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

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

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

Partie 4: Étalonnage des dosimètres de zone 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 (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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

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

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

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

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

This second edition cancels and replaces the first edition (ISO 4037-4:2004), which has been technically revised.

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

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

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

ISO 4037, focusing on photon reference radiation fields, is divided into four parts. ISO 4037-1 gives the methods of production and characterization of reference radiation fields in terms of the quantities photon fluence and air kerma free-in-air. ISO 4037-2 describes the dosimetry of the reference radiation qualities in terms of air kerma and in terms of the phantom related operational quantities of the International Commission on Radiation Units and Measurements (ICRU)[2]. ISO 4037-3 describes the methods for calibrating and determining the response of dosemeters and doserate meters in terms of the operational quantities of the ICRU[2]. This document gives special considerations and additional requirements for calibration of area and personal dosemeters in low energy X reference radiation fields, which are reference fields with generating potential lower or equal to 30 kV.

The general procedures described in ISO 29661 including Amendment 1 are used as far as possible in this document. In addition, the symbols used are in line with ISO 29661.

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.

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

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

1 Scope

This document gives guidelines on additional aspects of the characterization of low energy photon radiations and on the 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 document concentrates on the accurate determination of conversion coefficients from air kerma to $H_\mathrm{p}(10)$, $H^*(10)$, $H_\mathrm{p}(3)$ and $H'(3)$ and 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 documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 4037-3:2019, *Radiological protection — X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy — Part 3: Calibration of area and personal dosemeters and the measurement of their response as a function of energy and angle of incidence*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4037-1, ISO 29661 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
low energy X-ray reference radiation
all radiation qualities with nominal tube potentials up to and including 30 kV

Note 1 to entry: These radiation qualities are as specified in ISO 4037-1 and all continuous reference filtered X radiations.

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/m³
ρ_0	air density under reference conditions: ρ_0 = 1,197 4 kg/m³	kg/m³
ρ_{irr}	air density prevailing during irradiation	kg/m³
ρ_{con}	air density prevailing during determination of the conventional quantity value of the measurand	kg/m³
ρ_{cal}	air density prevailing during calibration of the instrument	kg/m³
ρ_{MC}	air density prevailing during calibration of the monitor chamber	kg/m³
ρ_{spec}	air density prevailing during the spectral measurements	kg/m³
$\Delta\rho$	change of air density	kg/m³
α	angle of radiation incidence to the normal of the phantom surface	deg
$\Delta\alpha$	change of angle of radiation incidence	deg
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
$H_p(3)$	personal dose equivalent at 3 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
$H'(3)$	directional dose equivalent at 3 mm depth	Sv
$H'(0,07)$	directional dose equivalent at 0,07 mm depth	Sv
$h_{pK}(10; \alpha)$	conversion coefficient from K_a to $H_p(10)$ for angle of radiation incidence α	Sv/Gy
$h^*_p(10)$	conversion coefficient from K_a to $H^*(10)$	Sv/Gy
$h_{pK}(3; \alpha)$	conversion coefficient from K_a to H_p (3) for angle of radiation incidence α	Sv/Gy

Table 1 *(continued)*

Symbol	Meaning	Unit
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

In ISO 4037-2, two methods are given to determine the phantom related dose equivalent quantities for low energy X reference fields. Both methods require a reference field according to ISO 4037-1. The first method, method I, requires the dosimetry with respect to air kerma free-in-air and after that, the selected operational quantity is derived by the application of a conversion coefficient that relates the air kerma free-in-air to the selected operational quantity. For matched reference fields this conversion coefficient is taken from ISO 4037-3, for characterized reference fields the conversion coefficient is determined using spectrometry. 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 needed for the low energy X reference radiation fields. For the four other dose equivalent quantities $H_p(10)$, $H^*(10)$, $H_p(3)$ and $H'(3)$ 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. This is because the conversion coefficients depend strongly on the photon energy and the angle of radiation incidence. A detailed description of all the measurements and methods necessary to avoid these additional uncertainties is given by Ankerhold et al.[3][4] and by Behrens[5].

The second method, method II, to determine the phantom related dose quantities is based on the use of (secondary) standards directly calibrated in terms of these dose equivalent quantities. This method can also be used for all non-validated radiation qualities, for which the recommended conversion coefficients cannot be used. This method is described in ISO 4037-2:2019, Clause 6.

If the reference field cannot be validated, then, method I can still be used if a spectrometer is used to measure the spectrum of the radiation quality under consideration. From this spectrum, the specific conversion coefficient can be calculated and applied to the measured value of the air kerma K_a free-in-air.

This document defines the conditions that shall 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 4037-2:2019, 9.2) is used as a transfer device additional corrections shall be applied for differences in the air density prevailing during calibration of the monitor chamber and during calibration of the instrument under test. The standard does not give advice on the construction of the instruments necessary for both ways. Examples for the instruments and the experimental steps for both ways are given by Ankerhold et al.[3][4], Behrens[5] and Duftschmid et al.[6].

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

6.1 General

This subclause specifies the characteristics by which a laboratory can produce the reference filtered X radiations specified in ISO 4037-1 for the given purposes. For various influence quantities, data are given on the required stability of these influence quantities. These data indicate how large the change in value of these influence quantities can be until a change of the measurand of 2 % is caused. 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 4037-1:2019, 4.2, consider partly the special requirements for low energy reference radiations for the quantities $H_p(10)$ or $H^*(10)$. These special requirements are, to less extent, also valid for the dose equivalent quantities $H'(3)$, $H_p(3)$. Therefore, this document focuses on the quantities $H_p(10)$ or $H^*(10)$ and assumes that for the dose equivalent quantities $H'(3)$, $H_p(3)$ nearly the same requirements are valid.

6.2 Tube potential

This subclause is relevant for method I and method II. The dose equivalent quantities $H_p(10)$, $H^*(10)$, $H_p(3)$ and $H'(3)$ are for low energy X radiation more sensitive to the tube potential than the air kerma, K_a, free-in-air. The requirements on the tube potential given in ISO 4037-1:2019, Table 7 are valid. This Table 7 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.

6.3 Spectral fluence and conversion coefficients

This subclause is relevant for method I only. Knowledge of the spectral fluence is necessary to determine the conversion coefficient from air kerma to the measurand for every radiation quality of the X-ray facility. In ISO 4037-2:2019, Annex B, an example for the determination of the spectral fluence is given. The spectral fluence is converted to a spectral air kerma by multiplying the spectral fluence with the monoenergetic fluence to air kerma conversion coefficients. This spectral air kerma is then multiplied with the monoenergetic conversion coefficients for the respective measurand (see ISO 4037-3) to get the spectral $H_p(10)$, $H^*(10)$, $H_p(3)$ or $H'(3)$ distribution which is then integrated to get the actual conversion coefficient. The obtained conversion coefficients are valid only for the air density ρ_{spec} prevailing during the spectral measurements.

7 Dosimetry of low energy reference radiations

7.1 General

The instruments to be used shall be standard instruments as described in ISO 4037-2:2019, Clause 4. The general procedures in ISO 4037-2:2019, Clauses 5 and 6, and, where appropriate, the procedures applicable to ionization chambers in ISO 4037-2:2019, Clause 7, shall be followed.

7.2 Stability check facility

Where appropriate, a radioactive check source may be used to verify the satisfactory operation of the instrument prior to periods of use.

8 Calibration and determination of the response as a function of photon energy and angle of radiation incidence

8.1 General

The general methods given in ISO 4037-3 shall be followed. For an unsealed standard ionization chamber this includes correction for air temperature, pressure and humidity according to ISO 4037-2:2019, 7.4.2. In Cause 8, additional requirements and advice on the selection of calibration method are given. Moreover, for the dose equivalent quantity $H_p(10)$ limits are given for the adjustment of the angle of incidence.

8.2 Selection of calibration method

This subclause gives information, additional to ISO 4037-2, on the choice of dosimetric method, which can be used for determination of the conventional quantity value of the dose quantities of interest. As explained in Clause 5, two methods are possible to determine the conventional quantity value of the dose quantities of interest.

For the highest level of dissemination of the phantom related quantities, e.g., by National Metrology Institutes, Method I, using spectrometry and reference instruments for K_a is required to achieve an uncertainty of the conventional quantity value of about 6 % (k = 2) or less. The air kerma, K_a, shall be determined by a primary or at least directly traceable standard and spectrometry of the reference field shall be performed according to ISO 4037-2:2019, Annex B, both at the point of test.

Method II, using secondary standard instruments, which measure directly dose equivalent quantities, may be used by all other laboratories. The achievable uncertainty is between 6 % and 10 % (k = 2) depending on the radiation quality.

The time period starting from the determination of the conventional quantity value of the measurand until the calibration of the instrument under test and determination of its response as function of photon energy and angle of radiation incidence has to be considered, because the stability of certain parameters over this period shall be maintained.

8.3 Calibration by using reference instruments for K_a

8.3.1 General

This subclause is relevant for method I only. During the potentially long time period between the determination of the conversion coefficient (see 6.3) and the calibration of the instrument the requirements on tube potential of 6.2 shall be followed. In addition, the air density at all measuring events shall be constant within the limits given in Table 2, otherwise the appropriate corrections, provided in Annex A, shall be applied.

The additional corrections for the use of a monitor chamber as a transfer device are also provided in Annex A.

As an example, Table 2 gives values for the percentage change of air density that causes a change in the value of the air kerma, K_a, and the conversion coefficients $h_{pK}(10, 0°)$, $h^*_K(10)$ and $h_{pK}(10, 60°)$ of 2 % at 2,5 m distance of the point of test from the focus and for 0° and 60° radiation incidence. These conditions are representative for calibrations with respect to $H_p(10)$ performed on a ISO water slab phantom (see ISO 4037-3).

8.3.2 Conventional quantity value of the air kerma

Within the short time period (typically one or a few hours) from the measurement of the conventional quantity value of the air kerma and the determination of the required phantom related quantity value to the calibration of the instrument the air density shall not change by more than the limits given in Table 2. These data are valid for a distance of 2,5 m, which is typical for calibrations with respect to $H_p(10)$ performed on an ISO water slab phantom. Normally, these air density requirements are fulfilled and no correction is necessary, in the other few cases the correction method given in the Annex A shall be applied as follows. If ρ_{con} is the air density prevailing during determination of the conventional quantity value of the air kerma K_a and ρ_{cal} those during calibration of the instrument, then the conventional quantity value of K_a during calibration is

$$K_a(\rho_{cal}) = \frac{k(\rho_{cal}, K_a)}{k(\rho_{con}, K_a)} K_a(\rho_{con}) \qquad (1)$$

For the air density correction factor $k(\rho, K_a)$ for the quantity air kerma K_a see Formula (A.2).