INTERNATIONAL STANDARD

ISO 4037-2

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

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 2: Dosimétrie pour la radioprotection dans les gammes d'énergie de 8 keV *à* 1,3 MeV *et de* 4 MeV *à* 9 MeV

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

This first edition of ISO 4037-2, along with ISO 4037-1, cancels and replaces the first edition of ISO 4037:1979, which has been technically revised.

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 of X and gamma reference radiation 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*

Annexes A and B of this part of ISO 4037 are for information only.

Introduction

The term "dosimetry" is used in this part of ISO 4037 to describe the method by which the value of a physical quantity characterizing the interaction of radiation with matter may be measured at a given point by the use of a calibrated standard instrument. Dosimetry is the basis for the calibration of radiation protection instruments and devices and the determination of their response as a function of the energy of the radiation of interest.

At present, the quantities in which photon secondary-standard instruments or sources are calibrated for use in radiological protection calibration laboratories relate to measurements made in free air, i.e. air kerma.

NOTE Throughout this part of ISO 4037, kerma is used as an abbreviation for air kerma.

In order to correlate measured physical quantities with the magnitude of a biological effect, a quantity of the dose equivalent type [1] is required for use in radiation protection. ICRU has defined such quantities [2] and a further International Standard will be issued containing tables of conversion coefficients from air kerma to these dose equivalent quantities (see ISO 4037-3).

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

1 Scope

This part of ISO 4037 specifies the procedures for the dosimetry of X and gamma reference radiation for the calibration of radiation protection instruments over the energy range from approximately 8 keV to 1,3 MeV and from 4 MeV to 9 MeV. The methods of production and nominal kerma rates obtained from these reference radiations are given in ISO 4037-1.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 4037. At the time of the publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on the part of ISO 4037 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 4037-1:–[1]), *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 4037-3:–[2]), *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.*

ICRU Report 33:1980, *Radiation quantities and units.*

VIM, 1984, *International Vocabulary of Basic and General Terms in Metrology,* BIPM-IEC-ISO-OIML.

1) To be published. (Revision of ISO 4037:1979)

2) To be published.

3 Definitions

For the purposes of this part of ISO 4037, the definitions given in ICRU Report 33, in the *International Vocabulary of Basic and General Terms in Metrology* (VIM) and the following definitions apply.

3.1 reference conditions
conditions of use for a measuring instrument prescribed for performance testing or conditions to ensure valid comparison of results of measurements [VIM]

NOTE The reference conditions generally specify reference values or reference ranges for the parameters affecting the measuring instrument. For the purposes of this part of ISO 4037, the reference values for temperature, atmospheric pressure and relative humidity are as follows :

ambient temperature : 293,15 K;

atmospheric pressure : 101,3 kPa;

relative humidity : 65 %.

3.2 standard test conditions
value (or range of values) of the influence quantities [VIM] or instrument parameters that are specified for the dosimetry of the radiation fields.

NOTE The range of values for ambient temperature, atmospheric pressure and relative humidity are as follows :

ambient temperature : 291,15 K to 295,15 K;

ambient pressure : 86 kPa to 106 kPa;

relative humidity : 30 % to 75 %.

Working outside this range may result in reduced accuracy.

3.3 ionization chamber
ionization detector consisting of a chamber filled with a suitable gas, in which an electric field, insufficient to induce gas multiplication, is provided for the collection at the electrodes of charges associated with the ions and the electrons produced in the sensitive volume of the detector by the ionizing radiation [3]

NOTE The ionization chamber includes the sensitive volume, the collecting and polarizing electrodes, the guard electrode, if any, the chamber wall, the parts of the insulator adjacent to the sensitive volume and any necessary caps to ensure electron equilibrium.

3.4 ionization chamber assembly
ionization chamber and all other parts to which the chamber is permanently attached, except the measuring assembly

NOTE For a cable-connected chamber, it includes the stem, the electrical fitting and any permanently attached cable or pre-amplifier. For a thin-window chamber, it includes any block of material in which the ionization chamber is permanently embedded.

3.5 measuring assembly
device for measuring the current or charge from the ionization chamber and converting it into a form suitable for display, control or storage

3.6 reference point of the ionization chamber
point to which the measurement of the distance from the radiation source to the chamber at a given orientation refers

NOTE The reference point should be marked on the assembly by the manufacturer of the instrument. If this proves impossible, the reference point should be indicated in the accompanying documentation supplied with the instrument.

3.7 point of test
location of the reference point of the ionization chamber for calibration purposes and at which the conventionally true kerma rate (see 3.11) is known

3.8 chamber orientation effect
change in the ionization current from the ionization chamber as the directional incidence of the reference radiation is varied

3.9 calibration factor
<ionization chamber assembly with an associated measuring assembly> ratio of the conventional true value of the quantity the instrument is intended to measure divided by the indication of the instrument, corrected to stated reference conditions

3.10 calibration factor
<ionization chamber calibrated on its own without a specified measuring assembly> factor which converts the ionization current or charge, corrected to reference conditions, to the conventional true value of the dosimetric quantity at the reference point of the chamber

3.11 true value
value which characterizes a quantity perfectly defined, in the conditions which exist when that quantity is considered

NOTE The true value of a quantity is an ideal concept and, in general, cannot be known exactly. Indeed, quantum effects may preclude the existence of a unique true value [VIM].

3.12 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

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.

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.

3.13 response
ratio between the indication of the measuring assembly and the conventional true value of the measured quantity at the position of the reference point in space

NOTE The response usally varies with the spectral and directional distribution of the incident radiation.

3.14 response time
time interval between the instant when a stimulus is subjected to a specified abrupt change and the instant when the response reaches and remains within specified limits of its final steady value [VIM]

3.15 deviation from linearity
δ

Percentage deviation from linearity given by :

$$\delta = 100\ (mQ/Mq - 1)$$

where

M and Q refer to the indication and input at a chosen test point, respectively ;

m is the indication observed for some other input signal q.

NOTE For multirange instruments, the above definition is applicable to each range.

3.16 leakage current
total detector current flowing at the operating bias in the absence of radiation [3]

3.17 zero drift
slow variation with time of the indication of the measuring assembly when the input is short-circuited

3.18 zero shift
sudden change in the scale reading of either polarity of a measuring assembly when the setting control is changed from the "zero" mode to the "measure" mode, with the input connected to an ionization chamber in the absence of ionizing radiation other than ambient radiation

3.19 primary standard
standard of a particular quantity which has the highest metrological qualities in a given field

3.20 secondary standard
standard, the value of which is fixed by direct or indirect comparison with a primary standard

4 Apparatus

4.1 General

The instrument to be used for the measurement of the reference radiation shall be a secondary standard or other appropriate instrument. Generally this comprises an ionization chamber assembly and measuring assembly. In some applications, for example the determination of low kerma rates, other devices such as scintillation dosemeters are used. For high energies from 4 MeV to 9 MeV (see 10.2 and 10.6.3) other types of instruments such as TLDs and Fricke dosemeters are also used.

4.2 Calibration

The standard instrument shall be calibrated for the range of energies and quantities that are intended to be used.

4.3 Energy dependence of the response of the instrument

Above a mean energy (see ISO 4037-1) of 30 keV, the ratio of the maximum to minimum response of the instrument shall not exceed 1,1 over the energy range for which the standard instrument is to be used. For mean energies between 8 keV and 30 keV, the limit of this ratio shall not exceed 1,2.

Whenever practicable, the reference radiations used to calibrate the secondary standard instrument should be the same as those used for the calibration of radiation protection instruments.

4.4 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.

5 General procedures

The procedures described in this clause are common to the dosimetry of both X and gamma reference radiation.

5.1 Operation of the standard instrument

The mode of operation of the standard instrument shall be in accordance with the instrument calibration certificate and the instrument instruction manual. The time interval between periodic calibrations of the standard instrument, or that between periodic verifications of the stability of calibrations performed with the standard instrument, should be within the acceptable period defined by national regulations. Where no such regulations exist, the time interval should not exceed three years.

5.2 Stability check

Measurements shall be made to check the stability using either an appropriate radioactive check source or calibrated radiation fields to determine that the reproducibility of the instrument is within ± 2 %. Corrections shall be applied for the radioactive decay of the source and for changes in air pressure and temperature from the reference calibration conditions.

NOTE For a multirange instrument, the check source may test only a particular range of the instrument. If the check source may be used to test more than one range, the range that provides the greatest precision for the reading of the indication should be used.

5.3 Warm-up and response times

Sufficient time shall be allowed for the instrument to stabilize before any measurements are carried out. Sufficient time shall be allowed between measurements so that the measurements are independent of the response time of the instrument. For measuring kerma rates, the time interval between successive readings shall not be less than five times the value of the response time of the instrument range in use. The manufacturer shall state both the warm-up and response times of the instrument.

5.4 Zero-setting

If a set-zero control is provided, it shall be adjusted for the instrument range in use, with the detector connected.

5.5 Number of readings

The standard instrument shall be used to make at least four successive readings. However, sufficient readings shall be taken to ensure that the mean value of such readings may be estimated with sufficient precision.

5.6 Energy dependence of response of the standard instrument

The calibration factors for the standard instrument refer to specific spectra. If the response of the standard chamber is energy-dependent, a corrction factor may have to be applied when the spectral distribution of the radiations is significantly different from that used to calibrate the standard.

5.7 Instrument scale and range nonlinearities

Corrections for scale and range nonlinearities shall be applied to the indication of the standard instrument.

5.8 Shutter transit time

If the standard instrument is of the integrating type with the irradiation time determined by the operation of a shutter, then it may be necessary to correct the irradiation time interval due to the transit time of the shutter (see ISO 4037-1,). For example, the shutter transit time Δt, can be determined by use of the "multiple exposure technique". In this technique, a nominal irradiation time, t, and two apparent kerma values of K_1 and K_n are determined, where K_1 refers to a single irradiation having a nominal duration of t, in seconds, and K_n refers to the sum of n irradiations each having a nominal duration of t/n, in seconds. The shutter transit time, Δt, is therefore given by the following formula :

$$\Delta t = \frac{t(K_n - K_i)}{(nK_1 - K_n)}$$

This technique gives good results when the source output is stable or the measurement is repeated several times to obtain a mean Δt value.

5.9 Conversion from the measured quantity to the required quantity

If the standard instrument is calibrated in terms of a quantity different from the required quantity, appropriate conversion coefficients shall be applied to the measured values.

6 Procedures applicable to ionization chambers

6.1 Ionization chamber assembly calibrated separately from measuring assembly

If an ionization chamber assembly is calibrated in isolation from the complete measurement system, the calibration of the associated charge or current measuring assembly shall be traceable to appropriate electrical standards.

6.2 Influence of the angle of incidence of the radiation on the response of the ionization chamber

The orientation of the chamber with respect to the incident radiation will, in general, have an influence on the result of the measurement. The error introduced by imprecise orientation shall not exceed ± 2 % (2σ). The reference orientation of the chamber shall be stated in the certificate.

Where applicable it shall be in accordance with the manufacturer's specifications.

For instruments designed to measure the kerma rate, the leakage current of the measuring assembly in the absence of radiation other than ambient radiation shall be less than 2 % of the maximum indication on the most sensitive scale. For instruments designed to measure kerma, the accumulated leakage indication shall correspond to less than 2 % of the indication produced by the reference radiation over the time of measurement. Correction shall be made for leakage currents, if significant.

NOTE 1 The following are examples of sources of leakage currents :

a) post-irradiation leakage - This effect, produced by the radiation, arises in the chamber insulator and in part of the stem or cable that is irradiated in the beam. The effect continues after the radiation has ceased and commonly decreases exponentially with time ;

b) insulator leakage in the absence of radiation - These currents may be produced either on the surface or within the volume of insulating materials used for the construction of the chamber, cables, connectors and high-impedance input components of the electrometer and/or the preamplifier ;

c) instruments in which the signal from the chamber is digitized may not indicate leakage currents of polarity opposite to that produced by ionization within the chamber.

The magnitude of the leakage current cannot, in this case, be determined unless appropriate radiations of known kerma rate or known ratios of kerma rate are available.

NOTE 2 There are other sources of error that produce effects similar to leakage currents, for example :

a) cable microphony - A coaxial cable may generate electrical noise whenever it is flexed or otherwise deformed. A low noise, non-microphonic cable should be used and sufficient time should elapse for the mechanically induced currents to subside ;

b) preamplifier-induced signal - The preamplifier should, whenever possible, be positioned outside the area of the radiation beam to eliminate induced leakage currents. If this is not possible, then the preamplifier should be adequately shielded.

6.4 Location and orientation of the standard chamber

The standard chamber shall be set up as specified by the calibration laboratory on the axis of the reference-radiation beam at the desired distance from the source to the reference point of the chamber and its reference orientation to the beam shall be as stated by the manufacturer.

6.5 Geometrical conditions

The cross-sectional area of the reference-radiation beam should be sufficient to irradiate the standard chamber or the device to be calibrated, whichever is the larger. The variation of kerma rate over the useful beam area shall be less than 5 %, and the contribution of scattered radiation to the total kerma rate shall be less than 5 % (see ISO 4037-1). Corrections shall be applied as considered necessary.

The finite size of the chamber may affect the measurement of the radiation at small source-chamber distances [4].

6.3 Measurement of the effect of leakage

6.6 Chamber support and stem scatter

The structure supporting the standard chamber in the beam shall be designed to contribute a minimum of scattered radiation. Since the effect of stem scatter and radiation-induced currents in the stem under the calibration conditions is included in the calibration factor for the standard instrument, no correction factor for these effects should be applied unless the beam area is significantly different from that used to calibrate the standard.

The effect of stem scatter may be found from measurements with and without a replicate stem in appropriate geometrical conditions.

NOTE Stem scatter is a function of the reference-radiation quality and the beam area. However, the effect of scattered radiation on subsequent use of the beams to calibrate instruments will be dependent on the type of instrument and the method of its support unless the standard and the instrument are identical.

6.7 Measurement corrections

The indication of the standard instrument shall be corrected where necessary for the effects described in 5.6 and 5.7 to determine the result of a measurement.

6.7.1 Zero shift

This effect may be significant on the more sensitive measurement ranges and shall, where necessary, be corrected for, or preferably excluded, by appropriate measurement techniques.

6.7.2 Corrections for electrical and radiation-induced leakage, including ambient radiation

Where appropriate, corrections shall be applied for the effect of leakage as described in 6.3.

6.7.3 Corrections for air temperature, pressure and humidity variation from reference calibration conditions

For an unsealed standard ionization chamber, the following ideal gas corrections shall be applied for any differences between the conditions during measurement and reference calibration conditions :

$$M = M_i \times C_{\mathrm{T,p}} \times C_{\mathrm{h}}$$

where:

M is the value corrected to the following reference calibration conditions, p_o, T_o and h_o :

- p_o is the reference air pressure, 101,3 kPa ;
- T_o is the reference air temperature, 293,15 K ;
- h_o is the reference relative humidity, 65 % ;

M_i is the value obtained under the following conditions of measurement : p, T and h:

- p is air pressure during measurement ;
- T is the air temperature during measurement ;
- h is the relative humidity during measurement ;

$C_{\mathrm{T,p}}$ is the correction factor for air temperature and pressure given by the following formula :

$$C_{\mathrm{T,p}} = \frac{p_o \times T}{p \times T_o}$$

C_{h} is the correction factor for any difference in relative humidity between the reference calibration conditions and conditions during measurement. The value of C_{h} is determined from an empirical relationship between the response of ionization chambers as a function of relative humidity [5].The magnitude of this correction factor is usually small, and it is assumed that $C_{\mathrm{h}} = 1$ for the range of relative humidities generally encountered.

Some types of instrument have automatic temperature and/or pressure compensation, obviating the need for further correction, provided that the compensation is to the reference calibration conditions.

NOTE It is possible to adjust temperature and humidity within the range of values given for the standard test conditions. This is not the case for pressure. Working outside the range of values given in this part of ISO 4037 may result in reduced accuracy, or a special treatment of the correction factors may be required.

6.7.4 Incomplete ion collection

When the standard instrument is used on its high dose rate ranges, corrections may be necessary for incomplete ion collection of the ionization chamber assembly.

NOTE 1 The use of electrical signals to determine the correction at the higher ranges of the instrument should be avoided if possible. If such electrical signals are used, then a correction for incomplete ion collection in the chamber may be necessary.

NOTE 2 It is preferable to irradiate the complete detector assembly, as this method tests the complete measuring system.

6.7.5 Beam non-uniformity

The variation of kerma rate over the beam area shall be determined by surveying the beam area with a small area detector or photographic emulsion.

7 Additional procedures and precautions specific to gamma radiation dosimetry using radionuclide sources

7.1 Use of certified source output

The certificated output from a source shall not be used to provide the calibration of the radiation field. Dosimetry of all reference radiation fields shall be performed using a calibrated standard instrument. This procedure avoids errors due to differences in the geometrical conditions between initial measurements of the certificated source output and subsequent use of the source.

However, for the measurement of environmental kerma rates less than approximately 10 µGy h-1 the use of appropriate calibrated radioactive sources and techniques is acceptable.The accurate dosimetry for, and calibration of, instruments measuring environmental kerma/kerma rates presents many problems. A detailed consideration of the problems involved and recommended techniques for calibration is given in reference [6].

7.2 Use of electronic equilibrium caps

All measurements shall be performed with the cap that was used at each energy during the calibration of the standard instrument ; otherwise the calibration factor for the standard instrument is invalid.

7.3 Radioactive source decay

When required, a correction shall be applied for the radioactive decay of the source (see ISO 4037-1 for details on the half-lives of radionuclides).

7.4 Radionuclide impurities

Since freshly prepared sources of ^{137}Cs may contain a significant amount of ^{134}Cs, the application of decay corrections based on the assumption of isotopically pure ^{137}Cs could be in error.

Specifications of the impurities shall be given by the manufacturer of the source (see ISO 4037-1).