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Reference beta radiations for calibrating dosemeters and doseratemeters and for determining their response as a function of beta radiation energy

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

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Foreword

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Reference beta radiations for calibrating dosemeters and doseratemeters and for determining their response as a function of beta radiation energy

1 Scope and field of application

This International Standard specifies the requirements for reference beta radiations produced by radionuclide sources to be used for the calibration of protection level dosemeters and doseratemeters*, and for the determination of their response as a function of beta 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 energy and the absorbed dose rate** at a depth of 7 $mg \cdot cm^{-2}$ in a semi-infinite tissue-equivalent medium. The energy range involved lies between 66 keV*** and 3,6 MeV and the absorbed dose rates are in the range from about 10 $\mu Gy \cdot h^{-1}$ (1 $mrad \cdot h^{-1}$) to at least 10 $Gy \cdot h^{-1}$ (10^3 $rad \cdot h^{-1}$).

This International Standard proposes two series of beta reference radiations from which the radiation necessary for determining the characteristics (calibration and energy response) of an instrument shall 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 $mGy \cdot h^{-1}$ (0,5 $rad \cdot h^{-1}$).

Series 2 reference radiations are produced without the use of beam flattening filters which allows 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 $Gy \cdot h^{-1}$ (10^3 $rad \cdot h^{-1}$).

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2 Terminology

2.1 Absorbed dose

The absorbed dose, D, is the 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 joules per kilogram ($J \cdot kg^{-1}$). The special name for the unit of absorbed dose is gray (Gy):

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

The special unit of absorbed dose, rad, may be used temporarily:

$$1 \text{ rad} = 10^{-2} \text{ J} \cdot \text{kg}^{-1}$$

* This also includes personal dosemeters.

** Throughout this International Standard where the term "dose" is used, "absorbed dose to tissue" is implied, except where otherwise stated.

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

2.2 Absorbed dose rate

The absorbed dose rate, $\dot{D}$, is the 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 joules per kilogram second ($J \cdot kg^{-1} \cdot s^{-1}$). The special name, gray (Gy), may be substituted for joule per kilogram :

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

The special unit, rad, may be used temporarily :

$$1\ rad \cdot s^{-1} = 10^{-2}\ J \cdot kg^{-1} \cdot s^{-1}$$

2.3 Total mass stopping power

The total mass stopping power, S/ϱ, of a material for charged particles is the 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.

$$\frac{S}{\varrho} = \frac{1}{\varrho}\left(\frac{dE}{dl}\right)$$

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 and hence S/ϱ may be expressed in electronvolt square metre per kilogram ($eV \cdot m^2 \cdot kg^{-1}$).

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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

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

where

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

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

2.4 Tissue

When the word "tissue" is used in this International Standard, a material with a density of $1\ g \cdot cm^{-3}$ and the following composition in terms of mass fraction for soft tissue is implied (see ICRU 33)[2] :

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.

2.5 Tissue equivalence

Tissue equivalence is the property possessed by a material when the collision mass stopping power and the radiation interaction 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).

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.

2.6 Maximum energy of a beta spectrum

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... The maximum energy of the beta spectrum, E_{max}, characteristic of the particular nuclide listed in table 1 is the highest value of the $E_{i max}$ values.

2.7 Residual maximum beta energy

The residual maximum beta energy, E_{res}, is the maximum energy of the beta spectrum from all beta 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.

2.8 Residual maximum beta range

The residual maximum beta range, R_{res}, is the range in an absorbing material of a beta spectrum of residual maximum energy, E_{res}.

2.9 Units

The system of units recommended is the International System of Units (SI).

The following SI units are used throughout this International Standard :

— for activity : becquerel (Bq) : $1\ Bq = 1\ s^{-1}$ ($1\ Ci = 3{,}7 \times 10^{10}\ Bq$);

— for temperature : kelvin (K);

— for pressure : pascal (Pa) : $1\ Pa = 1\ N \cdot m^{-2}$ ($1\ bar = 10^5\ Pa$).

Furthermore, for practical reasons, the following units are used in this International Standard :

— for energy : electronvolt (eV) ($1\ eV = 1{,}602 \times 10^{-19}\ J$);

— for time : year (365,25 d), day (d), hour (h).

Multiples and sub-multiples of SI units may be used and in the case of rates, units of time such as minute (min), hour (h) and day (d) should be used to suit the circumstances.

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 2.7 and 5.1.2).

3.2 Shape of the beta spectrum

The beta 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 absorbed dose rate

The absorbed dose rate in tissue 70 µm below the surface of a semi-infinitely extended tissue equivalent phantom generated by the reference radiation should be as uniform as possible. 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 called uniform over a certain radiation field diameter, if the absorbed dose rate in tissue 70 µm below the surface 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).

3.4 Photon contamination

The photon dose rate due to contamination of the reference radiation by gamma, X-ray and bremsstrahlung radiation should be less than 5 % of the beta dose rate recorded by the detector under calibration.

3.5 Variation of the beta emission rate with time

The beta emission rate decreases with time due to the radioactive decay of the beta source. The half-life of a radionuclide should be as long as possible, preferably longer than one year.

4 Radionuclides suitable for reference beta radiations

Table 1 gives the characteristics of beta emitting radionuclides of a suitable energy range. Beta 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_{max}, characteristic of the particular nuclide.

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

5 Source characteristics and their measurement

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5.1 Fundamental characteristics of reference sources

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5.1.1 Construction of reference sources

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

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

b) The construction and encapsulation should be sufficiently robust and stable to withstand normal use without

Table 1 — Beta radionuclide data

Radionuclide	Approximate half life Years	Maximum energy of spectrum E_{max} (MeV)	Photon radiations emitted*
^{14}C	5730	0,156	None
^{147}Pm	2,62	0,225	γ : 0,121 MeV, (0, 01 %) Sm X-rays 5,6 to 7,2 keV 39,5 to 46,6 keV
^{204}Tl	3,78	0,763	Hg X-rays 9,9 to 13,8 keV 68,9 to 82,5 keV
$^{90}Sr + {}^{90}Y$	28,5	2,274	None
$^{106}Ru + {}^{106}Rh$	1,01	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 %)

* The values given in this column are for information purposes only.

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 value of E_{res} at the calibration distance shall equal or exceed the values given in table 2.

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

Source	E_{res} MeV
^{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 and/or window absorption.

The residual maximum energy, E_{res}, at the calibration distance shall be calculated from the following relationship[4]:

$$E_{res} = \sqrt{\frac{(9{,}1\,R_{res} + 1)^2 - 1}{22{,}4}}$$

where E_{res} is in mega electronvolts (MeV) and R_{res} is the residual maximum beta range in grams per square centimetre ($g \cdot cm^{-2}$).

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 polymethylmethacrylate*, polystyrene, polyethylene, polyethylene terephthalate** 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), then 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 grams per square centimetre $g \cdot cm^{-2}$.

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.

5.1.3 Beta contamination

The radionuclide sources should be of adequate radiochemical purity. It is difficult to check for the presence of beta-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 listed in table 2 and the corresponding E_{max} value listed in table 1 for the appropriate radionuclide.

NOTE — Where E_{res} exceeds E_{max}, this means that the source contains a radioactive contaminant which emits higher energy particles than the reference radionuclide(s) and that 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 absorb totally 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 B.

5.2.1 Series 1 reference beta radiations

When dose rates uniform over a large area are required, the sources listed in table 3 should 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

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* Perspex, Lucite, Plexiglas are commercial names for this plastic.

** Melinex, Mylar, Hostaphan are commercial names for this plastic.

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.

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.

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

5.2.2 Series 2 reference beta radiations

When high dose rates are required, the sources listed in table 5 should be used. These sources are not used with beam flattening filters and may be used at calibration distances approaching the surface of the source up to the distance shown in table 5.

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 in-

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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 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 area 7 mg·cm^{-2}, plus 1 disc of polyethylene terephthalate, of 2,75 cm radius and mass per area 25 mg·cm^{-2}
$^{90}Sr + {}^{90}Y$	30	10	3 concentric discs of polyethylene terephthalate, each with mass per area of 25 mg·cm^{-2} and of radii 2 cm, 3 cm and 5 cm

* For details and diagrams, see [5].

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

Radionuclide	Approximate absorbed dose rate to tissue per activity pGy·h^{-1}·Bq^{-1} (mrad·h^{-1}·mCi^{-1})
^{147}Pm	6,2 (23)
^{204}Tl	68 (250)
$^{90}Sr + {}^{90}Y$	65 (240)

struments. 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 the Series 1.

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

6 Source calibration

For beta radiation, the quantity recommended for the calibration of protection instruments is the absorbed dose or dose rate to tissue at a specified depth below the skin surface. Sources should be calibrated in terms of the absorbed dose rate at a depth corresponding to a mass per area of 7 $mg \cdot cm^{-2}$ below the surface of a semi-infinite tissue equivalent medium[1].

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 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[6] :

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 C).

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Table 5 — Activities and dose rates from Series 2 reference beta radiations

Radionuclide	Source characteristics		Dose rate, $Gy \cdot h^{-1}$ ($rad \cdot h^{-1}$)	
	Nominal activity Bq (mCi)	Approximate active area cm^2	Estimated values at surface of source*	Typical values at the listed distance
^{14}C	10^6 (0,03)	9	0,06 (6)	0,006 (0,6) at 5 cm
^{147}Pm	10^8 (3)	25	3 (300)	0,003 (0,3) at 20 cm
^{204}Tl	10^8 (3)	14	10 (1 000)	0,003 (0,3) at 50 cm
$^{90}Sr + {}^{90}Y$	10^7 (0,3)	35	0,6 (60)	0,000 1 (0,01) at 100 cm
$^{106}Ru + {}^{106}Rh$	10^8 (3)	1,5	6 (600)	0,001 (0,1) at 100 cm

* Surface dose rates should be measured with a detector whose area is less than that of the source.

Annex A

Tissue equivalent materials

The composition of soft tissue adopted here is the one given by ICRU[2]. Its density, electron density and composition by weight as well as those for other materials commonly used as tissue equivalent are presented in table 6.

Table 6 — Tissue equivalent

Materials	Density $g \cdot cm^{-3}$	Electron density $10^{23} \cdot g^{-1}$	Weight, % H	C	N	O	Other
Soft tissue	1	3,31	10,1	11,1	2,6	76,2	
Graphite	1,7	3,01	—	100	—	—	
Polyethylene terephthalate	1,38	3,13	4,2	62,5	—	33,3	
Polymethyl methacrylate	1,19	3,25	8,0	60,0	—	32,0	
Polystyrene	1,06	3,23	7,7	92,3	—	—	
A-150 Shonka plastic	1,12	3,30	10,1	77,6	3,5	5,2	1,7 F 1,8 Ca

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Annex B

Characteristics of the recommended sources

Examples of source construction

Examples of source construction leading to radiation fields with suitable characteristics are given in table 7, together with acceptable measured values of E_{res} for these source constructions. The uniformity of the active materials may be investigated by autoradiography.

Table 7 — Examples of source construction

Radionuclide	Chemical form	Encapsulation material	Window material and mass per area $mg \cdot cm^{-2}$	Protective coating material and mass per 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 (15)	Gold (5)	0,53
$^{90}Sr + {}^{90}Y$	Strontium carbonate	Silver	Silver (40)	Gold (10)	1,80
$^{106}Ru + {}^{106}Rh$	Ruthenium metal	Silver	Silver (40)	Gold (10)	2,80