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**Nuclear energy — Reference beta-  
particle radiation —**

Part 2:  
**Calibration fundamentals related to  
basic quantities characterizing the  
radiation field**

*Énergie nucléaire — Rayonnement bêta de référence —*

*Partie 2: Concepts d'étalonnage en relation avec les grandeurs  
fondamentales caractérisant le champ de rayonnement*

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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 document 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](http://www.iso.org/directives)).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at [www.iso.org/patents](http://www.iso.org/patents). ISO shall not be held responsible for identifying any or all such patent rights.

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For an explanation of 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 [www.iso.org/iso/foreword.html](http://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 third edition of ISO 6980-2 cancels and replaces ISO 6980-2:2022, of which it constitutes a minor revision.

The main changes are as follows:

- editorial changes throughout the document.

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](http://www.iso.org/members.html).

## Introduction

ISO 6980 series covers the production, calibration, and use of reference beta-particle radiation fields for the calibration of dosimeters and dose-rate meters for protection purposes. This document describes the procedures for the determination of absorbed dose rate to a reference depth of tissue from reference beta particle radiation fields. ISO 6980-1 describes methods of production and characterization of the reference radiation. ISO 6980-3 describes procedures for the calibration of dosimeters 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 dosimeters 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 this document. 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 dosimeter. Depending on the type of dosimeter under test, the irradiation is either carried out on a phantom or free-in-air for personal and area dosimeters, 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 dosimeters 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  $H_p(3)$ .

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# Nuclear energy — Reference beta-particle radiation —

## Part 2:

# Calibration fundamentals related to basic quantities characterizing the radiation field

## 1 Scope

This document specifies methods for the measurement of the absorbed-dose rate in a tissue-equivalent slab phantom in the ISO 6980 reference beta-particle radiation fields. The energy range of the beta-particle-emitting isotopes covered by these reference radiations is 0,22 MeV to 3,6 MeV maximum beta energy corresponding to 0,07 MeV to 1,2 MeV mean beta energy. Radiation energies outside this range are beyond the scope of this document. While measurements in a reference geometry (depth of 0,07 mm or 3 mm at perpendicular incidence in a tissue-equivalent slab phantom) with an extrapolation chamber used as primary standard are dealt with in detail, the use of other measurement systems and measurements in other geometries are also described, although in less detail. However, as noted in ICRU 56<sup>[5]</sup>, 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 intended for those organizations wishing to establish primary dosimetry capabilities for beta particles and serves as a guide to the performance of dosimetry with an extrapolation chamber used as primary standard for beta-particle dosimetry in other fields. Guidance is also provided on the statement of measurement uncertainties.

## 2 Normative references

ISO 6980-2:2023

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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) 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 terminology 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

#### extrapolation curve

curve given by a plot of the corrected ionization current versus the extrapolation chamber depth

### 3.2

#### **ionization chamber**

ionizing radiation detector consisting of a chamber filled with a suitable gas (almost always air), in which an electric field, insufficient to induce gas multiplication, is provided for the collection at the electrodes of charges associated with the ions and electrons produced in the measuring volume of the detector by ionizing radiation

Note 1 to entry: The ionization chamber includes the measuring volume, the collecting and polarizing electrodes, the guard electrode, if any, the chamber wall, the parts of the insulator adjacent to the sensitive volume and any additional material placed in front of the ionization chamber to simulate measurement at depth.

### 3.3

#### **extrapolation (ionization) chamber**

*ionization chamber* (3.2) capable of having an ionization volume which is continuously variable to a vanishingly small value by changing the separation of the electrodes and which allows the user to extrapolate the measured ionization density to zero collecting volume

### 3.4

#### **ionization density**

measured ionization per unit volume of air

### 3.5

#### **leakage current**

$I_B$   
*ionization chamber* (3.2) current measured at the operating bias voltage in the absence of radiation

### 3.6

#### **maximum beta energy**

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

### 3.7

#### **mean beta energy**

$E_{\text{mean}}$   
fluence averaged energy of the beta particle spectrum at the calibration distance free in air

### 3.8

#### **parasitic current**

$I_p$   
negative current produced by beta particles stopped in the collecting portion of the collecting electrode and diffusing to this electrode and the wire connecting this electrode to the electrometer connector

### 3.9

#### **phantom**

artefact constructed to simulate the scattering properties of the human body or parts of the human body such as the extremities

Note 1 to entry: A phantom can be used for the definition of a quantity and made of artificial material, e.g. ICRU tissue, or for the calibration and then be made of physically existing material, see ISO 29661:2012, 6.6.2, for details.

Note 2 to entry: In principle, the ISO water slab phantom, the ISO rod phantom, the ISO water cylinder phantom, or the ISO pillar phantom should be used, see ISO 29661. For the purposes of this document, however, a polymethyl methacrylate (PMMA) slab, 20 cm × 20 cm in cross-sectional area by at least 2 cm thickness, is sufficient to simulate the backscatter properties of the trunk of the human body, while tissue substitutes such as polyethylene terephthalate (PET) are sufficient to simulate the attenuation properties of human tissue (see 6.2).

[SOURCE: ISO 29661:2012, 3.1.22, modified — Note 2 to entry added.]



**3.10****reference point of the extrapolation chamber**

point to which the measurement of the distance from the radiation source to the chamber at a given orientation refers, i.e., the centre of the back surface of the high-voltage electrode of the chamber

**3.11****reference absorbed dose**
 $D_R$ 

absorbed dose to tissue,  $D_t(0,07)$ , in a slab *phantom* (3.9) made of ICRU 4-element tissue with an orientation of the *phantom* (3.9) in which the normal to the *phantom* (3.9) surface coincides with the (mean) direction of the incident radiation

Note 1 to entry: The absorbed dose to tissue,  $D_t(0,07)$ , is defined in ICRU 51<sup>[4]</sup> as personal absorbed dose,  $D_p(0,07)$ . For the purposes of this document, this definition is extended to a slab phantom.

Note 2 to entry: It is considered that the rear part of the extrapolation chamber approximates a slab phantom with sufficient accuracy by the material surrounding the standard instrument (extrapolation chamber) used for the measurement of the beta radiation field<sup>[7][8]</sup>.

Note 3 to entry:  $H_p(0,07)$  is obtained by the multiplication of the absorbed dose to tissue at 0,07 mm depth,  $D_t(0,07) = D_R$ , with the conversion coefficient  $1 \text{ Sv Gy}^{-1}$ , see ISO 6980-3:2023, 5.2.2.2, Formula (3).

**3.12****reference beta-particle absorbed dose**
 $D_{R\beta}$ 

reference absorbed dose,  $D_{R\beta}$  (3.11) at a depth of 0,07 mm only due to beta particles

Note 1 to entry: As a first approximation, the ratio  $D_{R\beta}/D_R$  is given by the correction factor for bremsstrahlung,  $k_{br}$ , and other photons (see C.3).

**3.13****tissue equivalence**

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

Note 1 to entry: See ISO 6980-1:2023, Annex A; more tissue substitutes are given by ICRU 44.

Note 2 to entry: Further details are given in 6.2.

**3.14****transmission function**
 $T_m(\rho_m \cdot d_m; \alpha)$ 

ratio of absorbed dose,  $D_m(\rho_m \cdot d_m; \alpha)$ , in medium m at an area depth,  $\rho_m \cdot d_m$ , and angle of radiation incidence,  $\alpha$ , to absorbed dose,  $D_m(0; 0^\circ)$ , at the surface of a *phantom* (3.9)

**3.15****tissue transmission function,**
 $T_t(\rho_t \cdot d_t; \alpha)$ 

ratio of absorbed dose,  $D_t(\rho_t \cdot d_t; \alpha)$ , in ICRU tissue at an area depth,  $\rho_t \cdot d_t$ , and angle of radiation incidence,  $\alpha$ , to absorbed dose,  $D_t(0; 0^\circ)$ , at the surface of an ICRU tissue slab *phantom* (3.9)

**3.16****zero point**

reading of the extrapolation chamber depth indicator which corresponds to a chamber depth of zero, or no separation of the electrodes

**4 Symbols and abbreviated terms and reference and standard test conditions**

A list of symbols and abbreviated terms is given in [Table 1](#).

**Table 1 — Symbols and abbreviated terms**

Symbol	Meaning
$a$	effective area of the extrapolation-chamber collecting electrode
$BG$	Bragg-Gray
$C$	external feedback capacitance capacitor
$C_k$	extrapolation chamber capacitance
$c_i$	sensitivity coefficient
$d_{abs}$	thickness of the absorber in front of the extrapolation chamber
$d_m$	depth in a medium $m$
$d_t$	depth in ICRU tissue
$d_t^m$	tissue-equivalent thickness of medium $m$
$d_0$	reference depth in tissue of 0,07 mm or 3 mm
$D_m(d_m)$	absorbed dose at a depth $d_m$ in medium $m$
$D_R$	reference absorbed dose
$D_{R\beta}$	reference beta-particle absorbed dose
$\bar{D}(d_m, v, r_m)$	volume-averaged dose in a detector of thickness $v$ , density $\rho_m$ at depth $d_m$
$E$	particle energy (photon energy or electron kinetic energy)
$E_1$	constant in the saturation correction Formula
$E_{max}$	maximum beta energy (kinetic) of a beta-particle spectrum
$e$	charge of an electron
$f_i$	coefficients used for the calculation of $k_{pe}$
$H_p(d)$	personal dose equivalent at depth $d$ in ICRU tissue
$H'(d; \Omega)$	directional dose equivalent at depth $d$ , on a radius having direction $\Omega$
$I$	ionization current
$I_L$	leakage current, not induced by pre-irradiation of the chamber
$I_{br}$	ionization current caused by bremsstrahlung and other photons
$I_p$	parasitic current
$I_+$	current measured with positive polarity of collecting voltage
$I_-$	current measured with negative polarity of collecting voltage
ICRU	International Commission on Radiation Units and Measurements
ISO	International Organization for Standardization
$k$	product of the extrapolation chamber correction factors which vary during the extrapolation curve measurement
$k'$	product of the extrapolation chamber correction factors which are constant during the extrapolation curve measurement
$k_{abs}$	correction factor for variations in the attenuation and scattering of beta particles between the source and the collecting volume and inside the collection volume due to variations from reference conditions and for differences of the entrance window to a tissue-equivalent thickness of 0,07 mm
$k_{ad}$	correction factor for the variations of air density in the collecting volume from reference conditions
$k_{ba}$	correction factor for the difference in backscatter between tissue and the material of the collecting electrode and guard ring
$k_{br}$	correction factor for the effect of bremsstrahlung from the beta-particle source and other photons
$k_{de}$	correction factor for radioactive decay of the beta particle source
$k_{el}$	correction factor for electrostatic attraction of the entrance window due to the collecting voltage
$k_{hu}$	correction factor for the effect of humidity of the air in the collecting volume on $\bar{W}_0$

Table 1 (continued)

Symbol	Meaning
$k_{ih}$	correction factor for the inhomogeneity of the absorbed dose rate inside the collecting volume
$k_{in}$	correction factor for interface effects between the air of the collecting volume and the adjacent entrance window and collecting electrode
$k_{pe}$	correction factor for perturbation of the beta-particle flux density by the side walls of the extrapolation chamber
$k_{ph}$	correction factor for the change of the source to chamber distance once absorbers are placed in front of the chamber (to increase the phantom depth)
$k_{SA}$	correction factor for the stopping power ratio of tissue-to-air to use the Spencer-Attix theory instead of the Bragg-Gray theory
$k_{sat}$	correction factor for ionization collection losses due to ionic recombination
$k_{Sta}$	correction factor for the change of the stopping power ratio at different phantom depth
$\ell$	extrapolation chamber depth, the air gap between the collecting electrode and the entrance window
$\ell_0$	intercept of the extrapolation curve with the chamber depth axis
$m_a$	mass of the air in the collecting volume of an extrapolation chamber
$p$	ambient atmospheric pressure
PMMA	polymethyl methacrylate
PET	polyethylene terephthalate
PTFE	polytetrafluoroethylene
$q_m$	measured ionization density
$(S/\rho)_{el,m}$	mass-electronic stopping power in medium m
SA	Spencer-Attix
$s_{t,a}$	ratio of mass-electronic stopping powers of ICRU tissue and air
$T$	ambient air temperature
$T_i$	parameter for transmission functions
$T_m(\rho_m \cdot d_m; \alpha)$	transmission function $D_m(\rho_m \cdot d_m; \alpha)/D_m(0; 0^\circ)$ in medium m
$T_t(\rho_t \cdot d_t; \alpha)$	transmission function $D_t(\rho_t \cdot d_t; \alpha)/D_t(0; 0^\circ)$ in tissue
$t$	integration time for a current measurement
$t_m$	time at which a measurement is performed
$t_0$	reference time to which measurements are corrected to account for radioactive decay
$t_{1/2}$	half-life of a radioisotope
$U$	absolute value of the collecting voltage in the extrapolation chamber
$U_1, U_2$	initial and final voltages on the feedback capacitor charged by current from the extrapolation chamber
$v$	thickness of a detector
$\bar{W}_0$	average energy to produce an ion pair in air under reference conditions
$x_c$	diameter of the geometric collecting electrode area
$x_g$	width of the insulating gap between the collecting and guard electrodes
$y_0$	distance from the source to the reference point of the detector
$z$	distance from the beam axis, perpendicular to that axis
$\bar{Z}_m$	effective atomic number of medium m
$\alpha$	angle between the direction of the beam axis and the normal of the surface of the phantom
$\Gamma_0$	constant in the saturation-correction-factor Formula
$\epsilon_a$	dielectric constant for air
$\eta_{m1,m2}$	beta-particle attenuation scaling factor of medium $m_1$ relative to medium $m_2$

**Table 1 (continued)**

Symbol	Meaning
$\rho_a$	density of air at ambient conditions
$\rho_{a0}$	density of air at reference conditions
$\rho_m$	density of medium m
$\rho_t$	density of ICRU tissue
$\sigma$	standard deviation
$\tau_{br}$	contribution to the dose due to bremsstrahlung and other photons, i.e. $\tau_{br} = 1 - k_{br}$
$\Phi_E$	spectral distribution of beta-particle fluence

The reference conditions as well as the standard test conditions are given in [Annex A](#). All calibrations and measurements shall be conducted under standard test conditions in accordance with [Tables A.1](#) and [A.2](#).

## 5 Calibration and traceability of reference radiation fields

The reference absorbed-dose rate of a radiation field established for a calibration in accordance with this document shall be traceable to a recognized national standard. The method used to provide this calibration link is achieved through utilization of a transfer standard. This may be a radioactive source or an approved transfer standard instrument. The calibration of the field is valid in exact terms only at the time of the calibration, and thereafter shall be inferred, for example, from a knowledge of the half-life and isotopic composition of the radioactive source.

The measurement technique used by a calibration laboratory for calibrating a beta-particle measuring device shall also be approved as required by national regulations if available. An instrument of the same, or similar, type to that routinely calibrated by the calibration laboratory shall be calibrated by both a reference laboratory recognized by a country's approval body or institution, if available, and the calibration laboratory. These measurements shall be performed within each laboratory using its own approved calibration methods. In order to demonstrate that adequate traceability has been achieved, the calibration laboratory should obtain the same calibration factor, within agreed-upon limits, as that obtained in the reference laboratory. The use by the calibration laboratory of standardized sources and holders which have been calibrated in a national reference laboratory is sufficient to demonstrate traceability to the national standard.

The frequency of a field calibration should be such that there is reasonable confidence that its value will not move outside the limits of its specification between successive calibrations. The calibration of the laboratory-approved transfer instrument, and the check on the measurement techniques used by the calibration laboratory should be carried out at least every five years, or whenever there are significant changes in the laboratory environment or as required by national regulations.

## 6 General principles for calibration of beta-particle radiation fields

### 6.1 General

Area and personal doses from beta-particle radiation are often difficult to measure because of their marked non-uniformity over the skin and variation with depth. In order to correctly measure the absorbed-dose rate at a point in a phantom in a beta-particle field, a very small detector with very similar absorption and scattering characteristics as the medium of which the phantom is composed, is needed. Since there is no ideal detector, recourse shall be made to compromise both in detector size and composition. The concepts of "scaling factor" and "transmission function" are helpful to account for these compromises.

## 6.2 Scaling to derive equivalent thicknesses of various materials

Scaling factors have been developed by Cross<sup>[9]</sup> to relate the absorbed dose determined in one material to that in another. These were developed from the observation that, for relatively high-energy beta-particle sources, dose distributions in different media have the same shape, differing only by a scaling factor, which Cross denoted as  $\eta$ . Originally observed in the comparison of beta ray attenuation curves in different media, where  $\eta_{m,a}$ , the scaling factor from medium  $m$  to air, was determined from the ratios of measured attenuation, the concept has been extended such that, for a plane source of infinite lateral extent, whether isotropic or a parallel beam, the absorbed dose at an area depth  $\rho_{m1} \cdot d_{m1}$  in medium  $m_1$  is related to the absorbed dose, in medium  $m_2$ , at the same area depth  $\rho_{m2} \cdot d_{m2}$ , but scaled to  $\eta_{m1,m2} \cdot \rho_{m2} \cdot d_{m2}$ , by

$$D_{m1}(\rho_{m1} \cdot d_{m1}) = \eta_{m1,m2} \cdot D_{m2}(\eta_{m1,m2} \cdot \rho_{m2} \cdot d_{m2}) = \eta_{m1,m2} \cdot D_{m2}(\rho_{m1} \cdot d_{m1}) \quad (1)$$

provided that

$$\rho_{m1} \cdot d_{m1} = \rho_{m2} \cdot d_{m2} \quad (2)$$

$\eta_{m1,m2}$  is defined as the scaling factor from medium  $m_1$  to medium  $m_2$ . It should be noted that the scaling factors are ratios, so that  $\eta_{m1,m2} = 1/\eta_{m2,m1}$  and  $\eta_{m1,m3} = \eta_{m1,m2} \cdot \eta_{m2,m3}$ .

The user should be cautioned that this concept has been demonstrated only for materials of  $Z$  or effective atomic number,  $\bar{Z}_m$ , less than 18. Values of  $\eta_{m,t}$  calculated for various materials relative to tissue are shown in [Table 2](#). The data from Table A.2 in ICRU 56<sup>[5]</sup> were multiplied by  $\eta_{t,w}$ .

If  $m_2$  be tissue, and  $m_1$  be a medium  $m$ , [Formula \(1\)](#) reduces to

$$D_m(\rho_m \cdot d_m) = \eta_{m,t} \cdot D_t(\eta_{m,t} \cdot \rho_m \cdot d_m) \quad (3)$$

If another depth,  $d'_m$  in medium  $m$  is considered, a similar formula is obtained

$$D_m(\rho_m \cdot d'_m) = \eta_{m,t} \cdot D_t(\eta_{m,t} \cdot \rho_m \cdot d'_m) \quad (4)$$

The ratio of the absorbed dose at an arbitrary depth to that at the surface ( $d'_m = 0$ ) is defined as the transmission function. Thus, making this substitution and dividing [Formula \(3\)](#) by [Formula \(4\)](#), the following is obtained

$$T_m(\rho_m \cdot d_m) = \frac{D_m(\rho_m \cdot d_m)}{D_m(0)} = \frac{D_t(\eta_{m,t} \cdot \rho_m \cdot d_m)}{D_t(0)} \quad (5)$$

or

$$T_m(\rho_m \cdot d_m) = T_t(\eta_{m,t} \cdot \rho_m \cdot d_m) \quad (6)$$

The transmission through a layer of thickness of tissue,  $\eta_{m,t} \cdot \rho_m \cdot d_m$ , in tissue is equal to the transmission through a layer of thickness of medium  $m$ ,  $\rho_m \cdot d_m$ , in medium  $m$ . Thus the thickness  $\rho_m \cdot d_m$  is said to be equivalent to tissue with a thickness of  $\eta_{m,t} \cdot \rho_m \cdot d_m$  since the transmissions are equal. The equivalent tissue thickness  $d_t^m$  can be defined as

$$d_t^m = \eta_{m,t} \cdot \rho_m \cdot d_m \cdot \rho_t^{-1} \quad (7)$$

In general, the dose and the transmission functions are functions of both the depth and angle of incidence in a medium. When they are expressed as above with no angle given, the angle shall be taken as  $0^\circ$ . Materials with tissue equivalence are listed in ISO 6980-1:2023, Annex A.

### 6.3 Characterization of the radiation field in terms of penetrability

The tissue transmission function,  $T_t(\rho_t \cdot d; \alpha)$ , is an important parameter of the reference beta-particle radiation field. Because of the finite thickness of all detectors used to measure absorbed-dose rate, the radiation field shall be characterized in terms of penetrability before it can be properly calibrated. Since the energy fluence of the beta particles in a field changes as the beta particles penetrate the medium, the determination of the relative dose as a function of depth (or depth-dose function) in a medium shall be performed with a detector that is not sensitive to this change in energy fluence. For this reason, the relative depth-dose function shall be determined with a thin (2 mm or less) air ionization chamber. A recommended method for making this determination with the extrapolation chamber is given in References [10][11]. The depth-dose functions are then used to construct transmission functions, examples of which are shown in Figures 1 and 2[11][12][13][14]. The measured transmission functions, in conjunction with the calculated equivalent tissue thicknesses described above, can be used to determine corrections in the measured absorbed-dose rate to account for depth other than 0,07 mm in a phantom, e.g. 3 mm, and for finite detector size and non-medium equivalence of the detector material. They can also be used to account for variations in the absorbed-dose rate at the reference point due to variations in the air density between the source and the reference point, and for attenuation in non-tissue material in front of the detector, further details are given as follows (see Clause 7).

For thick detectors, it shall be accounted for the fact that the absorbed-dose rate is averaged over the volume of a detector. Neglecting any variation in the absorbed dose rate in the plane transverse to the normal direction of the field, the average absorbed-dose rate of a detector with a thickness  $v$  and density  $\rho$ , whose front surface is at a depth  $d$  in a phantom of unit density  $\rho_t$ , is given by

$$\bar{D}_m(d, v, \rho) = \frac{\int_{\rho_t \cdot d}^{\rho_t \cdot d + \rho \cdot v} D_m(\delta) \cdot d\delta}{\rho \cdot v} = \frac{D_m(0) \cdot \int_{\rho_t \cdot d}^{\rho_t \cdot d + \rho \cdot v} T(\delta) \cdot d\delta}{\rho \cdot v} = D_m(0) \cdot \bar{T}(d, v, \rho) \quad (8)$$

where  $\bar{T}(d, v, \rho)$  is the transmission function averaged over the detector volume. For thick detectors ( $v > 0,1$  mm), this effect may be compensated for by shifting the reference point towards the source.

## 7 Calibration procedures using an extrapolation chamber

### 7.1 General

An extrapolation chamber is a primary measurement device for specifying dose rate in beta-particle fields. It is a parallel plate chamber which consists of components which allow a variable ionization volume to be achieved, by movement of one of the plates towards the other. A typical design[15] is shown in Figure 3, which utilizes a fixed entrance window and a movable collecting electrode. The entrance window also serves as the high-voltage electrode and consists of a very thin conducting plastic foil. The window shall be thin enough to not unduly attenuate the beta-particle radiation, yet strong enough to not be deformed by attraction to the grounded collecting electrode. Carbonized PET foils of about  $0,7 \text{ mg} \cdot \text{cm}^{-2}$  are now typical of commercially available devices. The collecting electrode is maintained at ground potential and defines the cross-sectional area of the collecting ionization volume. It shall be of conducting material or have a coating of conductive material, and shall be surrounded by, and electrically insulated from, a guard region. This insulation shall be thin enough to not perturb the electric field lines in the chamber volume, which ideally are uniform, and everywhere perpendicular to the two electrodes. In the design shown in Figure 3, the collecting electrode is constructed from polymethyl methacrylate (PMMA) which has a thin coating of conductive material in which a narrow groove has been inscribed to define the collecting area. The device shall be equipped with an accurate means to determine incremental changes in the distance between the two electrodes, hereafter referred to as the chamber depth; a micrometer attached to the piston which drives the collecting electrode is usually employed. A bipolar, variable voltage DC power source is used to supply the high voltage to the entrance window while the collecting electrode is grounded, and a low-noise electrometer is used to measure the current collected by the collecting electrode. Details of the measurement of the ionization current are given in Annex B.