INTERNATIONAL STANDARD

ISO 6980-1

Second edition
2022-10

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 6980-1:2022(E)

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Published in Switzerland

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 2, *Radiological protection*.

This second edition of ISO 6980-1 cancels and replaces ISO 6980-1:2006, which has been technically revised.

The main changes are the following:

— inclusion of the quantities $H_p(3)$ and $H'(3;\Omega)$;

— inclusion of ^{106}Ru/^{106}Rh series 1 sources;

— inclusion of energy-reduced beta-particle fields produced by ^{90}Sr/^{90}Y sources;

— removal of ^{14}C sources;

— a reference to ISO 29661 and its terms and definitions in Clause 3.

A list of all the parts in the ISO 6980 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

ISO 6980 series covers the production, calibration, and use of beta-particle reference radiation fields for the calibration of dosemeters and dose-rate meters for protection purposes. This document describes the methods of production and characterization of the reference radiation. ISO 6980-2 describes procedures for the determination of absorbed dose rate to a reference depth of tissue from beta particle reference radiation fields. ISO 6980-3 describes procedures for the calibration of dosemeters and dose-rate meters and the determination of their response as a function of beta-particle energy and angle of beta-particle incidence.

For beta particles, the calibration and the determination of the response of dosemeters and dose-rate meters is essentially a three-step process. First, the basic field quantity, absorbed dose to tissue at a depth of 0,07 mm (and optionally also at a depth of 3 mm) in a tissue-equivalent slab geometry is measured at the point of test, using methods described in ISO 6980-2. Then, the appropriate operational quantity is derived by the application of a conversion coefficient that relates the quantity measured (reference absorbed dose) to the selected operational quantity for the selected irradiation geometry. Finally, the reference point of the device under test is placed at the point of test for the calibration and determination of the response of the dosemeter. Depending on the type of dosemeter under test, the irradiation is either carried out on a phantom or free-in-air for personal and area dosemeters, respectively. For individual and area monitoring, this document describes the methods and the conversion coefficients to be used for the determination of the response of dosemeters and dose-rate meters in terms of the ICRU operational quantities, i.e., directional dose equivalent, $H'(0{,}07;\Omega)$ and $H'(3;\Omega)$, as well as personal dose equivalent, $H_p(0{,}07)$ and $H_p(3)$.

Nuclear energy — Reference beta-particle radiation —

Part 1:
Methods of production

1 Scope

This document specifies the requirements for reference beta radiation fields produced by radioactive 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 $H_p(0,07)$, $H'(0,07;\Omega)$, $H_p(3)$ and $H'(3;\Omega)$, and for the determination of their response as a function of beta particle energy and angle of incidence. The basic quantity in beta dosimetry is the absorbed-dose rate in a tissue-equivalent slab phantom. This document 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 0,22 and 3,6 MeV maximum beta energy corresponding to 0,06 MeV to 1,1 MeV mean beta energy and the dose equivalent 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 dose equivalent rate as a function of the angle of incidence are given. However, as noted in ICRU Report 56[3], the ambient dose equivalent, $H^*(10)$, used for area monitoring, and the personal dose equivalent, $H_p(10)$, as used for individual monitoring, of strongly penetrating radiation, are not appropriate quantities for any beta radiation, even that which penetrates 10 mm of tissue (E_{max} > 2 MeV).

This document is applicable to 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 radioactive 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 ^{106}Ru/^{106}Rh, ^{90}Sr/^{90}Y, ^{85}Kr, ^{204}Tl and ^{147}Pm produce maximum dose equivalent rates of approximately 200 mSv·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 series also include radiation fields using polymethylmethacrylate (PMMA) absorbers to reduce the maximum beta particle energy. The radionuclides used are those of series 1; these sources produce dose equivalent rates of up to 10 Sv·h^{-1}.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments (AMD)) applies.

ISO 29661, *Reference radiation fields for radiation protection — Definitions and fundamental concepts*

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 29661, ISO/IEC Guide 99 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
tissue equivalence
property of a material that approximates the radiation attenuation and scattering properties of ICRU tissue

Note 1 to entry: See Annex A; more tissue substitutes are given by ICRU report 44[4].

Note 2 to entry: Further details are given in ISO 6980-2:2022, 6.2.

3.2
maximum beta energy
E_{max}
highest value of the energy of beta particles emitted by a particular radionuclide that can emit one or several continuous spectra of beta particles with different maximum energies

3.3
mean beta energy
E_{mean}
fluence average energy of the beta particle spectrum at the calibration distance at 0,07 mm tissue depth in an ICRU 4-element tissue phantom

3.4
residual maximum beta energy
E_{res}
highest value of the energy of a beta-particle spectrum at the calibration distance after having been modified by scattering and absorption

3.5
residual maximum beta particle range
R_{res}
range in an absorbing material of a beta-particle spectrum of residual maximum energy, E_{res}

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

4.1 Standard test conditions

All calibrations and measurements shall be conducted under standard test conditions in accordance with Tables B.1 and B.2. The range of values of influence quantities within the standard test conditions are given in Tables B.1 and B.2 for radiation-related and other parameters, respectively.

4.2 Energy of the reference radiation fields

The energy of the reference radiation field is defined to be equal to E_{res} (see 3.4 and 6.1.2).

4.3 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.

4.4 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 $E_{res} \geq 300$ keV and by not more than ±10 % for $E_{res} < 300$ keV (see 6.2.2).

4.5 Photon contamination

The photon dose rate contributing to the total dose rate due to contamination of the reference radiation by gamma, X-ray and bremsstrahlung radiation, H_{photon}, should be less than 2 % of the beta particle dose rate, H_{beta}, i.e. $H_{photon}/H_{beta} < 0{,}02$. This shall be valid for the considered quantity, i.e. for $H_p(0{,}07)$, $H'(0{,}07;\Omega)$, $H_p(3)$ or $H'(3;\Omega)$.

Regarding the determination of the photon contribution and the indication of the instrument under test see 6.1.4.

4.6 Variation of the beta-particle emission with time

The beta-particle emission rate decreases with time due to the radioactive decay of the beta emitting radionuclide. 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_{max}, characteristic of the particular nuclide.

A radionuclide normally requires encapsulation to be a source which may be handled. Such encapsulating material produces bremsstrahlung and characteristic X-rays.

Table 1 — Beta particle radionuclide data

Radionuclide	**Half life**[a] days	**Maximum energy emitted**[ab] E_{max} (approximate values) MeV	**Photon radiation**[ac] (approximate values)
^{147}Pm	958,18 (0,15)	0,224	γ: 0,121 MeV (0,002 7 %) Sm X-rays: 5,0 to 7,5 keV 39,5 to 46,8 keV

[a] The values in this column are taken from the Nuclear Data Sheets (NDS); the values in brackets are the standard uncertainties[5][6][7][8][9].

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

[c] The values in brackets are emission probabilities per decay.

[d] "Negligible" indicates levels of emissions that do not affect the detection of beta radiation.

Table 1 *(continued)*

Radionuclide	Half life[a] days	Maximum energy emitted[ab] E_{max} (approximate values) MeV	Photon radiation[ac] (approximate values)
^{85}Kr	3 922 (5)	0,687	γ: 0,514 MeV (0,44 %) Rb X-rays: 13,3 to 15,2 keV
^{204}Tl	1 382 (4)	0,764	γ: none Hg X-rays: 8,7 to 14,8 keV 68,9 to 83,0 keV Pb X-rays: 72,8 to 87,9 keV
$^{90}Sr/^{90}Y$	10 559 (11)	2,279	Negligible[d]
$^{106}Ru/^{106}Rh$	371,8 (1,8)	3,546	^{106}Rh γ: 0,512 MeV (21 %) 0,616 MeV (0,7 %) 0,622 MeV (10 %) 0,87 MeV (0,4 %) 1,05 MeV (1,5 %) 1,13 MeV (0,4 %) 1,56 MeV (0,16 %) Pd X-rays: 2,5 to 24,3 keV

[a] The values in this column are taken from the Nuclear Data Sheets (NDS); the values in brackets are the standard uncertainties[5][6][7][8][9].

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

[c] The values in brackets are emission probabilities per decay.

[d] "Negligible" indicates levels of emissions that do not affect the detection of beta radiation.

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_{res} to exceed the minimum values recommended in Table 2.

c) The typical set of radionuclides shown in Table 2 can be complemented by two energy-reduced radiation fields from $^{90}Sr/^{90}Y$ sources. Such fields can be obtained by placing 3 mm or 4 mm thick polymethylmethacrylate (PMMA) absorbers in front of the source. The absorber shall be positioned with its end face 4 cm from the source, i.e. with its front face 3,7 cm and 3,6 cm for the 3 mm and 4 mm plate, respectively, and its diameter shall be at least 20 cm[10][11].

6.1.2 Measurement and/or simulation of characteristics of the reference radiation fields

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

Table 2 — Minimum value of the residual maximum beta energy, $E_{res,min}$, at the calibration distance

Radionuclide	$E_{res,min}$ MeV
^{147}Pm	0,13
^{85}Kr	0,53
^{204}Tl	0,53
$^{90}Sr/^{90}Y$	1,80
$^{106}Ru/^{106}Rh$	2,50

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

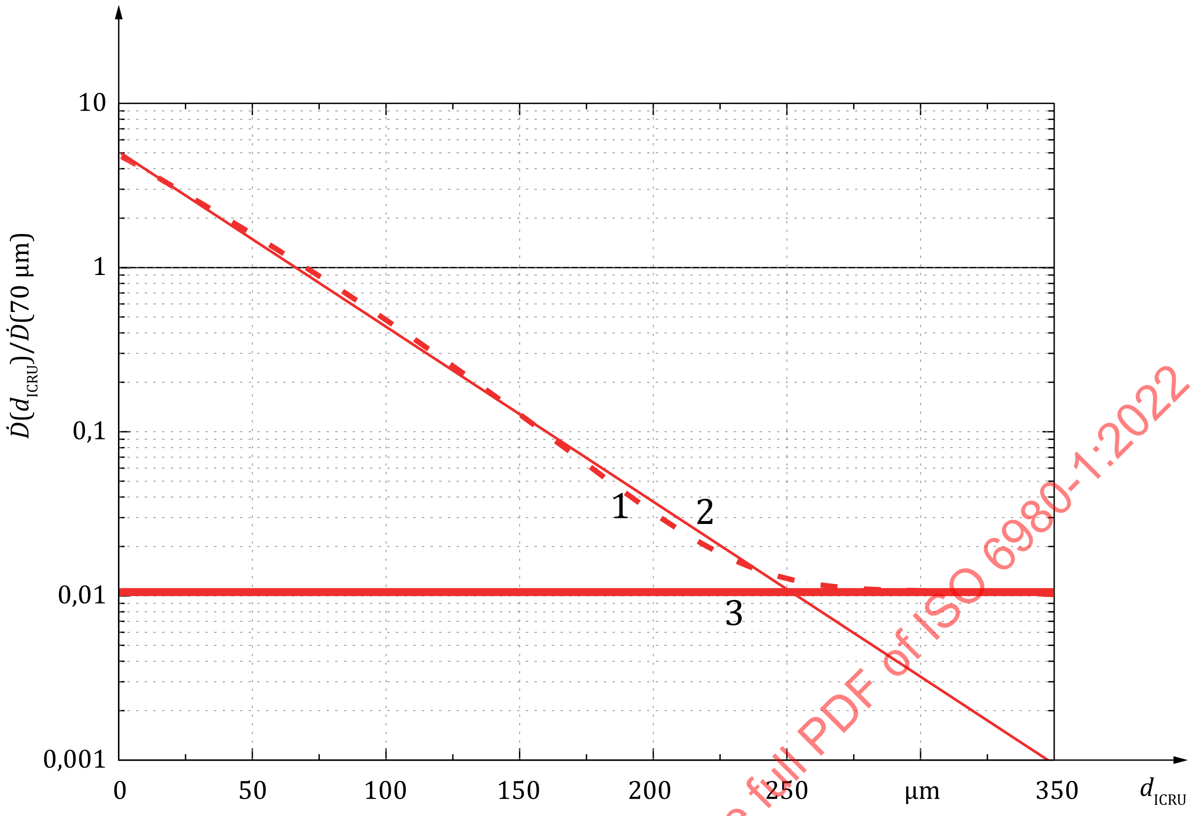
The residual maximum beta energy, E_{res}, shall be calculated from Formula (1)[12]:

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

where

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

R_{res} shall be measured by a suitable detector (extrapolation chamber, 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 made of a tissue-equivalent substance, e.g. PMMA, polystyrene, polyethylene, polyethylene terephthalate (PET) or an equivalent material. A list of tissue-equivalent substances is given in Annex A. 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. a series 1 reference radiation is produced (see 6.2.2), 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 (mass) thickness and a plot shall be made of the logarithm of signal versus absorber (mass) thickness, expressed in tissue equivalent milligrams per square centimetre ($mg \cdot cm^{-2}$) or micrometre (µm). The tissue equivalent thickness can be derived with Formula (7) in ISO 6980-2. R_{res} is defined as the intersection of the extrapolated linear portion of the measured signal versus (mass) thickness and the lower level signal due to the residual photon background. This is illustrated in Figure 1 for the example of ^{147}Pm.



Key

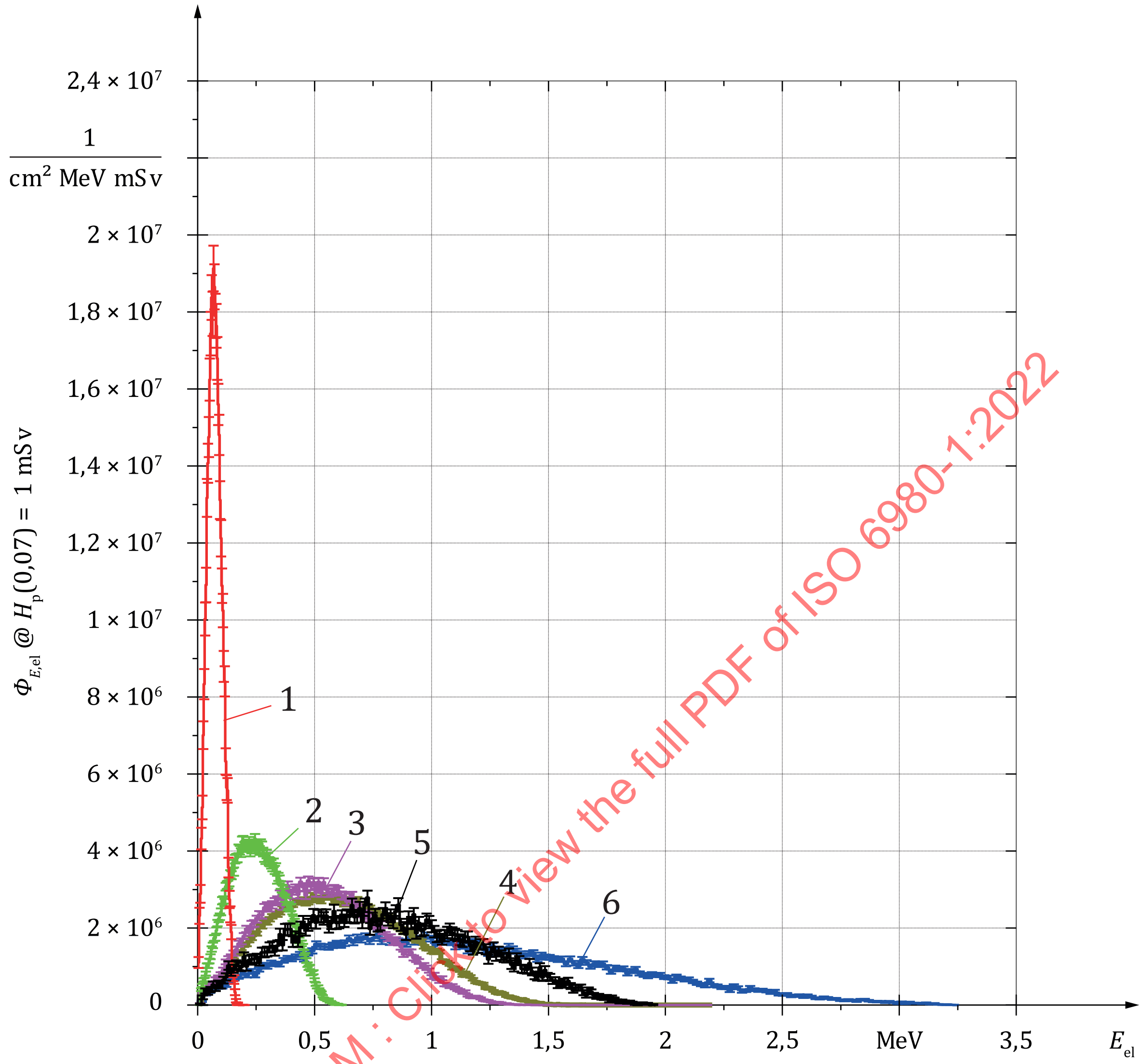
d_{ICRU}:	tissue equivalent depth in an ICRU 4-element tissue phantom
$D(d_{ICRU})/D(70\ \mu m)$:	dose rate at d_{ICRU} divided by dose rate at 0,07 mm (70 µm)
1 ^{147}Pm, 20 cm, with filter:	depth dose curve
2 ^{147}Pm, 20 cm, with filter:	exponential fit
3 ^{147}Pm, 20 cm, with filter:	photon contribution

Figure 1 — Illustration of the determination of R_{res} for the example of a ^{147}Pm source with R_{res} = 250 µm = 25 mg/cm²

E_{res} may also be determined using a beta-particle spectrometer employing, for example, Si(Li) semiconductor detectors (see ICRU 56[3]), or from spectra obtained via Monte Carlo transport simulations. The electron fluence at calibration distance shall be plotted as a function of the electron energy on linear scales. Then, E_{res} is defined as the intersection of the two following lines: the extrapolated linear portion of the electron fluence versus electron energy and the lower level signal due to the residual background.

Figures 2, 3, 4 and 5 show examples of simulated beta- and photon-particle fluence spectra for the radiation fields of Table 2. The fluence spectra were calculated using particle transport free in air and at different depths in an ICRU tissue phantom[10][13][14][15]. The calculated values of the spectral fluence are normalized to a dose of $H_p(0,07)$ = 1 mSv at the reference position. The calibration distances and filtration are given in Table 3. The $^{90}Sr/^{90}Y$ and the $^{106}Ru/^{106}Rh$ spectra are produced predominantly by ^{90}Y and ^{106}Rh beta particles, respectively, due to the heavy encapsulation of the source (see Annex C, Table C.1). A survey of a number of calculated beta-particle spectra is given in ICRU 56[3]. The spectra include the X-ray, gamma ray and bremsstrahlung emission for the radiation fields of Table 2.

Figures 6 and 7 show the simulated dose profiles at a depth of 0,07 mm and 3 mm in an ICRU tissue phantom, respectively, for several geometries of the reference radiation fields. The two graphs represent beam profiles for $H_p(0,07)$ and $H_p(3)$, respectively[10][13][14][15].



Key

E_{el}: electron energy

$\Phi_{E,el}$ @ $H_p(0,07)$ = 1 mSv: spectral electron fluence for a dose rate of $H_p(0,07)$ = 1 mSv at the reference distance

1 ^{147}Pm, 20 cm, with beam-flattening filter

2 ^{85}Kr, 30 cm, with beam-flattening filter

3 ^{90}Sr/^{90}Y, 20 cm, with 4 mm PMMA absorber

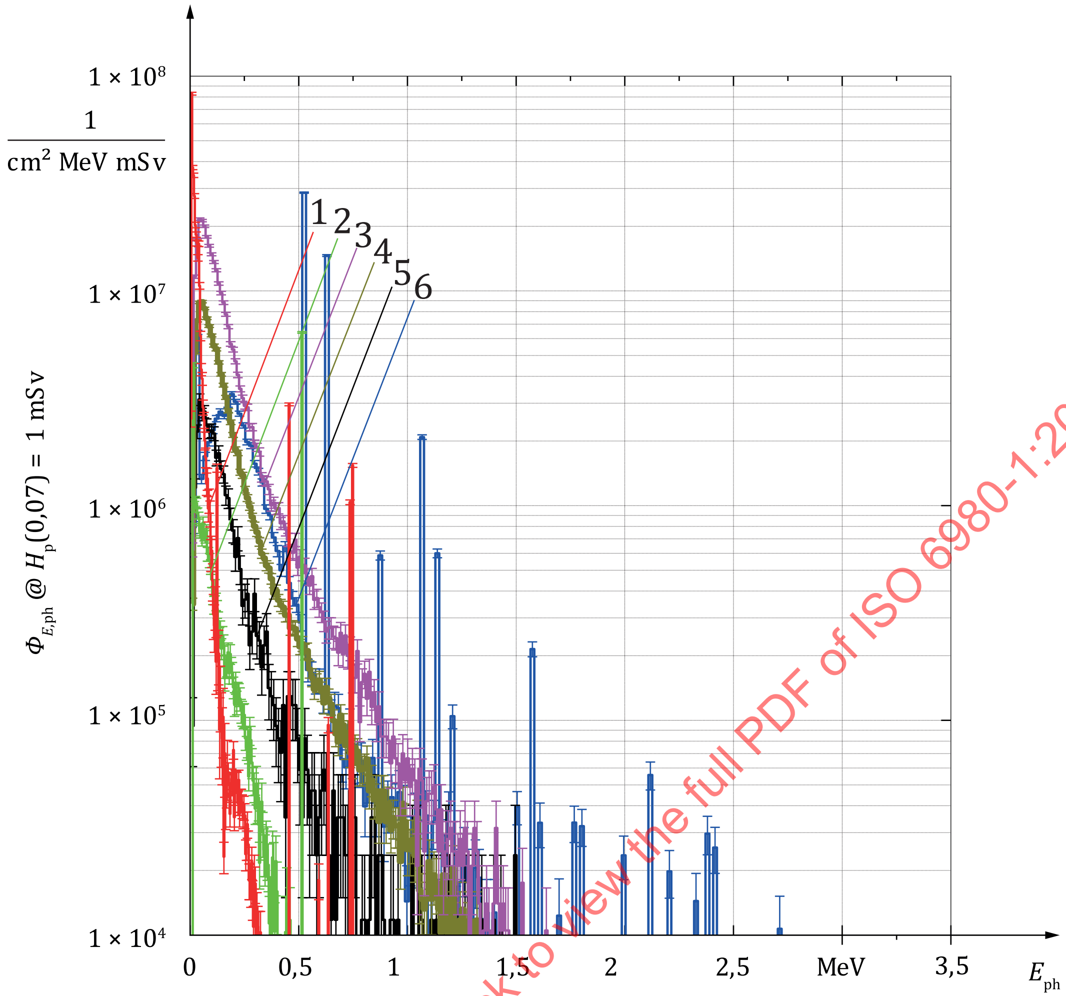
4 ^{90}Sr/^{90}Y, 20 cm, with 3 mm PMMA absorber

5 ^{90}Sr/^{90}Y, 30 cm, with beam-flattening filter

6 ^{106}Ru/^{106}Rh, 30 cm, with beam-flattening filter

NOTE The uncertainty bars represent the statistical fluctuations of the simulations.

Figure 2 — Examples of beta-particle fluence spectra for the reference radiation fields free in air without backscatter radiation[10][13][14][15]



Key

E_{ph}: photon energy

$\Phi_{E,ph}$ @ $H_p(0{,}07)$ = 1 mSv:spectral photon fluence for a dose rate of $H_p(0{,}07)$ = 1 mSv at the reference distance

1 ^{147}Pm, 20 cm, with beam-flattening filter

2 ^{85}Kr, 30 cm, with beam-flattening filter

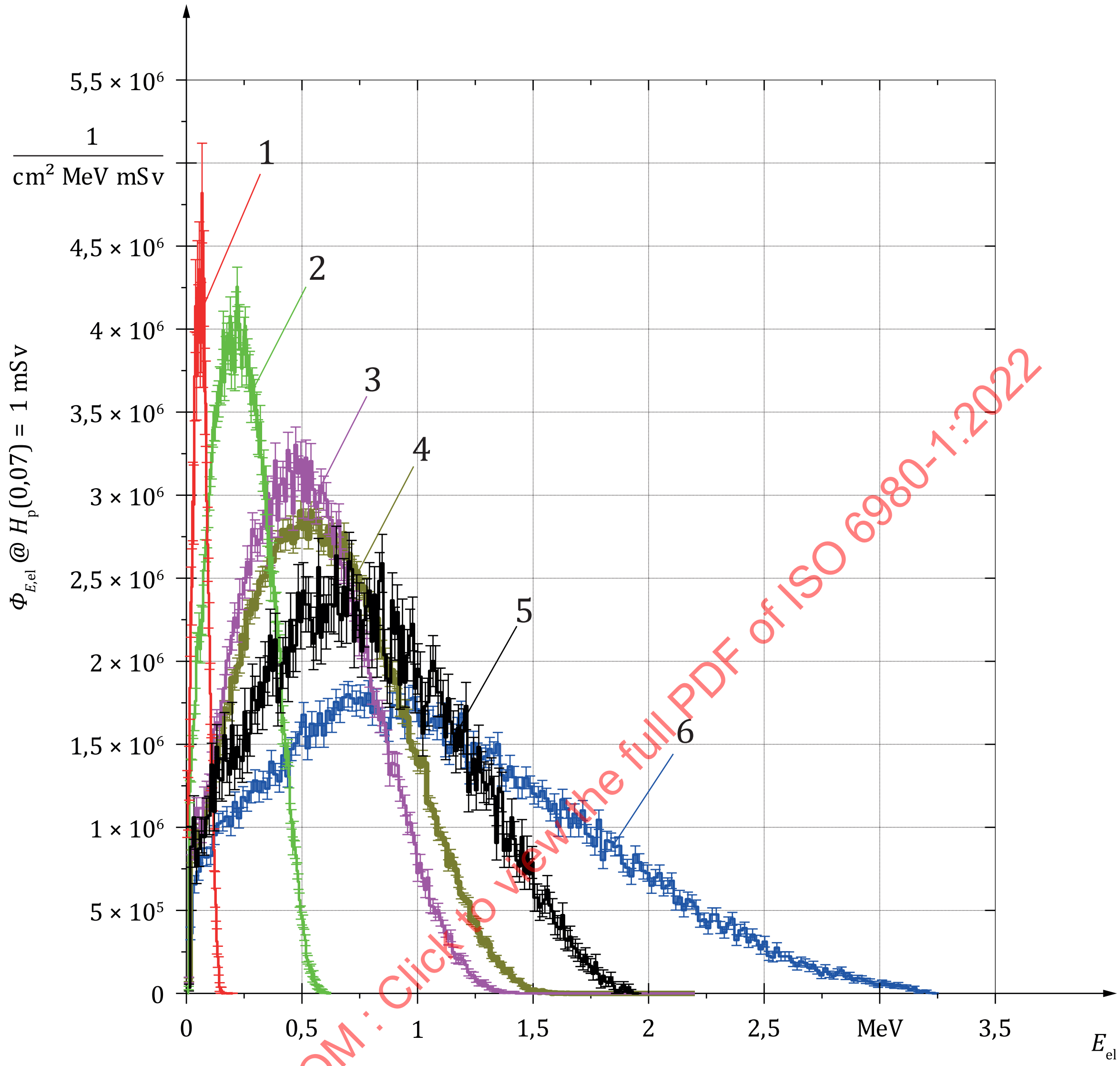
3 ^{90}Sr/^{90}Y, 20 cm, with 4 mm PMMA absorber

4 ^{90}Sr/^{90}Y, 20 cm, with 3 mm PMMA absorber

5 ^{90}Sr/^{90}Y, 30 cm, with beam-flattening filter

6 ^{106}Ru/^{106}Rh, 30 cm, with beam-flattening filter

Figure 3 — Examples of photon-particle fluence spectra for the reference radiation fields free in air without backscatter radiation[10][13][14][15]



Key

E_{el}: electron energy

$\Phi_{E,el}$ @ $H_p(0,07) = 1$ mSv: spectral electron fluence for a dose rate of $H_p(0,07) = 1$ mSv at the reference distance

1 ^{147}Pm, 20 cm, with beam-flattening filter

2 ^{85}Kr, 30 cm, with beam-flattening filter

3 $^{90}Sr/^{90}Y$, 20 cm, with 4 mm PMMA absorber

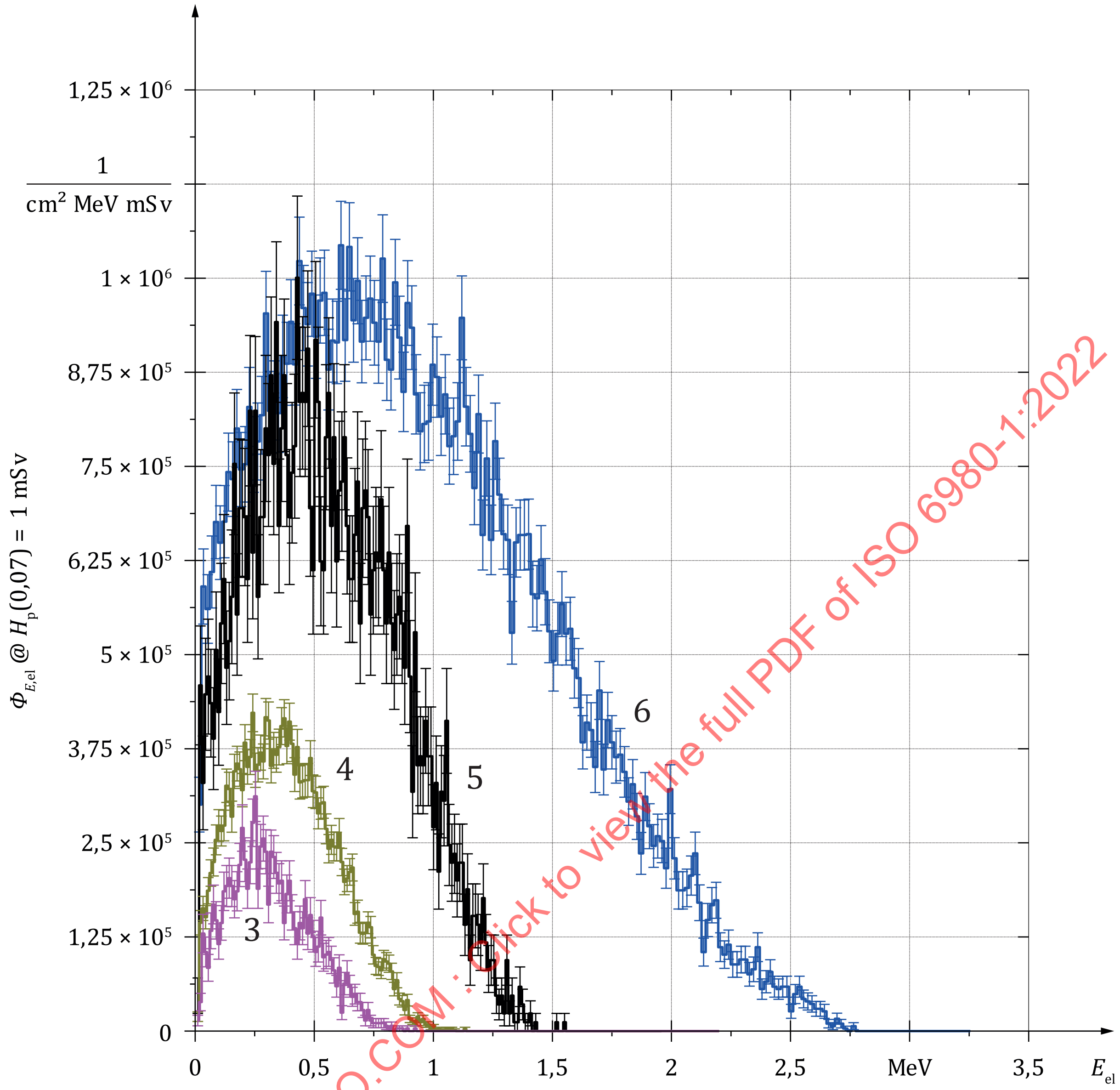
4 $^{90}Sr/^{90}Y$, 20 cm, with 3 mm PMMA absorber

5 $^{90}Sr/^{90}Y$, 30 cm, with beam-flattening filter

6 $^{106}Ru/^{106}Rh$, 30 cm, with beam-flattening filter

NOTE The uncertainty bars represent the statistical fluctuations of the simulations.

Figure 4 — Examples of beta-particle fluence spectra for the reference beta radiation fields at 0,07 mm depth in an ICRU 4 element tissue phantom including backscatter radiation[10][13][14][15]



Key

E_{el}: electron energy

$\Phi_{E,el}$ @ $H_p(0,07)$ = 1 mSv: spectral electron fluence for a dose rate of $H_p(0,07)$ = 1 mSv at the reference distance

3 $^{90}Sr/^{90}Y$, 20 cm, with 4 mm PMMA absorber

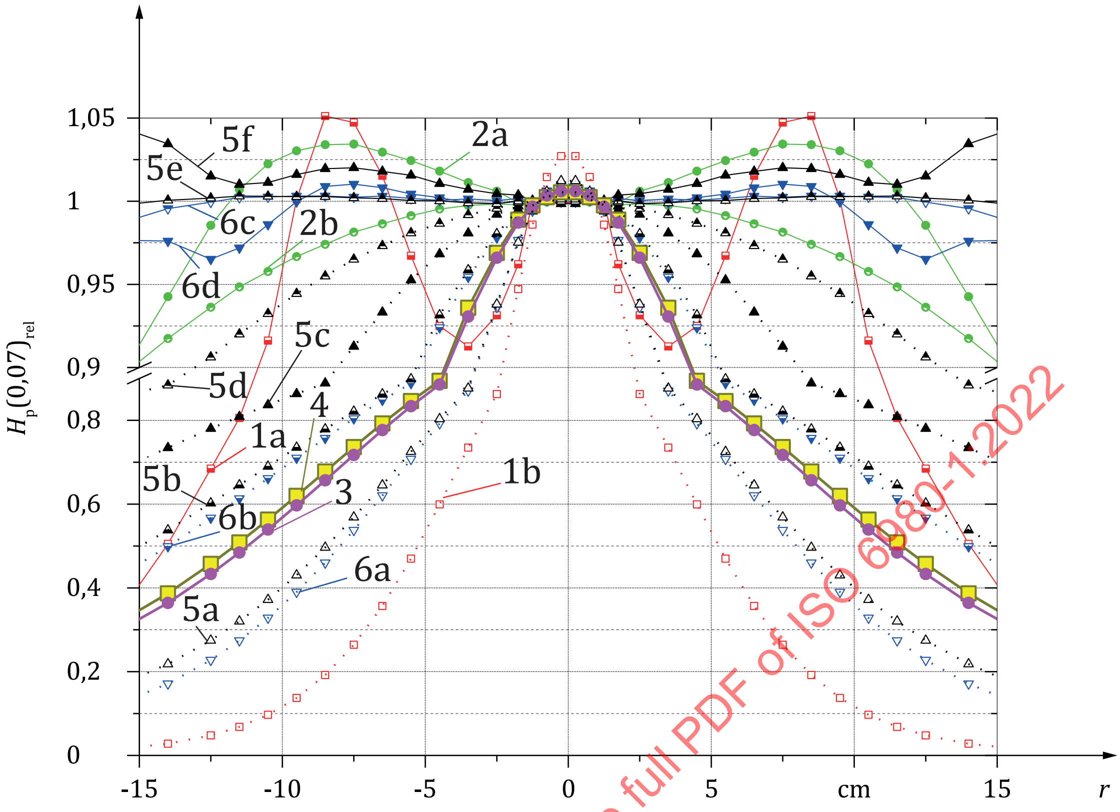
4 $^{90}Sr/^{90}Y$, 20 cm, with 3 mm PMMA absorber

5 $^{90}Sr/^{90}Y$, 30 cm, with beam-flattening filter

6 $^{106}Ru/^{106}Rh$, 30 cm, with beam-flattening filter

NOTE The uncertainty bars represent the statistical fluctuations of the simulations.

Figure 5 — Examples of beta-particle fluence spectra for the reference beta radiation fields at 3 mm depth in an ICRU 4 element tissue phantom including backscatter radiation[10][13][14][15]



Key

r: radial position in phantom

$H_p(0,07)_{rel}$: $H_p(0,07; r)/H_p(0,07; 0...1,5\text{ cm})$: dose rate at a radial position *r* divided by the dose rate at the radial centre of the phantom – both at 0,07 mm tissue equivalent depth

1a: ^{147}Pm at 20 cm distance with a beam-flattening filter

1b: ^{147}Pm at 11 cm distance without a beam-flattening filter

2a: ^{85}Kr at 30 cm distance with a beam-flattening filter

2b: ^{85}Kr at 50 cm distance with a beam-flattening filter

3: ^{90}Sr/^{90}Y at 20 cm distance with a 4 mm PMMA absorber

4: ^{90}Sr/^{90}Y at 20 cm distance with a 3 mm PMMA absorber

5a: ^{90}Sr/^{90}Y at 11 cm distance without a beam-flattening filter

5b: ^{90}Sr/^{90}Y at 20 cm distance without a beam-flattening filter

5c: ^{90}Sr/^{90}Y at 30 cm distance without a beam-flattening filter

5d: ^{90}Sr/^{90}Y at 50 cm distance without a beam-flattening filter

5e: ^{90}Sr/^{90}Y at 50 cm distance with a beam-flattening filter

5f: ^{90}Sr/^{90}Y at 30 cm distance with a beam-flattening filter

6a: ^{106}Ru/^{106}Rh at 11 cm distance without a beam-flattening filter

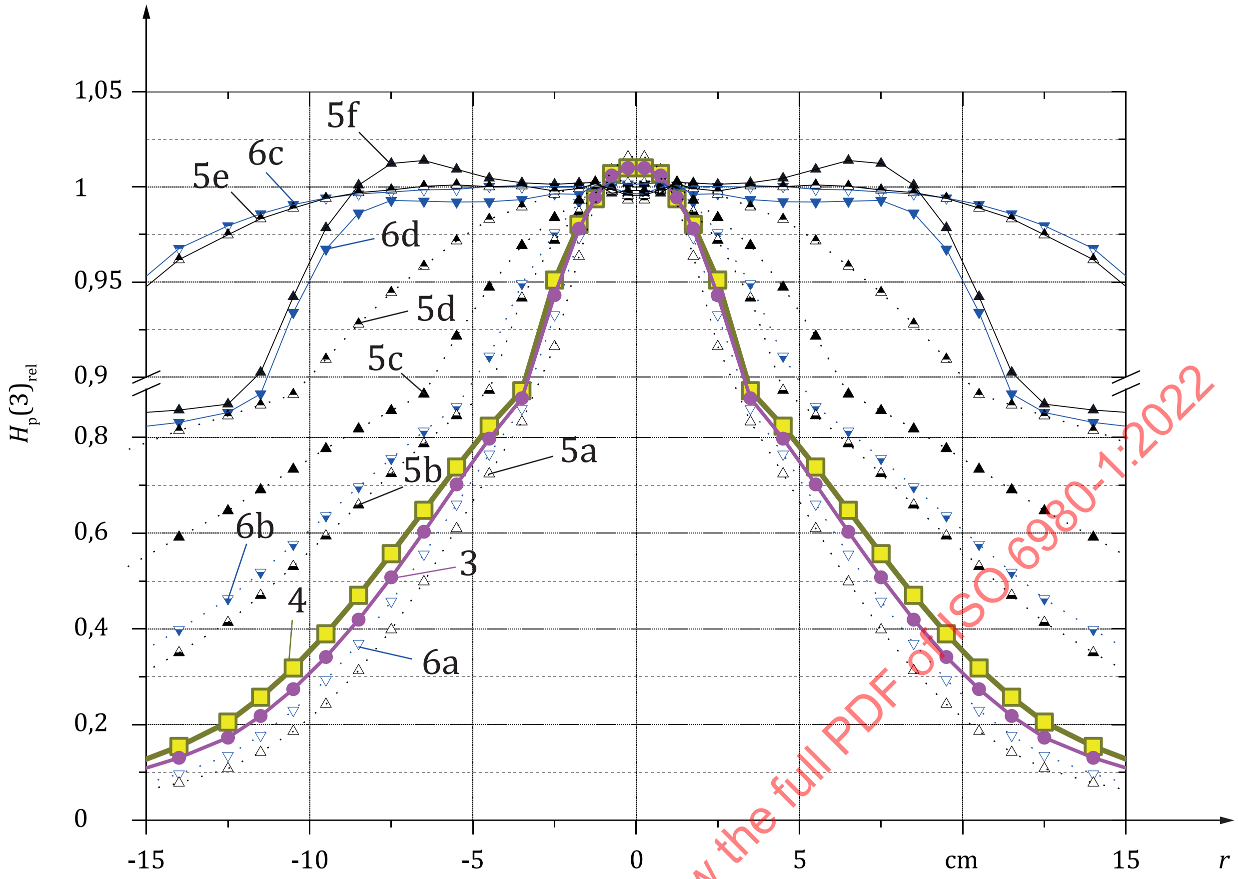
6b: ^{106}Ru/^{106}Rh at 20 cm distance without a beam-flattening filter

6c: ^{106}Ru/^{106}Rh at 50 cm distance with a beam-flattening filter

6d: ^{106}Ru/^{106}Rh at 30 cm distance with a beam-flattening filter

NOTE The ordinate is broken at a value of 0,9 with different scales before and after the break. The data are normalized to a 0,07 mm depth and a radius of 1,5 cm.

Figure 6 — Examples of simulated dose profiles at a depth of 0,07 mm in an ICRU 4 element tissue slab phantom for several geometries of the reference beta radiation fields (beam profile for $H_p(0,07)$[10][13][14][15])



Key

r:	radial position in phantom
$H_p(3)_{rel}$:	$H_p(3; r)/H_p(3; 0...1,5\text{ cm})$: dose rate at a radial position *r* divided by the dose rate at the radial centre of the phantom – both at 3 mm tissue equivalent depth
3:	$^{90}Sr/^{90}Y$ at 20 cm distance with a 4 mm PMMA absorber
4:	$^{90}Sr/^{90}Y$ at 20 cm distance with a 3 mm PMMA absorber
5a:	$^{90}Sr/^{90}Y$ at 11 cm distance without a beam-flattening filter
5b:	$^{90}Sr/^{90}Y$ at 20 cm distance without a beam-flattening filter
5c:	$^{90}Sr/^{90}Y$ at 30 cm distance without a beam-flattening filter
5d:	$^{90}Sr/^{90}Y$ at 50 cm distance without a beam-flattening filter
5e:	$^{90}Sr/^{90}Y$ at 50 cm distance with a beam-flattening filter
5f:	$^{90}Sr/^{90}Y$ at 30 cm distance with a beam-flattening filter
6a:	$^{106}Ru/^{106}Rh$ at 11 cm distance without a beam-flattening filter
6b:	$^{106}Ru/^{106}Rh$ at 20 cm distance without a beam-flattening filter
6c:	$^{106}Ru/^{106}Rh$ at 50 cm distance with a beam-flattening filter
6d:	$^{106}Ru/^{106}Rh$ at 30 cm distance with a beam-flattening filter

NOTE The ordinate is broken at a value of 0,9 with different scales before and after the break. The data are normalized to a 3 mm depth and a radius of 1,5 cm.

Figure 7 — Examples of simulated dose profiles at a depth of 3 mm in an ICRU tissue phantom for several geometries of the reference beta radiation fields (beam profile for $H_p(3)$[10][13][14][15])

6.1.3 Beta particle contamination

The radioactive 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 plots used to measure R_{res} and/or E_{res} (see Figure 1 and corresponding explanation in 6.1.2) have a/have linear section(s);

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.

R_{res} and E_{res} need to be remeasured when the experimental environment is significantly changed.

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

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 detector's 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 radioactive 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 Table A.1. To obtain a material thickness that is just sufficiently thick to totally absorb the beta radiation, Table A.2 provides the continuous slowing down approximation (CSDA) ranges for the materials listed in Table A.1. These CSDA ranges can be assumed to be of a sufficient material thickness, see Annex A.

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 C.

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. If the dose rate at the calibration distance shall be varied, sources of different activities shall be used to maintain the uniformity of the dose rate over the area. The variation of dose rate over the area at the calibration distance shall be less than ±5 % for $^{106}Ru/^{106}Rh$, $^{90}Sr/^{90}Y$, ^{85}Kr 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. 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[3][13]. Figures 6 and 7 show beam profiles for both series 1 as well as series 2 sources[10][13][14][15].

Table 3 gives details of calibration distances and examples of filter constructions for the series 1 reference radiation fields[10][13][14][15][16]. Table 4 gives the approximate dose equivalent rate per unit activity[10][13][14][15].

A maximum source diameter of 16 mm is recommended.

Table 3 — Calibration distances and filters for series 1 reference beta-particle radiation fields[10][13][14][15][16]

Radionuclide	Calibration distance cm	Source-to-filter distance cm	Filter material and dimensions
^{147}Pm	20	10	1 disc of PET, 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 or 50	10	2 concentric discs, 1 disc of PET, of 4 cm radius and mass per unit area 7 mg·cm^{-2}, plus 1 disc of PET, of 2,75 cm radius and mass per unit area 25 mg·cm^{-2}.
^{90}Sr/^{90}Y	30 or 50	10	3 concentric discs of PET, each with mass per unit area of 25 mg·cm^{-2} and of radii 2 cm, 3 cm and 5 cm.
^{106}Ru/^{106}Rh	30 or 50	10	3 concentric discs of PET, each with mass per unit area of 25 mg·cm^{-2} and of radii 2 cm, 3 cm and 5 cm.
PET: polyethylene terephthalate			

Table 4 — Approximate directional dose equivalent rate at the calibration distance per unit activity for series 1 beta-particle reference radiation fields[10][13][14][15]

Radionuclide	Approximate personal dose equivalent rate, $\dot{H}_p(0,07)$, per unit activity µSv·h^{-1} MBq^{-1}
^{147}Pm at 20 cm with flattening filter [a]	2,9
^{85}Kr at 30 cm with flattening filter [a]	46
^{90}Sr/^{90}Y at 30 cm with flattening filter [a]	85
^{106}Ru/^{106}Rh at 30 cm with flattening filter [a]	131
[a] Beam flattening filters are described in Table 3.	

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 distances 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 radiation field is substantially less uniform, see Figures 6 and 7.

The non-uniformity should be measured at the distance used for calibration and if the values exceed those stated in 4.4, corrections should be applied during the calibration of instruments. The distances given in Table 5 are intended to be the normal useful calibration distances and resulting dose rates[10].

Well established examples of distances and absorbers as well as mean beta energies are listed in Table 6 and Table 7, respectively.

Table 5 — Examples of activities and dose rates, $H_p(0,07)$ in mSv/h at nominal source activity, for series 1 and series 2 reference beta-particle radiation fields[10][13][14][15]

Radionuclide (*source*); nominal source activity GBq	Calibration distance 11 cm, without filter	20 cm, without filter	20 cm, with filter or absorber	30 cm, without filter	30 cm, with filter	50 cm, without filter	50 cm, with filter
^{147}Pm; 3,7	931		10,7				
^{85}Kr; 3,7					172		50,9
^{90}Sr/^{90}Y; 0,46	444	137	3 mm PMMA: 31,7 4 mm PMMA: 13,3	60,8	38,9	21,5	14,1
^{106}Ru/^{106}Rh; 0,02	27,7	8,68			2,62		0,934

Table 6 — Examples of calibration distances and absorbers for series 2 reference beta-particle radiation fields[10][13][14][15]

Radionuclide	Calibration distance cm	Source-to-absorber distance cm	Filter material and dimensions
^{147}Pm	11	---	None
^{90}Sr/^{90}Y	20	4	3 mm absorber made of PMMA or 4 mm absorber made of PMMA
^{90}Sr/^{90}Y	11 or 20 or 30 or 50	---	None
^{106}Ru/^{106}Rh	11 or 20	---	None

Table 7 — Examples of mean beta energies [a], E_{mean} , in MeV, for series 1 and series 2 reference beta-particle radiation fields[10][13][14][15]

Radionuclide (*source*)	11 cm, without filter	20 cm, without filter	20 cm, with filter or absorber	30 cm, without filter	30 cm, with filter	50 cm, without filter	50 cm, with filter
^{147}Pm	0,084		0,071				
^{85}Kr					0,254		0,250
^{90}Sr/^{90}Y	0,85	0,85	3 mm PMMA: 0,62 4 mm PMMA: 0,54	0,84	0,81	0,83	0,80
^{106}Ru/^{106}Rh	1,16	1,16			1,16		1,14

[a] The mean beta energies are weighted over the fluence of the beta particle spectrum free in air at the calibration distance, indicated in the first line.

7 Source calibration

The quantities recommended for the calibration of protection instruments are specified in ISO 29661. ISO 6980-3 specifies the phantoms and conditions to be used in calibrations. For the series 1 reference beta-radiation fields that that are obtained with the use of 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[3][13].

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 measured by one of the following methods (see ICRU 56[3]):

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.