

Specification for

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

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- Electricity Supply Industry in England and Wales*
- Health and Safety Executive*
- Lloyd's Register of Shipping
- National Radiological Protection Board*
- Radiochemical Centre
- Scientific Instrument Manufacturers' Association*
- The Institution of Nuclear Engineers*
- United Kingdom Atomic Energy Authority*
- Water-tube Boilermakers' Association

The organizations marked with an asterisk in the above list, together with the following, were directly represented on the committee entrusted with the preparation of this British Standard:

- Association of University Protection Officers
- Association of X-ray Equipment Manufacturers
- British Institute of Radiology
- British Ship Research Association
- British Steel Industry
- Department of Industry (National Physical Laboratory)
- Electronic Engineering Association
- Hospital Physicists Association
- Institute of Physics
- Ministry of Defence
- Society for Radiological Protection

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National foreword

This British Standard is identical with ISO 4037:1979 “*X and γ reference radiations for calibrating dosimeters and dose ratemeters and for determining their response as a function of photon energy*” published by the International Organization for Standardization (ISO). This British Standard is published under the direction of the Nuclear Engineering Standards Committee. The United Kingdom has taken part in the preparation of the International Standard by Technical Committee 85, Nuclear Energy, of ISO.

Terminology and conventions. The text of the International Standard has been approved as suitable for publication, without deviation, as a British Standard. Some terminology and certain conventions are not identical with those used in British Standards; attention is especially drawn to the following.

Wherever the words “International Standard” appear, referring to this standard, they should be read as “British Standard”.

The comma has been used throughout as a decimal marker. In British Standards it is current practice to use a full point on the baseline as the decimal marker.

Cross-references

International Standard	Corresponding British Standard
ISO 1677:1977	BS 5288:1976 <i>Sealed radioactive sources</i> (Technically equivalent)
ISO 3534:1977	BS 5532:1978 <i>Statistics — Vocabulary and symbols</i> (Identical)

NOTE 1 The reference to ISO/TR 197-1, for which there is, at present, no corresponding British Standard, constitutes informative matter only, and since no mandatory requirements are involved, the validity of this British Standard is not affected.

NOTE 2 *Textual errors.* When the text of the International Standard was adopted, the errors, listed below, were noticed. They have been reported to ISO in a proposal to amend the text of the International Standard.

Existing text	Correction
Subclause 3.1.1.3, line 1. “(HLV)”	“(HVL)”
Subclause 3.1.4.4, a) in the expression following line 6. “lg”	“log”
Subclause 3.2.2.1, line 1. “dosimeters”	“dosemeters”
Subclause 3.3.1, line 1. “dosimeters”	“dosemeters”
Bibliography, reference [12]. “ARDRON”	“ARDRAN”
Table 2. In columns 8 and 9, eight of the values are given to only one decimal place.	The values to be given to two decimal places, e.g. “2,40” “3,90” etc.

NOTE 3 Modifications. The following modifications have been proposed to ISO.

Existing text	Required modification
Subclause 3.1.4.4, b) In lines 1 and 2 “exposure rate” In line 5 “exposure rate”	“selected quantity (e.g. exposure rate)” “selected quantity”
Subclause 3.1.4.5. In each of the four paragraphs, the value “± 1 % ”	“± 2 % ”
Table 5. The heading in column 9 “Minimum mass per unit area of relevant chemical form”	“Thickness (mass per unit area) of relevant chemical form”
Table 9. The subheading “% (m/m)”	“% by weight”

NOTE 4 In Figure 18, top right hand, the value “210 kV” is under review.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 34, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope and field of application

This International Standard specifies the X and γ reference radiations for calibrating protection level dosimeters and dose ratemeters* at exposure rates from $10^{-6}\text{C kg}^{-1}\text{ h}^{-1}$ (a few mR h^{-1}) to $10^{-2}\text{C kg}^{-1}\text{ h}^{-1}$ (of the order of tens of R 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.

Table 1 — Review, X and gamma reference radiations

Narrow spectrum series ^a	
A	B
8,6 keV K fluorescent X radiations	33 kev continuous filtered 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	
37,4 keV K fluorescent X radiations	
40,1 keV K fluorescent X radiations	
49,1 keV K fluorescent X radiations	
59,3 keV K fluorescent X radiations	
59,5 keV γ radiation from americium-241 ^c	65 keV continuous filtered X radiations
68,8 keV K fluorescent X radiations	83 keV continuous filtered X radiations
75,0 keV K fluorescent X radiations	
98,4 keV K fluorescent 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 ^c	
1 173 } keV γ radiation from cobalt-60 ^c	
1 333 }	
Wide spectrum series ^b	
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	

^a 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.

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

^c The precise values of energies are given in Table 7.

2 References

ISO/TR 197, *Copper and copper alloys — Terms and definitions — Part 1: 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 $\phi_E = \frac{d\phi(E)}{dE}$ 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 %

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

²⁾ See ICRU report No. 17.

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 kiloelectronvolts (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.

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 Figure 2 to Figure 10)³⁾, and
- a wide-spectrum series (see Figure 11 to Figure 17)³⁾.

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, tabnote b).

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.

³⁾ 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.

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 $\pm 1\%$. It should be possible to display the mean value of the high voltage with a tolerance of $\pm 1\%$.

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.

Table 2 — Calibration conditions of filtered X reference radiations

Series	Mean energy keV ^a	Resolution <i>R_e</i> %	Constant potential ^b kVcp	Additional filtration ^c 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 $2,6 \times 10^{-4} \text{ C kg}^{-1} \text{ h}^{-1}$ (1 R h⁻¹) and $2,6 \times 10^{-3} \text{ C kg}^{-1} \text{ h}^{-1}$ (10 R h⁻¹)^d for the narrow spectrum series, and between $2,6 \times 10^{-3} \text{ C kg}^{-1} \text{ h}^{-1}$ (10 R h⁻¹) and $2,6 \times 10^{-2} \text{ C kg}^{-1} \text{ h}^{-1}$ (100 R h⁻¹)^d for the wide spectrum series.

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

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

^b The constant potential is measured under load.

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

^d 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 $\pm 5 \%$ 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 ^a	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

^a 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^a

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

^a 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 $1\,000 \times$ 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 repeatability⁴⁾ 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 continuous compensation and a linear potentiometer).

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

⁴⁾ See ISO 3534