International Standard ISO 4037

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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

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FOREWORD

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Austria	Germany, F.R	Spain
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Brazil	Japan	Switzerland
Bulgaria	Mexico	United Kingdom
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Finland	Portugal	
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The member body of the following country expressed disapproval of the document on technical grounds :

Australia

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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 $10^{-6}C \cdot kg^{-1} \cdot h^{-1}$ (a few $mR \cdot h^{-1}$) to $10^{-2}C \cdot kg^{-1} \cdot h^{-1}$ (of the order of tens of $R \cdot h^{-1}$), 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 keV γ radiation from cobalt-60[3]	
1 333	
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 $\phi_E = \frac{d\phi(E)}{dE}$ 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 %.

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.

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 1m from the tube, the exposure rate range usually obtained is between $2,6 \times 10^{-4}$ $C \cdot kg^{-1} \cdot h^{-1}$ ($1\ R \cdot h^{-1}$) and $2,6 \times 10^{-3}$ $C \cdot kg^{-1} \cdot h^{-1}$ ($10\ R \cdot h^{-1}$)[4] for the narrow spectrum series, and between $2,6 \times 10^{-3}$ $C \cdot kg^{-1} \cdot h^{-1}$ ($10\ R \cdot h^{-1}$) and $2,6 \times 10^{-2}$ $C \cdot kg^{-1} \cdot h^{-1}$ ($100\ R \cdot h^{-1}$)[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/dm³
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.

TABLE 5 – **Radiators and filters used for K-fluorescence reference radiations**

No.	Theoretical energy K_{α_1} Line	Radiator			High voltage[2]	Total primary filtration	Secondary filtration	
		Material[1]	Recommended chemical form	Recommended mass of relevant chemical form per unit area		Minimum thickness mass per unit area	Material and recommended chemical form[1]	Minimum mass per unit area of relevant chemical form
	keV			g/cm^2	kV	g/cm^2		g/cm^2
1	9,89	Germanium	GeO_2	0,180	60	Al 0,135	–	–
2	15,8	Zirconium	Zr	0,180	80	Al 0,27	$SrCO_3$	0,053
3	23,2	Cadmium	Cd	0,150	100	Al 0,27	Ag	0,053
4	31,0	Caesium	Cs_2SO_4	0,190	100	Al 0,27	TeO_2	0,132
5	40,1	Samarium	Sm_2O_3	0,175	120	Al 0,27	CeO_2	0,195
6	49,1	Erbium	Er_2O_3	0,230	120	Al 0,27	Gd_2O_3	0,263
7	59,3	Tungsten	W	0,600	170	Al 0,27	Yb_2O_3	0,358
8	68,8	Gold	Au	0,600	170	Al 0,27	W	0,433
9	75,0	Lead	Pb	0,700	190	Al 0,27	Au	0,476
10	98,4	Uranium	U	0,800	210	Al 0,27	Th	0,776

For the series above numbered 1 to 10 the radiators and filters consist of either metallic foils or suitable chemical compounds.

An alternative series covering the same energy region but consisting solely of metallic radiators and filters can be used and is formed by replacing 1 to 7 above with the following radiators and filters, numbered 11 to 16.

11	8,64	Zinc	Zn	0,180	50	Al 0,135	–	–
12	17,5	Molybdenum	Mo	0,150	80	Al 0,27	Zr	0,035
13	25,3	Tin	Sn	0,150	100	Al 0,27	Ag	0,071
14	37,4	Neodymium[3]	Nd	0,150	110	Al 0,27	Ce[3]	0,132
15	49,1	Erbium	Er	0,200	120	Al 0,27	Gd	0,233
16	59,3	Tungsten	W	0,600	170	Al 0,27	Yb	0,322

1) During the manipulation of the materials, it is essential to take precautions because of possible radiation exposure and toxicity of the materials used.

2) If higher exposure rates are required, it is possible to use higher values of high voltage, but this will result in a lower purity of the radiation.

3) These foils should be properly sealed to prevent oxidation.

Table 6 gives, as a guide, for a current in the X-ray tube of 10 mA and a distance of 30 cm from the radiator centre, the percentage of exposure due to extraneous radiation and the exposure rates which were measured in an X-ray beam having the characteristics given in table 5.

NOTE – Extraneous radiation includes characteristic emissions other than the K_α radiation of the radiator and the scattered radiations originating from the radiator itself and its support, from the diaphragms and from the filters. It does not include the radiation scattered from the environment, mentioned later. However, for the germanium and zinc radiators (Nos. 1 and 11 of table 5) no secondary filter is used. In these two cases the percentage of exposure due to extraneous radiation is calculated in terms of that due to the total K fluorescence radiation; K_α is then replaced by $(K_\alpha + K_\beta)$ in the formula below.

TABLE 6 – **Exposure rates and extraneous radiation**

Energy obtained	**Exposure rate 30 cm from the centre of the radiator**	**Percentage of exposure due to extraneous radiation***
keV	$C \cdot kg^{-1} \cdot h^{-1}$	%
From 10 to 25	From $1{,}8 \times 10^{-3}$ to $3{,}9 \times 10^{-3}$ (7 to $15\ R \cdot h^{-1}$)	About 10
From 25 to 98,4	From $7{,}7 \times 10^{-4}$ to $1{,}8 \times 10^{-3}$ (3 to $7\ R \cdot h^{-1}$)	

* Given by the formula

$$\frac{\text{Exposure of extraneous radiation}}{K_\alpha \text{ radiation exposure} + \text{exposure of extraneous radiation}} \times 100$$

NOTE – The purity of the radiation should be checked by spectrometry at reference laboratories and by half value layer measurements at linked laboratories.

3.2.3 *Characteristics of a fluorescence X-ray installation*

The installation comprises : an X-ray unit and a fluorescence device made up of a radiator, filters, a primary diaphragm, a secondary diaphragm and a trap (see figure 19).

3.2.3.1 X-RAY UNIT

It is possible to use the same X-ray unit as the one described in 3.1. However, it is sufficient merely to stabilise the high voltage so that variations do not exceed ± 5 % of the preset voltage.

In order to take account of possible fluctuations in the exposure rate, use shall be made of a monitor chamber, irradiated by the secondary radiation, the chamber being constructed or placed so that it does not increase the secondary filtration significantly.

3.2.3.2 FLUORESCENCE DEVICE

a) **the radiators :** The characteristics of the radiators are listed in table 5. The materials shall have a minimum purity of 99,9 %. The radiators may be in the form of thin metal foils or in any powdered form (oxide, carbonate or sulphate) dispersed in a plastic binder which contains only materials having atomic numbers low compared with those of the fluorescence elements (i.e. $Z_{eff} \leqslant 8$). The radiator support should also be constructed from materials having atomic numbers low compared with those of the radiator element.

b) **the filters :** The primary filters are used to limit the low-energy components of the primary beam that do not contribute to the production of the fluorescence radiations. The filters in the secondary beam are to eliminate the L lines and reduce the intensity of the K_β lines relative to K_α lines. Their characteristics are given in table 5.

c) **the primary diaphragm :** Situated at the output of the tube, the primary diaphragm limits the area of the exciting beam to that of the radiator in order to avoid any extraneous scatter from the supports of the latter and from the walls of the fluorescence device.

d) **the secondary diaphragm :** This diaphragm limits the angle of the beam of fluorescence radiation, and thus reduces the magnitude of the radiation scattered by the environment[1].

e) **the trap :** This is intended to trap the primary radiation to prevent the latter impairing the fluorescence radiation after scatter. It may consist of a room having large dimensions, if possible, into which the primary beam is released. The zone reserved for experiments shall be isolated with the aid of a X-ray screen or other protective device.

3.2.3.3 GEOMETRICAL CONDITIONS

The radiator shall be angled at $45° \pm 5°$ relative to the axis of the primary X-ray beam emitted by the X-ray tube, and fluorescence radiation whose direction forms an angle of $90°$ with that of the primary beam shall be used (see figure 19).

To provide sufficiently high exposure rates in the secondary beam the tube should be brought as close as possible to the radiator and the primary beam should irradiate the greatest possible area of the radiator.

1) The environment consists of the walls, the supports and other accessories.

The detector should be placed at the greatest possible distance compatible with the exposure rate desired, and the variation in the exposure rate of the secondary beam over the area of the detector shall not be greater than 5 %.

The contribution of the radiation due to scattering of the primary and secondary beams from the environment shall not exceed 5 % of the exposure rate due to the fluorescence radiation.

3.2.4 *Checks for compliance of an installation*

3.2.4.1 With the aid of an ionization chamber of the cavity type that has been selected for the energy range in question and calibrated in the reference laboratory, measure the contribution due to scattered radiation at the location of the instrument to be calibrated. The contribution due to scattered radiation shall be less than 5 % of the exposure rate due to the fluorescence radiation.

NOTE – The variations in response per unit exposure of ionization chamber as a function of the spectrum and direction should be small and known over the energy range in question.

3.2.4.2 The value of the exposure rate at the point of dosimeter calibration shall be measured. Then the chamber shall be displaced 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. Two diametrically opposite measurements shall be carried out in this manner. The results of either of these latter two measurements shall not exceed 5 % of those of the first measurement.

NOTE – If this limit is exceeded, check particularly the effectiveness of the X-ray screen. For this purpose, measure at the point of dosimeter calibration and with the aid of the ionization chamber the value of the residual exposure rate with the secondary beam completely absorbed.

3.3 Gamma radiations emitted by radionuclides

3.3.1 *Radionuclides used for the production of gamma radiations*

Calibrations of dosimeters and dose ratemeters by means of gamma radiations emitted by radionuclides shall be carried out with radiations from the radionuclides listed in table 7.

TABLE 7 – **Radionuclide properties**

Radionuclide	Energy of the radiation	Half-life	Exposure rate constant*
	keV	years	$C \cdot kg^{-1} \cdot h^{-1} \cdot m^2 \cdot Bq^{-1}$ ($R \cdot h^{-1} \cdot m^2 \cdot Ci^{-1}$)
Cobalt-60	1 173,3 1 332,5	5,272	$0{,}913 \times 10^{-14}$ (1,31)
Caesium-137	661,6	30,1	$0{,}234 \times 10^{-14}$ (0,336)
Americium-241	59,54	433	$0{,}906 \times 10^{-16}$ (0,013)

* The Exposure rate constant (see ICRU report No. 19) is valid only in the case of an unshielded point source. It is therefore given only as a guide.

3.3.2 *Characteristics of the radiation sources*

3.3.2.1 Sources

Since the source shall be as small as possible, it is essential that use be made of radioactive substance having sufficient activity per unit mass. The exposure rate due to the principal radioactive impurity shall be less than 1 % of the exposure rate due to the radiation utilised.

Table 8 gives examples of specific activities and recommended chemical forms of the specified radioactive nuclides.

NOTE – Cobalt-60 is particularly suitable for providing sources having high activity per unit mass.

TABLE 8 – **Specific activity and recommended chemical form of radioactive nuclides**

Radioactive nuclide	Specific activity per unit mass	Recommended chemical form
	$Bq \cdot kg^{-1}$ (Ci/g)	
Cobalt-60	$3{,}7 \times 10^{15}$ (100)	Metal
Caesium-137	$8{,}51 \times 10^{14}$ (23)	Chloride
Americium-241	$1{,}11 \times 10^{14}$ (3)	Oxide

3.3.2.2 Encapsulation

The encapsulation of the sources used shall comply with the requirements of ISO 1677.

The capsules shall be sufficiently thick to absorb the β radiation from the sources i.e. it shall have a mass per unit area of 0,2 g/cm^2 in the case of cobalt-60 and 0,5 g/cm^2 for caesium-137. For americium-241 it shall have a mass per unit area of 0,32 g/cm^2 of stainless steel to attenuate the 26 keV γ radiation to less than 1,0 % of the 59,5 keV γ radiation.

3.3.3 *Characteristics of the reference radiations*

The exposure rate due to the radiation scattered by the environment shall not exceed 5 % of the direct radiation.

This can be obtained either

a) with uncollimated geometry by means of a room with sufficiently large dimensions (see 3.3.4); or

b) with collimated geometry, an example of which is given in 3.3.5.

3.3.4 *Recommendations for an uncollimated geometry installation*

The source should be used in a shielded room having minimum internal dimensions 4 m × 4 m × 3 m high. The source and detector (ionization chamber) should be used on

supports that are constructed from the minimum amount of low atomic number materials such as polymethyl methacrylate or aluminium. They should both be positioned at half the height of the room. Measurements should be made for source-to-centre of ionization chamber distances from approximately 30 cm to 130 cm to ensure that departures from the inverse square law shall not exceed 5 % after correction has been made for air attenuation. The ionization chamber should be of the cavity type, have small dimensions and be selected for the energy range in question and calibrated in the reference laboratory.

Variations in exposure levels shall be made by varying the source activity rather than using distances for which the variation exceeds this 5 %.

NOTE — The variation in response per unit exposure of the ionization chamber as a function of the energy and direction should be small and known for the energy range in question.

3.3.5 *Recommendations for a collimated geometry installation*

The principal characteristics and schematic diagram of an example for an acceptable device, particularly applicable in the case of cobalt-60 and caesium-137[1] are shown in figure 1.

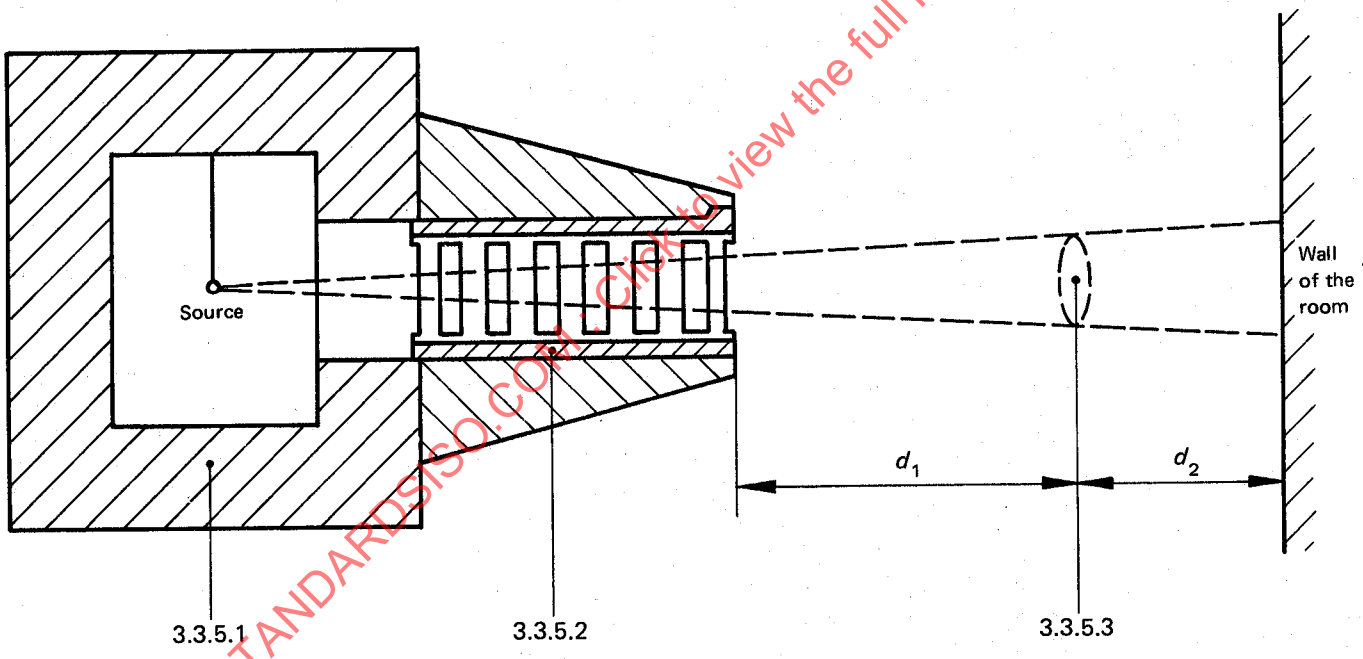

FIGURE 1 — **Example of a collimated installation**

1) This kind of installation produces at most 5 % scattered photons for caesium-137 and less for cobalt-60.

3.3.5.1 The safety enclosure should be made of lead of sufficient thickness to reduce the fluence of the extraneous beam passing through the enclosure to one thousandth of the useful beam. For cobalt-60, the thickness is 12,5 cm and for caesium-137 is 6,5 cm. These values may have to be increased in order to limit radiation exposure of users to acceptable levels.

3.3.5.2 The function of the collimator is to define, in space, the shape and size of the photon beam. The collimated installation shown in figure 1 employs a collimator that is conical in shape with the source at the apex. This collimator is made up of a succession of at least six diaphragms having a total thickness of about 90 mm separated from each other by 20 mm interstices which serve as traps for the photons scattered by the edges of the preceding diaphragms. The final diaphragm has a thickness of 3 mm and an aperture slightly greater than the cross-section of the beam at that point. These diaphragms are made of a tungsten alloy. An example for the composition of such an alloy is given in table 9.

NOTE – In an improved method of operation, the collimator is extended by an output tube. The tube-collimator assembly which is closed at its ends by thin windows made of ethylene glycol polyterephthalate forms an enclosure in which a vacuum is created, thereby reducing air scatter within this assembly.

TABLE 9 – **Example for composition of diaphragm alloy used in the collimator of figure 1**

Element	Content
	% (*m/m*)
Tungsten	89
Nickel	7
Copper	4

3.3.5.3 The beam cross-section shall be larger than that of the detectors to be irradiated. The distance d_1 shall be greater than or equal to 30 cm. The distance d_2 shall be sufficiently great for the contribution to the total exposure rate of photons backscattered by the walls of the room to be compatible with the requirements given in 3.3.6.

3.3.6 *Checking the conformity of an installation*

The following test shall be carried out in order to check that, at the various experimental distances the contribution due to scattered radiation extraneous to that from the source capsule, does not exceed 5 % of the total exposure rate.

This test is carried out with the aid of an ionization chamber of the cavity type, whose variations in response per unit exposure as a function of the energy and direction are small and known for the energy range in question.

Measure the exposure rates on the axis of the beam at the various calibration points adopted and check that, after allowing for air attenuation, they are proportional within 5 % to the inverse square of the distance from the centre of source to centre of detector.

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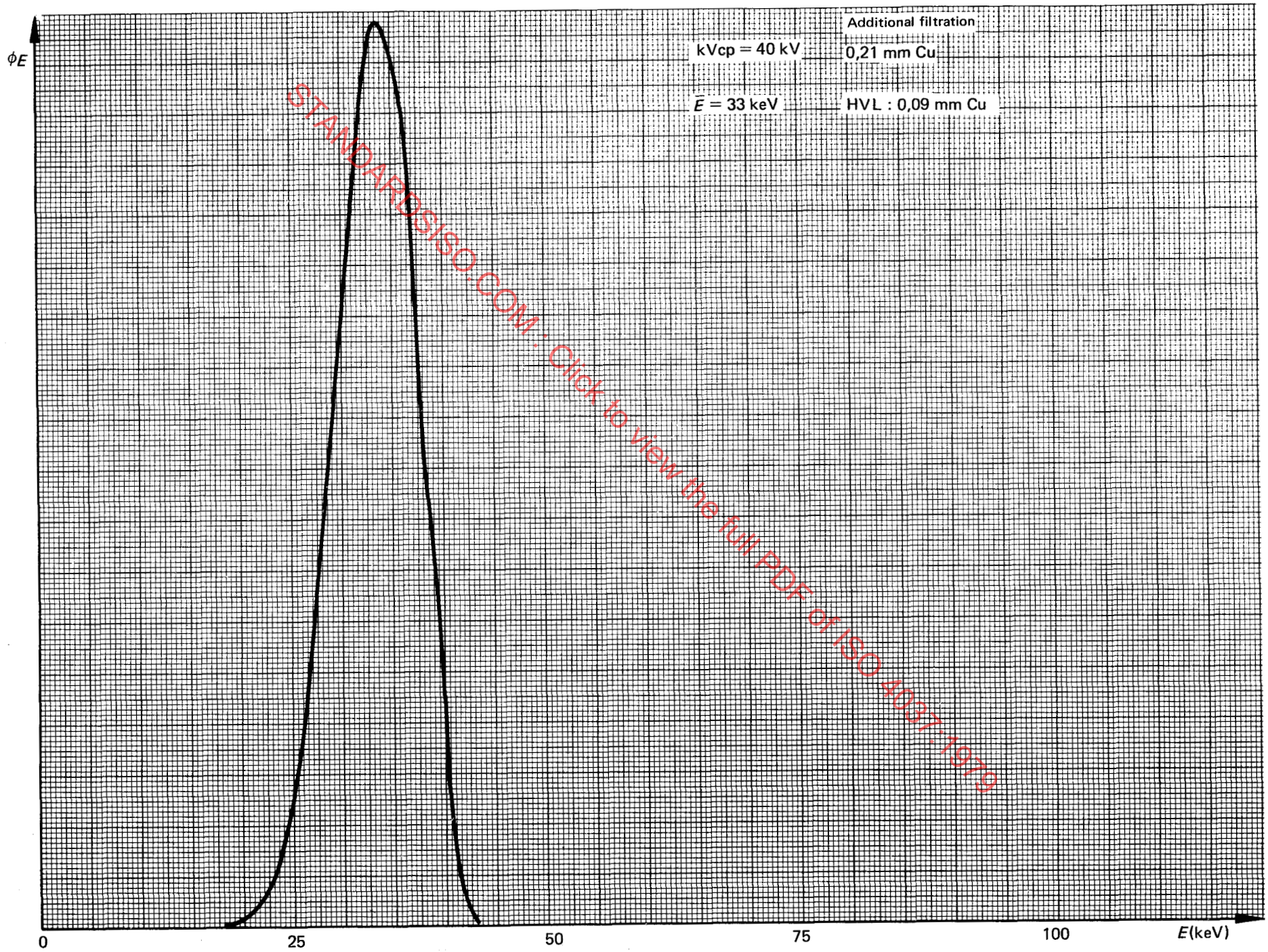

FIGURE 2

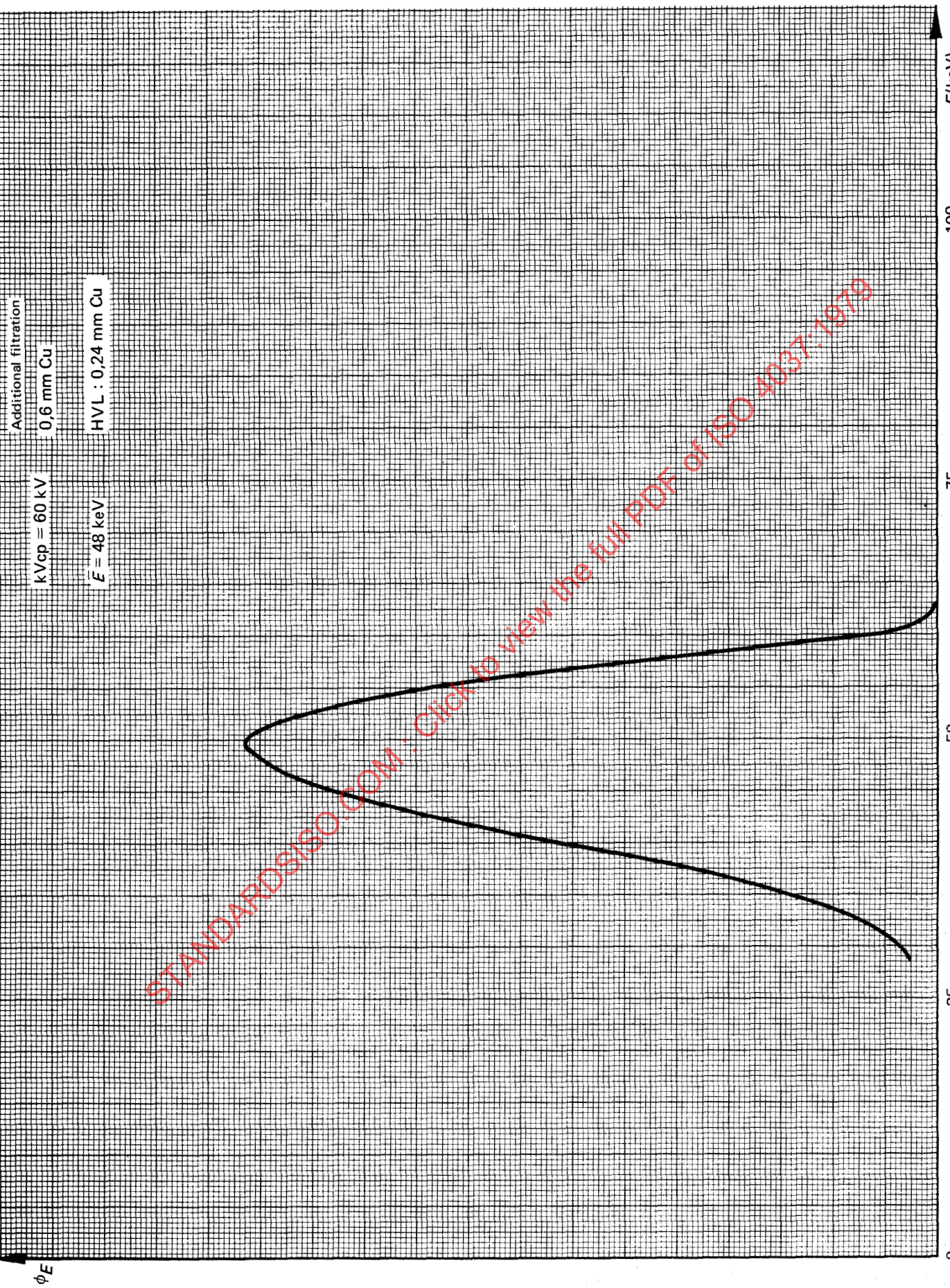

FIGURE 3

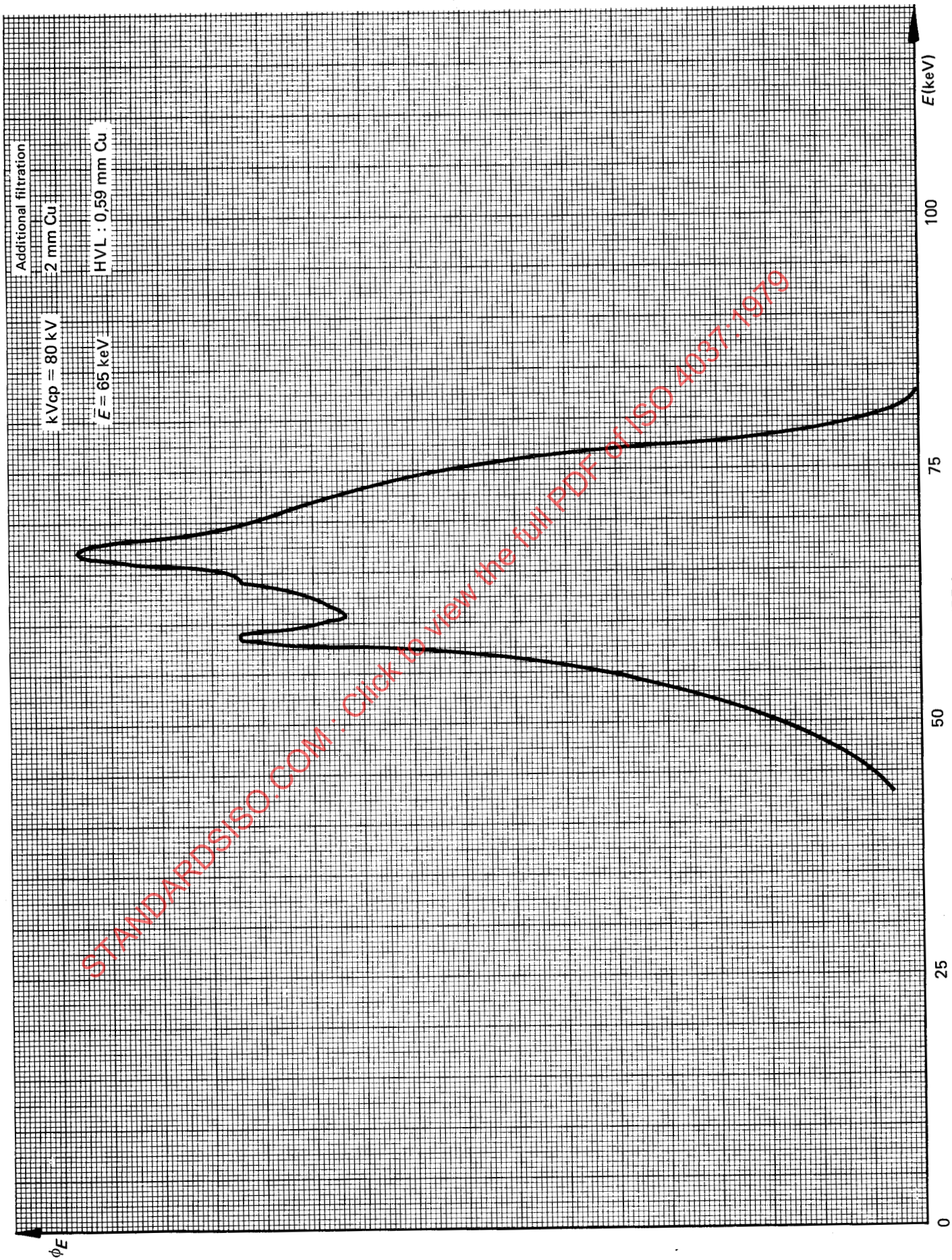

FIGURE 4

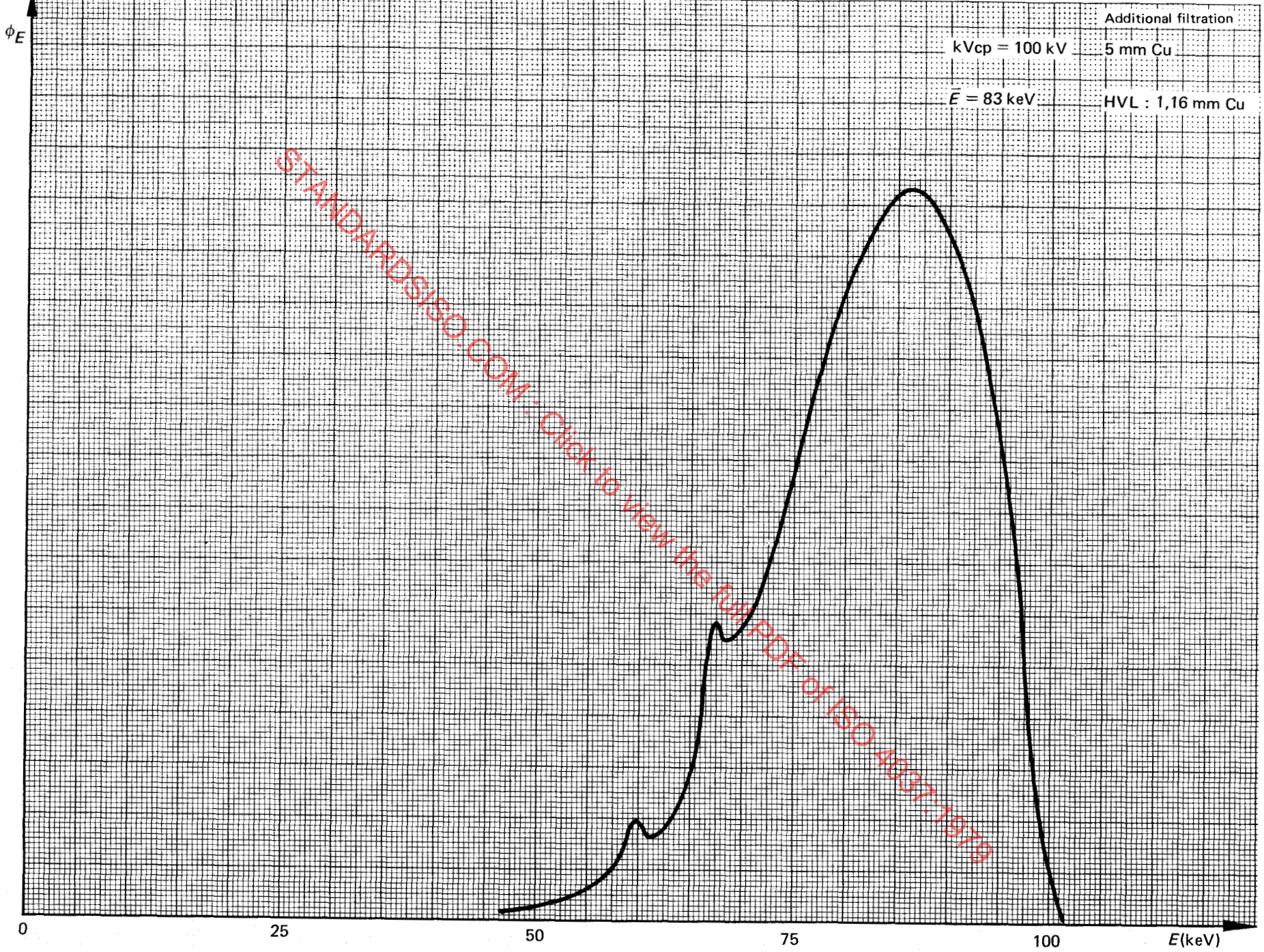

FIGURE 5

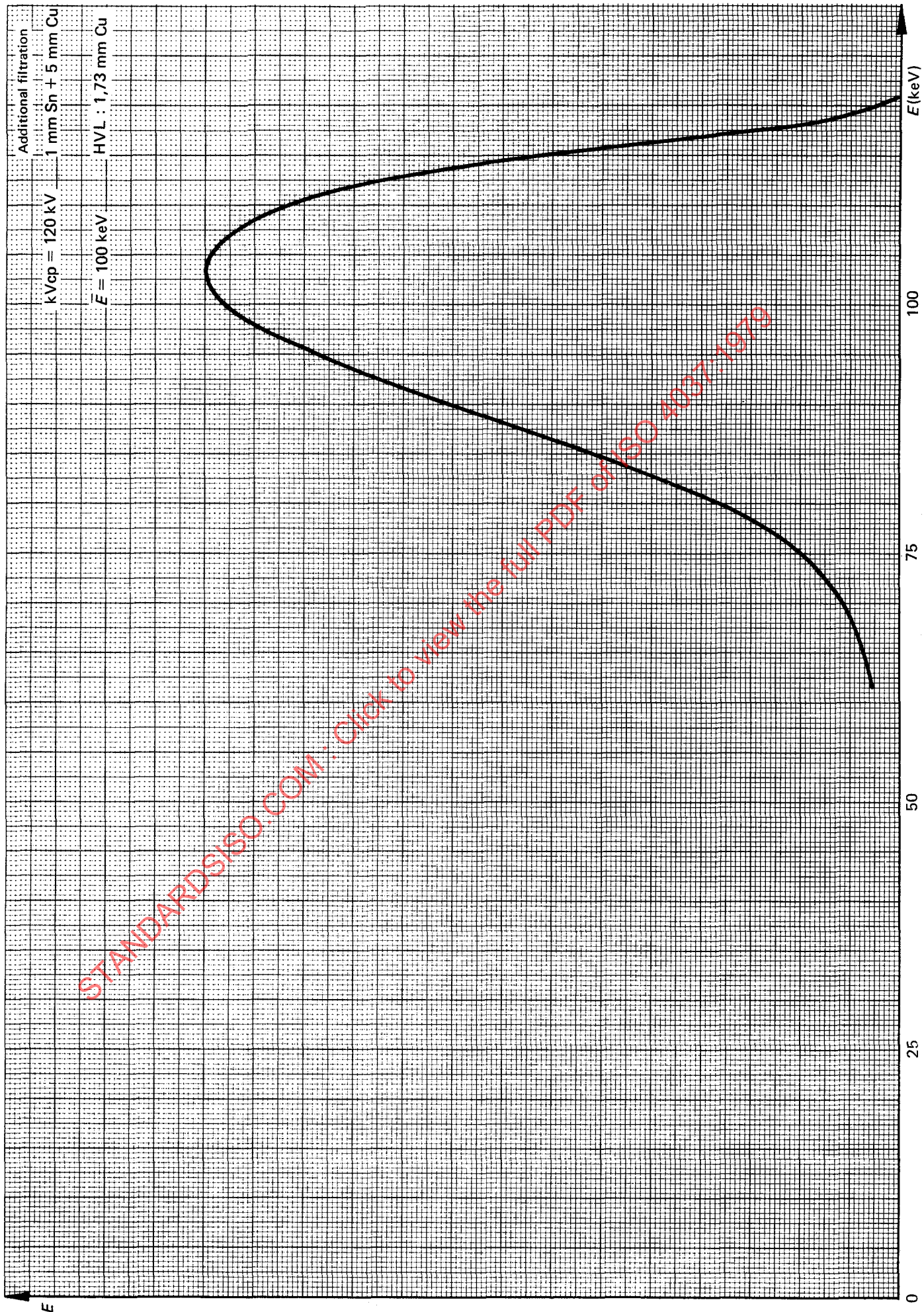

FIGURE 6

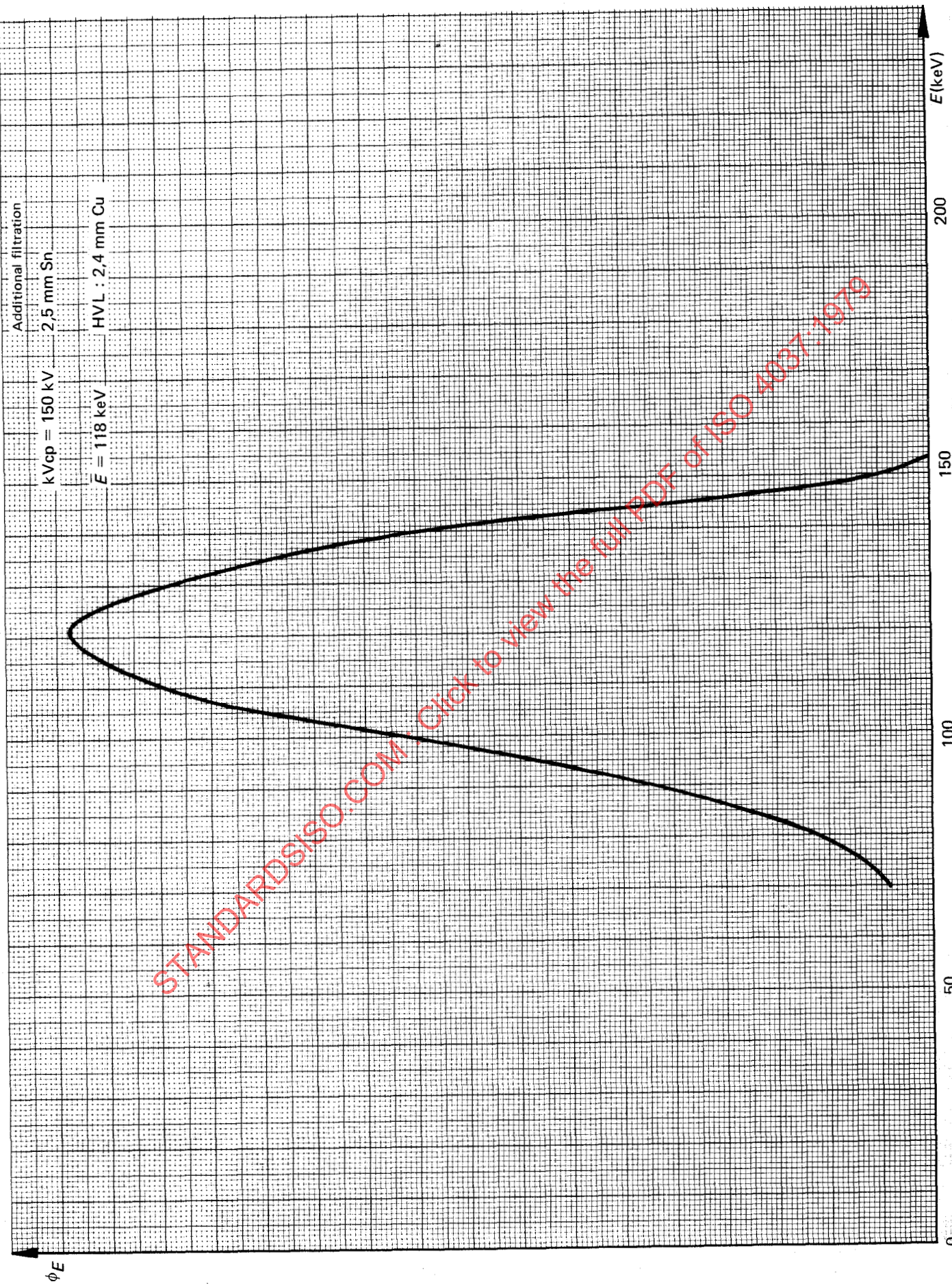

FIGURE 7

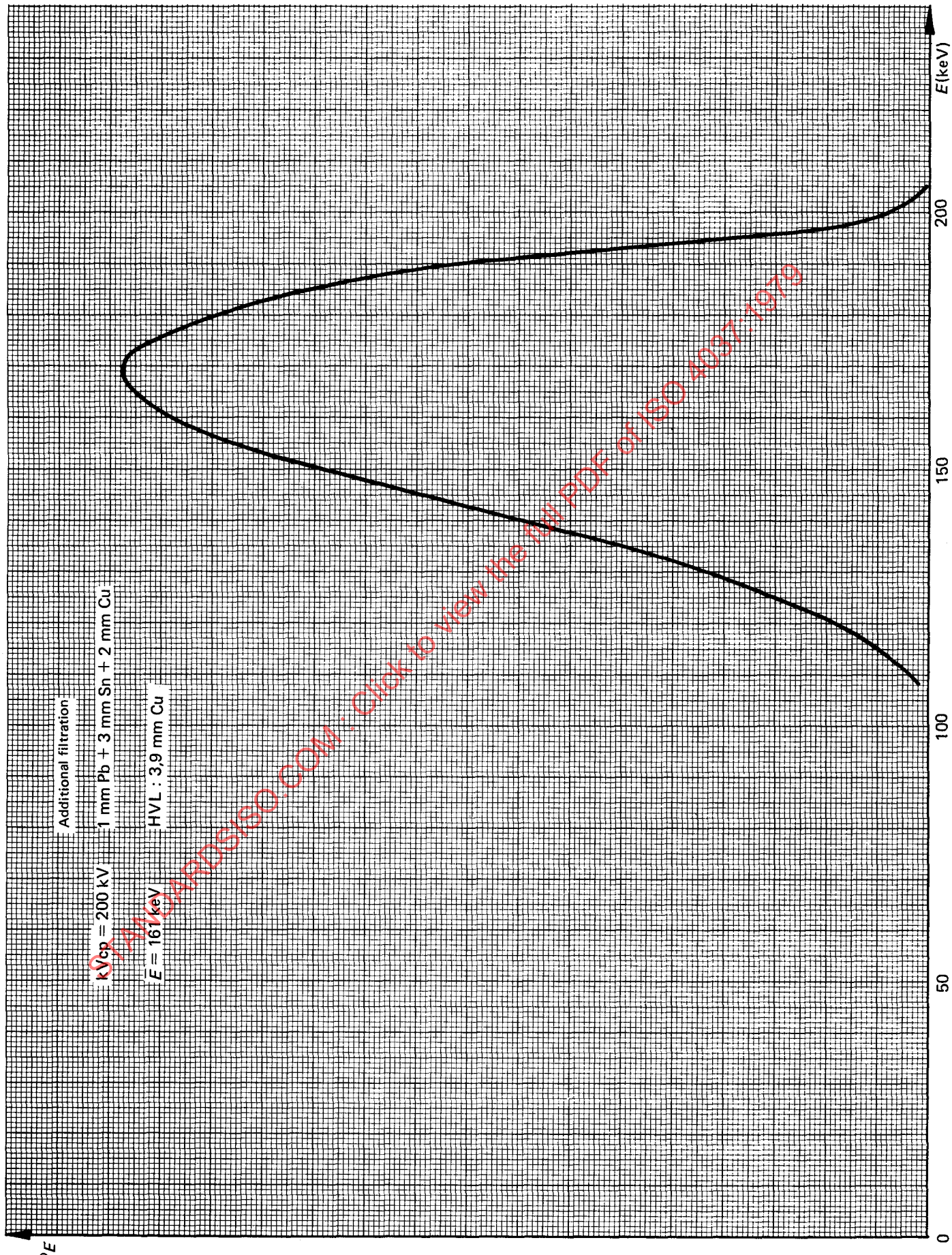

FIGURE 8

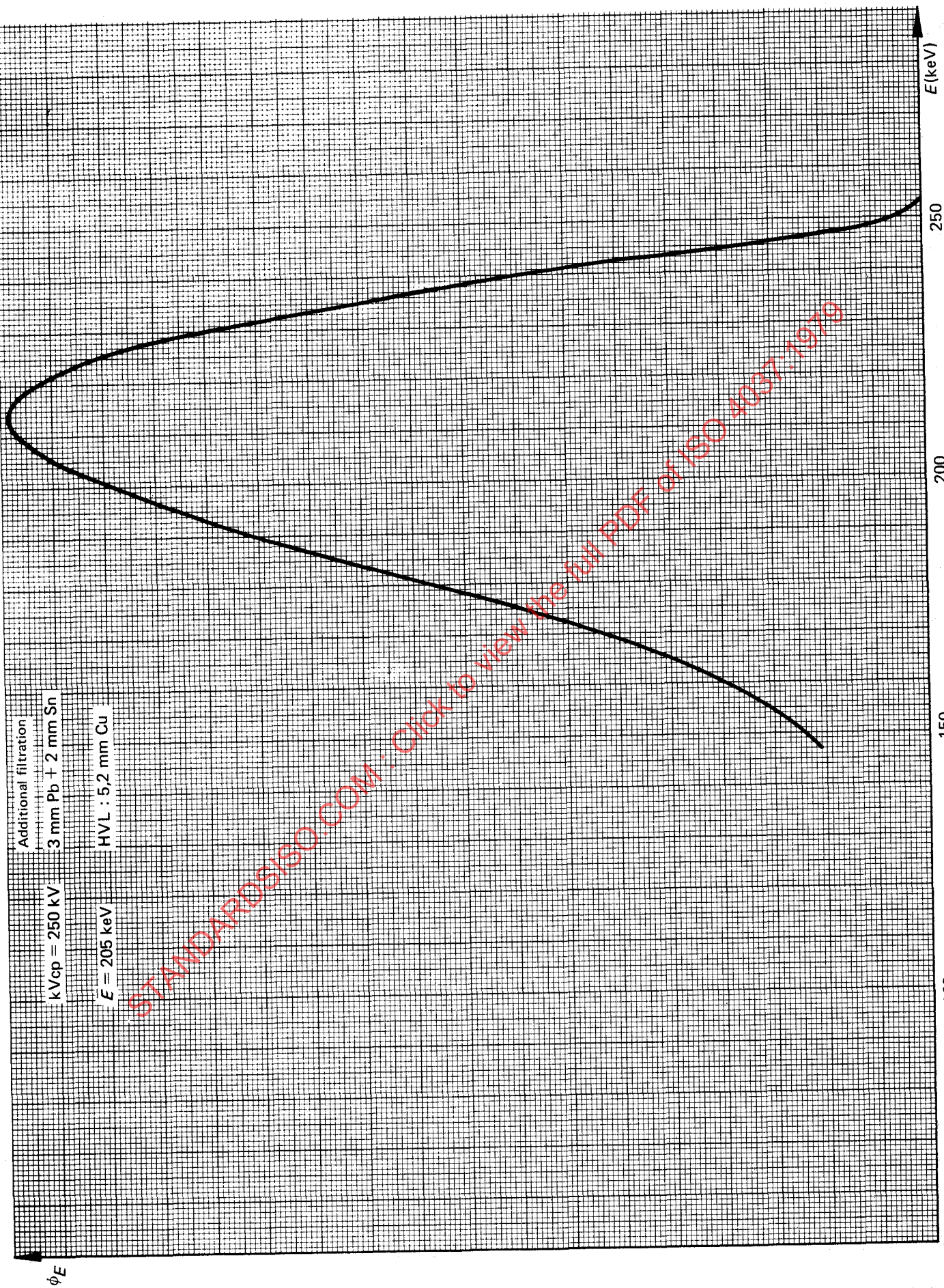

FIGURE 9

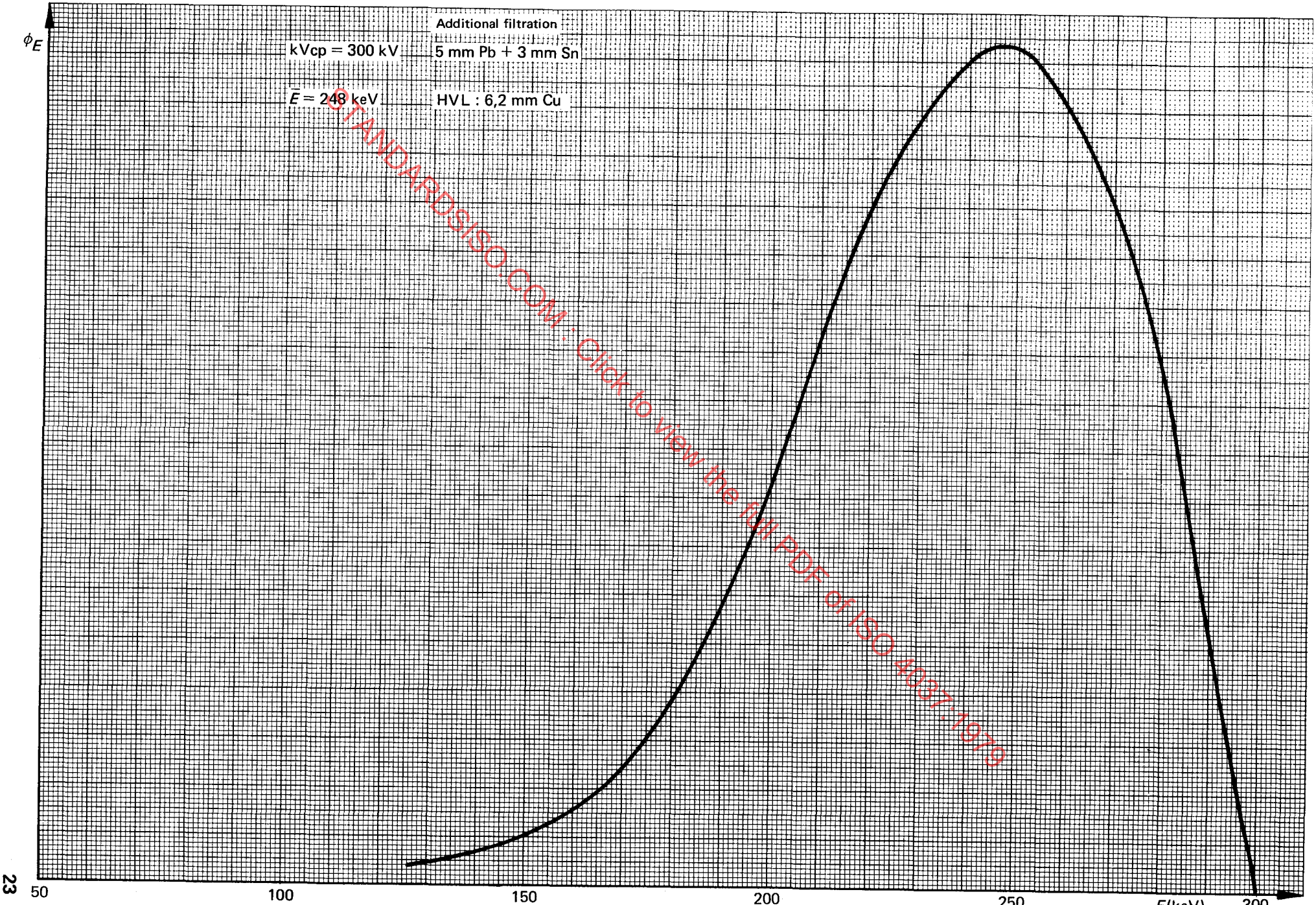

FIGURE 10

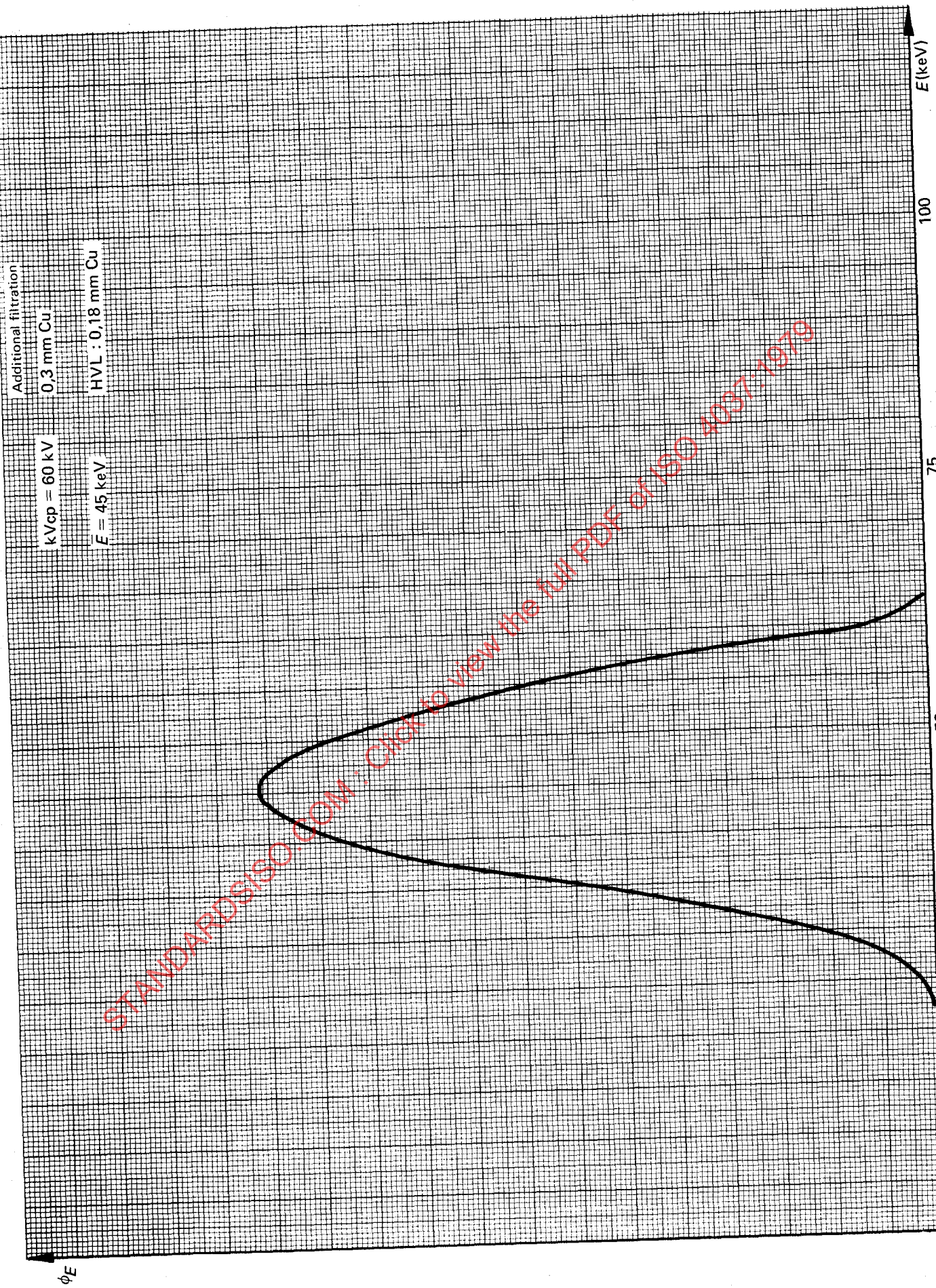

FIGURE 11