# INTERNATIONAL STANDARD

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# Nuclear energy — Reference beta-particle radiation —

## Part 1:
## Methods of production

*Énergie nucléaire — Rayonnement bêta de référence —*

*Partie 1: Méthodes de production*

Reference number
ISO 6980-1:2006(E)

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# Contents

# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 6980-1 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

This first edition of ISO 6980-1, together with the first edition of ISO 6980-2 and the first edition of ISO 6980-3 cancels and replaces ISO 6980:1996, which has been technically revised

ISO 6980 consists of the following parts, under the general title *Nuclear energy — Reference beta-particle radiations*:

- *Part 1: Methods of production*
- *Part 2: Calibration fundamentals related to basic quantities characterizing the radiation field*
- *Part 3: Calibration of area and personal dosemeters and the determination of their response as a function of beta radiation energy and angle of incidence*

# Nuclear energy — Reference beta-particle radiation —

## Part 1:
## Methods of production

## 1 Scope

This part of ISO 6980 specifies the requirements for reference beta radiation fields produced by radionuclide sources to be used for the calibration of personal and area dosemeters and dose-rate meters to be used for the determination of the quantities $H_\mathrm{p}(0{,}07)$ and $H'(0{,}07)$, and for the determination of their response as a function of beta particle energy and angle of incidence. It gives the characteristics of radionuclides that have been used to produce reference beta radiation fields, 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 0,07 mm in the International Commission on radiation units and measurements (ICRU) sphere. The energy range involved lies between 66 keV[1)] and 3,6 MeV and the dose equivalent rates are in the range from about 10 µSv $\mathrm{h}^{-1}$ to at least 10 Sv $\mathrm{h}^{-1}$. In addition, for some sources variations of the dose equivalent rate as a function of the angle of incidence are given.

This part of ISO 6980 proposes two series of beta reference radiation fields, from which the radiation necessary for determining the characteristics (calibration and energy and angular dependence of response) of an instrument can be selected.

Series 1 reference radiation fields are produced by radionuclide sources used with beam flattening filters designed to give uniform dose equivalent rates over a large area at a specified distance. The proposed sources of $^{90}\mathrm{Sr} + {}^{90}\mathrm{Y}$, $^{85}\mathrm{Kr}$, $^{204}\mathrm{Tl}$ and $^{147}\mathrm{Pm}$ produce maximum dose equivalent rates of approximately 200 mSv $\mathrm{h}^{-1}$.

Series 2 reference radiation fields are produced without the use of beam-flattening filters, which allows large area planar sources 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 $^{14}\mathrm{C}$ and $^{106}\mathrm{Ru} + {}^{106}\mathrm{Rh}$; these sources produce dose equivalent rates of up to 10 Sv $\mathrm{h}^{-1}$.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

*International vocabulary of basic and general terms in metrology,* (VIM), *BIPM/IEC/IFCC/ISO/IUPAC/IUPAP/OIML*

ICRU 51:1993, *Quantities and Units in Radiation Protection Dosimetry*

ISO 6980-3, *Nuclear energy — Reference beta-particle radiations — Part 3: Calibration of area and personal dosemeters and determination of their response as a function of beta radiation energy and angle of incidence*

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1) The lower limit of the energies being considered is the energy of an electron that can just penetrate to the depth of interest, 0,07 mm[1].

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ICRU Report 51, VIM and ISO 6980-3 and the following apply.

### 3.1
**absorbed dose**

$D$

quotient of d$\bar{\varepsilon}$ by d$m$, where d$\bar{\varepsilon}$ is the mean energy imparted by ionizing radiation to matter of mass d$m$

$$D = \mathrm{d}\bar{\varepsilon} / \mathrm{d}m \tag{1}$$

NOTE The unit of the absorbed dose is joule per kilogram (J kg$^{-1}$) with the special name of gray (Gy).

### 3.2
**absorbed dose rate**

$\dot{D}$

quotient of d$D$ by d$t$, where d$D$ is the increment of absorbed dose in the time interval, d$t$

$$\dot{D} = \mathrm{d}D / \mathrm{d}t \tag{2}$$

NOTE The SI unit of absorbed dose rate is gray per second (Gy 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 h$^{-1}$).

### 3.3
**dose equivalent**

$H$

product of the absorbed dose, $D$, and the quality factor, $Q$, at a point in an irradiated medium

$$H = DQ \tag{3}$$

NOTE 1 For beta, X and gamma radiation, $Q$ can be taken as equal to unity for external radiation[1].

NOTE 2 The SI unit of dose equivalent is joule per kilogram (J kg$^{-1}$) with the special name of sievert (Sv).

### 3.4
**dose equivalent rate**

$\dot{H}$

quotient of d$H$ by d$t$, where d$H$ is the increment of dose equivalent in the time interval, d$t$

$$\dot{H} = \mathrm{d}H / \mathrm{d}t \tag{4}$$

NOTE The SI unit of dose equivalent rate is the sievert per second (Sv 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 h$^{-1}$).

### 3.5
**directional dose equivalent for weakly penetrating radiation**

$H'(0{,}07;\vec{\Omega})$

dose equivalent that, at a point in a radiation field, is produced by the corresponding expanded field in the ICRU sphere at a depth of 0,07 mm on a radius in a specified direction, $\vec{\Omega}$

NOTE 1 The unit of the directional dose equivalent is joule per kilogram (J kg$^{-1}$) with the special name sievert (Sv).

NOTE 2 In the expanded field, the fluence and its angular and energy distributions have the same value over the volume of interest as in the actual field at the point of measurement.

NOTE 3 See ICRU 56[2].

### 3.6
### personal dose equivalent for weakly penetrating radiation

$H_p(0{,}07)$

dose equivalent in soft tissue below a specified point on the body at a depth of 0,07 mm

NOTE 1 The unit of the personal dose equivalent is joule per kilogram (J $\text{kg}^{-1}$) with the special name sievert (Sv).

NOTE 2 In a unidirectional field, the direction can be specified in terms of the angle, $\alpha$, between the direction opposing the incident field and a specified normal on the phantom surface.

### 3.7
### total mass stopping power

$S/\rho$

the quotient of d$E$ by $\rho$d$l$, where d$E$ is the energy lost by a charged particle in traversing a distance, d$l$, in a material of mass density, $\rho$

$$\frac{S}{\rho} = \frac{1}{\rho}\frac{\mathrm{d}E}{\mathrm{d}l} \tag{5}$$

NOTE 1 The SI unit of mass stopping power is joule per square metre (J $\text{m}^2$ $\text{kg}^{-1}$). $E$ can be expressed in electronvolts (eV) and hence $S/\rho$ can be expressed in eV $\text{m}^2$ $\text{kg}^{-1}$.

NOTE 2 $S$ is the total linear stopping power.

NOTE 3 For energies at which nuclear interactions can be neglected, the total mass stopping power is

$$\frac{S}{\rho} = \frac{1}{\rho}\left(\frac{\mathrm{d}E}{\mathrm{d}l}\right)_{\text{col}} + \frac{1}{\rho}\left(\frac{\mathrm{d}E}{\mathrm{d}l}\right)_{\text{rad}} \tag{6}$$

where

$(\mathrm{d}E/\mathrm{d}l)_{\text{col}} = S_{\text{col}}$ is the linear collision stopping power;

$(\mathrm{d}E/\mathrm{d}l)_{\text{rad}} = S_{\text{rad}}$ is the linear radiative stopping power.

### 3.8
### ICRU tissue

material with a density of 1 g $\text{cm}^{-3}$ and a mass composition of 76,2 % oxygen, 10,1 % hydrogen, 11,1 % carbon, and 2,6 % nitrogen

NOTE See ICRU report 39[10].

### 3.9
### tissue equivalence

property of a material that approximates the radiation attenuation and scattering properties ICRU tissue

NOTE See Annex A; more tissue substitutes are given by ICRU report 44 [3].

### 3.10
### maximum beta energy

$E_{\text{max}}$

highest value of the energy of beta particles emitted by a particular nuclide that can emit one or several continuous spectra of beta particles with different maximum energies

**3.11**

**residual maximum beta energy**

$E_{\mathrm{res}}$

highest value of the energy of a beta-particle spectrum at the calibration distance after having been modified by scattering and absorption

**3.12**

**residual maximum beta particle range**

$R_{\mathrm{res}}$

range in an absorbing material of a beta-particle spectrum of residual maximum energy, $E_{\mathrm{res}}$

# 4 Requirements for reference beta-particle radiation fields at the calibration distance

## 4.1 Energy of the reference radiation fields

The energy of the reference radiation field is defined to be equal to $E_{\mathrm{res}}$ (see 3.11 and 6.1.2).

## 4.2 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, $E_{\mathrm{max}}$, 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.

## 4.3 Uniformity of the dose rate

The dose rate at the calibration distance should be as uniform as possible over the area of the detector. Since available sources for series 1 reference radiation fields (see 6.2.2) cannot at present produce high absorbed dose rates with satisfactory uniformity for large radiation field diameters, a further series (series 2) of reference beta-particle radiation fields is proposed (see 6.2.3). A beta-particle radiation field is considered to be uniform over a certain radiation field diameter if the dose rate does not vary by more than ± 5 % for $E_{\mathrm{res}} \geqslant 300$ keV and by not more than ± 10 % for $E_{\mathrm{res}} < 300$ keV (see 6.2.2).

## 4.4 Photon contamination

The photon dose rate contributing to $H_{\mathrm{p}}(0{,}07)$ due to contamination of the reference radiation by gamma, X-ray and bremsstrahlung radiation should be less than 5 % of the beta particle dose rate recorded by the detector under calibration.

## 4.5 Variation of the beta-particle emission 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.

# 5 Radionuclides suitable for reference beta-particle radiation fields

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

Note that a radionuclide normally requires encapsulation to be a practical source and that the encapsulating material produces bremsstrahlung and characteristic X-rays.

**Table 1 — Beta particle radionuclide data**

| Radionuclide | Half life[a]<br>days | Maximum energy emitted [b]<br>$E_{\text{max}}$<br>MeV | Photon radiation |
|---|---|---|---|
| $^{14}$C | 2 093 000 | 0,156 | None |
| $^{147}$Pm | 958,2 | 0,225 | $\gamma$: 0,121 MeV (0,01 %)<br>Sm X-rays: 5,6 to 7,2 keV<br>39,5 to 46,6 keV |
| $^{85}$Kr | 3 915 | 0,687 | $\gamma$: 0,514 MeV (0,4 %) |
| $^{204}$Tl | 1 381 | 0,763 | Hg X-rays: 9,9 to 13,8 keV<br>68,9 to 82,5 keV |
| $^{90}$Sr + $^{90}$Y | 10 523 | 2,274 | None |
| $^{106}$Ru + $^{106}$Rh | 373,6 | 3,54 | $^{106}$Rh $\gamma$: 0,121 MeV (0,01 %)<br>0,622 MeV (11 % doublet)<br>1,05 MeV (1,5 % doublet)<br>1,13 MeV (0,5 % doublet)<br>1,55 MeV (0,2 %) |

[a] The values in this column taken from ISO 6980-2:2004 Table C.4 [11].

[b] The values given in this column are for information purposes only.

# 6 Source characteristics and their measurement

## 6.1 Fundamental characteristics of reference sources

### 6.1.1 Construction of reference sources

The construction of the reference sources should have the following characteristics to meet the requirements of Clause 4.

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

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

### 6.1.2 Measurement of characteristics of the reference radiation fields

The values of the residual maximum beta energy, $E_{\mathrm{res}}$, shall equal or exceed the values given in Table 2.

**Table 2 — Minimum value of $E_{\mathrm{res}}$ at the calibration distance**

| Radionuclide | $E_{\mathrm{res}}$ MeV |
|---|---|
| $^{14}$C | 0,09 |
| $^{147}$Pm | 0,13 |
| $^{85}$Kr | 0,53 |
| $^{204}$Tl | 0,53 |
| $^{90}$Sr + $^{90}$Y | 1,80 |
| $^{106}$Ru + $^{106}$Rh | 2,80 |

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

The residual maximum beta energy, $E_{\mathrm{res}}$, shall be calculated from Equation (7) [5]:

$$E_{\mathrm{res}} = \sqrt{\left[(0{,}009\,1 \cdot R_{\mathrm{res}} + 1)^2 - 1\right] / 22{,}4} \qquad (7)$$

where

$E_{\mathrm{res}}$ is expressed in MeV and $R_{\mathrm{res}}$ is the residual maximum beta particle range, expressed in milligrams per square centimetre.

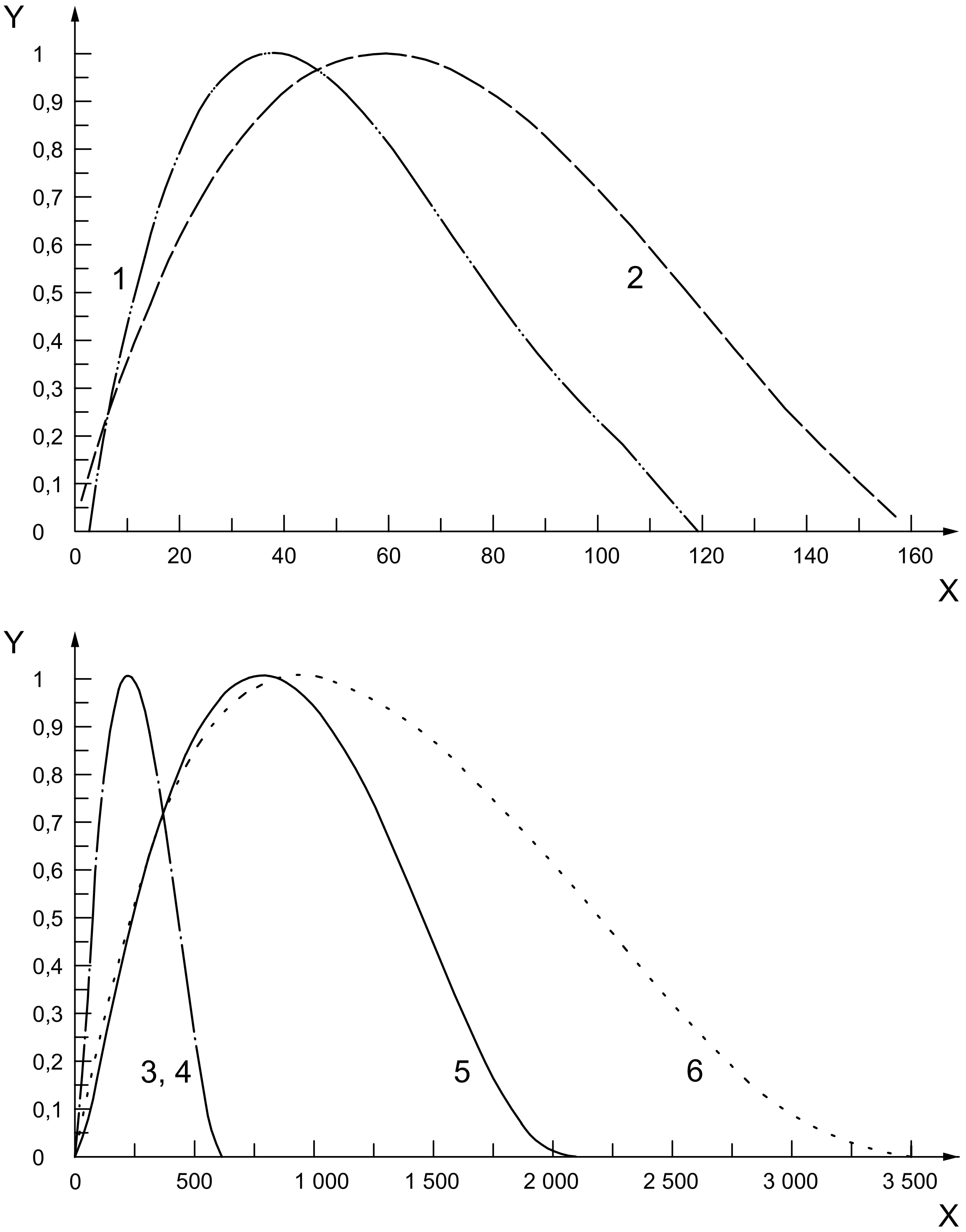
$R_{\mathrm{res}}$ shall be measured by a suitable detector (thin-window ionization chamber, Geiger Müller counter, beta-sensitive phosphor, etc.) that shall be positioned at the calibration distance with its entrance window facing the source. For the measurements, various thicknesses of absorber shall be placed immediately in front of the detector. The absorber shall be either polymethylmethacrylate, polystyrene, polyethylene, polyethylene terephthalate or an equivalent material. The thickness of the detector window used for these measurements shall be taken into account in the measurement of $R_{\mathrm{res}}$.

If the source uses a beam flattening filter, i.e. is a series 1 reference radiation (see 6.2.2), then this filter shall be in position for the measurement of $R_{\mathrm{res}}$.

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, expressed in milligrams per square centimetre.

$R_{\mathrm{res}}$ 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.

$E_{\mathrm{res}}$ may also be determined by a beta-particle spectrometer employing, for example, Si(Li) semiconductor detectors (see ICRU 56[2]). Figure 1 shows an example of measured beta-particle spectra for the radiation fields of Table 2. The $^{90}$Sr + $^{90}$Y spectrum is produced by $^{90}$Y beta particles only due to the heavy encapsulation of the source (Table B.1). A survey of a number of calculated beta-particle spectra is given in ICRU 56[2].



Key

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| X | energy, expressed in KeV | 1 | $^{14}$C — series 2 [b] | 3 | $^{204}$Tl — series 1 [a] | 5 | $^{90}$Sr $^{90}$Y — series 1 [a] |
| Y | relative values | 2 | $^{147}$Pm — series 1 [a] | 4 | $^{85}$Kr — series 1 [a] | 6 | $^{106}$Ru $^{106}$Rh — series 2 [b] |

The spectra are measured with an effectively windowless, uncooled Si(Li) semiconductor detectors.

The measured values of the spectral fluence are normalized to the same maximum value, but not corrected for instrumental resolution or detector backscattering loss.

[a] The calibration distances and filtration are given in Table 3.

[b] The measurement distance is 10 cm.

Figure 1 — Examples of beta-particle spectra for the reference beta radiation fields

### 6.1.3 Beta particle contamination

The radionuclide sources should be of adequate radiochemical purity. It is difficult to check for the presence of beta-particle emitting impurities, but their presence can 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 can be considered adequate for use as a reference radiation if

a) the plot used to measure $R_{\mathrm{res}}$ (see 6.1.2) has a linear section;

b) $E_{\mathrm{res}}$ has a value between that listed in Table 2 and the corresponding $E_{\mathrm{max}}$ value listed in Table 1 for the appropriate radionuclide.

NOTE If $E_{\mathrm{res}}$ exceeds $E_{\mathrm{max}}$, the source contains a radioactive contaminant that emits higher energy particles than the reference radionuclide(s) and it, therefore, does not meet the requirements of this part of ISO 6980.

$R_{\mathrm{res}}$ and, hence, $E_{\mathrm{res}}$ shall be measured every two years.

### 6.1.4 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 or stainless steel. 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 to the detector signal shall, therefore, be measured for each type of detector and radionuclide source, prior to the start of the calibration procedure by comparing the detector signal with and without an absorber made of one of the materials listed in 6.1.2 (see Table A.1) and just sufficiently thick to absorb totally the beta radiation.

## 6.2 Characteristics of the two series of reference beta-particle radiation fields

### 6.2.1 General

Details of the construction of suitable sources for producing both series of reference radiation fields are given, as examples, in Annex B.

### 6.2.2 Series 1 reference beta-particle radiation fields

When uniform dose rates over a large area are required, the sources listed in Table 3 should be used with suitable beam-flattening filters to produce a uniform dose rate over a minimum area of 15 cm in diameter at the calibration distance. The filters shall 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 $^{90}\mathrm{Sr} + {}^{90}\mathrm{Y}$, $^{85}\mathrm{Kr}$ and $^{204}\mathrm{Tl}$, and ± 10 % for $^{147}\mathrm{Pm}$. 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. An example of such a chamber is a thin window parallel plate ionization chamber.

The uniformity of the dose (rate) over the calibration area is optimal only at a specified distance for a given filter construction[2].

Table 3 gives details of calibration distances and examples of filter constructions for the series 1 reference radiation fields. Table 4 gives the approximate dose equivalent rate per unit activity.

A maximum source diameter of 16 mm is recommended.

Table 3 — Calibration distances and filters for series 1 reference beta-particle radiation fields

| 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. |
| $^{85}$Kr and $^{204}$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 tere-phthalate, each with mass per unit area of 25 mg cm$^{-2}$ and of radii 2 cm, 3 cm and 5 cm. |

Table 4 — Approximate directional dose equivalent rate at the calibration distance per unit activity for Series 1 beta-particle reference radiation fields

| Radionuclide | Approximate directional dose equivalent rate per unit activity µSv h$^{-1}$ MBq$^{-1}$ |
|---|---|
| $^{147}$Pm | 3 |
| $^{85}$Kr | 49 |
| $^{204}$Tl | 58 |
| $^{90}$Sr + $^{90}$Y | 78 |

### 6.2.3 Series 2 reference beta-particle radiation fields

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

At these larger distances, it is particularly important, because of air attenuation, to verify that $E_{\mathrm{res}}$ 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 4.3, 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 contain two additional radionuclide sources: $^{14}$C and $^{106}$Ru + $^{106}$Rh; they should be used where calibration is required outside the energy limits of the 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 for series 2 reference beta-particle radiation fields**

| **Source characteristics** | | | **Dose equivalent rate**<br>Sv h$^{-1}$ | |
|---|---|---|---|---|
| **Radionuclide** | **Nominal activity**<br>MBq | **Nominal active area**<br>cm$^2$ | **Estimated values at the surface of the source** [a] | **Typical values at the distance listed** |
| $^{14}$C | 1 | 9 | 0,6 | 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 |

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

## 7 Source calibration

The quantities recommended for the calibration of protection instruments are specified in 3.5 and 3.6. ISO 6980-3 specifies the phantoms and conditions to be used in calibrations. For the series 1 reference beta-radiation fields that 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 radiation fields 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 should be checked and corrections applied if necessary.

The dose rates from the reference sources shall be determined by one of the following methods (see ICRU 56[2]):

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.

# Annex A
(informative)

# Tissue equivalent materials

The composition of soft tissue adopted here is the one given by ICRU 39[10] and ICRU 44[3]. Its density and composition by mass as well those for other materials commonly used as tissue equivalent materials are presented in Table A.1.

**Table A.1 — Tissue equivalent materials**

| **Material** | **Density** | **Number of electrons per unit volume** $10^{27}$ $m^{-3}$ | **Elemental composition** (% by mass) | | | | |
|---|---|---|---|---|---|---|---|
| | | | **H** | **C** | **N** | **O** | **Others** |
| Soft tissue | 1,00 | 331 | 10,1 | 11,1 | 2,6 | 76,2 | — |
| Polyethylene | 0,92 | 316 | 14,4 | 85,6 | | | |
| Graphite | 1,70 | 511 | — | 100 | — | — | — |
| Polyethylene terephthalate | 1,40 | 439 | 4,2 | 62,5 | — | 33,3 | — |
| Polymethyl-methacrylate | 1,19 | 380 | 8,0 | 60,0 | — | 32,0 | — |
| Polystyrene | 1,05 | 340 | 7,7 | 92,3 | — | — | — |
| A150 plastic | 1,12 | 370 | 10,1 | 77,7 | 3,5 | 5,2 | 1,7 F<br>1,8 Ca |

# Annex B
(informative)

## Characteristics of the recommended sources — Examples of source construction

Examples of source construction leading to radiation fields with suitable characteristics are given in Table B.1, together with acceptable measured values of $E_{\text{res}}$ for these source constructions. The uniformity of the active materials should be investigated by autoradiography.

**Table B.1 — Examples of source construction**

| Radionuclide | Chemical form | Encapsulation material | Window mass per unit area mg cm$^{-2}$ | Lower limit of $E_{\text{res}}$ MeV |
|---|---|---|---|---|
| $^{14}C$ | Poly(methyl-$^{14}C$) methacrylate | See chemical form | none | 0,09 |
| $^{147}Pm$ | Carbonate | Titanium | 2 | 0,13 |
| $^{85}Kr$ | Gas | Titanium | 22 | 0,53 |
| $^{204}Tl$ | Thallous chromate | Silver | 20 | 0,53 |
| $^{90}Sr$ + $^{90}Y$ | Strontium carbonate | Stainless steel | 80 | 1,80 |
| $^{106}Ru$ + $^{106}Rh$ | Ruthenium metal | Silver | 50 | 2,80 |

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