INTERNATIONAL STANDARD

ISO 4037-1

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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 1:
Radiation characteristics and production methods

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 1: Caractéristiques des rayonnements et méthodes de production

Reference number
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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 4037-1 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

This first edition of ISO 4037-1, along with ISO-4037-2, 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*

Annex A of this part of ISO 4037 is for information only.

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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 1:
Radiation characteristics and production methods

1 Scope

This part of ISO 4037 specifies the characteristics and production methods of X and gamma reference radiation for calibrating protection-level dosemeters and rate dosemeters at air kerma rates from 10 μGy·h^{-1} to 10 Gy·h^{-1} and for determining their response as a function of photon energy. The methods for producing a group of reference radiations for a particular photon-energy range are described in four sections which define the characteristics of these radiations. The four groups of reference radiation are:

a) in the energy range from about 7 keV to 250 keV, continuous filtered X radiation and the gamma radiation of americium-241;

b) in the energy range 8 keV to 100 keV, fluorescence X radiation;

c) in the energy range 600 keV to 1,3 MeV, gamma radiation emitted by radionuclides;

d) in the energy range 4 MeV to 9 MeV, gamma radiation produced by reactors and accelerators.

These reference radiations should be selected from table 1.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part 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 this 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 197-1:1983, *Copper and copper alloys — Terms and definitions — Part 1: Materials.*

ISO 1677:1977, *Sealed radioactive sources — General.*

ISO 3534-1:1993, *Statistics — Vocabulary and symbols — Part 1: Probability and general statistical terms.*

ISO 8963:1988, *Dosimetry of X and gamma reference radiations for radiation protection over the energy range from 8 keV to 1,3 MeV.*

ICRU Report 10b, *Physical Aspects of Irradiation*, National Bureau of Standards Handbook **85**(1964).

Table 1 — List of X and gamma reference radiation and their mean energies

Values in kiloelectronvolts

Fluorescence X radiation, mean energy	Mean energy, filtered X radiation				Gamma radiation, mean energy
	Low air-kerma rate series	Narrow-spectrum series	Wide-spectrum series	High air-kerma rate series	
8,6	8,5	8		7,5	
9,9					
		12		13	
15,8		16			
17,5	17				
		20		20	
23,2		24			
25,3	26				
	30				
31					
		33			
37,4				37	
40,1			45		
	48	48			
49,1					
59,3	60		57	57	59,5 (^{241}Am)
		65			
68,8					
75,0			79		
98,4	87	83			
		100	104	102	
	109				
		118		122	
	149		137	146	
				147	
		164	173		
	185	208	208		
	211	250			
					662 (^{137}Cs)
					1 173 and 1 333 (^{60}Co)
					4 440 (^{12}C)
					6 000 (Ti)
					6 130[1)] ^{16}O* and ^{16}N
					8 500 (Ni)

1) When produced by protons of energy near the reaction theshold, see 7.1).

3 Definitions

For the purposes of this part of ISO 4037, the following definitions apply:

3.1 mean photon energy, $\overline{E}$ **:** Ratio defined by the formula:

$$\overline{E} = \frac{\int_0^{E\max} \Phi_E \, E \mathrm{d}E}{\int_0^{E\max} \Phi_E \, \mathrm{d}E}$$

where Φ_E is the derivative of the fluence Φ_E of the primary photons of energy E with respect to energies between E and $E + \mathrm{d}E$[1], defined as

$$\Phi_E = \frac{\mathrm{d}\Phi(E)}{\mathrm{d}E}$$

In this part of ISO 4037, this definition is abbreviated to "mean energy".

3.2 spectral resolution, R_E (full width at half maximum)**:** Ratio, expressed as a percentage, defined by the formula:

$$R_E = \frac{\Delta E}{E} \times 100$$

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

NOTE — In the case where fluorescence radiation is present in the spectrum, the spectrum width measured is based upon the continuum only.

In this part of ISO 4037 this definition is abbreviated to resolution.

3.3 half-value layer (air kerma), HVL or $\mathrm{HVL_x}$[2]**:** Thickness of the specified material which attenuates the beam of radiation to an extent such that the air kerma rate is reduced to 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.

3.4 homogeneity coefficient, h**:** Ratio of the first half-value layer to the second half-value layer (air kerma):

$$h = \frac{1^{\mathrm{st}}\ \mathrm{HVL}}{2^{\mathrm{nd}}\ \mathrm{HVL}}$$

3.5 effective energy, E_{eff} (of radiation comprised of X-rays with a range of energies)**:** Energy of the monoenergetic X-rays which have the same HVL.

3.6 value of peak-to-peak voltage; ripple: 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.

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

3.8 X-ray tube: Vacuum tube designed to produce X-rays by bombardment of the anode by a beam of electrons accelerated through a potential difference.

3.9 monitor: Instrument used to monitor the stability of the air kerma rate during irradiation or to compare values of air kerma after successive irradiations.

3.10 primary radiation (or beam): Radiation or beam emitted by the X-ray tube.

3.11 secondary [fluorescence] radiation: Radiation or beam emitted by a radiator.

3.12 X-ray tube shielding: Fixed or mobile panel intended to reduce the contribution of scatter X-radiation to the primary or fluorescence (secondary) beam.

4 Continuous reference filtered X radiation

4.1 General

This clause specifies the characteristics of the reference filtered X radiation and the method by which a laboratory can produce a specified reference radiation.

4.1.1 Radiation quality

The quality of a filtered X radiation is characterized in this part of ISO 4037 by the following parameters:

a) mean energy, $\bar{E}$, of a beam, expressed in kiloelectronvolts (keV);

b) resolution, R_E, expressed in percent;

c) half-value layer (air kerma), HVL, expressed in millimetres of Al or Cu;

d) homogeneity coefficient, h.

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

— the high-voltage across the X-ray tube,

— the thickness and nature of the total filtration, and

— the properties of the target.

In order to ensure the production of the reference radiation in conformance with the given specifications, the installation shall comply with certain conditions. These are described in 4.2.

4.1.2 Choice of reference radiation

This part of ISO 4037 specifies four series of reference radiation (see table 2), each series being characterized by the resolution of the spectrum:

a) a low air-kerma rate series (see figure 1);

b) a narrow-spectrum series (see figure 2);

c) a wide-spectrum series (see figure 3);

d) a high air-kerma rate series (see figure 4).

The spectra shown in figures 1 to 4 are for the most part based upon theoretical calculations[3] and are only given as examples. Some practical spectra are also included and examples of practical measurements of spectra are given in references [4], [5], [6], [7] and [8].

The narrowest spectra, i.e. those with the lowest resolution, should be used for measurements of the variation of the response of an instrument with proton energy, provided that the air-kerma rates of that series are consistent with the range of the instrument under test. The high air-kerma rate series is suitable for determining the overload characteristics of some instruments.

Details of the operating conditions for each of the four series are given in tables 3, 4, 5 and 6. Table 7 shows an example of the additional filtration required to produce the radiation qualities of the high air-kerma rate series for particular values of the fixed filtration.

For the lower air-kerma rate, the narrow-spectrum and the wide-spectrum series, a "reference laboratory" shall verify, by a spectrometric study, that the value of the mean energy produced is within ± 3 %, and the resolution, R_E, of the spectra is within ± 10 % of the values listed in tables 3, 4 and 5.

For reference radiation for these three series having mean energies lower than 30 keV, the mean energies shall be within ± 5 % and the resolutions within ± 15 % of the values in tables 3, 4 and 5. For reference radiation using additional filtration of 1 mm Al or less, the target angle, target condition and air path strongly influence the values of the mean energies, resolutions and HVLs.

If a laboratory does not have a spectrometry system, the high voltages and filtration characteristics listed in tables 3, 4 and 5 shall be used and the reference radiation produced shall be checked by the simple method described in 4.3.

Table 2 — Specifications of filtered X radiation

Name of series	**Resolution, R_E** %	**Homogeneity coefficient, h** (approximate values)	**Typical air-kerma rates** 1), 2) Gy·h^{-1}
Low air-kerma rate	18 to 22	1,0	3×10^{-4} 3)
Narrow spectrum	27 to 37	0,75 to 1,0	10^{-3} to 10^{-2} 3)
Wide spectrum	48 to 57	0,67 to 0,98	10^{-2} to 10^{-1} 3)
High air-kerma rate	Not specified	0,64 to 0,86	10^{-2} to 0,5

1) At a distance of 1 m from the X-ray focal spot, with the tube operating at 1 mA.
2) Under conditions of charged-particle equilibrium, the value of air kerma is approximately equal to the absorbed dose to air.
3) At mean energies of less than 30 keV, other values may apply.

Table 3 — Characteristics of low air-kerma rate series

Mean energy, $\bar{E}$ keV	Resolution, R_E %	Tube potential[1)] kV	Additional filtration[2)] mm				1st HVL[4)] mm
			Pb	Sn	Cu	Al	
8,5		10				0,3[3)]	0,058 Al
17	21	20				2,0[3)]	0,42 Al
26	21	30			0,18	4,0[3)]	1,46 Al
30	21	35			0,25		2,20 Al
48	22	55			1,2		0,25 Cu
60	22	70			2,5		0,49 Cu
87	22	100		2,0	0,5		1,24 Cu
109	21	125		4,0	1,0		2,04 Cu
149	18	170	1,5	3,0	1,0		3,47 Cu
185	18	210	3,5	2,0	0,5		4,54 Cu
211	18	240	5,5	2,0	0,5		5,26 Cu

1) The tube potential is measured under load.

2) Except for the three lowest energies, where the recommended inherent filtration is 1 mm of beryllium, the total filtration consists of the additional filtration plus the inherent filtration, adjusted to 4 mm of aluminium (see 4.2.3).

3) The recommended inherent filtration is 1 mm Be, but other values may be used provided tht the mean energy is within ± 5 % and the resolution is within ± 15 % of the values given in the table.

4) The HVLs are measured at 1 m from the focal spot. The second HVL is not included for this series, since it is not significantly different from the first HVL.

Table 4 — Characteristics of narrow-spectrum series

Mean energy, $\bar{E}$ keV	Resolution, R_E %	Tube potential[1)] kV	Additional filtration[2)] mm				1st HVL[4)] mm	2nd HVL[4)] mm
			Pb	Sn	Cu	Al		
8	28	10				0,1[3)]	0,047 Al	0,052 Al
12	33	15				0,5[3)]	0,14 Al	0,16 Al
16	34	20				1,0[3)]	0,32 Al	0,37 Al
20	33	25				2,0[3)]	0,66 Al	0,73 Al
24	32	30				4,0[3)]	1,15 Al	1,30 Al
33	30	40			0,21		0,084 Cu	0,091 Cu
48	36	60			0,6		0,24 Cu	0,26 Cu
65	32	80			2,0		0,58 Cu	0,62 Cu
83	28	100			5,0		1,11 Cu	1,17 Cu
100	27	120		1,0	5,0		1,71 Cu	1,77 Cu
118	37	150		2,5			2,36 Cu	2,47 Cu
164	30	200	1,0	3,0	2,0		3,99 Cu	4,05 Cu
208	28	250	3,0	2,0			5,19 Cu	5,23 Cu
250	27	300	5,0	3,0			6,12 Cu	6,15 Cu

1) The tube potential is measured under load.

2) Except for the five lowest energies, where recommended inherent filtration is 1 mm Be, the total filtration consists of the additional filtration plus the inherent filtration, adjusted to 4 mm of aluminium (see 4.2.3).

3) The recommended inherent filtration is 1 mm Be, but other values may be used provided that the mean energy is within ± 5 % and the resolution is within ± 15 % of the values given in the table.

4) The HVLs are measured at 1 m from the focal spot.

Table 5 — Characteristics of wide-spectrum series

Mean energy, $\overline{E}$ keV	Resolution, R_E %	Tube potential[1)] kV	Additional filtration[2)] mm Sn	Additional filtration[2)] mm Cu	1st HVL Cu[3)] mm	2nd HVL Cu[3)] mm
45	48	60		0,3	0,18	0,21
57	55	80		0,5	0,35	0,44
79	51	110		2,0	0,96	1,11
104	56	150	1,0		1,86	2,10
137	57	200	2,0		3,08	3,31
173	56	250	4,0		4,22	4,40
208	57	300	6,5		5,20	5,34

1) The tube potential is measured under load.
2) The total filtration consists, in each case, of the additional filtration plus inherent filtration, adjusted to 4 mm of aluminium (see 4.2.3).
3) The HVLs are measured at 1 m from the focal spot.

Table 6 — Characteristics of high air-kerma rate series

Tube potential[1)] kV	First HVL[3)] mm Al	First HVL[3)] mm Cu
10	0,04	
20	0,11	
30	0,35	
60	2,4	0,077
100		0,29
200		1,7
250		2,5
280[2)]		3,4
300		3,4

1) The constant potential is measured under load.
2) This reference radiation has been introduced as an alternative to that generated at 300 kV, for use when 300 kV cannot be attained under conditions of maximum load.
3) The HVLs are measured at 1 m from the focal spot.

Table 7 — Approximate characteristics of high air-kerma rate series

Tube potential kV	Additional filtration[1)] mm Al	Cu	Air	Half-value layer[2)] mm First Al	First Cu	Second Al	Second Cu	Mean photon energy, $\overline{E}$ keV
10			750	0,036	0,010	0,041	0,011	7,5
20	0,15		750	0,12	0,007	0,16	0,009	12,9
30	0,52		750	0,38	0,013	0,60	0,018	19,7
60	3,2		750	2,42	0,079	3,25	0,11	37,3
100	3,9	0,15	750	6,56	0,30	8,05	0,47	57,4
200		1,15	2 250	14,7	1,70	15,5	2,40	102
250		1,6	2 250	16,6	2,47	17,3	3,29	122
280		3,0	2 250	18,6	3,37	19,0	3,99	146
300		2,5	2 250	18,7	3,40	19,2	4,15	147

NOTE — The values listed in this table have been taken from Seelentag *et al.*[5] tables B4 and B5 and the spectra shown in figure 4 were calculated using the conditions listed in the tables [3]. The length of air path employed, which has been included in the additional filtration, is significant for the lower energy radiation. The actual spectral distributions obtained for a given X-ray facility will depend significantly upon the target angle and roughness.

1) For tube potentials above 100 kV, the total filtration consists, in each case, of the additional filtration plus the inherent filtration, adjusted to 4 mm of aluminium (see 4.2.3). For tube potentials at 100 kV and below, the examples given above refer to an inherent filtration of approximately 4 mm Be.

2) The HVLs are measured at 1 m from the focal spot.

For the high air-kerma rate series, the quality of the reference radiation is specified in terms of the X-ray tube potential, and the first HVL. The method for producing the high air-kerma rate series is described in 4.4.

4.2 Conditions and methods for producing reference radiation

4.2.1 Characteristics of the X-ray units

X radiation shall be produced by an X-ray unit whose tube potential shall have a ripple of less than 10 %. It is preferable to use an X-ray unit having a ripple as low as possible. X-ray units are commercially available which have a ripple of <1 %. It should be possible to display the value of this tube potential to whithin ± 1 %.

The target of the X-ray tube shall be made of tungsten, shall be of the "reflection" type and shall be orientated at an angle of not less than 20° to the direction of the bombarding electrons.

During irradiation, the mean value of the tube potential shall be stable to within ± 1 %.

NOTE — The X-ray tube should be operated in such a way that ageing effects are minimized, since these effects increase the inherent filtration (see 4.2.3).

4.2.2 Tube potential

The reference laboratory shall calibrate, at several points and under operating conditions, the equipment used to indicate the tube potential. The best methods employ an appropriately calibrated resistor chain or involve the measurement of the maximum photon energy by high resolution spectrometry. If the calibration is determined by spectrometry, the tube potential shall be found from the intersection of the extrapolated linear high-energy part of the spectrum with the energy axis. The conventionally true value of the tube potential shall be known to within ± 2 %.

For laboratories without these facilities, it is possible to set the tube potential to produce any of the radiation described in tables 3, 4 and 5.

This may be accomplished in one of the following ways.

a) For radiation generated at potentials 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.

b) Alternatively, and for tube potentials above 116 kV, using the method described in 4.3. The inherent filtration shall be determined as described in 4.2.3 and the fixed filtration shall be adjusted to the required value with an additional aluminium filter (the total being regarded as constituting the new fixed filtration). The tube potential calibration shall be determined by achieving the reference HVL by the method specified in 4.3.

4.2.3 Filtration

NOTE — The total filtration is made up of the fixed filtration and the additional filtration. For radiation having the three lowest mean energies of 8,5 keV, 17 keV and 26 keV of the low air-kerma rate series and for radiation having the five lowest mean energies of 8 keV, 12 keV, 16 keV, 20 keV and 24 keV of the narrow-spectrum series, the fixed filtration comprises the recommended inherent filtration of the tube of 1 mm Be. Other values of the tube filtration may be used [see footnote 3) of tables 3 and 4].

4.2.3.1 For all other reference X radiation, the fixed filtration comprises:

a) 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 fluorescence radiation from the additional filtration;

b) 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 voltage, as the thickness of an aluminium filter which, in the absence of hte constituent elements of the tube, would supply a radiation having the same first HVL. A tube whose inherent filtration exceeds 3,5 mm of aluminium should be not used;

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

4.2.3.2 Determination of the inherent filtration shall be made by measuring, with aluminium absorbers of 99,9 % purity, the first HVL of the beam produced by the tube without additional filtration, at 60 kV, in the following way.

a) The method of measurement of the HVL should be in accordance with ICRU Report 10b and reference [9].

b) If a monitor ionization 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 correspond to radiation backscattered from the absorbers.

c) The first HVL shall be determined using an ionization chamber with a known response per unit air-kerma rate over the energy range of interest. Corrections shall be applied for any variation in detector response with changes in the photon spectrum as the thickness of the aluminium absorber is increased.

d) The inherent filtration measurements shall be made in a manner such that negligible scattered radiation from the aluminium absorbers reaches the detector, since such radiation would increase the measured HVL. For radiation produced at potentials above 100 kV, extrapolation to infinitely small field size should be made.

e) 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 location shall be just sufficient to irradiate it completely and uniformly. The distancae from the aluminium absorbers to the detector should be at least five times the diameter of the beam at the detector.