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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 4: Calibration of area and personal dosemeters in low energy X reference radiation fields

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 4: Étalonnage des dosimètres de zone (ou d'ambiance) et individuels dans des champs de référence X de faible énergie

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies

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ISO 4037-4 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 from 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*

— *Part 4: Calibration of area and personal dosemeters in low energy X reference radiation fields*

Introduction

This part of ISO 4037 is closely related to the three other parts of ISO 4037. The first, ISO 4037-1, describes the methods of production and characterisation of the photon reference radiations. The second, ISO 4037-2, describes the dosimetry of the reference radiations and the third, ISO 4037-3, 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] for radiation protection purposes.

This part of ISO 4037 is the fourth part of the series, and it describes special procedures for low energy X reference radiation fields. In ISO 4037-3, all the dose quantities used are based on the air kerma K_a free in air. Either K_a is the selected measuring quantity, or one of the dose-equivalent quantities $H'(0,07)$, $H_p(0,07)$, $H_p(10)$ and $H^*(10)$ is determined using conversion coefficients from air kerma K_a to the appropriate dose-equivalent quantity. For the dose-equivalent quantities $H'(0,07)$ and $H_p(0,07)$, this procedure is associated with only a small additional uncertainty, because the conversion coefficients depend only slightly on the photon energy and angle of radiation incidence for the ranges given in ISO 4037-3. Therefore, for these dose-equivalent quantities, no special attention is given for the low energy X reference radiation fields. For the two other dose-equivalent quantities $H_p(10)$, and $H^*(10)$, this is different. For them, the use of conversion coefficients can be associated with large additional uncertainties if low energy X reference radiation fields are considered; see the remark already given in these cases in ISO 4037-3. This is because the conversion coefficients depend strongly on the photon energy and the angle of radiation incidence. For nominally the same radiation quality as defined in ISO 4037-1, the conversion coefficients can differ by several tens of percent. A detailed description of all the measurements and methods necessary to avoid these additional uncertainties is given by Ankerhold *et al.* [4, 5] and by Behrens [6].

NOTE For irradiation of the whole body, $H_p(10)$ and $H^*(10)$ are relevant for radiation protection, as long as they are closer to their limit than $H'(0,07)$ and $H_p(0,07)$. This is the case down to about 15 keV.

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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 4:
Calibration of area and personal dosemeters in low energy X reference radiation fields

1 Scope

This part of ISO 4037 gives guidelines on additional aspects of the characterization of low energy photon radiations. This part of ISO 4037 also describes procedures for calibration and determination of the response of area and personal dose(rate)meters as a function of photon energy and angle of incidence. This part of ISO 4037 concentrates on the accurate determination of conversion coefficients from air kerma to $H_p(10)$ and $H^*(10)$ for the spectra of low energy photon radiations. As an alternative to the use of conversion coefficients, the direct calibration in terms of these quantities by means of appropriate reference instruments is described.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4037-1:1996, *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 from 8 keV to 1,3 MeV and 4 MeV to 9 MeV*

ISO 4037-3:1999, *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*

BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, *Guide to the Expression of Uncertainty in Measurement*, 1995

ICRU Report 51:1993, *Quantities and Units in Radiation Protection Dosimetry*, International Commission on Radiation Units and Measurements, Bethesda, Maryland 20814, USA

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4037-3 and the following apply.

3.1
low energy X-ray reference radiation
all radiation qualities as specified in ISO 4037-1 and ISO 4037-3 with nominal tube potentials up to and including 30 kV

NOTE These radiation qualities are all continuous reference filtered radiations and fluorescence radiations.

3.2
spectral fluence
distribution of fluence Φ with respect to photon energy E

$$\Phi_E = \frac{\mathrm{d}\Phi}{\mathrm{d}E}$$

3.3
spectral air kerma
distribution of air kerma, K_{a} with respect to photon energy E

$$\left(K_{\mathrm{a}}\right)_E = \frac{\mathrm{d}K_{\mathrm{a}}}{\mathrm{d}E}$$

3.4
pulse height spectrum
dN/dQ
distribution of number of pulses N with respect to charge Q generated in the detector

3.5
spectral-fluence response function
function $R(E, Q)$ describing the relationship between spectral-fluence Φ_{E} and the pulse height spectrum, dN/dQ

$$\frac{\mathrm{d}N}{\mathrm{d}Q} = \int_{E_0}^{E_{\mathrm{max}}} R(E,Q) \cdot \Phi_{\mathrm{E}} \ \mathrm{d}E$$

3.6
unfolding
determination of the spectral-fluence Φ_{E} from the (measured) pulse height spectrum, dN/dQ

3.7
spectral-fluence response matrix
matrix where each column represents the response function $R(E, Q)$ for photons with energy E

4 Symbols (and abbreviated terms)

The symbols (and abbreviated terms) used are given in Table 1.

Table 1 — Symbols (and abbreviated terms)

Symbol	Meaning	Unit
ρ	air density	kg/m^3
ρ_0	air density under reference conditions: ρ_0 = 1,1974 kg/m^3	kg/m^3
ρ_{irr}	air density prevailing during irradiation	kg/m^3
ρ_{con}	air density prevailing during determination of the conventionally true value of the measurand	kg/m^3
ρ_{cal}	air density prevailing during calibration of the instrument	kg/m^3
ρ_{MC}	air density prevailing during calibration of the monitor chamber	kg/m^3
ρ_{spec}	air density prevailing during the spectral measurements	kg/m^3
$\Delta\rho$	change of air density	kg/m^3
α	angle of radiation incidence to the normal of the phantom surface	° (degree)
$\Delta\alpha$	change of angle of radiation incidence	° (degree)
U	tube potential	V
ΔU	change in tube potential	V
T	air temperature	K
T_0	air temperature under reference conditions: T_0 = 293,15 K (equivalent to 20 °C)	K
r	relative air humidity	—
r_0	relative air humidity under reference conditions: r_0 = 0,65 (equivalent to 65 %)	—
p	air pressure	kPa
p_0	air pressure under reference conditions: p_0 = 101,3 kPa	kPa
m_d	gradient of the gradient $m(d_{air})$	m^2/kg
$m(d_{air})$	gradient for distance d_{air}	m^3/kg
m(1,0 m)	gradient for distance 1,0 m	m^3/kg
K_a	air kerma free in air	Gy
$k(\rho, M)$	air density correction factor for measurand M	—
$H_p(10)$	personal dose-equivalent at 10 mm depth	Sv
$H_p(0,07)$	personal dose-equivalent at 0,07 mm depth	Sv
$H^*(10)$	ambient dose-equivalent at 10 mm depth	Sv
$H'(0,07)$	directional dose-equivalent at 0,07 mm depth	Sv
$h_{p,K}(10, \alpha)$	conversion coefficient from K_a to $H_p(10)$ for angle of radiation incidence α	Sv/Gy
$h^*_K(10)$	conversion coefficient from K_a to $H^*(10)$	Sv/Gy
E	photon energy	eV
d_{MC}	distance from the beam exit window of the X-ray tube to the monitor chamber	m
d_{air}	distance from the beam exit window of the X-ray tube to the point of test	m
$\Phi_E(E)$	spectral fluence at the photon energy E	m^{-2}·eV^{-1}
N	number of pulses generated in the detector	—
Q	charge Q generated in the detector by one photon	C
$R(E, Q)$	response function	m^2·C^{-1}

5 General procedures for calibrating and determining response

All criteria and procedures in Parts 1 to 3 of ISO 4037 are based on the measuring quantity air kerma, K_a, free in air. Either K_a is the selected measuring quantity or one of the dose-equivalent quantities $H'(0{,}07)$, $H_p(0{,}07)$, $H_p(10)$ and $H^*(10)$ is determined using conversion coefficients from air kerma K_a to it. K_a is measured using a secondary standard or other appropriate instruments exactly calibrated. For the dose-equivalent quantities $H'(0{,}07)$ and $H_p(0{,}07)$, this procedure is associated with only a small additional uncertainty, because, for the ranges given in ISO 4037-3, the conversion coefficients depend only slightly on the photon energy and the angle of radiation incidence. Therefore, the only correction given for them for the low energy X reference radiation fields, in addition to Parts 1 to 3 of ISO 4037, is the air density correction and the same applies to the air kerma K_a free in air. For the two other dose-equivalent quantities $H_p(10)$ and $H^*(10)$, this is different. For them, the use of conversion coefficients can be associated with large additional uncertainties if low energy X reference radiation fields are considered, see the remarks already given in these cases in ISO 4037-3:1999 in Tables 9 to 11, 28 to 30 and 32. This is because the conversion coefficients $h_{pK}(10, \alpha)$ and $h^*_K(10)$ depend strongly on the photon energy, and $h_{pK}(10, \alpha)$ depends in addition on the angle of radiation incidence. For nominally the same radiation quality as defined in ISO 4037-1, the conversion coefficients can differ by several tens of percent.

There are two possible approaches to overcome this deficiency. For method I, a spectrometer is used to measure the spectrum of the radiation quality under consideration. From this spectrum, the exact conversion coefficient can be calculated and applied to the measured value of air kerma, K_a, free in air. For method II, a special standard chamber for $H_p(10)$ or $H^*(10)$ is used. This chamber must have, for these quantities, a similarly small variation in response with energy and, for $H_p(10)$, in-addition angle dependence of the response as required for the standard instrument for air kerma K_a free in air in ISO 4037-2:1997, 4.3.

This part of ISO 4037 defines the conditions that must be met to use one of the two methods and the experimental steps to be used for the selected method. If a monitor chamber (see ISO 4037-2:1997, 8.2) is used as a transfer device, additional corrections must be applied for differences in the air density prevailing during calibration of the monitor chamber and during calibration of the instrument under test. This part of ISO 4037 does not give advice on the construction of the instruments necessary for both methods. Examples for the instruments and the experimental steps for both methods are given by Ankerhold *et al.* [4, 5], Behrens [6] and Duftschmid *et al*. [7].

6 Characterization and production of low energy X-ray reference radiations

6.1 General

This clause specifies the characteristics by which a laboratory can produce the reference filtered X radiations given in ISO 4037-1 for the given purposes. For various influence quantities, data are given on the change which causes a change of the measurand of 2 %. These data shall either be interpreted as limits for the deviation from its nominal value or, where possible, as a criterion for the necessity of corrections.

The requirements given in ISO 4037-1:1996, 4.1.2, paragraph 5 (mean energies within ± 5 % and resolution within ± 15 % of the values given in Tables 3, 4 and 5 of ISO 4037-1) must not be used for the quantities $H_p(10)$ or $H^*(10)$ for low energy reference radiations, as they are not sufficient in these cases and shall be replaced by the requirements in this clause.

6.2 Tube potential

This subclause is relevant for methods I and II. The dose-equivalent quantities $H_p(10)$ and $H^*(10)$ are, for low energy X radiation, more sensitive to the tube potential than the air kerma, K_a, free in air. Table 2 gives values for the change of tube potential that cause a change in the value of the conversion coefficient of 2 %, if all other parameters are unchanged. For methods I and II, the requirements on the absolute value of the tube potential (given in ISO 4037-1:1996, 4.2.2) of ± 2 % are sufficient, but the change in tube voltage must not exceed the limits given in Table 2.

NOTE All calculations in this subclause are based on the following assumptions. Firstly, for the purpose of calculating changes of the value of the conversion coefficient to the dose-equivalent quantity, $H_p(10)$ or $H^*(10)$, for a given radiation quality, the respective conversion coefficient can be replaced by the monoenergetic one for the mean energy. Secondly, the relative change of tube potential and the relative change of the mean energy are equal to each other.

Table 2 — Change of tube potential that causes a change in the value of the conversion coefficients of 2 % for radiation qualities with nominal tube potentials up to and including 30 keV

Radiation quality[a]	Tube potential U kV	Mean energy[b] keV	ΔU causing a change of 2 % of the conversion coefficient V		$\Delta U/U$ causing a change of 2 % of the conversion coefficient %	
			$h_{p,K}(10, 0°)$ $h^*_K(10)$	$h_{p,K}(10, 60°)$	$h_{p,K}(10, 0°)$ $h^*_K(10)$	$h_{p,K}(10, 60°)$
L-10	10	9,2	12	5,4	0,12	0,054
L-20	20	17,4	150	79	0,74	0,40
L-30	30	26,7	450	320	1,5	1,1
N-10	10	8,9	10	5,6	0,1	0,056
N-15	15	12,7	41	22	0,28	0,15
N-20	20	16,5	130	67	0,63	0,33
N-25	25	20,4	250	150	0,99	0,61
N-30	30	24,7	450	300	1,5	0,99
H-10	10	8,7	9	4,6	0,09	0,046
H-20	20	14,0	83	41	0,41	0,21
H-30	30	20,1	300	180	1,0	0,59

a See Table 1 of ISO 4037-3:1999.

b Values were taken from reference [8] in the Bibliography for a distance of 2,5 m, a typical distance for calibrations with respect to $H_p(10)$ performed on an ISO water slab phantom.

6.3 Field uniformity and scattered radiation

This subclause is relevant for methods I and II. The cross-sectional area of the reference-radiation beam should be sufficient to completely irradiate area dosemeters and doserate meters, or the phantom used for the calibration of personal dosemeters. The variation of the air kerma rate over the beam area shall be less than 5 %, and the contribution of scattered radiation to the total air kerma rate shall be less than 5 % (see ISO 4037-1:1996, 4.5). Test 1 of ISO 4037-1:1996, 4.5.3.1 shall not be performed, because the corrections for air attenuation are large and can only be performed if the spectral fluence is known.

6.4 Spectral fluence and conversion coefficients

This subclause is relevant for method I only. For every radiation quality, the knowledge of the spectral fluence is necessary to determine the conversion coefficient from air kerma to the measurand under consideration for the X-ray facility used. In informative Annex B, an example for the determination of the spectral fluence is given. The spectral fluence is converted to a spectral air kerma by folding the spectral fluence with the monoenergetic fluence to air-kerma conversion coefficients. This spectral air kerma is then folded with the monoenergetic conversion coefficients for the respective measurand (see ISO 4037-3) to get the spectral $H_p(10)$ or $H^*(10)$ distribution which is then integrated to get the actual conversion coefficient. The conversion coefficients obtained are valid only for the air density, ρ_{spec}, prevailing during the spectral measurements.