,0	1,61
L-170	1,0 - 3,0	1,50
L-210	1,0 - 3,0	1,42
L-240	1,0 - 3,0	1,38

[a] With these radiation qualities, care needs to be taken as variations in energy distribution may have a substantial influence on the numerical values of conversion coefficients (see 4.1.2).

5.3.2.4 Narrow series

See Table 11.

Table 11 — Conversion coefficient $h^*_K(10;N)$ from air kerma, K_a, to ambient dose equivalent $H^*(10)$ for radiation qualities given in ISO 4037-1 (expanded and aligned field) and the ICRU sphere, reference distance 2 m

Radiation quality	**Irradiation distance** m	$h^*_K(10;N)$ Sv /Gy
N-25 [a]	1,0 - 2,0	0,52
N-30 [a]	1,0 - 2,0	0,80
N-40	1,0 - 3,0	1,18
N-60	1,0 - 3,0	1,59
N-80	1,0 - 3,0	1,73
N-100	1,0 - 3,0	1,71
N-120	1,0 - 3,0	1,64
N-150	1,0 - 3,0	1,58
N-200	1,0 - 3,0	1,46
N-250	1,0 - 3,0	1,39
N-300	1,0 - 3,0	1,35

[a] With these radiation qualities, care needs to be taken as variations in energy distribuition may have a substantial influence on the numerical values of conversion coefficients (see 4.1.2).

5.3.2.5 Wide series

See Table 12.

Table 12 — Conversion coefficient $h^*_K(10;W)$ from air kerma, K_a, to ambient dose equivalent $H^*(10)$ for radiation qualities given in ISO 4037-1 (expanded and aligned field) and the ICRU sphere, reference distance 2 m

Radiation quality	**Irradiation distance** m	$h^*_K(10;W)$ Sv/Gy
W-60	1,0 - 3,0	1,49
W-80	1,0 - 3,0	1,66
W-110	1,0 - 3,0	1,71
W-150	1,0 - 3,0	1,62
W-200	1,0 - 3,0	1,52
W-250	1,0 - 3,0	1,44
W-300	1,0 - 3,0	1,39

5.3.2.6 High air kerma rate series

See Table 13.

Table 13 — Conversion coefficient $h^*_K(10;\mathrm{H})$ from air kerma, K_a, to ambient dose equivalent $H^*(10)$ for radiation qualities given in ISO 4037-1 (expanded and aligned field) and the ICRU sphere, reference distance 2 m

Radiation quality	Irradiation distance m	$h^*_K(10;\mathrm{H})$ Sv/Gy
H-60	1,0 - 3,0	1,15
H-100	1,0 - 3,0	1,57
H-200	1,0 - 3,0	1,61
H-250	1,0 - 3,0	1,54
H-280	1,0 - 3,0	1,49
H-300	1,0 - 3,0	1,48

5.3.2.7 Radionuclides and high energy reference radiations

See Table 14.

Table 14 — Conversion coefficient $h^*_K(10;\mathrm{S})$ and $h^*_K(10;\mathrm{R})$ from air kerma, K_a, to ambient dose equivalent $H^*(10)$ for radiation qualities given in ISO 4037-1 (expanded and aligned field) and the ICRU sphere for collimated beams, reference distance 2 m.

Radiation quality	Irradiation distance m	Build-up layer thickness mm	k_{PMMA}	$h^*_K(10;\mathrm{S})$ $h^*_K(10;\mathrm{R})$ Sv/Gy
S-Am	1,0 - 2,0	--	---	1,74
S-Cs	1,0 - 3,0	2	1,00	1,20
S-Co	1,0 - 3,0	4	1,00	1,16
R-C	1,0 - 3,0	25	0,94	1,12
R-F	1,0 - 3,0	25	0,94	1,11
R-Ti	1,0 - 3,0	25	0,94	1,11
R-Ni	1,0 - 3,0	25	0,94	1,11
R-O	1,0 - 3,0	25	0,94	1,11

When using an uncollimated irradiation geometry, the irradiation distance should also be in the range recommended in ISO 4037-2 for this parameter.

6 Particular procedures for personal dosemeters

6.1 General principles

These principles apply to the calibration of all personal dosemeters, i.e. whole body and extremity dosemeters. The irradiation should be performed on a phantom. Measurements of the response may be necessary in the photon energy range from 8 keV to 9 MeV and at various irradiation distances.

Subclauses 6.4.2 and 6.4.3 contain conversion coefficients $h_{pK}(d)$ to convert air kerma free in air to the operational quantities $H_p(0{,}07)$ and $H_p(10)$ defined in 3.1.2.3. These conversion coefficients pertain to the nominal photon fluence spectra given in ISO 4037-1.

If the energy distribution of the reference radiation differs from the nominal distribution, 4.1.2 shall be observed. 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 15, 21, 27 and A.3.

6.2 Quantities to be measured

The quantities to be measured for individual monitoring are the personal dose equivalent, $H_p(0{,}07)$ and $H_p(10)$. The depth shall be chosen in agreement with the properties of the dosemeter under test. Tables 15 to 30 contain conversion coefficients converting the air kerma K_a to the personal dose equivalent $H_p(d)$. Depending on the value of d, the conversion coefficients pertain to different phantoms. For $d = 0{,}07$ mm, conversion coefficients are provided for the rod and the pillar phantom. The conversion coefficients for a depth $d = 10$ mm refer to the 30 cm × 30 cm × 15 cm slab phantom of the four component ICRU tissue with a density of 1 g cm^{-3}. All conversion coefficients pertain to the reference radiations recommended in ISO 4037-1.

NOTE Conversion coefficients from air kerma to $H_p(0{,}07)$ in the ICRU slab phantom are given in A.2.

6.3 Experimental conditions

6.3.1 Use of phantoms

Measurements of the response as a function of radiation energy and direction of radiation incidence and calibrations of personal dosemeters should be carried out on a phantom that is suitable in view of the depth of measurement and of the type of dosemeter. As a rule, the depth of 0,07 mm will be applicable only for extremity dosemeters (see note below). For dosemeters worn on the fingers, the ISO rod phantom should be used and, for those worn on the wrist or the ankle, the ISO pillar phantom should be used. 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 have a thickness of 10 mm. For dosemeters worn on the body to measure $H_p(10)$, a phantom of outer dimensions 30 cm × 30 cm × 15 cm with PMMA walls (front wall 2,5 mm thick, other walls 10 mm thick) filled with water and termed the ISO water slab phantom, should be used. When using reference radiations with a mean energy equal to or above that of the radionuclide ^{137}Cs, 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 properties between these phantoms and those of ICRU tissue.

Routine calibrations (see note in 3.2.11) need not always be performed on a phantom but may sometimes be done more simply, free in air, or with another type of radiation than that which the dosemeter is intended to measure. Such simplifications, if they are to be applied, shall be justified prior to their adoption by demonstrating that they lead to results identical to those from procedures described in this part of ISO 4037, or that any differences can be corrected for reliably. This may be done on the basis of the results of a type test.

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.

6.3.2 Geometrical considerations in divergent beams

The point of test shall be chosen at a distance from the source such that the field size in the plane of measurement is 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 radiation incidence. 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 is perpendicular to the beam axis. The irradiation of the dosemeter under test shall be made under conditions identical to those prevailing during the irradiation of the standard instrument, but now with the phantom present. The calibration factor or the value of the response shall be obtained from the formula in 4.2.2.1 or 4.2.2.2, respectively. 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 A.1.

NOTE 1 In this part of ISO 4037 the entity of the personal dosemeter and phantom is considered as the dosemeter to be tested. The reference point of the entity is the reference point of the dosemeter. The value of the quantity to be measured pertains to the value of the dose equivalent at depth, *d*, inside the reference phantom in the absence of the dosemeter.

NOTE 2 This concept is consistent with the definition of H_p which, at least in principle, requires the determination of the dose equivalent at a non-accessible point inside the body. Placing the reference point of the dosemeter at the point of test has two practical advantages. The first one is that the dose due to the primary radiation coming from the source is always measured correctly, irrespective of the extent of beam divergence. As this part of the dose always represents the majority contribution to the total dose, including the scattered radiation from the phantom, the convention adopted implies that the calibration factor of the dosemeter does not depend unnecessarily on the distance between the source and point of test. The second advantage arises in an experimental determination of the dependence of response on the direction of radiation incidence. If the reference point and the point of test coincide, the reading of the dosemeter under test does not have to be corrected for a variation of the distance between source and reference point with the angle of rotation.

NOTE 3 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.

6.3.3 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. The values of d_F depend on the radiation quality and they are given in Tables 28 to 33. If smaller irradiation distances than those given in Tables 16 to 20 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 4.1.5.

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: a) 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 b) possibly different distances of the reference points from the radiation source have to be considered.

Such differences in distance should be taken account of according to 4.1.4. Before such a practice is adopted, it shall be verified that it leads to results identical to within 2 % of those obtained when one dosemeter alone is irradiated in the centred position of the phantom.

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.

6.3.4 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 Ω. 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 A.2 shows, as a function of photon energy, that for an angle of rotation of 60° around either of the two axis, the value of $h_{pK}(0,07;E,\alpha)$ remains between 0,95 and 1,05 of the value of normal incidence. The data for Figure A.2 are taken from references [11] and [12]. For smaller angles of rotation, these variations are always smaller. Due to the small magnitude of the angular variation of the conventional true value of $H_p(0,07)$, it is assumed in this part of ISO 4037 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 part of ISO 4037.

NOTE 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 part of ISO 4037. This does not jeopardize the objective of this part of ISO 4037 to provide reliable and accurate calibration procedures, but rather reduces the size and number of the tables.

6.4 Conversion coefficients

6.4.1 General

The conversion coefficients in 6.4.2 to 6.4.4 refer to the rod, the pillar and the slab phantom made of ICRU tissue. Calibrations of individual dosemeters shall be perfomed on the phantom described in 6.3.1 which suits 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 phantom of ICRU tissue with identical shape.

In practice, calibrations are always performed in divergent beams. This is taken account of by referring the conversion coefficients to a reference distance between the radiation source and point of test. 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 and actual orientation of the dosemeter in the field.

When necessary, a PMMA build-up plate with a cross-sectional area of 30 cm × 30 cm shall be positioned with its rear face 15 cm in front of the reference point of the dosemeter. This plate shall remain stationary when the dosemeter or the dosemeter phantom combination is rotated (see 4.1.8 and Figure A.1).

6.4.2 Conversion coefficients from air kerma to $H_p(0,07)$ in the rod phantom consisting of ICRU tissue

6.4.2.1 Mono-energetic radiations

See Table 15.

Table 15 — Conversion coefficient $h_{pK}(0,07;E)$ from air kerma, K_a, to the dose equivalent $H_p(0,07)$ for mono-energetic and parallel photon radiation and the rod phantom

Energy keV	$h_{pK}(0,07;E)$ Sv/Gy
5	0,76
6	0,84
8	0,92
10	0,95
12,5	0,96
15	0,98
20	1,01
25	1,04
30	1,06
40	1,09
50	1,12
60	1,14
80	1,16
100	1,17
125	1,16
150	1,16
200	1,15
300	1,14

6.4.2.2 Fluorescence radiations and ^{241}Am

See Table 16.

Table 16 — Conversion coefficient $h_{pK}(0{,}07;F)$ and $h_{pK}(0{,}07;S)$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for radiation qualities given in ISO 4037-1 and the rod phantom, reference distance 2 m

Radiation quality	Irradiation distance m	$h_{pK}(0{,}07;F)$ and $h_{pK}(0{,}07;S)$ Sv/Gy
F-Zn	1,0 - 2,0	0,93
F-Ge	1,0 - 2,0	0,95
F-Zr	1,0 - 2,0	0,98
F-Mo	1,0 – 2,0	0,99
F-Cd	1,0 - 2,0	1,03
F-Sn	1,0 - 2,0	1,04
F-Cs	1,0 - 2,0	1,06
F-Nd	1,0 - 2,0	1,08
F-Sm	1,0 - 2,0	1,09
F-Er	1,0 - 2,0	1,13
F-W	1,0 - 2,0	1,14
F-Au	1,0 - 2,0	1,15
F-Pb	1,0 - 2,0	1,16
F-U	1,0 - 2,0	1,17
S-Am	1,0 - 2,0	1,14

6.4.2.3 Low air kerma rate series

See Table 17.

Table 17 — Conversion coefficient $h_{pK}(0{,}07;L)$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for radiation qualities given in ISO 4037-1 and the rod phantom, reference distance 2 m

Radiation quality	Irradiation distance m	$h_{pK}(0{,}07;L)$ Sv/Gy
L-10	1,0 - 2,0	0,91
L-20	1,0 - 2,0	0,99
L-30	1,0 - 2,0	1,03
L-35	1,0 - 2,0	1,06
L-55	1,0 - 2,0	1,11
L-70	1,0 - 2,0	1,14
L-100	1,0 - 2,0	1,17
L-125	1,0 - 2,0	1,17
L-170	1,0 - 2,0	1,16
L-210	1,0 - 2,0	1,15
L-240	1,0 - 2,0	1,15

6.4.2.4 Narrow series

See Table 18.

Table 18 — Conversion coefficient h_{pK}(0,07;N) from air kerma, K_a, to the dose equivalent H_p(0,07) for radiation qualities given by ISO 4037-1 and the rod phantom, reference distance 2 m

Radiation quality	**Irradiation distance** m	h_{pK}(0,07;N) Sv/Gy
N-10	1,0 - 2,0	0,91
N-15	1,0 - 2,0	0,95
N-20	1,0 - 2,0	0,98
N-25	1,0 - 2,0	1,00
N-30	1,0 - 2,0	1,03
N-40	1,0 - 2,0	1,07
N-60	1,0 - 2,0	1,11
N-80	1,0 - 2,0	1,15
N-100	1,0 - 2,0	1,17
N-120	1,0 - 2,0	1,17
N-150	1,0 - 2,0	1,17
N-200	1,0 - 3,0	1,16
N-250	1,0 - 3,0	1,15
N-300	1,0 - 3,0	1,14

6.4.2.5 Wide series

See Table 19.

Table 19 — Conversion coefficient h_{pK}(0,07;W) from air kerma, K_a, to the dose equivalent H_p(0,07) for radiation qualities given in ISO 4037-1 and the rod phantom, reference distance 2 m

Radiation quality	**Irradiation distance** m	h_{pK}(0,07;W) Sv/Gy
W-60	1,0 - 2,0	1,10
W-80	1,0 - 2,0	1,13
W-110	1,0 - 2,0	1,16
W-150	1,0 - 2,0	1,17
W-200	1,0 - 3,0	1,16
W-250	1,0 - 3,0	1,15
W-300	1,0 - 3,0	1,15

6.4.2.6 High air kerma rate series

See Table 20.

Table 20 — Conversion coefficient $h_{pK}(0{,}07;\mathrm{H})$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for radiation qualities given in ISO 4037-1 and the rod phantom, reference distance 2 m

Radiation quality	Irradiation distance m	$h_{pK}(0{,}07;\mathrm{H})$ Sv/Gy
H-10	1,0 - 2,0	0,89
H-20	1,0 - 2,0	0,95
H-30	1,0 - 2,0	0,99
H-60	1,0 - 2,0	1,07
H-100	1,0 - 2,0	1,12
H-200	1,0 - 2,0	1,16
H-250	1,0 - 3,0	1,16
H-280	1,0 - 3,0	1,16
H-300	1,0 - 3,0	1,16

6.4.3 Conversion coefficients from air kerma to $H_p(0{,}07)$ in the pillar phantom consisting of ICRU tissue

6.4.3.1 Mono-energetic radiations

See Table 21.

Table 21 — Conversion coefficient $h_{pK}(0{,}07;E)$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for mono-energetic and parallel photon radiation and the pillar phantom

Energy keV	$h_{pK}(0{,}07;E)$ Sv/Gy
5	0,76
6	0,84
8	0,92
10	0,95
12,5	0,96
15	0,98
20	1,04
25	1,10
30	1,18
40	1,29
50	1,37
60	1,39
80	1,38
100	1,35
125	1,32
150	1,28
200	1,25
300	1,21

6.4.3.2 Fluorescence radiations and ^{241}Am

See Table 22.

Table 22 — Conversion coefficient $h_{pK}(0,07;F)$ and $h_{pK}(0,07;S)$ from air kerma, K_a, to the dose equivalent $H_p(0,07)$ for radiation qualities given in ISO 4037-1 and the pillar phantom, reference distance 2 m

Radiation quality	Irradiation distance m	$h_{pK}(0,07;F)$ $h_{pK}(0,07;S)$ Sv/Gy
F-Zn	1,0 - 2,0	0,93
F -Ge	1,0 - 2,0	0,95
F -Zr	1,0 - 2,0	0,99
F-Mo	1,0 - 2,0	1,01
F-Cd	1,0 - 2,0	1,08
F-Sn	1,0 - 2,0	1,10
F-Cs	1,0 – 2,0	1,19
F -Nd	1,0 - 2,0	1,27
F-Sm	1,0 - 2,0	1,29
F-Er	1,0 - 2,0	1,36
F-W	1,0 - 2,0	1,39
F-Au	1,0 - 2,0	1,39
F-Pb	1,0 - 2,0	1,39
F-U	1,0 - 2,0	1,35
S-Am	1,0 - 2,0	1,39

6.4.3.3 Low air kerma rate series

See Table 23.

Table 23 — Conversion coefficient $h_{pK}(0,07;L)$ from air kerma, K_a, to the dose equivalent $H_p(0,07)$ for radiation qualities given in ISO 4037-1 and the pillar phantom, reference distance 2 m

Radiation quality	Irradiation distance m	$h_{pK}(0,07;L)$ Sv/Gy
L-10	1,0 - 2,0	0,91
L-20	1,0 - 2,0	1,00
L-30	1,0 - 2,0	1,08
L-35	1,0 - 2,0	1,17
L-55	1,0 - 2,0	1,34
L-70	1,0 - 2,0	1,39
L-100	1,0 - 2,0	1,37
L-125	1,0 - 2,0	1,34
L-170	1,0 - 2,0	1,29
L-210	1,0 - 2,0	1,26
L-240	1,0 - 2,0	1,24

6.4.3.4 Narrow series

See Table 24.

Table 24 — Conversion coefficient h_{pK}(0,07;N) from air kerma, K_a, to the dose equivalent H_p(0,07) for radiation qualities given by ISO 4037-1 and the pillar phantom, reference distance 2 m

Radiation quality	Irradiation distance m	h_{pK}(0,07;N) Sv/Gy
N-10	1,0 - 2,0	0,91
N-15	1,0 - 2,0	0,96
N-20	1,0 - 2,0	0,99
N-25	1,0 - 2,0	1,02
N-30	1,0 - 2,0	1,08
N-40	1,0 - 2,0	1,20
N-60	1,0 - 2,0	1,33
N-80	1,0 - 2,0	1,39
N-100	1,0 - 2,0	1,38
N-120	1,0 - 2,0	1,35
N-150	1,0 - 2,0	1,32
N-200	1,0 - 2,0	1,27
N-250	1,0 - 2,0	1,24
N-300	1,0 - 2,0	1,22

6.4.3.5 Wide series

See Table 25.

Table 25 — Conversion coefficient h_{pK}(0,07;W) from air kerma, K_a, to the dose equivalent H_p(0,07) for radiation qualities given in ISO 4037-1 and the pillar phantom, reference distance 2 m

Radiation quality	Irradiation distance m	h_{pK}(0,07;W) Sv/Gy
W-60	1,0 - 2,0	1,30
W-80	1,0 - 2,0	1,36
W-110	1,0 - 2,0	1,38
W-150	1,0 - 2,0	1,34
W-200	1,0 - 2,0	1,30
W-250	1,0 - 2,0	1,26
W-300	1,0 - 2,0	1,24

6.4.3.6 High air kerma rate series

See Table 26.

Table 26 — Conversion coefficient $h_{pK}(0{,}07;H)$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for radiation qualities given in ISO 4037-1 and the pillar phantom, reference distance 2 m

Radiation quality	**Irradiation distance** m	$h_{pK}(0{,}07;H)$ Sv/Gy
H-10	1,0 - 2,0	0,89
H-20	1,0 - 2,0	0,96
H-30	1,0 - 2,0	1,00
H-60	1,0 - 2,0	1,20
H-100	1,0 - 2,0	1,33
H-200	1,0 - 2,0	1,33
H-250	1,0 - 2,0	1,31
H-280	1,0 - 2,0	1,28
H-300	1,0 - 2,0	1,28

6.4.4 Conversion coefficient from air kerma to $H_p(10)$ in the ICRU slab phantom

6.4.4.1 Mono-energetic radiation

See Table 27.

Table 27 — Conversion coefficient $h_{pK}(10;E,\alpha)$ from air kerma, K_a, to the dose equivalent $H_p(10)$ for mono-energetic and parallel photon radiation and the slab phantom

Photon energy keV	$h_{pK}(10;E,\alpha)$ in Sv/Gy for angle of incidence of									
	0°	10°	20°	30°	40°	45°	50°	60°	70°	80°
10	0,01	0,01	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00
12,5	0,10	0,09	0,09	0,07	0,05	0,04	0,03	0,01	0,00	0,00
15	0,26	0,26	0,25	0,22	0,18	0,15	0,12	0,07	0,02	0,00
20	0,61	0,61	0,59	0,56	0,50	0,47	0,42	0,32	0,17	0,04
30	1,11	1,10	1,09	1,06	1,00	0,96	0,92	0,80	0,60	0,28
40	1,49	1,48	1,46	1,43	1,37	1,33	1,28	1,13	0,91	0,50
50	1,77	1,75	1,74	1,70	1,63	1,57	1,52	1,38	1,13	0,67
60	1,89	1,88	1,86	1,83	1,77	1,72	1,66	1,50	1,25	0,79
80	1,90	1,90	1,88	1,85	1,78	1,75	1,69	1,54	1,32	0,86
100	1,81	1,80	1,79	1,76	1,72	1,68	1,64	1,51	1,28	0,87
125	1,70	1,69	1,69	1,66	1,62	1,59	1,56	1,45	1,26	0,86
150	1,61	1,60	1,60	1,58	1,54	1,52	1,49	1,40	1,24	0,86
200	1,49	1,49	1,49	1,48	1,45	1,43	1,41	1,34	1,21	0,87
300	1,37	1,37	1,37	1,36	1,36	1,35	1,33	1,27	1,17	0,87
400	1,30	1,30	1,30	1,30	1,29	1,29	1,28	1,24	1,16	0,89
500	1,26	1,26	1,26	1,26	1,26	1,26	1,25	1,22	1,15	0,90
600	1,23	1,23	1,23	1,23	1,23	1,23	1,23	1,20	1,14	0,92
800	1,19	1,19	1,19	1,19	1,20	1,20	1,20	1,17	1,13	0,93
1 000	1,17	1,17	1,17	1,16	1,17	1,18	1,17	1,15	1,12	0,95
1 250	1,15	1,15	1,15	1,15	1,16	1,16	1,16	1,14	1,12	0,96
1 500	1,14	1,14	1,14	1,14	1,14	1,15	1,15	1,14	1,12	0,97
3 000	1,12	1,12	1,13	1,13	1,12	1,12	1,12	1,12	1,10	1,00
6 000	1,11	1,11	1,11	1,11	1,10	1,10	1,10	1,11	1,12	1,06
10 000	1,11	1,11	1,11	1,11	1,10	1,10	1,10	1,10	1,09	1,05

6.4.4.2 Fluorescence radiation

See Table 28

Table 28 — Conversion coefficient $h_{pK}(10;F,\alpha)$ from air kerma, K_a, to the dose equivalent $H_p(10)$ for radiation qualities given in ISO 4037-1 and the slab phantom, reference distance 2 m

Radiation quality	Irradiation distance m	d_F cm (see 6.3.3)	$h_{pK}(10;F,\alpha)$ in Sv/Gy for angle of incidence of 0°	10°	20°	30°	40°	45°	50°	60°	70°	80°
F-Zr [a]	1,0 - 2,0	25	0,32	0,32	0,30	0,27	0,23	0,20	0,16	0,10	0,04	0,00
F-Mo [a]	1,0 - 2,0	25	0,44	0,44	0,42	0,39	0,34	0,31	0,27	0,19	0,08	0,01
F-Cd	1,0 - 2,0	20	0,79	0,78	0,77	0,74	0,68	0,65	0,60	0,48	0,31	0,11
F-Sn	1,0 - 2,0	20	0,89	0,88	0,87	0,84	0,78	0,75	0,70	0,58	0,40	0,16
F-Cs	1,0 - 3,0	16	1,15	1,14	1,13	1,10	1,04	1,00	0,96	0,84	0,64	0,30
F-Nd	1,0 - 3,0	13	1,40	1,39	1,37	1,34	1,29	1,25	1,20	1,06	0,84	0,45
F-Sm	1,0 - 3,0	12	1,49	1,48	1,46	1,43	1,37	1,33	1,28	1,13	0,91	0,50
F-Er	1,0 - 3,0	11	1,75	1,73	1,72	1,68	1,61	1,55	1,50	1,36	1,11	0,66
F-W	1,0 - 3,0	11	1,89	1,88	1,86	1,82	1,76	1,71	1,65	1,50	1,24	0,78
F-Au	1,0 - 3,0	11	1,90	1,89	1,88	1,86	1,78	1,74	1,68	1,53	1,29	0,83
F-Pb	1,0 - 3,0	11	1,90	1,90	1,88	1,86	1,78	1,75	1,69	1,54	1,31	0,85
F-U	1,0 - 3,0	11	1,82	1,81	1,80	1,77	1,72	1,69	1,65	1,51	1,29	0,87

[a] With these radiation qualities, care needs to be taken as energy impurities may have a substantial influence on the numerical values of conversion coefficients (see 4.1.2).

6.4.4.3 Low air kerma rate series

See Table 29.

Table 29 — Conversion coefficient $h_{pK}(10;L,\alpha)$ from air kerma, K_a, to the dose equivalent $H_p(10)$ for radiation qualities given in ISO 4037-1 and the slab phantom, reference distance 2 m

Radiation quality	Irradiation distance m	d_F cm (see 6.3.3)	$h_{pK}(10;L,\alpha)$ in Sv/Gy for angle of incidence of 0°	10°	20°	30°	40°	45°	50°	60°	70°	80°
L-20 [a]	1,0 - 2,0	25	0,37	0,37	0,36	0,33	0,28	0,25	0,22	0,15	0,06	0,01
L-30 [a]	1,0 - 3,0	18	0,91	0,90	0,89	0,86	0,79	0,76	0,71	0,60	0,41	0,17
L-35	1,0 - 3,0	16	1,09	1,08	1,07	1,04	0,98	0,94	0,90	0,77	0,58	0,27
L-55	1,0 - 3,0	11	1,67	1,66	1,65	1,61	1,54	1,49	1,44	1,29	1,06	0,61
L-70	1,0 - 3,0	11	1,87	1,86	1,84	1,81	1,75	1,70	1,64	1,49	1,24	0,78
L-100	1,0 - 3,0	11	1,87	1,87	1,85	1,81	1,76	1,73	1,67	1,53	1,31	0,86
L-125	1,0 - 3,0	11	1,77	1,76	1,75	1,72	1,68	1,65	1,61	1,49	1,27	0,87
L-170	1,0 - 3,0	12	1,62	1,61	1,61	1,59	1,55	1,53	1,50	1,41	1,24	0,86
L-210	1,0 - 3,0	12	1,52	1,52	1,52	1,51	1,47	1,45	1,43	1,36	1,22	0,87
L-240	1,0 - 3,0	13	1,47	1,47	1,47	1,46	1,44	1,42	1,40	1,33	1,20	0,87

[a] With these radiation qualities, care needs to be taken as variations in energy distribution may have a substantial influence on the numerical values of conversion coefficients (see 4.1.2).

6.4.4.4 Narrow series

See Table 30.

Table 30 — Conversion coefficient $h_{pK}(10;N,\alpha)$ from air kerma, K_a, to the dose equivalent $H_p(10)$ for radiation qualities given in ISO 4037-1 and the slab phantom, reference distance 2 m

Radiation quality	Irradiation distance m	d_F cm (see 6.3.3)	$h_{pK}(10;N,\alpha)$ in Sv/Gy for angle of incidence of									
			0°	10°	20°	30°	40°	45°	50°	60°	70°	80°
N-15 [a]	1,0 - 2,0	25	0,06	0,06	0,06	0,04	0,03	0,03	0,02	0,01	0,00	0,00
N-20 [a]	1,0 - 2,0	25	0,27	0,27	0,26	0,23	0,20	0,17	0,15	0,09	0,04	0,00
N-25 [a]	1,0 - 3,0	23	0,55	0,55	0,53	0,50	0,44	0,41	0,37	0,28	0,15	0,04
N-30	1,0 - 3,0	20	0,79	0,78	0,77	0,74	0,68	0,65	0,60	0,49	0,32	0,12
N-40	1,0 - 3,0	16	1,17	1,16	1,15	1,12	1,06	1,02	0,98	0,85	0,65	0,32
N-60	1,0 - 3,0	11	1,65	1,64	1,62	1,59	1,52	1,47	1,42	1,27	1,04	0,60
N- 80	1,0 - 3,0	11	1,88	1,87	1,86	1,83	1,76	1,71	1,66	1,50	1,26	0,80
N-100	1,0 - 3,0	11	1,88	1,88	1,86	1,82	1,76	1,73	1,68	1,53	1,31	0,86
N-120	1,0 - 3,0	11	1,81	1,80	1,79	1,76	1,71	1,68	1,64	1,51	1,28	0,87
N-150	1,0 - 3,0	11	1,73	1,72	1,71	1,68	1,64	1,61	1,58	1,46	1,26	0,86
N-200	1,0 - 3,0	12	1,57	1,56	1,56	1,55	1,51	1,49	1,46	1,38	1,23	0,86
N-250	1,0 - 3,0	13	1,48	1,48	1,48	1,47	1,44	1,42	1,40	1,33	1,21	0,87
N-300	1,0 - 3,0	15	1,42	1,42	1,42	1,41	1,40	1,38	1,36	1,30	1,19	0,87

[a] With these radiation qualities, care needs to be taken as variations in energy distribution may have a substantial influence on the numerical values of conversion coefficients (see 4.1.2).

6.4.4.5 Wide series

See Table 31.

Table 31 — Conversion coefficient $h_{pK}(10;W,\alpha)$ from air kerma, K_a, to the dose equivalent $H_p(10)$ for radiation qualities given in ISO 4037-1 and the slab phantom, reference distance 2 m

Radiation quality	Irradiation distance m	d_F cm (see 6.3.3)	$h_{pK}(10;W,\alpha)$ in Sv/Gy for angle of incidence of									
			0°	10°	20°	30°	40°	45°	50°	60°	70°	80°
W-60	1,0 - 3,0	11	1,55	1,53	1,52	1,49	1,42	1,37	1,33	1,18	0,95	0,54
W-80	1,0 - 3,0	11	1,77	1,76	1,74	1,71	1,65	1,60	1,54	1,39	1,15	0,70
W-110	1,0 - 3,0	11	1,87	1,86	1,85	1,82	1,76	1,72	1,67	1,52	1,29	0,84
W-150	1,0 - 3,0	11	1,77	1,77	1,76	1,73	1,68	1,65	1,61	1,49	1,28	0,86
W-200	1,0 - 3,0	12	1,65	1,64	1,64	1,61	1,57	1,55	1,52	1,42	1,25	0,86
W-250	1,0 - 3,0	13	1,54	1,54	1,54	1,52	1,49	1,47	1,44	1,36	1,22	0,87
W-300	1,0 - 3,0	14	1,47	1,47	1,47	1,46	1,44	1,42	1,40	1,33	1,20	0,87

6.4.4.6 High air kerma rate series

See Table 32.

Table 32 — Conversion coefficient $h_{pK}(10;H,\alpha)$ from air kerma, K_a, to the dose equivalent $H_p(10)$ for radiation qualities given in ISO 4037-1 and the slab phantom, reference distance 2m

Radiation quality	Irradiation distance m	d_F cm (see 6.3.3)	$h_{pK}(10;H,\alpha)$ in Sv/Gy for angle of incidence of									
			0°	10°	20°	30°	40°	45°	50°	60°	70°	80°
H-30 [a]	1,0 - 3,0	20	0,39	0,39	0,38	0,36	0,32	0,29	0,26	0,20	0,11	0,03
H-60	1,0 - 3,0	12	1,19	1,18	1,17	1,13	1,07	1,03	0,99	0,86	0,66	0,33
H-100	1,0 - 3,0	12	1,68	1,67	1,65	1,62	1,56	1,51	1,46	1,31	1,08	0,65
H-200	1,0 - 3,0	12	1,75	1,74	1,73	1,71	1,66	1,62	1,58	1,46	1,26	0,85
H-250	1,0 - 3,0	14	1,67	1,66	1,66	1,64	1,59	1,57	1,53	1,43	1,25	0,86
H-280	1,0 - 3,0	14	1,60	1,59	1,59	1,57	1,54	1,51	1,48	1,39	1,23	0,86
H-300	1,0 - 3,0	15	1,59	1,59	1,58	1,57	1,53	1,51	1,48	1,39	1,23	0,86

[a] With this radiation quality, care needs to be taken as variations in energy distribution may have a substantial influence on the numerical values of conversion coefficients (see 4.1.2).

6.4.4.7 Radionuclide sources and high energy photon radiations

See Table 33.

Table 33 — Conversion coefficient $h_{pK}(10;S,\alpha)$ and $h_{pK}(10;R,\alpha)$ from air kerma, K_a, to the dose equivalent $H_p(10)$ for radiation qualities given in ISO 4037-1 and the slab phantom

Radiation quality	Irradiation distance m	d_F cm (see 6.3.3)	Build-up. layer	k_{PMMA}	$h_{pK}(10;S,\alpha)$ and $h_{pK}(10;R,\alpha)$ in Sv/Gy for angle of incidence of									
					0°	**10°**	**20°**	**30°**	**40°**	**45°**	**50°**	**60°**	**70°**	**80°**
S-Am	2,0 - 3,0	11	--	--	1,89	1,88	1,86	1,83	1,77	1,72	1,66	1,50	1,25	0,79
S-Cs	1,5 - 4,0	15	2	1,00	1,21	1,22	1,22	1,22	1,22	1,22	1,22	1,19	1,14	0,92
S-Co	1,5 - 4,0	15	4	1,00	1,15	1,15	1,15	1,15	1,16	1,16	1,16	1,14	1,12	0,96
R-C	1,0 - 5,0	15	25	0,94	1,11	1,11	1,12	1,12	1,11	1,11	1,11	1,11	1,10	1,03
R-F	1,0 - 5,0	15	25	0,94	1,12	1,12	1,12	1,11	1,11	1,11	1,11	1,12	1,13	1,07
R-Ti	1,0 - 5,0	15	25	0,94	1,11	1,11	1,11	1,11	1,10	1,11	1,11	1,11	1,12	1,05
R-Ni	1,0 - 5,0	15	25	0,94	1,11	1,11	1,11	1,11	1,10	1,10	1,10	1,11	1,12	1,06
R-O	1,0 - 5,0	15	25	0,94	1,12	1,12	1,12	1,11	1,11	1,11	1,11	1,12	1,13	1,07

7 Presentation of results

7.1 Records and certificates

National regulations often specify details and format of both calibration records and certificates as well as the frequency of calibration and the length of time for which calibration records should be kept.

The records or certificates should include:

a) date and place of calibration;

b) description of dosemeter, its type and serial number;

c) owner of the dosemeter;

d) details of the radiation sources and secondary standard instruments used;

e) reference conditions, calibration conditions and/or standard test conditions;

f) results;

g) name of person carrying out the calibration;

h) any special observations.

7.2 Statement of uncertainties

The statement of uncertainty shall be consistent with the approaches recommended by the ISO Guide to the Expression of Uncertainty in Measurement (1993).

The following component uncertainties shall be taken into account. Numerical values given are to serve as a guideline, they refer to a confidence level of 68 % (one standard deviation). For further information, see ISO 4037-2.

a) uncertainty of the conventional true value: as taken from the calibration certificate;

b) uncertainty in the exact positioning of standard and test instrument (see 4.1.5): to be assessed by the test laboratory;

c) uncertainty resulting from different irradiation distances: 1 % for irradiation distances greater than 2 m, otherwise to be assessed by the test laboratory;

d) uncertainty of the conversion coefficient: usually 2 %, apart for those reference radiations marked by "a" in certain tables of clauses 5 and 6, in these cases, the test laboratory shall assess the uncertainty on the basis of the conditions prevailing;

e) uncertainty due to field inhomogeneities 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': 2 % for distances between source and point of test source greater than 2 m;

f) uncertainty due to the simultaneous irradiation of several dosemeters (see 6.3.3); an estimate of the effect of absorption of the primary radiation by the dosemeters shall be made and added to the component uncertainties, where applicable, upper limit 2 %;

g) uncertainties due to simplified procedures (see 6.3.1); where applicable, to be assessed by the test laboratory, upper limit 2 %;

h) uncertainty introduced by using a build-up plate, where applicable 1 %;

i) uncertainty due to long-term variation of response of standard instrument, upper limit 2 % (see 4.2.1).

Annex A
(informative)

Additional information

A.1 Statement of reference conditions and required standard test conditions

A.1.1 Radiological parameters

See Table A.1.

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

Influence quantities	Reference conditions	Standard test conditions (unless otherwise indicated)
Photon energy	^{137}Cs [a]	^{137}Cs [a]
Angle of radiation incidence	Reference orientation	Reference orientation ± 5°
Contamination by radioactive elements	Negligible	Negligible
Radiation background	Ambient dose equivalent rate $\dot{H}^*(10)$ 0,1 µSv h^{-1} or less if practical	Ambient dose equivalent rate $\dot{H}^*(10)$ less than 0,25 µSv h^{-1}

[a] Another radiation quality may be used if the rated energy range of the dosemeter does not comprise the energy of the photons emitted by ^{137}Cs.

A.1.2 Other parameters

See Table A.2.

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

Influence quantities	Reference conditions	Standard test conditions (unless otherwise indicated)
Ambient temperature	20° C	18 °C to 22 °C [a]
Relative humidity	65 %	50 % to 75 % [a]
Atmospheric pressure	101,3 kPa	86 kPa to 106 kPa [a]
Stabilization time	15 min	> 15 min
Power supply voltage	Nominal power supply voltage	Nominal power supply voltage ± 3 %
Frequency [b]	Nominal frequency	Nominal frequency ± 1 % [b]
A.C. power supply	Sinusoidal	Sinusoidal with total wave-form harmonic distortion less than 5 % [b]
Electromagnetic field of external origin	Negligible	Less than the lowest value that causes interference
Magnetic induction of external origin	Negligible	Less than twice the value of the induction due to the earth's magnetic field
Assembly controls	Set up for normal operation	Set up for normal operation

[a] The actual values of these quantities at the time of test shall be stated. The values in this table are intended for calibrations performed in temperate climates. In other climates, it may be permitted to extend the range of standard test conditions beyond those stated where dosemeters are to be used in these climates. Similarly, a lower limit of pressure of 70 kPa may be permitted where dosemeters are to be used at higher altitudes.

[b] Only for assemblies which are operated from the main voltage supply.

A.2 Conversion coefficients from air kerma to $H_p(0,07)$ in the ICRU slab phantom

A.2.1 Mono-energetic radiations

See Table A.3.

Table A.3 — Conversion coefficient $h_{pK}(0,07;E,\alpha)$ from air kerma, K_a, to the dose equivalent $H_p(0,07)$ for mono-energetic and parallel photon radiation (expanded field) and the slab phantom

Energy	$h_{pK}(0,07;E,\alpha)$ in Sv/Gy for angle of incidence of									
keV	0°	10°	20°	30°	40°	45°	50°	60°	70°	80°
5	0,75	0,75	0,74	0,72	0,69	0,67	0,65	0,58	0,45	0,21
6	0,84	0,84	0,84	0,83	0,80	0,79	0,77	0,72	0,63	0,40
8	0,92	0,92	0,91	0,91	0,90	0,90	0,89	0,86	0,82	0,67
10	0,95	0,94	0,94	0,94	0,94	0,94	0,93	0,91	0,89	0,80
12,5	0,96	0,96	0,96	0,96	0,95	0,95	0,95	0,94	0,92	0,87
15	0,98	0,98	0,98	0,98	0,98	0,98	0,97	0,97	0,95	0,91
20	1,04	1,04	1,04	1,04	1,03	1,03	1,03	1,03	1,01	0,97
30	1,23	1,22	1,22	1,22	1,20	1,20	1,19	1,16	1,13	1,07
40	1,44	1,44	1,43	1,43	1,41	1,39	1,38	1,33	1,28	1,18
50	1,63	1,63	1,62	1,60	1,57	1,56	1,54	1,48	1,40	1,28
60	1,72	1,71	1,70	1,69	1,66	1,65	1,63	1,57	1,49	1,36
80	1,73	1,72	1,72	1,72	1,69	1,67	1,66	1,61	1,53	1,42
100	1,67	1,66	1,66	1,65	1,63	1,62	1,61	1,58	1,52	1,43
125	1,59	1,59	1,59	1,58	1,57	1,57	1,56	1,53	1,50	1,42
150	1,52	1,52	1,52	1,52	1,51	1,51	1,50	1,48	1,46	1,41
200	1,43	1,43	1,43	1,43	1,44	1,44	1,44	1,43	1,42	1,38
300	1,34	1,34	1,34	1,35	1,35	1,35	1,36	1,36	1,36	1,35

A.2.2 Fluorescence radiations and ^{241}Am

See Table A.4.

Table A.4 — Conversion coefficient $h_{pK}(0,07;F,\alpha)$ and $h_{pK}(0,07;S,\alpha)$ from air kerma, K_a, to the dose equivalent $H_p(0,07)$ for radiation qualities given in ISO 4037-1 and the slab phantom, reference distance 2 m

Radiation quality	Irradiation distance	d_F cm (see 6.3.3)	$h_{pK}(0,07;F,\alpha)$ and $h_{pK}(0,07;S,\alpha)$ in Sv /Gy for angle of incidence of									
	m		0°	10°	20°	30°	40°	45°	50°	60°	70°	80°
F-Zn	1,0 - 2,0	25	0,93	0,93	0,92	0,92	0,92	0,92	0,91	0,88	0,85	0,72
F-Ge	1,0 - 2,0	25	0,95	0,94	0,94	0,94	0,94	0,94	0,93	0,91	0,89	0,80
F -Zr	1,0 - 2,0	25	0,99	0,99	0,99	0,99	0,99	0,99	0,98	0,98	0,96	0,92
F-Mo	1,0 - 2,0	25	1,01	1,01	1,01	1,01	1,00	1,00	1,00	1,00	0,98	0,94
F-Cd	1,0 - 2,0	20	1,09	1,10	1,10	1,10	1,09	1,08	1,08	1,07	1,05	1,00
F-Sn	1,0 - 2,0	20	1,14	1,14	1,14	1,14	1,12	1,12	1,11	1,09	1,07	1,01
F-Cs	1,0 - 2,0	16	1,25	1,24	1,24	1,24	1,22	1,22	1,21	1,18	1,14	1,08
F -Nd	1,0 - 2,0	13	1,39	1,38	1,37	1,38	1,36	1,34	1,33	1,29	1,24	1,15
F-Sm	1,0 - 2,0	12	1,44	1,44	1,43	1,43	1,41	1,39	1,38	1,33	1,28	1,18
F-Er	1,0 - 2,0	11	1,62	1,62	1,61	1,59	1,56	1,55	1,53	1,47	1,39	1,27
F-W	1,0 - 2,0	11	1,72	1,71	1,70	1,69	1,66	1,65	1,63	1,57	1,49	1,36
F-Au	1,0 - 2,0	11	1,73	1,72	1,72	1,72	1,68	1,67	1,65	1,60	1,52	1,40
F-Pb	1,0 - 2,0	11	1,73	1,72	1,72	1,72	1,69	1,67	1,66	1,61	1,53	1,41
F-U	1,0 - 2,0	11	1,68	1,66	1,66	1,66	1,64	1,63	1,62	1,58	1,52	1,43
S-Am	1,0 - 2,0	11	1,72	1,71	1,70	1,69	1,66	1,65	1,63	1,57	1,49	1,36

A.2.3 Low air kerma rate series

See Table A.5.

Table A.5 — Conversion coefficient $h_{pK}(0,07;L,\alpha)$ from air kerma, K_a, to the dose equivalent $H_p(0,07)$ for radiation qualities given in ISO 4037-1 and the slab phantom, reference distance 2 m

Radiation quality	Irradiation distance	d_F cm (see 6.3.3)	$h_{pK}(0,07;L,\alpha)$ in Sv/Gy for angle of incidence of									
	m		0°	10°	20°	30°	40°	45°	50°	60°	70°	80°
L-10	1,0 - 2,0	25	0,93	0,93	0,92	0,92	0,91	0,91	0,90	0,87	0,84	0,70
L-20	1,0 - 2,0	25	1,00	1,00	1,00	1,00	0,99	0,99	0,99	0,99	0,97	0,93
L-30	1,0 - 2,0	18	1,14	1,14	1,14	1,14	1,13	1,12	1,12	1,10	1,08	1,02
L-35	1,0 - 2,0	16	1,22	1,21	1,21	1,21	1,20	1,19	1,19	1,16	1,13	1,06
L-55	1,0 - 2,0	11	1,57	1,56	1,55	1,54	1,52	1,50	1,48	1,43	1,36	1,25
L-70	1,0 - 2,0	11	1,71	1,70	1,69	1,68	1,65	1,64	1,62	1,56	1,48	1,35
L-100	1,0 - 2,0	11	1,71	1,70	1,70	1,70	1,67	1,65	1,64	1,60	1,53	1,43
L-125	1,0 - 2,0	11	1,64	1,63	1,63	1,62	1,61	1,60	1,59	1,56	1,51	1,43
L-170	1,0 - 2,0	12	1,53	1,53	1,53	1,53	1,52	1,52	1,51	1,49	1,47	1,41
L-210	1,0 - 2,0	12	1,45	1,45	1,45	1,46	1,46	1,46	1,45	1,44	1,43	1,39
L-240	1,0 - 2,0	13	1,42	1,42	1,42	1,42	1,43	1,43	1,43	1,42	1,42	1,37

A.2.4 Narrow series

See Table A.6.

Table A.6 — Conversion coefficient $h_{pK}(0{,}07;N,\alpha)$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for radiation qualities given by ISO 4037-1 and the slab phantom, reference distance 2 m

Radiation quality	Irradiation distance m	d_F cm (see 6.3.3)	$h_{pK}(0{,}07;N,\alpha)$ in Sv/Gy for angle of incidence of									
			0°	10°	20°	30°	40°	45°	50°	60°	70°	80°
N-10	1,0- 2,0	25	0,91	0,91	0,90	0,90	0,89	0,88	0,87	0,84	0,79	0,63
N-15	1,0 - 2,0	25	0,96	0,95	0,95	0,95	0,95	0,95	0,94	0,93	0,91	0,84
N-20	1,0 - 2,0	25	0,98	0,98	0,98	0,98	0,98	0,98	0,97	0,97	0,95	0,91
N-25	1,0 - 2,0	23	1,03	1,03	1,03	1,03	1,02	1,02	1,02	1,02	1,00	0,96
N-30	1,0 - 2,0	20	1,10	1,10	1,10	1,10	1,09	1,09	1,08	1,07	1,05	1,00
N-40	1,0 - 3,0	16	1,27	1,26	1,26	1,26	1,24	1,23	1,22	1,19	1,16	1,09
N-60	1,0 - 3,0	11	1,55	1,55	1,54	1,53	1,50	1,49	1,47	1,42	1,35	1,24
N-80	1,0 - 3,0	11	1,72	1,71	1,70	1,70	1,66	1,65	1,63	1,58	1,50	1,37
N-100	1,0 - 3,0	11	1,72	1,70	1,70	1,70	1,68	1,66	1,65	1,60	1,53	1,42
N-120	1,0 - 3,0	11	1,67	1,66	1,66	1,65	1,63	1,62	1,61	1,58	1,52	1,43
N-150	1,0 - 3,0	11	1,61	1,60	1,60	1,60	1,58	1,58	1,57	1,54	1,50	1,42
N-200	1,0 - 3,0	12	1,49	1,49	1,49	1,49	1,49	1,49	1,48	1,46	1,45	1,40
N-250	1,0 - 3,0	13	1,42	1,42	1,42	1,42	1,43	1,43	1,44	1,43	1,42	1,37
N-300	1,0 - 3,0	15	1,38	1,38	1,38	1,38	1,40	1,40	1,41	1,40	1,40	1,36

A.2.5 Wide series

See Table A.7.

Table A.7 — Conversion coefficient $h_{pK}(0{,}07;W,\alpha)$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for radiation qualities given in ISO 4037-1 and the slab phantom, reference distance 2 m

Radiation quality	Irradiation distance m	d_F cm (see 6.3.3)	$h_{pK}(0{,}07;W,\alpha)$ in Sv/Gy for angle of incidence of									
			0°	10°	20°	30°	40°	45°	50°	60°	70°	80°
W-60	1,5 - 3,0	11	1,49	1,48	1,48	1,47	1,44	1,43	1,42	1,37	1,31	1,21
W-80	1,5 - 4,0	11	1,64	1,63	1,62	1,61	1,58	1,57	1,55	1,50	1,43	1,31
W-110	1,5 - 4,0	11	1,71	1,70	1,70	1,69	1,67	1,65	1,64	1,59	1,52	1,41
W-150	1,5 - 4,0	11	1,64	1,64	1,64	1,63	1,61	1,60	1,59	1,56	1,51	1,42
W-200	1,5 - 4,0	12	1,55	1,55	1,55	1,54	1,53	1,53	1,52	1,50	1,47	1,41
W-250	1,5 - 4,0	13	1,47	1,47	1,47	1,47	1,47	1,47	1,47	1,45	1,44	1,39
W-300	1,5 - 4,0	14	1,42	1,42	1,42	1,42	1,43	1,43	1,44	1,43	1,42	1,37

A.2.6 High air kerma rate series

See Table A.8.

Table A.8 — Conversion coefficient $h_{pK}(0{,}07;H,\alpha)$ from air kerma, K_a, to the dose equivalent $H_p(0{,}07)$ for radiation qualities given in ISO 4037-1 and the slab phantom, reference distance 2 m

Radiation quality	Irradiation distance m	d_F cm (see 6.3.3)	$h_{pK}(0{,}07;H,\alpha)$ in Sv/Gy for angle of incidence of 0°	10°	20°	30°	40°	45°	50°	60°	70°	80°
H-10	1,5 - 3,0	25	0,89	0,89	0,88	0,88	0,86	0,86	0,84	0,80	0,74	0,56
H-20	1,5 - 3,0	25	0,95	0,95	0,95	0,95	0,94	0,94	0,94	0,92	0,90	0,81
H-30	1,5 - 3,0	20	1,01	1,01	1,01	1,01	1,00	1,00	1,00	0,99	0,97	0,92
H-60	1,5 - 3,0	12	1,29	1,29	1,29	1,28	1,27	1,26	1,25	1,22	1,18	1,10
H-100	1,5 - 4,0	12	1,58	1,57	1,57	1,56	1,53	1,52	1,51	1,46	1,39	1,28
H-200	1,5 - 4,0	12	1,62	1,62	1,62	1,61	1,59	1,59	1,57	1,54	1,49	1,40
H-250	1,5 - 4,0	14	1,56	1,56	1,56	1,56	1,55	1,54	1,53	1,51	1,47	1,40
H-280	1,5 - 4,0	14	1,51	1,51	1,51	1,51	1,51	1,50	1,50	1,48	1,46	1,40
H-300	1,5 - 4,0	15	1,51	1,50	1,50	1,50	1,50	1,50	1,50	1,48	1,45	1,39

A.3 Effects associated with electron ranges

Electrons above about 65 keV and above about 2 MeV can penetrate 0,07 mm and 10 mm of ICRU tissue, respectively. This is of importance for all reference radiations in which secondary electrons with energies above these values may be generated. The fact that the range of electrons is larger than the depth of measurement has the consequence that the dose equivalent in the depth of 0,07 mm or 10 mm can differ substantially from the value which would be obtained under conditions of transient secondary electron equilibrium. In other words, the dose in the depth of interest **cannot** be calculated in the so-called kerma approximation, in which it is assumed that the energy transferred in a photon interaction process is deposited at the point of interaction.

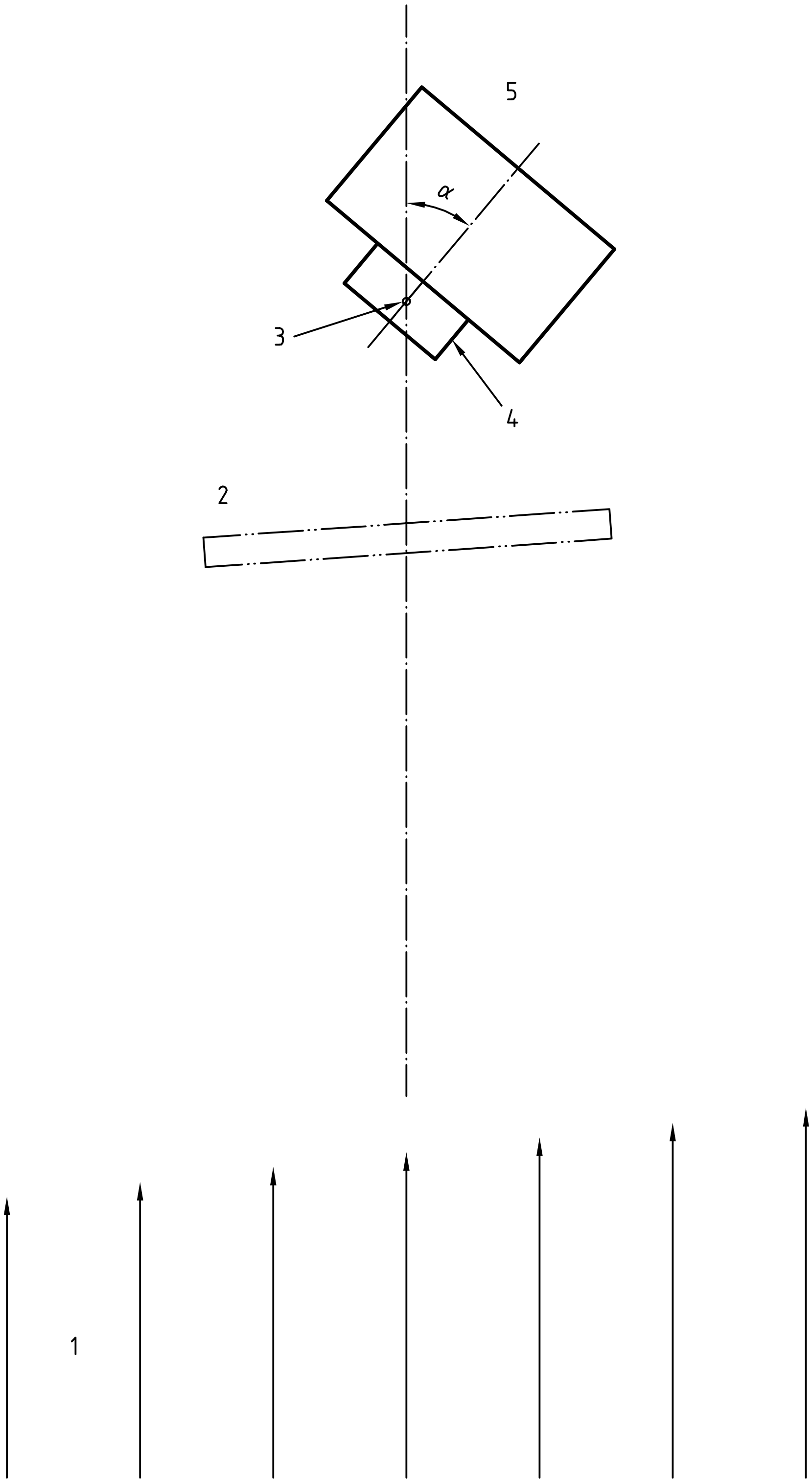
Figures A.3 a) and A.3 b) give examples of depth ionization curves obtained in the R-Ni and R-F reference radiation fields, respectively, showing that transient secondary electron equilibrium is achieved only at depths greater than about 3 cm. Depending on the nature of the radiation source and on the kind and geometry of materials between the source and point of test, the depth dose curve may rise or fall with increasing depth as long as the conditions of electron equilibrium are not fulfilled or, as most radiation detectors do not work under conditions of electron equilibrium, as long as build-up is not completed. A rise in the depth dose curve indicates that the electron fluence in the photon beam is smaller than it would be under equilibrium conditions and vice versa. In the following, the term "build-up" is used in a generic sense implying that the depth dose curve may rise or fall with increasing depth (see Figures A.3a) and A.3b).

The depths of measurement for area and individual monitoring recommended by the ICRU are 0,07 mm and 10 mm, irrespective of whether the build-up is completed in the depth of interest. Therefore, it is not reasonable to use conversion coefficients assuming electronic equilibrium and hence completed build-up. On the other hand, the sign and magnitude of the deviations of the dose from its value under electronic equilibrium depend on the particular experimental set-up actually being used, which excludes the use of universally applicable conversion coefficients.

The solution to the problem adopted in this part of ISO 4037 is the following. In reference photon radiation fields with maximum energies above 65 keV and 2 MeV, the conventional true value of the quantities $H(0{,}07)$ and $H(10)$ shall be determined in the usual way by measuring, at the point of test, the air kerma (see ISO 4037-2) converted to the dose equivalent quantity of interest by multiplication with the conversion coefficient given in Tables 2 to 33 or A.3 to A.8. This means that, for the experimental determination of the conventional true value of the quantity measured, no additional build-up material is actually employed. As the conversion coefficients in the tables of this part of ISO 4037 are valid only under conditions of secondary electron equilibrium, the instrument under test must be irradiated accordingly, i.e. in a radiation field where secondary electron equilibrium is established. If the detector of the instrument under test is not surrounded by a sufficient amount of material to secure complete build-up, this shall be achieved by adding a layer of sufficient thickness of a material which is reasonably tissue equivalent. In this part of ISO 4037 a PMMA plate is used for this purpose.

The reading of the instrument to be tested which is to be related to the conventional true value of the dose equivalent shall be determined with the PMMA plate located in front of the reference point of the dosemeter. The plate shall have a square cross-sectional area with dimensions of 30 cm × 30 cm. The influence of the PMMA plate on the photon field by scattering and attenuation is taken into account by a correction factor k_{PMMA}. As a rule, the plate should be positioned immediately in front of the detector. However, if the variation of response with the direction of radiation incidence is examined, it may be practical to locate the plate a certain distance away from the detector in the direction of the radiation source to allow a rotation of the dosemeter or of the combination of dosemeter and phantom, holding the plate stationary as shown in Figure A1. This arrangement also secures complete build-up for angles of rotation around 90° and it requires only one value of k_{PMMA} for all angles of rotation.

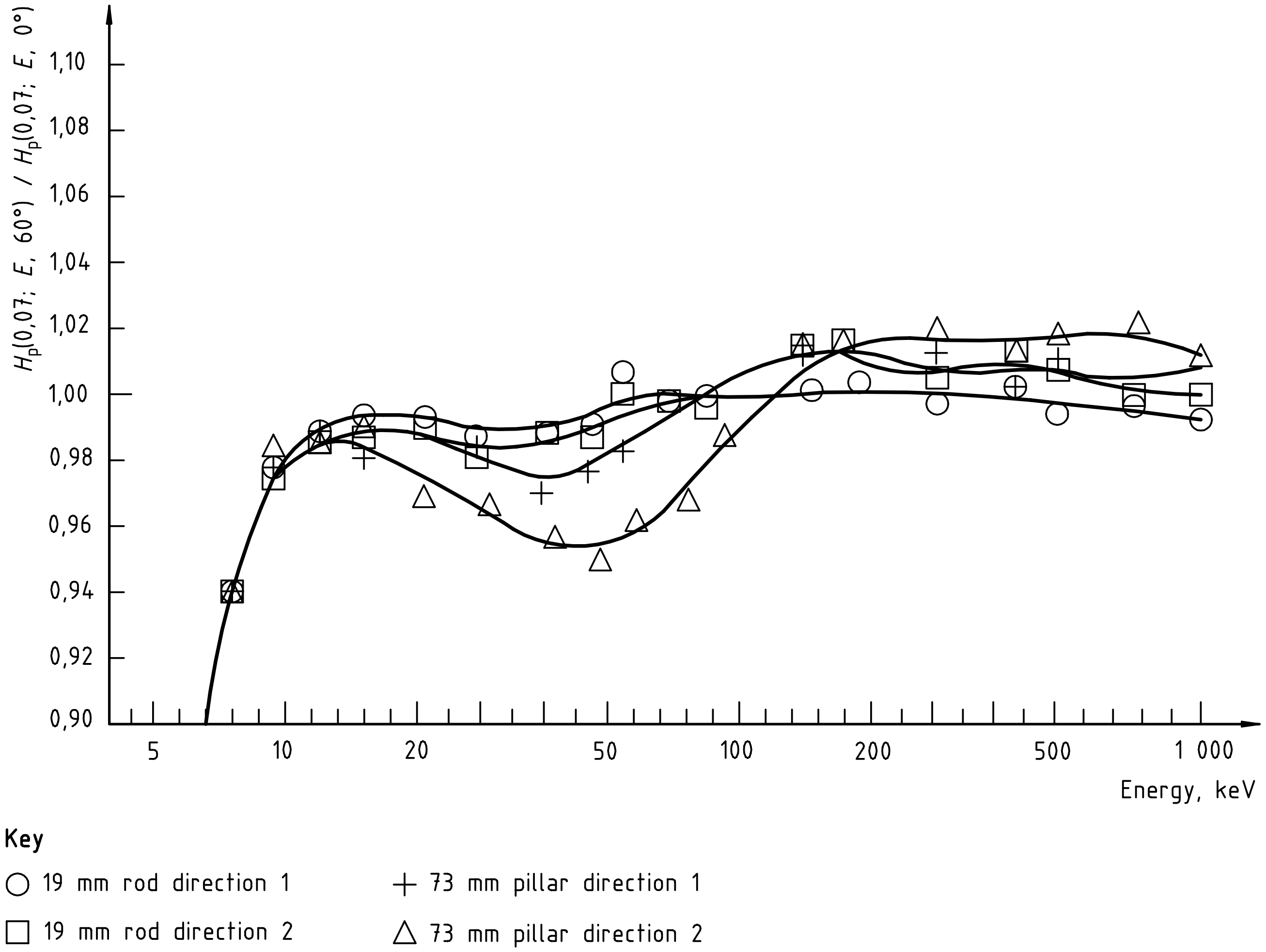
The above procedure makes sure that the result of a calibration is independent of possible deviations from complete build-up. It assures that, in the absence of the PMMA plate, the instrument performs correct measurements in photon fields under conditions of electronic equilibrium. It does not secure a correct measurement of the dose equivalent in cases of mixed photon and electron fields, where the range of electrons is larger than the depth of measurement. A correct measurement of dose equivalent in these cases also requires a calibration in suitable electron reference radiation fields for $H(0{,}07)$ and $H(10)$ (see ISO 6980-1), which is beyond the scope of this part of ISO 4037.



Key

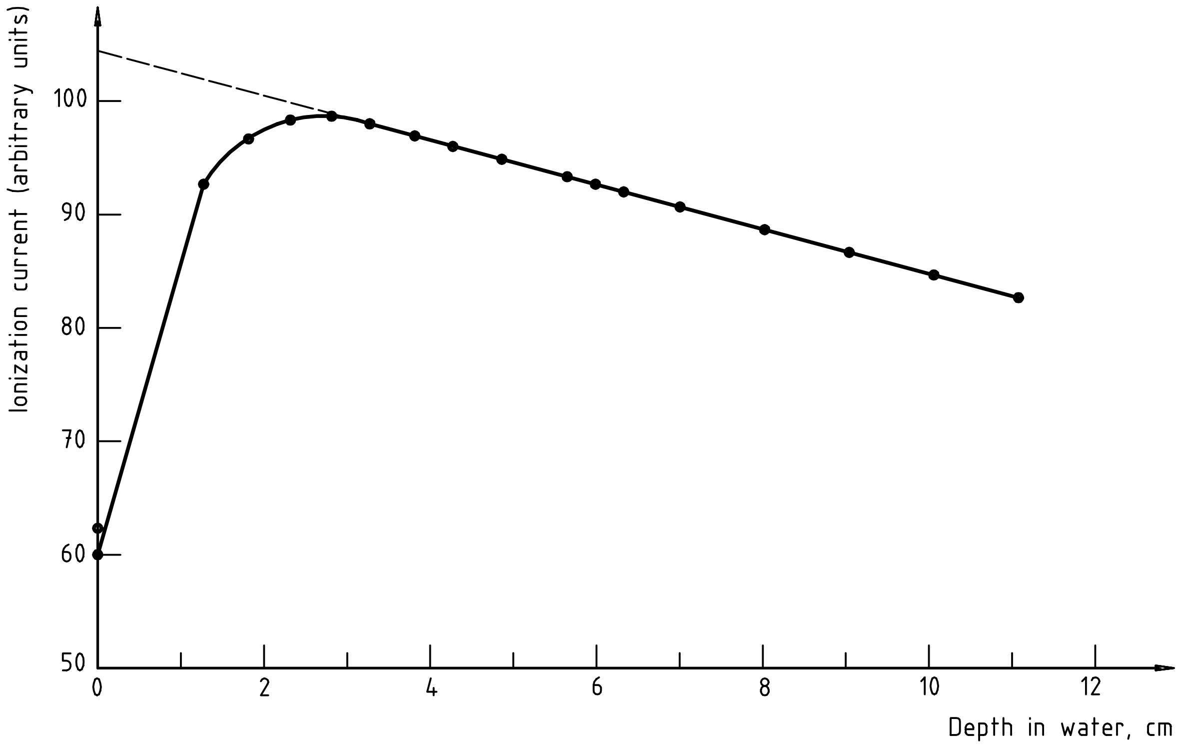
1 Near-parallel beam
2 Build-up layer if required
3 Reference point
4 Dosemeter
5 Slab phantom

Figure A.1 — Arrangement for the calibration of personal dosemeters at angle α

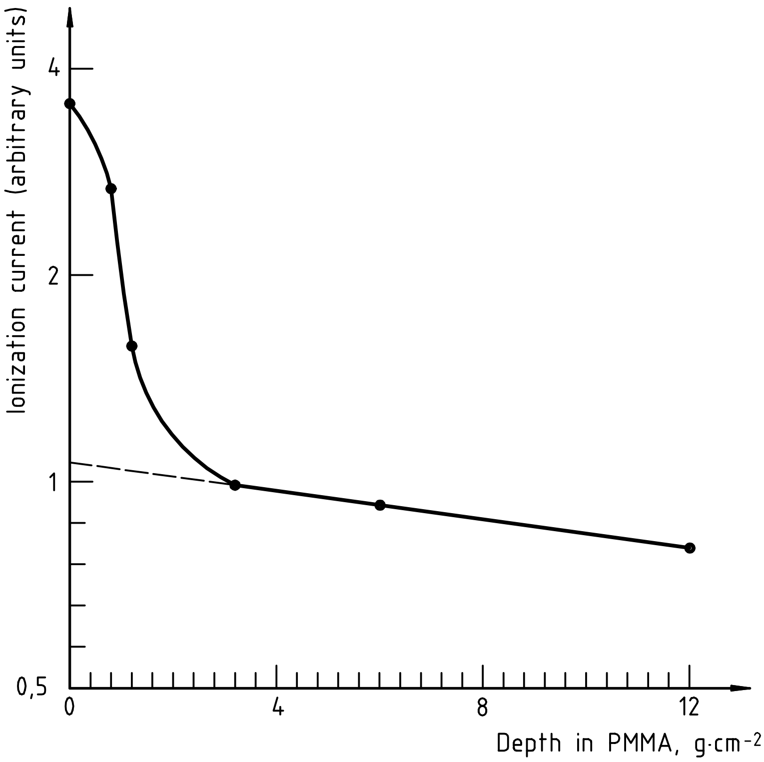


NOTE Direction 1 represents a rotation around the cylinder axis and direction 2 around the axis perpendicular to the cylinder axis and to the direction of radiation incidence.

Figure A.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



a) R – Ni



b) R – F

Key

1 Ionization current (arbitrary units)
2 Depth in water, in centimetres
3 Depth in PMMA, in grams per square centimetre

Figure A.3 — Examples of build-up curves in high energy photon fields

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