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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*



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Foreword

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International Standard ISO 6980 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, subcommittee 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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International Organization for Standardization
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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 meters¹⁾, 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·cm⁻² in the ICRU sphere. The energy range involved lies between 66 keV²⁾ and 3,6 MeV and the absorbed dose rates are in the range from about 10 μSv·h⁻¹ to at least 10 Sv·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 ⁹⁰Sr + ⁹⁰Y, ²⁰⁴Tl and ¹⁴⁷Pm produce maximum dose rates of approximately 5 mSv·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 ¹⁴C and ¹⁰⁶Ru + ¹⁰⁶Rh; these sources produce dose rates of up to 10 Sv·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·kg⁻¹) and has been given the special name gray (Gy):

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

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·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 .

$$\dot{D} = \frac{dD}{dt}$$

The SI unit of absorbed dose rate is the gray per second ($\text{Gy} \cdot \text{s}^{-1}$). 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. $\text{mGy} \cdot \text{h}^{-1}$).

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 ($\text{J} \cdot \text{kg}^{-1}$) and has been given the special name sievert (Sv):

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

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 .

$$\dot{H} = \frac{dH}{dt}$$

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

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 $1 \text{ g} \cdot \text{cm}^{-3}$.
- 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 .

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

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

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

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

where

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

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

2.7 tissue: Material with a density of $1 \text{ g} \cdot \text{cm}^{-3}$ 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 $1 \text{ g} \cdot \text{cm}^{-3}$ (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 $E_{i, \text{max}}$ 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 $E_{i, \text{max}}$, $i = 1, 2, \dots$

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 $\pm 20\%$. 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 $\pm 5\%$ for $E_{\text{res}} \geq 300$ keV and by not more than $\pm 10\%$ for $E_{\text{res}} < 300$ keV (see 5.2.1).

NOTE — $1 \text{ eV} = 1,602 \times 10^{-19} \text{ J}$

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: