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Dosimetry of X and γ reference radiations for radiation protection over the energy range from 8 keV to 1,3 MeV

Dosimétrie des rayonnements de référence X et gamma pour la radioprotection dans le domaine d'énergie compris entre 8 keV *et* 1,3 MeV

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

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Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

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0 Introduction

The term "dosimetry" is used in this International Standard to describe the method by which the value of a physical quantity characterizing the interaction of the radiation field 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[1]; for simplicity, the term "kerma" is used instead of "air kerma" throughout this International Standard.

In order to correlate measured physical quantities with the magnitude of a biological effect, a quantity of the dose-equivalent type[2] is required for use in radiation protection. ICRU1) has recently defined such a quantity[3] and will publish tables of conversion coefficients to convert kerma to dose equivalent quantities.

1 Scope and field of application

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

It applies mainly to secondary laboratories.

2 Reference

ISO 4037, *X and γ reference radiations for calibrating dosemeters and dose ratemeters and for determining their response as a function of photon energy.*

3 Definitions

For the purposes of this International Standard, 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[4].

NOTE — The reference conditions generally specify reference values or reference ranges for the influence quantities affecting the measuring instrument.

For the purposes of this International Standard, 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 : A value (or a range of values) of the influence quantities[4] 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 to 295,15 K
Ambient pressure : 86 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[5].

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.

1) ICRU : International Commission on Radiation Units and Measurements.

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

3.7 point of test : Point at which the reference point of the ionization chamber is placed 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 : For an ionization chamber assembly with an associated measuring assembly, factor which converts the indication, corrected to stated reference conditions, to the conventional true value of the dosimetric quantity at the reference point of the ionization chamber.

For an 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 dosimetric quantity at the reference point of the chamber.

3.10 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[4].

3.11 conventional true value : Value of a quantity which, for a given purpose, may be substituted for the true value.

NOTE — A conventional true value is, in general, regarded as sufficiently close to the true value for the difference to be insignificant for the given purpose[4].

3.12 response : Ratio between the signal of the ionization chamber and the conventional true value of the measured quantity at the position of the reference point in space.

3.13 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[4].

3.14 deviation from linearity, δ_l : Percentage deviation from linearity, l, given by

$$\delta_l = 100 \left(\frac{mQ}{Mq} - 1 \right)$$

where

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

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

NOTE — For multi-range instruments, the above definition is applicable to each range.

3.15 leakage current : Total detector current flowing at the operating bias in the absence of radiation[5].

3.16 zero drift : Slow variation with time of the indication of the measuring assembly when the input is shorted to ground.

3.17 zero shift : Sudden change in the scale reading 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.

4 Apparatus

4.1 General

The instrument to be used for the measurement of the reference radiations shall be a secondary standard or other appropriate instrument comprising generally an ionization chamber assembly and measuring assembly. In some applications, for example the determination of low kerma rates, other types of instrument, e.g. scintillation dosemeters, may be used providing that the requirements of this International Standard are met.

4.2 Calibration

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

4.3 Energy dependence of the response of the instrument

Above a mean energy (see ISO 4037) 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 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

A radioactive check source should be used to verify the satisfactory operation of the instrument between periods of use.

4.5 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 standards.

4.6 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. In order to avoid the need for extreme precision in the angular positioning of the chamber, the variation of response of the chamber with angle of incidence shall not exceed ± 0,5 % over 5° in any direction from the reference orientation. The reference orientation of the chamber shall be marked.

5 General procedures

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

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 shall be within the acceptable period defined by national regulations and should not in any case exceed 2 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 multi-range 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. For measuring kerma rates, sufficient time shall be allowed between measurements so that the measurements are independent of the response time of the instrument. 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 Measurement of the effect of leakage

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. If it is significant, the effect of leakage currents shall be corrected for.

NOTES

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 the 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 pre-amplifier.

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.

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

a) Cable microphony

A high-insulation coaxial cable may generate electrical noise whenever it is flexed or otherwise deformed, unless it is of a non-microphonic type.

b) Pre-amplifier-induced signal

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

5.6 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, using the reference point of the chamber and its reference orientation to the beam.

5.7 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). 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[6].

5.8 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 under the calibration conditions is included in the calibration factor for the standard instrument, no correction factor for stem scatter 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 — The stem effect 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.

5.9 Dosimetry of the reference radiations

The standard instrument shall be used to make at least four successive readings. The experimental standard deviation of the group of measurements should be consistent with the expected performance of the standard instrument. For measuring kerma rates, the time interval between successive readings shall not be less than five times the value of the time constant of the instrument range in use in order to ensure that the readings are statistically independent.

5.10 Measurement corrections

The indication of the standard instrument shall be corrected where necessary for the effects described in 5.10.1 to 5.10.9 to determine the result of a measurement.

5.10.1 Zero shift

A charge-measuring instrument may produce a change of scale indication when the setting control is changed from the zero mode to the measurement mode; this charge may be of either polarity. 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.

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

Where appropriate, corrections shall be applied for the effect of leakage as described in 5.5.

5.10.3 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 :

$$M_o = M \times C_{t,p} \times C_h$$

where

M_o is the value corrected to the following reference calibration conditions :

p_o, t_o and h_o

in which

p_o is the reference air pressure (101,3 kPa at 293,15 K),

t_o is the reference air temperature (293,15 K),

h_o is the reference relative humidity (65 % r.h.);

M is the value obtained under the following conditions of measurement :

p, t and h

in which

p is the air pressure during measurement,

t is the air temperature during measurement,

h is the relative humidity during measurement;

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

$$C_{t,p} = \frac{p_o \times t}{p \times t_o}$$

in which p_o, t_o, p and t are as given above;

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[7]. The magnitude of this correction factor is usually small, and it is assumed that $C_h = 1$ for the range of relative humidities generally encountered.

Some types of instruments 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 International Standard may result in reduced accuracy, or a special treatment of the correction factors may be required.

5.10.4 Energy dependence of response of the standard instrument

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

5.10.5 Instrument scale and range non-linearities

Corrections for scale and range non-linearities shall be applied to the indication of the standard instrument.

5.10.6 Incomplete ion collection

To avoid corrections for incomplete ion collection of the ionization chamber assembly, often necessary for these ranges, the standard instrument shall be calibrated up to the maximum kerma rate to be measured.

NOTES

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

2 It is preferable to calibrate the complete instrument by the use of ionizing radiation as this method tests the complete measuring system.

5.10.7 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.

5.10.8 Stem scatter

Corrections may be necessary for the effects of scatter if the beam area is significantly different from that used to calibrate the standard (see 5.8).

5.10.9 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 : 1979, 3.1.3.4). 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 :

$$\Delta t = \frac{t\,(K_1 - K_n)}{K_n - nK_1}$$

5.11 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 Additional procedures and precautions specific to γ radiation dosimetry

6.1 Use of certified source output

The certified 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 certified source output and subsequent use of the source.

However, for the measurement of environmental dose rates, or in kerma rates less than approximately 10 $\mu Gy \cdot h^{-1}$, the use of appropriate calibrated radioactive sources and techniques is acceptable. The accurate dosimetry for, and calibration of, instruments measuring environmental doses/dose rates presents many problems. A detailed consideration of the problems involved and recommended techniques for calibration is given in [8].

6.2 Use of necessary caps to ensure electron equilibrium

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.

6.3 Radioactive source decay

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

6.4 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.

6.5 Interpolation between calibration positions

The determination of the kerma rate by interpolation for distances other than those at which measurements have been performed shall be permitted only over the range of distances for which the departure from the inverse square law relationship between kerma rate and distance is less than $\pm$ 5 % (see ISO 4037).

7 Additional procedures and precautions specific to X radiation dosimetry

7.1 Variation of X radiation output

Given the possible temporal variation in the radiation output from X-ray generators, the output of the generator shall be monitored by means of a monitor ionization chamber.