

# INTERNATIONAL STANDARD

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**4037-3**

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## **X and gamma reference radiation for calibrating dosimeters and doserate meters and for determining their response as a function of photon energy —**

### **Part 3:**

Calibration of area and personal dosimeters  
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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## 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 dosimeters and dose rate 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 dosimeters 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 dosimeters 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 dosimeters 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 dosimeter under test, the irradiation is either carried out on a phantom or free in air for personal and area dosimeters, 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 dosimeters and doserate meters in terms of the ICRU operational quantities for photons.

# X and gamma reference radiation for calibrating dosimeters and doserate meters and for determining their response as a function of photon energy —

## Part 3:

## Calibration of area and personal dosimeters 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 dosimeters 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 dosimeters are covered and for area monitoring both portable and installed dosimeters 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 dosimeters which will be covered in a future standard.

The procedures to be followed for the different types of dosimeters 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 dosimeter 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 dosimeters 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 dosimeters 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]):

$$H = QD \quad (1)$$

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  $\Omega$

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,  $\alpha$ , 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 dosimeters, 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 dosimeter 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**

(dosimeter) 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 dosimeter.

### 3.2.6

#### **point of test**

point in the radiation field at which the reference point of a dosimeter 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 dosimeter, with respect to which the angle to the direction of radiation incidence is measured in unidirectional fields

### 3.2.8

#### **reference orientation**

(dosimeter) orientation for which the direction of incident radiation coincides with the reference direction of the dosimeter

**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 dosimeter 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  $\Omega$  of the incident monodirectional radiation.  $R(E)$  describes the "energy dependence" and  $R(\Omega)$  the "angular dependence" of response; for the latter  $\Omega$  may be expressed by the angle  $\alpha$  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 dosimeter 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.  $M_{H_1} + M_{H_2} \neq M_{H_1+H_2}$ . In such cases, the function  $R(E, \Omega)$  dealt with in the previous note is not sufficient to characterize the dosimeter in all radiation fields.

**3.2.11****calibration**

quantitative determination, under a controlled set of standard test conditions, of the reading given by a dosimeter 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 dosimeter. 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 dosimeter is intended to measure,  $H$ , divided by the dosimeter'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 dosimeter 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 dosimeter 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 dosimeter 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:

$$h_K = H / K_a \quad (4)$$

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 dosimeters

### 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 dosimeter 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			High energy photon radiations						
radiation quality	radio-nuclide	$\bar{E}$ keV	radiation quality		reaction		$\bar{E}$ MeV		
S-Am	<sup>241</sup> Am	59,5	R-C	<sup>12</sup> C (p,p' $\gamma$ ) <sup>12</sup> C		4,36 <sup>a</sup>			
S-Cs	<sup>137</sup> Cs	662	R-F	<sup>19</sup> F (p, $\alpha\gamma$ ) <sup>16</sup> O		6,61 <sup>a</sup>			
S-Co	<sup>60</sup> Co	1 250	R-Ti	(n, $\gamma$ ) capture in Ti		5,14 <sup>a</sup>			
			R-Ni	(n, $\gamma$ ) capture in Ni		6,26 <sup>a</sup>			
			R-O	<sup>16</sup> O (n,p) <sup>16</sup> N		6,61 <sup>a</sup>			
<sup>a</sup> 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 dosimeter 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  $\alpha$  between the reference direction of the dosimeter 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  $\pm 2\%$ . 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 dosimeter 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 dosimeters 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.