International Standard ISO 4037

X and γ reference radiations for calibrating dosemeters and dose ratemeters and for determining their response as a function of photon energy

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

iTeh STANDARD PREVIEW
(standards.iteh.ai)

First edition — 1979-05-15

ISO 4037:1979
https://standards.iteh.ai/catalog/standards/sist/997a1680-8f96-4bee-aa91-
3a22aba8d4c1/iso-4037-1979

UDC 535-34/-36 : 53.089.6

Ref. No. ISO 4037-1979 (E)

Descriptors : dosimeters, exposure flowmeters, calibrating, electromagnetic radiation, reference materials, test equipment, test results.

ISO 4037-1979 (E)

Price based on 32 pages

FOREWORD

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO member bodies). The work of developing International Standards is carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been set up 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.

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.

International Standard ISO 4037 was developed by Technical Committee ISO/TC 85, *Nuclear energy*, and was circulated to the member bodies in September 1976.

It has been approved by the member bodies of the following countries :

Austria	Germany, F.R	Spain
Belgium	Hungary	Sweden
Brazil	Japan	Switzerland
Bulgaria	Mexico	United Kingdom
Canada	Netherlands	USA
Czechoslovakia	Poland	Yugoslavia
Finland	Portugal	
France	South Africa, Rep. of	

The member body of the following country expressed disapproval of the document on technical grounds :

Australia

CONTENTS

X and γ reference radiations for calibrating dosemeters and dose ratemeters and for determining their response as a function of photon energy

1 SCOPE AND FIELD OF APPLICATION

This International Standard specifies the X and γ reference radiations for calibrating protection level dosemeters and dose ratemeters* at exposure rates from $10^{-6}\,\mathrm{C \cdot kg^{-1} \cdot h^{-1}}$ (a few $\mathrm{mR \cdot h^{-1}}$) to $10^{-2}\,\mathrm{C \cdot kg^{-1} \cdot h^{-1}}$ (of the order of tens of $\mathrm{R \cdot h^{-1}}$), and for determining their response as a function of photon energy.

These radiations are :

— in the energy range 30 keV to 250 keV, continuous filtered X radiations and the γ radiation of americium-241;

— in the energy range 8 keV to 100 keV, fluorescence X radiations;

— in the energy range 600 keV to 1,3 MeV, gamma radiations emitted by radioactive elements.

This International Standard establishes two series of X and γ reference radiations from which, for a particular case, the radiations for calibrating an instrument and for determining its response as a function of photon energy shall be selected. These series are reviewed in table 1. An addendum will define other series, particularly for lower or higher exposure rates and for energies up to 6 MeV.

---

* This also includes exposure meters and exposure rate meters.

TABLE 1 — Review, X and gamma reference radiations

Narrow spectrum series[1]	
A	B
8,6 keV K fluorescent X radiations	
9,9 keV K fluorescent X radiations	
15,8 keV K fluorescent X radiations	
17,5 keV K fluorescent X radiations	
23,2 keV K fluorescent X radiations	
25,3 keV K fluorescent X radiations	
31,0 keV K fluorescent X radiations	33 keV continuous filtered X radiations
37,4 keV K fluorescent X radiations	
40,1 keV K fluorescent X radiations	48 keV continuous filtered X radiations
49,1 keV K fluorescent X radiations	
59,3 keV K fluorescent X radiations	
59,5 keV γ radiation from americium-241[3]	
	65 keV continuous filtered X radiations
68,8 keV K fluorescent X radiations	
75,0 keV K fluorescent X radiations	
98,4 keV K fluorescent X radiations	83 keV continuous filtered X radiations
100 keV continuous filtered X radiations	
118 keV continuous filtered X radiations	
161 keV continuous filtered X radiations	
205 keV continuous filtered X radiations	
248 keV continuous filtered X radiations	
662 keV γ radiation from caesium-137[3]	
1 173 / 1 333 keV γ radiation from cobalt-60[3]	
Wide spectrum series[2]	
45 keV continuous filtered X radiations	
58 keV continuous filtered X radiations	
79 keV continuous filtered X radiations	
104 keV continuous filtered X radiations	
134 keV continuous filtered X radiations	
169 keV continuous filtered X radiations	
202 keV continuous filtered X radiations	

1) The radiations listed in column A should be used for tests of instrument response as a function of photon energy since their spectra are essentially line spectra whilst those in column B are continuous energy bands.

2) These radiations shall only be used for energy response measurements if the exposure rates of the narrow series prove inadequate.

3) The precise values of energies are given in table 7.

2 REFERENCES

ISO/TR 197, *Copper and copper alloys — Terms and definitions — Part I : Materials.*

ISO 1677, *Sealed radioactive sources — General.*

ISO 3534, *Statistics — Vocabulary and symbols.*

See also the bibliography.

3 CHARACTERISTICS AND METHODS FOR PRODUCING THE RADIATIONS

3.1 Filtered X radiations

This sub-clause specifies the characteristics of the reference filtered X radiations and the method by which a laboratory may reproduce these radiations.

3.1.1 Definitions

For the purposes of this International Standard, the following definitions apply :

3.1.1.1 mean energy, $\bar{E}$: The ratio defined by the formula

$$\bar{E} = \frac{\int_0^{E_{max}} \phi_E \, E \, dE}{\int_0^{E_{max}} \phi_E \, dE}$$

where $\phi_E = \dfrac{d\phi(E)}{dE}$ is the quotient of the fluence $d\phi(E)$ of the primary photons (main continuous spectrum) with energies between E and $E + dE$ and the energy interval dE.[1]

3.1.1.2 resolution, R_e : The ratio, expressed as a percentage, defined by the formula

$$R_e = \frac{\Delta E}{\bar{E}} \times 100$$

where ΔE represents the spectrum width corresponding to half the maximum ordinate of the spectrum.

These parameters are applicable only in cases where the spectrum is substantially symmetrical about the mean energy and continuous (i.e. in cases where the photon contribution of the fluorescence radiation is insignificant compared to the continuous spectrum).

3.1.1.3 half value layer (exposure) (HLV or HVL$_x$)[2] : The thickness of specified material which attenuates the beam of radiation to an extent such that the exposure rate is reduced to one half of its original value. In this definition, the contribution of all scattered radiation, other than any which might be present initially in the beam concerned, is deemed to be excluded.

3.1.1.4 constant potential : A voltage for which the value of the ripple is less than or equal to 10 %.

3.1.1.5 ripple : The ratio, expressed as a percentage, defined for a given current by the formula

$$\frac{(U_{max} - U_{min})}{U_{max}} \times 100$$

where U_{max} is the maximum value and U_{min} the minimum value between which the voltage oscillates.

3.1.1.6 X-ray unit : An assembly comprising a high voltage supply, an X-ray tube with its protective housing, and high voltage electrical connections.

3.1.1.7 constant potential X-ray unit : A unit in which the maximum ripple of the high voltage does not exceed 10 %.

3.1.1.8 X-ray tube : A vacuum tube designed to produce X-rays by bombardment of the anode by a beam of electrons accelerated by a potential difference.

3.1.1.9 monitor (ionization) chamber : The detector used to monitor the stability of the exposure rate during an irradiation or to compare exposures in the case of successive irradiations.

3.1.2 Characteristics of continuous filtered X reference radiations

3.1.2.1 RADIATION QUALITY

The quality of a filtered X radiation is characterized in this International Standard by the following parameters :

    a) mean energy of a beam expressed in kiloelectron-volts (keV);

    b) resolution expressed in percent;

    c) the half value layer (exposure);

    d) the homogeneity coefficient, h, the ratio of the first to the second half value layers (exposure).

In practice the quality of the radiation obtained depends primarily on :

    a) the high-voltage across the X-ray tube;

    b) the thickness and nature of the total filtration;

    c) the type and nature of the target.

---

1) See ICRU report No. 19 (International Commission on Radiation Units and Measurements).

2) See ICRU report No. 17.

In order to ensure accurate reproduction of the reference radiations, the installation shall satisfy certain conditions. These are defined in 3.1.3.

3.1.2.2 CHOICE OF RADIATIONS

This International Standard specifies two series of radiations (see table 2) each series being characterized by the resolution of the spectrum.

— a narrow-spectrum series (see figures 2 to 10)[1], and

— a wide-spectrum series (see figures 11 to 17)[1].

The wide spectrum series should only be used for energy response measurements if the exposure rates of the narrow series prove inadequate [see table 1, note 2)].

Any reference laboratory shall verify, by a spectrometric study, that their values of the mean energies produced are within ± 3 % of the values listed in table 2 and the resolutions, R_e, of the spectra are within ± 10 % of the values listed in table 2.

In the case of other laboratories, known as "linked" laboratories, if the high voltage and filtration characteristics listed in table 2 have been achieved, conformity between the radiation produced and one of the standardized radiations shall be checked by a simple method involving linking to the reference laboratory; this method is described in 3.1.4.

3.1.3 Conditions and methods for reproducing the radiation qualities

3.1.3.1 CHARACTERISTICS OF THE X-RAY UNITS

X radiations shall be produced by an X-ray unit of the constant potential type.

During an irradiation, the mean value of the high voltage shall be stable within ± 1 %. It should be possible to display the mean value of the high voltage with a tolerance of ± 1 %.

The target of the X-ray tube shall be made of tungsten, shall be of the "reflection" type and should be orientated at an angle of about 45° to the direction of the bombarding electrons.

NOTE — The X-ray tube should be operated in such a way that any ageing effect is minimized, since this effect increases the inherent filtration.

3.1.3.2 ADJUSTMENT OF THE HIGH VOLTAGE

The reference laboratory shall calibrate, at several points, and under operating conditions, the equipment used to indicate the high voltage applied to the tube. The best methods employ a calibrated resistor chain or involve the measurement of the maximum photon energy by spectrometry. If the calibration is determined by spectrometry the voltage shall be found from the intersection of the extrapolated linear high energy part of the spectrum with the energy axis.

In the case of a linked laboratory, without these facilities, it is possible in conjunction with a reference laboratory to set the high voltage to produce accurately any of the radiations described in table 2. This may be accomplished in one of the following ways :

a) If, for a particular radiation generated at a particular high voltage, the difference in the value of the inherent filtration applying in the reference and linked installations is known to be negligible compared to the total filtration, the procedure described in 3.1.4.4 and 3.1.4.5 may be followed;

b) Where these conditions do not apply, and for radiations generated at high voltages below 116 kV (i.e. below the K-absorption edge of uranium at 115,6 keV), the voltage measuring equipment or meter can be calibrated using techniques based on the excitation of the characteristic radiation from a selected element.

c) Alternatively, and for tube voltages above 116 kV, by using the method of 3.1.4.4 and 3.1.4.5 the voltage can be determined approximately for a radiation selected such that the actual inherent filtration is unlikely to represent too great a departure from the conditions above. The inherent filtration shall then be determined as described in 3.1.3.3, the fixed filtration adjusted to the required value with an additional aluminium filter (the total being regarded as constituting the new fixed filtration), and the high voltage determination repeated.

---

1) The spectra shown in these figures have not been corrected for the response of the detector and should therefore not be used for accurate calculations.

TABLE 2 — Calibration conditions of filtered X reference radiations

Series	Mean energy keV[1]	Resolution R_e %	Constant potential[2] kVcp	Additional filtration[3] mm			1st HVL$_x$	2nd HVL$_x$	Homogeneity coefficient
				Lead	Tin	Copper	mm of copper		
Narrow spectrum	33	30	40			0,21	0,09	0,12	0,75
	48	36	60			0,6	0,24	0,29	0,83
	65	31	80			2,0	0,59	0,64	0,93
	83	28	100			5,0	1,16	1,2	0,97
	100	27	120		1,0	5,0	1,73	1,74	0,99
	118	36	150		2,5		2,4	2,58	0,93
	161	32	200	1,0	3,0	2,0	3,9	4,29	0,91
	205	30	250	3,0	2,0		5,2	5,2	1,00
	248	34	300	5,0	3,0		6,2	—	—
Wide spectrum	45	48	60			0,3	0,18	0,26	0,69
	58	54	80			0,5	0,35	0,52	0,67
	79	57	110			2,0	0,94	1,16	0,81
	104	56	150		1,0		1,86	2,14	0,87
	134	58	200		2,0		3,11	3,53	0,88
	169	58	250		4,0		4,3	4,38	0,98
	202	58	300		6,5		5,0	—	—

NOTE — As a guide it is pointed out that, for a current of 10 mA and at 1 m from the tube, the exposure rate range usually obtained is between 2,6 × 10⁻⁴ C·kg⁻¹·h⁻¹ (1 R·h⁻¹) and 2,6 × 10⁻³ C·kg⁻¹·h⁻¹ (10 R·h⁻¹)[4] for the narrow spectrum series, and between 2,6 × 10⁻³ C·kg⁻¹·h⁻¹ (10 R·h⁻¹) and 2,6 × 10⁻² C·kg⁻¹·h⁻¹ (100 R·h⁻¹)[4] for the wide spectrum series.

Lower energy photons outside the main portion of the spectrum, whose shape is given in figures 2 to 17, amounting to less than 2 % of the main spectrum, are not shown.

---

1) The value of the mean energy adopted with a tolerance of ± 3 %, is taken from the results of a comparison of the spectra obtained in France, Germany and the United Kingdom (reference).

2) The constant potential is measured under load.

3) The total filtration includes, in each case, the fixed filtration adjusted to 4 mm of aluminium (see 3.1.3.3).

4) The actual value depends on the particular conditions of the installation.

3.1.3.3 FILTRATION

The total filtration is made up of the fixed filtration and the additional filtration.

a) The **fixed filtration** comprises :

The inherent filtration of the tube, plus that due to the monitor ionization chamber, if applicable, plus the aluminium filters which are added to obtain a total fixed filtration equivalent to that of 4 mm of aluminium at 60 kV. These aluminium filters shall be placed after the additional filtration (i.e. furthest from the X-ray focal spot) in order to reduce the fluorescence radiation from this additional filtration (copper and tin).

The inherent filtration of the tube is due to the various constituent elements (glass of the bulb, oil, window etc.) and is expressed, for a given high voltage, as the thickness of an aluminium filter which, in the absence of the constituent elements of the tube, would supply a radiation having the same first HVL_x. A tube whose inherent filtration exceeds 3,5 mm of aluminium should not be used.

The inherent filtration shall periodically be checked in order to make sure that this limit is not reached (because of tube ageing) and to proceed to the adjustment of the fixed filtration.

b) The **additional filtration** comprises :

The lead, tin and copper filters specified in table 2.

The filters used shall, in the case of each metal adopted, have a thickness which is specified with an accuracy of ± 5 % and be of adequate purity and as homogeneous as possible (without air-holes, flaws, cracks etc). The metals should have the properties shown in table 3.

TABLE 3 — Metal properties

Metal	Quality	Density kg/dm^3
Aluminium	Minimum purity 99,9 %	2,699 to 2,702
Copper[1]	Minimum purity 99,9 %	8,930 to 8,937
Tin	Minimum purity 99,9 %	7,200
Lead	Extra fine minimum purity 99,9 %	11,340

1) See ISO/TR 197/I.

The individual elements of the additional filtration shall be arranged, from the focus, in decreasing order of atomic number.

c) Measurement of the **inherent filtration** shall be made by determining, with aluminium absorbers, the first half-value layer of the beam produced by the tube without additional filtration at 60 kV in the following way :

If a monitor ionisation chamber is used during the measurement of inherent filtration it should be placed between the two sets of beam collimators and be followed by the aluminium absorbers in such a manner that it does not respond to radiation backscattered from the absorbers.

The first half-value layer shall be determined using an ionization chamber as the detector whose variation in response per unit exposure with the energy of the radiation being measured is known so that corrections, if required, may be applied for the variation in photon spectrum with the thickness of aluminium absorber.

The inherent filtration measurements shall be made in a manner such that negligible scattered radiation from the aluminium absorbers reaches the detector.

The aluminium absorbers should be located equidistant from the X-ray tube focus and from the detector. The diameter of the beam at the detector position shall be just sufficient to irradiate it completely and uniformly. The distance from the aluminium absorbers to the detector should be at least five times the diameter of the beam at the detector.

The attenuation curve in aluminium shall be plotted, the first half-value layer shall be determined and a deduction made from it of the value of the inherent filtration on the basis of table 4. The results shall be rounded to the nearest tenth of a millimetre.

TABLE 4 — Inherent filtration[1]

First HVL mm of aluminium at 60 kV	Inherent filtration mm of aluminium
1,15	1
1,54	1,5
1,83	2
2,11	2,5
2,35	3
2,56	3,5
2,75	4
2,94	4,5
3,08	5
3,35	6
3,56	7

1) Table 4 was obtained from results which appeared in Taylor, L.S., *Physical foundations of Radiology*, 2nd edition, 1959, Ch. XII, pp. 227-257.

The inherent filtration value, expressed in millimetres of aluminium, varies as a function of the energy in a manner which depends upon the constituent elements of the inherent filtration. In the case of filtered X radiation, the values determined on the basis of table 4 at 60 kV may be used for other high-voltage values, since changes in the inherent filtration, expressed in millimetres of aluminium, are small compared with the added filtration.

3.1.3.4 IRRADIATION TIME

The irradiation time shall be controlled by a shutter located between the output window of the tube and the collimation system. Irradiation times should be longer than 1 000 × the transit time of the shutter, or a correction should be made for the shutter transit time.

3.1.3.5 FIELD UNIFORMITY AND INFLUENCE OF THE SCATTERED RADIATION

a) **Field diameter :** The diameter of the field shall be just sufficient to completely and uniformly irradiate the detector at the closest experimental point from the focus. The field may remain unchanged for all other experimental points or may be reduced to be just sufficient to irradiate the detector uniformly at all other points.

b) **Field uniformity :** The exposure rate at each point of measurement shall not vary by more than 5 % over the entire cross-section area of the sensitive volume of the detector under test.

c) **Influence of the scattered radiation :** The following tests shall be carried out to check that, at the experimental distances the contribution due to scattered radiation is less than 5 % of the total exposure rate. These tests shall be carried out with the aid of an ionization chamber of the cavity type which has been calibrated in the reference laboratory and whose variations in response per unit exposure as a function of spectrum and direction within the spectrum range considered are small and known.

— Test 1 : Measure the exposure rates on the central axis of the beam at the various experimental distances, usually in excess of 50 cm from the focus of the X-ray tube. On the basis of this test, the exposure rates, after correction for air attenuation, shall be proportional within 5 % to the inverse square of the distance focus to detector.

— Test 2 : At each distance employed in test 1, measure the exposure rate after displacing the chamber in a plane perpendicular to the axis of the beam, by a distance which is equal to twice the radius of the beam plus its penumbra. On the basis of this test, the exposure rates measured outside the axis of the beam shall be less than, or equal to, 5 % of the corresponding exposure rates on the central axis.

3.1.4 *Method of linking an installation to a reference installation*

The present method of linking is intended to enable a laboratory that does not have the capability to measure the spectra to determine the adjustments that shall be made to the high voltage in order to produce a radiation which is as close as possible to the reference radiation.

3.1.4.1 PRINCIPLE

If the first and second half-value layers in a given material are equal for two X-ray beams, either with respect to the exposure rate or with respect to the reading of the same detector, these two beams are substantially of the same quality.

NOTE — In the remaining part of 3.1, the specified procedure only deals with the use of a single detector.

3.1.4.2 APPARATUS

This consists of the detector itself and the measuring equipment, permitting a repeatability[1] of at least 0,3 %.

3.1.4.2.1 Detector

An ionization chamber shall be used whose variation in response per unit exposure is small and known as a function of photon energy, over the energy range in question.

NOTE — It is necessary to use the same detector in the reference and linked installations (see 3.1.2.2).

3.1.4.2.2 Measuring equipment for ionization currents

The ionization currents may be measured by a null method such as a Townsend compensation method (a method involving charging rate, with continous compensation and a linear potentiometer).

NOTE — It is not necessary to specify the constituent elements of the equipment since the measurements are relative.

3.1.4.3 CORRECTION FACTORS

Certain precautions shall be taken when measuring the ionization currents; in particular, it is essential that saturation conditions always apply and corrections be made for background radiation levels, electronic noise or drift of measuring apparatus and for variations in atmospheric conditions.

A monitor chamber shall be used in order to permit application of corrections for fluctuations in the exposure rate.

3.1.4.4 MEASUREMENT PROCEDURES

a) For selected reference radiations corresponding to conditions specified in table 2, one of the two following procedures, (1) or (2), shall be carried out. The two methods are of comparable accuracy. However, procedure (2) is preferable since it is quicker and only requires two filters.

Procedure (1) : Plot the attenuation curve

$$\lg I_d = f(d)$$

where I_d is the value of the selected quantity (for example exposure rate) which is transmitted through a filter having the thickness d.

Determine the first and second half value layers.

---

1) See ISO 3534.

Procedure (2) : Determine the ratio r_1 for a single thickness of filter, d_1, in the vicinity of the first HVL_x and r_2 for another single thickness of filter, d_2, in the vicinity of the sum of the 1st and the 2nd HVL_x, using the following formula :

$$r = \frac{I_d}{I_0}$$

where I_0 is the value of the exposure rate for $d = 0$.

b) For all conditions specified in table 2, measurements of the exposure rate shall be carried out in a reference laboratory and then in a linked laboratory, using the same detector. Moreover, the reference laboratory shall determine the variation in exposure rate as a function of the variation of the high voltage about the standardized values given in table 2. The same filters shall be used in both laboratories.

3.1.4.5 INTERPRETATION OF RESULTS OBTAINED IN 3.1.4.4 a)

Procedure (1) — If values of the first and second half value layers agree within ± 1 % of those listed in table 2, it can be assumed that the quality of the reference radiation complies with this International Standard.

If this is not the case, the voltage used in the linked laboratory shall be adjusted and the measurements repeated until the 1 % criterion is complied with.

Procedure (2) — If the values of the ratios r_1 and r_2, measured at the linked laboratory, agree within ± 1 % with those measured at the reference laboratory, it can be assumed that the qualities of the beams in the two laboratories are the same.

If this is not the case, the voltage used in the linked laboratory shall be adjusted and the measurements repeated until the ± 1 % criterion is complied with

3.2 Fluorescence X radiations

3.2.1 *Definitions*

For the purposes of this International Standard, the following definitions apply :

3.2.1.1 primary radiation or beam : Exciting radiation or beam emitted by the X-ray tube.

3.2.1.2 secondary beam, or fluorescence radiation : Radiation or beam emitted by the radiator.

3.2.1.3 X-ray screen : A fixed or mobile panel intended to reduce the scattered X-ray contribution to the secondary beam.

3.2.2 *Characteristics of fluorescence radiations*

3.2.2.1 FLUORESCENCE LINES UTILIZED

The calibration of dosimeters and dose ratemeters by means of fluorescence radiations makes use of the K fluorescence lines of certain materials, whose energies are given, as a first approximation, by that of their K_{α_1} line (see figure 18)[1]. The contribution of the K_β lines is made negligible with the aid of secondary filters whose K absorption edges lie between the K_α and K_β lines (see table 5).

3.2.2.2 CHARACTERISTICS

Table 5 gives details of radiators and filters that shall be used to produce the reference radiations having energies between 8,6 keV and 100 keV, which are intended for the calibration of dosemeters and dose ratemeters.

---

1) This figure merely shows the qualitative appearance of the spectrum.