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Reference beta radiations for calibrating dosimeters and dose-rate meters and for determining their response as a function of beta-radiation energy

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

Reference number
ISO 6980:1996(E)

Foreword

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International Standard ISO 6980 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, subcommitte SC 2, *Radiation protection*.

This second edition cancels and replaces the first edition (ISO 6980:1984), of which it constitutes a technical revision.

Annexes A, B and C form an integral part of this International Standard.

Annexes D and E are for information only.

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Reference beta radiations for calibrating dosimeters and dose-rate meters and for determining their response as a function of beta-radiation energy

1 Scope

This International Standard specifies the requirements for reference beta radiations produced by radionuclide sources to be used for the calibration of protection level dosimeters and dose-rate meters[1)], and for the determination of their response as a function of beta particle energy. It gives the characteristics of radionuclides which have been used to produce reference beta radiations, gives examples of suitable source constructions and describes methods for the measurement of the residual maximum beta particle energy and the dose-equivalent rate at a depth of 7 $mg \cdot cm^{-2}$ in the ICRU sphere. The energy range involved lies between 66 keV[2)] and 3,6 MeV and the absorbed dose rates are in the range from about 10 $\mu Sv \cdot h^{-1}$ to at least 10 $Sv \cdot h^{-1}$. In addition, for some sources variations of the absorbed dose rate as a function of the angle of incidence are given.

This International Standard proposes two series of reference beta radiations from which the radiation necessary for determining the characteristics (calibration and energy response) of an instrument should be selected.

Series 1 reference radiations are produced by radionuclide sources used with beam-flattening filters designed to give uniform dose rates over a large area at a specified distance. The proposed sources of $^{90}Sr + ^{90}Y$, ^{204}Tl and ^{147}Pm produce maximum dose rates of approximately 5 $mSv \cdot h^{-1}$.

Series 2 reference radiations are produced without the use of beam-flattening filters, which allows planar sources of large area and a range of source-to-calibration plane distances to be used. Close to the sources, only relatively small areas of uniform dose rate are produced, but this Series has the advantage of extending the energy and dose rate ranges beyond those of Series 1. The radionuclides used are those of Series 1 with the addition of the radionuclides ^{14}C and $^{106}Ru + ^{106}Rh$; these sources produce dose rates of up to 10 $Sv \cdot h^{-1}$.

2 Definitions

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

2.1 absorbed dose, D: Quotient of $\overline{dE}$ by dm, where $\overline{dE}$ is the mean energy imparted by ionizing radiation to matter of mass dm.

$$D = \frac{\overline{dE}}{dm}$$

The SI unit of absorbed dose is joule per kilogram ($J \cdot kg^{-1}$) and has been given the special name gray (Gy):

$$1\ Gy = 1\ J \cdot kg^{-1}$$

1) These also include personal dosimeters.

2) This lower limit of the energies to be considered represents the energy of beta particles able to reach the sensitive layer of the skin which is situated nominally 7 $mg \cdot cm^{-2}$ below the skin surface according to ICRP 60[1].

2.2 absorbed dose rate, $\dot{D}$: Quotient of dD by dt, where dD is the increment of absorbed dose in the time interval dt.

$$\dot{D} = \frac{\mathrm{d}D}{\mathrm{d}t}$$

The SI unit of absorbed dose rate is the gray per second ($Gy \cdot s^{-1}$). Units of absorbed dose rate are any quotient of the gray or its decimal multiples or submultiples by an appropriate unit of time (e.g. $mGy \cdot h^{-1}$).

2.3 dose equivalent, H: At a point in an irradiated medium, the product of the absorbed dose D and the quality factor Q at this point.

$$H = DQ$$

NOTE — For beta, X and gamma radiation, Q may be taken as equal to unity for external radiation.

The SI unit of dose equivalent is joule per kilogram ($J \cdot kg^{-1}$) and has been given the special name sievert (Sv):

$$1\ Sv = 1\ J \cdot kg^{-1}$$

2.4 dose-equivalent rate, $\dot{H}$: Quotient of dH by dt, where dH is the increment of dose equivalent in the time interval dt.

$$\dot{H} = \frac{\mathrm{d}H}{\mathrm{d}t}$$

The SI unit of dose-equivalent rate is the sievert per second ($Sv \cdot s^{-1}$). Units of dose-equivalent rate are any quotient of the sievert or its decimal multiples and a suitable unit of time (e.g. $mSv \cdot h^{-1}$).

2.5 specification of the dose-equivalent quantities to be measured in reference beta radiation fields: This International Standard specifies reference beta radiation fields for which the following two dose-equivalent quantities have been defined by ICRU 51 (reference [2] in annex E) for practical measurements. These quantities are $H_p(0,07)$, the personal dose equivalent, and $H'(0,07, \Omega)$, the directional dose equivalent.

In defining these quantities, it is useful to stipulate a radiation field that is derived from the actual radiation field. The term "expanded" is used to characterize the derived radiation field. In the expanded field, the fluence and its angular and energy distribution are the same throughout the volume of interest as in the actual field at the point of reference.

2.5.1 personal dose equivalent, $H_p(0,07)$: Dose equivalent in soft tissue below a specified point on the body at a depth of 0,07 mm.

2.5.2 directional dose equivalent, $H'(0,07, \Omega)$: Dose equivalent, at a point in a radiation field, that would be produced by the corresponding expanded field in the ICRU sphere at a depth of 0,07 mm, on a radius in a specified direction, Ω.

NOTES

1 The ICRU sphere is a tissue-equivalent sphere of diameter 30 cm and density $1\ g \cdot cm^{-3}$.

2 An instrument which determines the dose equivalent at a depth of 0,07 mm in a plane slab of tissue-equivalent material will adequately determine $H'(0,07, \Omega)$ for weakly penetrating radiation if the slab surface is perpendicular to the specified direction Ω and the radiation field is uniform over the entrance face of the instrument.

In most cases, in practice $H_p(0,07)$ can be considered as equal to $H'(0,07, \Omega)$ in beta particle fields where the fluence and its angular and energy distributions have the same values within a sufficiently large volume. When the term "dose" or "dose rate" is used in this International Standard, no distinction is made between these dose-equivalent quantities. As the range of the beta particles is small compared with the diameter of the ICRU sphere, the curvature of this sphere is only of marginal influence, and depth dose curves in the sphere and a semi-infinitely extended slab phantom may be regarded as the same. Expanded field conditions, at least throughout a sufficiently large volume around the dosimeter on the phantom, shall be approximated for every calibration (see reference [3] in annex E).

2.6 total mass stopping power, S/ρ, (of a material for charged particles): Quotient of dE by ρdl, where dE is the energy lost by a charged particle in traversing a distance dl in a material of density ρ.

$$\frac{S}{\rho} = \frac{1 dE}{\rho \cdot dl}$$

The SI unit of mass stopping power is joule square metre per kilogram ($J \cdot m^2 \cdot kg^{-1}$). E may be expressed in electronvolts (eV) and hence S/ρ may be expressed in electronvolt square metres per kilogram ($eV \cdot m^2 \cdot kg^{-1}$).

NOTES

1 S is the total linear stopping power.

2 For energies at which nuclear interactions can be neglected, the total mass stopping power is

$$\frac{S}{\rho} = \frac{1}{\rho}\left(\frac{dE}{dl}\right)_{col} + \frac{1}{\rho}\left(\frac{dE}{dl}\right)_{rad}$$

where

$(dE/dl)_{col} = S_{col}$ is the linear collision stopping power;

$(dE/dl)_{rad} = S_{rad}$ is the linear radiative stopping power.

2.7 tissue: Material with a density of 1 $g \cdot cm^{-3}$ and the following composition in terms of mass fraction for soft tissue (see reference [2] in annex E):

O: 76,2% H: 10,1%

C: 11,1% N: 2,6%

Trace elements are generally not considered important for dosimetric purposes and have been ignored.

2.8 tissue equivalence: Property possessed by a material when the collision mass stopping power and the scattering properties of the material equal those of soft tissue. The density of the tissue-equivalent material is taken to be 1 $g \cdot cm^{-3}$ (see annex A; more tissue substitutes are given by ICRU 44[4]).

NOTE — In practice, tissue equivalence can only exist over a limited range of energies for a particular type of radiation, dependent upon the material utilized, unless the atomic composition is the same as that of tissue.

2.9 maximum energy of a beta particle spectrum, E_{max}: Highest value of the $E_{i,\,max}$ values, characteristic of the particular nuclide listed in table 1. A number of radionuclides emit one or several continuous spectra of beta particles with energies ranging from zero up to maximum values $E_{i,\,max}$, $i = 1, 2...$

2.10 residual maximum beta particle energy, E_{res}: Maximum energy of the beta particle spectrum from all beta particle decay branches of a radionuclide at the calibration distance. E_{res} is less than the corresponding E_{max} as the spectrum is modified by absorption and scattering in the source material itself, the source holder, the source encapsulation and other media between the source and the calibration position.

2.11 residual maximum beta particle range, R_{res}: Range in an absorbing material of a beta particle spectrum of residual maximum energy, E_{res}.

3 Requirements for reference beta radiations at the calibration distance

3.1 Energy of the reference radiations

The energy of the reference radiation is defined to be equal to E_{res} (see 2.10 and 5.1.2).

3.2 Shape of the beta particle spectrum

The beta particle spectrum of the reference radiation should ideally result from one beta decay branch from one radionuclide. In practice, the emission of more than one branch is acceptable provided that all the main branches have similar energies, E_{max}, within ± 20 %. In other cases, the lower energy branches shall be attenuated by the source encapsulation or by additional filtration to reduce their beta emission rates to less than 10 % of the emission rate from the main branch.

3.3 Uniformity of the dose rate

The dose rate at the calibration distance shall be as uniform as possible over the area of the detector. Since available sources for Series 1 reference radiations (see 5.2.1) cannot at present produce high absorbed dose rates with good uniformity for large radiation field diameters, a further series (Series 2) of reference beta radiations is proposed (see 5.2.2). Beta radiations are considered to be uniform over a certain radiation field diameter, if the dose rate does not vary by more than ± 5 % for $E_{res} \geqslant 300$ keV and by not more than ± 10 % for $E_{res} < 300$ keV (see 5.2.1).

NOTE — 1 eV = 1,602 × 10^{-19} J

3.4 Photon contamination

The photon dose rate contributing to $H_p(0,07)$ (see 2.5.1) due to contamination of the reference radiation by gamma, X-ray and bremsstrahlung radiation shall be less than 5 % of the beta particle dose rate recorded by the detector under calibration.

3.5 Variation of the beta particle emission rate with time

The beta particle emission rate decreases with time due to the radioactive decay of the beta particle source. The half-life of a radionuclide should be as long as possible, preferably longer than one year. The half-lives of the recommended sources are given in table 1.

4 Radionuclides suitable for reference beta radiations

Table 1 gives the characteristics of beta-emitting radionuclides of a suitable energy range. Beta-emitting radionuclides shall be selected from those listed in table 1. These radionuclides emit a continuous spectrum of beta particles with energies ranging from zero up to a maximum value, E_{max}, characteristic of the particular nuclide.

Note that, to be used as a practical source, a radionuclide normally requires encapsulation and that the encapsulating material will produce bremsstrahlung and characteristic X-rays.

Table 1 — Beta radionuclide data

Radionuclide	Approximate half-life d	Maximum energy of spectrum, E_{max} MeV	Photon radiations emitted[1)]
^{14}C	2 093 000	0,156	None
^{147}Pm	957	0,225	γ : 0,121 MeV (0,01 %) Sm X-rays: 5,6 keV to 7,2 keV 39,5 keV to 46,6 keV
^{204}Tl	1 381	0,763	Hg X-rays: 9,9 keV to 13,8 keV 68,9 keV to 82,5 keV
$^{90}Sr + {}^{90}Y$	10 483	2,274	None
$^{106}Ru + {}^{106}Rh$	372,6	3,54	^{106}Rh–γ : 0,512 MeV (21 %) 0,622 MeV (11 % doublet) 1,05 MeV (1,5 % doublet) 1,13 MeV (0,5 % doublet) 1,55 MeV (0,2 %)

1) The values given in this column are for information only.

5 Source characteristics and their measurement

5.1 Fundamental characteristics of reference sources

5.1.1 Construction of reference sources

The construction of the reference sources shall have the following characteristics to meet the requirements of clause 3:

a) The chemical form of the radionuclide shall be stable with time over the range of temperatures and humidities at which it will be used and stored.

b) The construction and encapsulation shall be sufficiently robust and stable to withstand normal use without damage to the source and leakage of the radioactivity, but shall allow E_{res} to exceed the minimum values recommended in table 2.

5.1.2 Measurement of characteristics of the reference radiations

The values of the residual maximum energy E_{res} at the calibration distance shall be equal to or exceed the values given in table 2.

Table 2 — Minimum value of E_{res} at calibration distance

Source	E_{res}
^{14}C	0,09
^{147}Pm	0,13
^{204}Tl	0,53
$^{90}Sr + ^{90}Y$	1,80
$^{106}Ru + ^{106}Rh$	2,80

The purpose in setting a lower limit to E_{res} is to prevent the use of sources which have excessive self absorption and/or window absorption.

The residual maximum energy, E_{res}, in megaelectronvolts at the calibration distance shall be calculated from the following relationship (see reference [5] in annex E):

$$E_{res} = \sqrt{\frac{(0{,}009\,1\,R_{res} + 1)^2 - 1}{22{,}4}}$$

where R_{res} is the residual maximum beta particle range in milligrams per square centimetre ($mg \cdot cm^{-2}$).

R_{res} shall be measured by a suitable detector (thin window ionization, chamber, Geiger Müller counter, beta-sensitive phosphor, etc.) which shall be positioned at the calibration distance with its entrance window facing the source, and various thicknesses of absorber shall be placed immediately in front of the detector. The absorber shall be one of the materials polymethyl methacrylate[3], polystyrene, polyethylene, polyethylene terephthalate[4] or an equivalent. The thickness of the detector window used for these measurements shall be taken into account in the measurement of R_{res}.

If the source uses a beam-flattening filter, i.e. is a Series 1 reference radiation (see 5.2.1), this filter shall be in position for the measurement of R_{res}.

The signal from the detector shall be determined as a function of absorber thickness and a plot shall be made of the logarithm of signal versus absorber thickness in milligrams per square centimetre.

R_{res} is defined as the intersection of the extrapolated linear portion of the measured signal versus thickness graph with the lower level signal due to the residual photon background.

E_{res} may also be determined by a beta particle spectrometer employing, for example, Si (Li) semiconductor detectors. Figure 1 shows an example of measured beta particle spectra for the radiations given in table 2: series 1 reference beta radiations (table 3) and series 2 reference beta radiations (^{14}C and $^{106}Ru + ^{106}Rh$, calibration distances 3 mm and 18 mm) measured at the calibration distances with effectively windowless uncooled Si (Li) semiconductor detectors. The measured flux densities Φ_E are normalized to the same maximum value $\Phi_E{}^{max}$ but not corrected for instrumental resolution or detector backscattering loss (see reference [6] in annex E). The ($^{90}Sr + ^{90}Y$) spectrum is produced by ^{90}Y beta particles only due to the heavy encapsulation of the source (type 1 in table C.1 of annex C), whereas two components are evident in the ($^{106}Ru + ^{106}Rh$) spectrum. A survey of a number of theoretical beta particle spectra is given in reference [7] in annex E.

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3) Perspex, Lucite, Plexiglas are examples of commercial names for this plastic.

4) Melinex, Mylar, Hostaphan are examples of commercial names for this plastic.

This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results

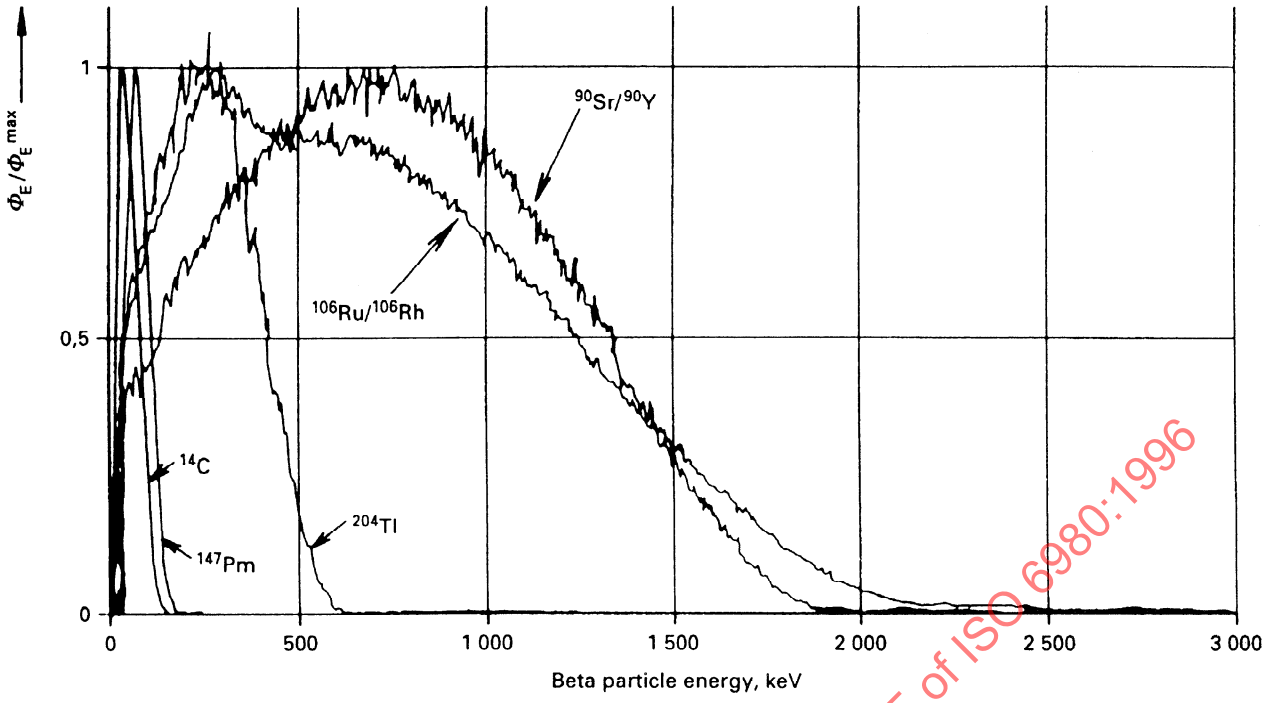

Figure 1 — Examples of beta particle spectra for series 1 and series 2 reference beta radiations

5.1.3 Beta contamination

The radionuclide sources shall be of adequate radiochemical purity. It is difficult to check for the presence of beta-particle-emitting impurities but their presence may be inferred from the detection of their associated photon radiation, if any, using a high resolution spectrometer, for example, a Ge (Li) detector and spectrometer system. The spectral purity of the beta radiation may be considered adequate for use as a reference radiation if

a) the plot used to measure R_{res} (see 5.1.2) has a linear section;

b) E_{res} has a value between that given in table 2 and the corresponding E_{max} value given in table 1 for the appropriate radionuclide.

NOTE — If E_{res} exceeds E_{max}, the source contains a radioactive contaminant which emits higher energy particles than the reference radionuclide(s) and it therefore does not meet the requirements of this International Standard.

R_{res} and, hence, E_{res} shall be remeasured every two years.

5.1.4 Photon contamination

The photon contamination of the beta reference radiation arises from photon radiation from the decay of the radionuclide, as given in table 1, and bremsstrahlung and characteristic X-rays from the source encapsulation which is typically silver. The significance of the photon contamination depends on the photon sensitivity and hence the type of detector placed in the reference radiation. The photon contribution shall therefore be measured for each type of detector and radionuclide source by comparing the detector response with and without an absorber, made of one of the materials listed in 5.1.2 and just sufficiently thick to totally absorb the beta radiation.

5.2 Characteristics of the two series of reference beta radiations

Details of the construction of suitable sources for producing both series of reference radiations are given, as examples, in annex D.

5.2.1 Series 1 reference beta radiations

When uniform dose rates over a large area are required, the sources listed in table 3 shall be used with beam-flattening filters to produce a uniform dose rate over a minimum area of 15 cm in diameter at the calibration distance. The filters should be positioned on the principal axis normal to the plane of the source. For each

radionuclide, the dose rate at the calibration distance shall be varied by using sources of different activities. The variation of dose rate over the area at the calibration distance shall be less than ± 5 % for (^{90}Sr + ^{90}Y) and ^{204}Tl and ± 10% for ^{147}Pm. This may be verified by using a detector with an area of about 1 cm^2 and a response independent of the incident beta particle energy.

The uniformity of the dose rate over the calibration area is optimal only at a specified distance for a given filter construction (references [8] and [9] in annex E).

As examples of Series 1 reference radiations, table 3 gives details of calibration distances and filter construction.

NOTE — A maximum source diameter of 16 mm is recommended.

The approximate dose rates per unit activity are listed in table 4, for the sources used under the conditions specified in table 3.

Table 3 — Calibration distances and filters for Series 1 reference beta radiations

Radionuclide	Calibration distance cm	Source-to-filter distance cm	Filter material and dimensions
^{147}Pm	20	10	1 disc of polyethylene terephthalate, of radius 5 cm and mass per unit area 14 mg·cm^{-2}, with hole of radius 0,975 cm at centre
^{204}Tl	30	10	2 concentric discs, 1 disc of polyethylene terephthalate, of 4 cm radius and mass per unit area 7 mg·cm^{-2}, plus 1 disc of polyethylene terephthalate, of 2,75 cm radius and mass per unit area 25 mg·cm^{-2}
^{90}Sr + ^{90}Y	30	10	3 concentric discs of polyethylene terephthalate, each with mass per unit area of 25 mg·cm^{-2} and of radii 2 cm, 3 cm and 5 cm

Table 4 — Approximate dose rates at the calibration distance per unit activity for Series 1 reference beta radiations

Radionuclide	Approximate dose rate per unit activity mSv·h^{-1}·MBq^{-1} 1)
^{147}Pm	6
^{204}Tl	68
^{90}Sr + ^{90}Y	65
1) 1 Bq = 1 s^{-1}	

5.2.2 Series 2 reference beta radiations

When high dose rates are required, sources with geometries other than specified in table 3 may be used. These can include high activity point sources or large area planar sources. These sources need not be used with beam-flattening filters. They may be used at calibration distances approaching the surface of the source up to the distance shown in table 5. Reference [10] in annex E gives examples of measurements with sources of large area.

At these larger distances it is particularly important, because of air attenuation, to verify that E_{res} equals or exceeds the values given in table 2.

By using shorter calibration distances than those specified for Series 1, higher dose rates are obtained but the irradiation field is substantially less uniform.

The non-uniformity should be measured at the distance used for calibration and, if the values exceed those stated in 3.3, corrections should be applied during the calibration of instruments. The distances given in table 5 are intended to be the normal maximum useful calibration distances.

Series 2 reference beta radiations contains two additional radionuclides, ^{14}C and (^{106}Ru + ^{106}Rh); they should be used where calibration is required outside the energy limits of Series 1.

As a guide, the approximate dose rates obtained from such sources are shown in table 5.

Table 5 — Examples of activities and dose rates from Series 2 reference beta radiations

Radionuclide	Source characteristics		Dose rate Sv·h^{-1}	
	Nominal activity MBq	Approximate active area cm^2	Estimated values at the surface of the source[1)]	Typical values at the listed distance
^{14}C	1	9	0,06	0,006 at 5 cm
^{147}Pm	10^2	25	3	0,003 at 20 cm
^{204}Tl	10^2	14	10	0,003 at 50 cm
^{90}Sr + ^{90}Y	10^3	0,7	700	0,03 at 50 cm
^{106}Ru + ^{106}Rh	10^2	1,5	6	0,001 at 100 cm

1) Surface dose rates should be measured with a detector whose area is equal to or less than that of the source.

6 Source calibration

The quantities recommended for the calibration of protection instruments are specified in 2.5. In the past, it became established practice to calibrate individual dosimetry systems by irradiating the dosimeters on the surface of an appropriate phantom, such as a polymethyl methacrylate slab with a side length of 200 mm and a thickness of 10 mm for calibrating planar dosimeters, or a polymethyl methacrylate rod, 200 mm in length and of an appropriate diameter, for calibrating finger dosimeters. Dosimeters for environmental monitoring are irradiated free-in-air.

For the Series 1 reference beta radiations which use beam-flattening filters, the uniformity of the dose rate over the calibration area is optimal only at a specified distance for a given filter construction. The calibration shall be carried out only at this distance.

The Series 2 reference beta radiations may be calibrated over a range of distances, bearing in mind that the area of uniform dose rate is likely to be relatively small, unless the calibration distance or the source area is large. The uniformity of the dose rate over the detector area shall be checked and corrections applied if necessary.

The dose rates from the reference sources shall be determined by one of the following methods (see references [11] and [12] in annex E).

a) direct measurement by a national standards laboratory;

b) comparison with similar sources calibrated at a national standards laboratory, or some other accessible primary or secondary calibration laboratory, using a suitable transfer instrument (for example, an extrapolation ionization chamber, see annex B).

Annex A
(normative)

Tissue-equivalent materials

The composition of soft tissue adopted here is the one given by ICRU[2]. Its density and composition by mass as well those for other materials commonly used as tissue-equivalent materials are given in table A.1.

Table A.1 — Tissue-equivalent materials

Materials	Density	Number of electrons per unit volume	Elemental composition % (*m*/*m*)				
	$g \cdot cm^{-3}$	$10^{27} \cdot m^{-3}$	H	C	N	O	Others
Soft tissue	1	331	10,1	11,1	2,6	76,2	
Graphite	1,7	511	—	100	—	—	
Polyethylene terephthalate	1,40	439	4,2	62,5	—	33,3	
Polymethyl methacrylate	1,17	380	8,0	60,0	—	32,0	
Polystyrene	1,05	340	7,7	92,3	—	—	
A-150 Shonka plastic	1,12	370	10,1	77,7	3,5	5,2	1,7 F 1,8 Ca

Annex B
(normative)

Determination of absorbed dose rate to tissue by means of an extrapolation ionization chamber

B.1 Extrapolation chamber

The dose rate to tissue, $\dot{D}_T$, at a point of interest in a radiation field from a beta particle source may be determined from measurements made with a suitable extrapolation ionization chamber or a thin fixed-volume ionization chamber (see references [13], [14] and [15] in annex E). It is recommended that the extrapolation chamber and the 7 mg·cm^{-2} front entrance window be constructed from a material with a low atomic number, for example, graphited plastic. To derive the corresponding tissue thickness for the window, the relative attenuation factors of Cross[15] should be applied for the material used.

The ionization volume should be surrounded by sufficient material to correspond to a semi-infinite tissue-equivalent phantom. This requires the material behind the volume and its side-wall thickness to be at least sufficiently thick to totally absorb the maximum beta energy present (i.e. thickness $\geqslant R_{res}$).

The area of the uniform beam of radiation should be at least that of the area of the minimum phantom described, above.

The dose rate to tissue, $\dot{D}_T$, is calculated by

$$\dot{D}_T = \dot{D}_A \cdot S_{T,A} \qquad \ldots (B.1)$$

where

$\dot{D}_T$ is the absorbed dose rate to tissue at 7 mg·cm^{-2} depth;

$\dot{D}_A$ is the absorbed dose rate to air in tissue at 7 mg·cm^{-2} depth, under Bragg-Gray conditions;

$S_{T,A}$ is the ratio of the average mass collision stopping power of tissue to that of air; for the radionuclides of table 1 a value of 1,12 is recommended (see reference [13] in annex E).

The dose rate to air in tissue, $\dot{D}_A$, is calculated by

$$\dot{D}_A = \frac{\overline{W}}{e} \cdot \left(\frac{dI}{dm_A} \right)_{m_A \to 0} \qquad \ldots (B.2)$$

where

$\frac{\overline{W}}{e}$ is the quotient of the mean energy $\overline{W}$ expended in dry air per ion pair formed by the elementary charge e (see reference [16] in annex E) $\left[\overline{W}/e = (33{,}97 \pm 0{,}05)\ \mathrm{J \cdot C^{-1}} \right]$;

$\left(\frac{dI}{dm_A} \right)_{m_A \to 0}$ is the limiting value of the quotient of the corrected mean ionization current I produced in the chamber by the air mass m_A in the collecting volume as it approaches zero.

I is the mean of the positive and negative ion currents.

The air mass m_A is calculated by

$$m_A = b \times \rho_A$$

where

b is the effective area of the collecting electrode (see reference [17] in annex E);

x is the depth of the collecting volume;

ρ_A is the air density in the collecting volume.

In most cases, the air mass, m_A, in the collecting volume can be changed by altering the depth x.

B.2 Corrections

Equation (2) has to be corrected to take into account the following effects.

a) Incomplete ion collection in the collecting volume (recombination losses). The polarizing voltage shall be sufficient to make this effect negligible for all dose rates and electrode separations used.

b) Direct collection of beta particles (polarity effect). To eliminate this effect, the ionization currents shall be measured for positive and negative polarizing voltages. In equation (B.2) it is recommended that the mean of these currents be used.

c) Electrostatic attraction of the entrance foil of the chamber. The electrostatic field existing between the collecting and polarizing electrodes may distort thin electrodes, causing a change in the collecting volume. This effect may be avoided by adjusting the polarizing voltage such that the field strength is maintained constant for all electrode separations.

d) Perturbation of the beta particle field by the medium surrounding the collecting volume. The effect of beta particle scattering into and out of the collecting volume depends on the beta energy and the shape and material of the chamber.

e) Photon emission of the beta source.

f) Background radiation.

g) Absorption of the beta radiation in the air between the source and the chamber at air pressures and temperatures different from standard conditions (see reference [18] in annex E).

h) Decreasing mean electron flux density with increasing chamber depth if the entrance window (foil) is in a fixed position during the measurements.

j) Humidity of air. The presence of water vapour in the atmosphere lowers the air path density from that of dry air at the same temperature and pressure. For the higher energy sources this effect is negligible, but for ^{147}Pm a 1% decrease in dose rate may result from a 25 % increase in humidity. The humidity of the air also slightly affects the mean energy per ion pair formed.

k) The Bragg-Gray conditions which are the preconditions for the validity of equation (B.1) are not fulfilled.

Annex C
(normative)

Variation of the absorbed dose rate as a function of the angle of incidence α

Calibration certificates supplied with sources often contain only data for the absorbed dose rate to soft tissue at the surface of the phantom, $\dot{D}(0, 0)$, and transmission factors $T(d, 0)$, $T(d, 0) = \dot{D}(d, 0)/\dot{D}(0, 0)$, for the tissue depth d and for the angle of incidence $\alpha = 0°$. In this case, the "angle of incidence" means the angle between the symmetry axis of the radiation field and the normal to the phantom surface. Table C.1 contains characteristic data for five "point sources" (diameter of the active material 1 cm) for which the variation of dose rate has been measured (references [6] and [19] in annex E). The sources are in compliance with this International Standard and commonly calibrated by national standards laboratories. To characterize the sources more completely, typical values of $T(d, 0)$ for the tissue depths 0,07 mm, 0,2 mm and 0,5 mm are included in table C.1.

There are, of course, numerous beta particles which impinge obliquely on the phantom even for $\alpha = 0°$, due to air-scatter and the finite size of the beta-radiation source. The variation of the absorbed dose rate as a function of the angle of incidence may be measured by means of an extrapolation chamber.

$\dot{H}'(0{,}07, \alpha)$ is calculated in good approximation from $\dot{D}(0, 0)$, $T(d, 0)$ and the quotient $\dot{D}(0{,}07, \alpha)/\dot{D}(0{,}07, 0)$ in table C.2 using the formula

$$\dot{H}'(0{,}07, \alpha) = \dot{D}(0, 0) \cdot T(0{,}07, 0) \left\{ \frac{\dot{D}(0{,}07, \alpha)}{\dot{D}(0{,}07, 0)} \right\}$$

Table C.1 — Examples of types of beta-radiation sources and filter combinations which can be used for determining the response of dosimeters and dose-rate meters as a function of the angle of incidence

Source type	1	2	3	4	5
Radionuclide	$^{90}Sr + ^{90}Y$	$^{90}Sr + ^{90}Y$	$^{90}Sr + ^{90}Y$	^{204}Tl	^{147}Pm
Mass per area of the inactive silver foil "window" $mg \cdot cm^{-2}$	50 ± 5	50 ± 5	50 ± 5	20 ± 3	5 ± 1
Protective coating material and mass per area $mg \cdot cm^{-2}$	Stainless steel (80)	Gold flashing (10)	Stainless steel (80)	Gold flashing (5)	Electroplating of nickel (0,5)
Filter according to table 3	Yes	Yes	No filter	Yes	Yes
Irradiation distance cm	30	30	30	30	20
$T(0{,}07, 0)$	1,04	1,02	1,06	0,99	0,18
$T(0{,}2, 0)$	1,09	1,04	1,12	0,79	—
$T(0{,}5, 0)$	1,12	1,02	1,16	—	—

Table C.2 — Quotient $\dot{D}(0{,}07, \alpha)/\dot{D}(0{,}07, 0)$ for different angles of incidence

Angle of incidence, α Degrees	$\dot{D}(0{,}07, \alpha)/\dot{D}(0{,}07, 0)$				
	Source type (see table C.1)				
	1	2	3	4	5
0	1	1	1	1	1
15	1,01	1,01	1,01	0,99	0,98
30	1,05	1,04	1,05	0,96	0,84
45	1,12	1,10	1,13	0,90	0,69
60	1,15	1,11	1,19	0,73	—
75	0,89	0,86	0,95	0,50	—

Annex D
(informative)

Characteristics of the recommended sources

Examples of source construction leading to radiation fields with suitable characteristics are given in table D.1, together with acceptable measured value of E_{res} for these source constructions. The uniformity of the active materials may be investigated by autoradiography.

Table D.1 — Examples of source construction

Radionuclide	Chemical form	Encapsulation material	Window material and mass per unit area $mg \cdot cm^{-2}$	Protective coating material and mass per unit area $mg \cdot cm^{-2}$	Lower limit of E_{res} MeV
^{14}C	Poly(methyl-^{14}C) methacrylate	See chemical form	None	None	0,09
^{147}Pm	Carbonate	Silver	Silver (5)	Nickel (0,5)	0,13
^{204}Tl	Thallous chromate	Silver	Silver (20)	Gold (5)	0,53
$^{90}Sr + ^{90}Y$	Strontium carbonate	Silver	Silver (50)	Gold (10)	1,80
$^{90}Sr + ^{90}Y$	Strontium carbonate	Silver	Silver (50)	Stainless steel (80)	1,80
$^{106}Ru + ^{106}Rh$	Ruthenium metal	Silver	Silver (50)	Gold (10)	2,80