Latest developments in beta-radiation metrology
(primary dosimetry, ISO 6980 revision, and ICRU 95 impact)

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Hyperlinks written in blue and underlined (PDF and video will be available at CCRI's website)
Introduction

Primary and secondary beta dosimetry

International comparison BIPM EURAMET.RI(I)-S16

Revision of ISO 6980 ↔ correction factors for beta dosimetry

Newly proposed operational quantities (ICRU 95)
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Types of radiation and their characteristics

Penetrating power of different types of radiation

α β γ neutron

PAPER ALUMINIUM LEAD CONCRETE

https://www.osha.gov/ionizing-radiation/background

Photons vs. charged particles:
Finite penetration probability with unchanged energy
vs.
continuous energy loss and finite range

\[ \Phi = \Phi_0 e^{-\mu d} \]

Ranges of charged particles in air

https://link.springer.com/chapter/10.1007/978-3-319-73398-2_14 (Figure 2)

https://link.springer.com/chapter/10.1007/978-3-319-73398-2_14 (Figure 3)
Beta radiation: what’s that?

Beta particle = electron (beta⁻) or positron (beta⁺) from a nuclear decay

Beta minus decay ⇒ electron  
Beta plus decay ⇒ positron

Electrons and positrons: Practically the same interaction - apart from the positron’s end...

https://www.radiation-dosimetry.org/what-is-positron-annihilation-definition/
Beta radiation: spectrum emission

Beta particle spectra in ICRP 107

Beta dosimetry for radiation protection: why?

Beta radiation in medicine, industry and research

Process control using $^{14}$C, $^{147}$Pm, $^{85}$Kr, $^{90}$Sr ...

Radiosynoviorthesis using $^{90}$Y for pain therapy

Ru-106 Eye Applicators
Beta Radiation for Eye Tumor Treatment

Mean beta energy

0.0 0.2 0.4 0.6 0.8 1.0 1.2 MeV

Beta radiation in medicine, industry and research

Physikalisch-Technische Bundesanstalt ■ Braunschweig and Berlin
Dr. R. Behrens, PTB 6.3: Latest developments in beta-radiation metrology

CCRI Webinar 2022-09-07
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Particle tracks in air: photons vs. electrons

Beta radiation: **Significant absorption and scattering of betas in rather small air volumes**

![Air cube of 1 cm x 1 cm x 1 cm](image)

Collimated beam (from left to right):
opening angle $\alpha = \pm 11^\circ$

10 keV photons

10 keV electrons
Principles of primary beta dosimetry

Beta radiation: Significant absorption and scattering of betas in ionization volume $V$ => Measurement at different chamber depth $l$ and extrapolation to $l = 0$

Ionization chamber with variable volume: Extrapolation chamber

Beta Primary Standards of PTB: BPS1, *Böhm chamber* (commercially available, PTW; world wide in use)

(developed at PTB)
Principles of primary beta dosimetry

Beta radiation: Significant absorption and scattering of betas in ionization volume $V$ => Measurement at different chamber depth $l$ and extrapolation to $l = 0$

Ionization chamber with variable volume: Extrapolation chamber

$250 \ldots 2500 \mu m$; $\varnothing = 3 \text{ cm}$

Beta Primary Standards of PTB: BPS1, Böhm chamber (commercially available, PTW; worldwide in use)

(developed at PTB)
Principles of primary beta dosimetry: Realization

Realization of the Gray: Principle of extrapolation chamber

Ionization chamber with variable volume:
Extrapolation chamber

ISO 6980-2:2004:
Absorbed dose rate to tissue: 

\[ \dot{D}_{RB} = \frac{(\bar{W}_0/e) \cdot s_{t,a}}{\rho_{a0} \cdot a} \left[ \frac{d}{dl} \{k \cdot k' \cdot I(l)\} \right]_{l=0} \]

Extrapolation curve

Extrapolation to slope at depth \( l = 0 \) µm

Ionization current \( I \)
Measurement
Linear fit

Chamber depth \( l \)

<table>
<thead>
<tr>
<th>µm</th>
<th>-500</th>
<th>0</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2500</th>
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</tbody>
</table>

Chamber depth \( l \)

250 \ldots 2500 \, \mu m;
\( \phi = 3 \, \text{cm} \)
Principles of primary beta dosimetry: Realization

Realization of the Gray: Principle of extrapolation chamber

Ionization chamber with variable volume: Extrapolation chamber

ISO 6980-2:2004:
Absorbed dose rate to tissue:

\[ \dot{D}_{R\beta} = \left( \frac{\bar{W}_0}{e} \right) \cdot \frac{s_{t,a}}{\rho_{a0} \cdot a} \left[ \frac{d}{dl} \left\{ k \cdot k' \cdot I(l) \right\} \right]_{l=0} \]

many correction factors...

Extrapolation curve

Deviation from linearity enlarged by a factor of 10 for illustration purposes.

Extrapolation to slope at depth \( l = 0 \) \( \mu m \) via quadratic fit.

ISO 6980-2
Principles of primary beta dosimetry: Realization

Realization of the Gray: correction factors $k'$ (constant with chamber depth $l$) and $k$ (variable with $l$):

\[
\dot{D}_R = \frac{\langle W_0/e \rangle \cdot s_{t,a}}{\rho a_0 \cdot a} \left[ \frac{d}{dl} \left\{ k \cdot k' \cdot I(l) \right\} \right]_{l=0}
\]

many correction factors...
Principles of primary beta dosimetry:  Realization

Realization of the Gray: Interpolation to relevant tissue depths: 0.07 mm & 3 mm
Absorbers of increasing thickness in front of chamber
Principles of primary beta dosimetry: Realization

Realization of the Gray: Interpolation to relevant tissue depths: 0.07 mm & 3 mm
Absorbers of increasing thickness in front of chamber
Principles of primary beta dosimetry: Realization

Realization of the Gray: Interpolation to relevant tissue depths: 0.07 mm & 3 mm

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Realization of the Gray:

- Interpolation to relevant tissue depths: 0.07 mm & 3 mm

Graph showing dose rate relative to different tissue equivalent depths in phantom. The graph includes points at $d = 0.07$ mm and $d = 3$ mm for the radionuclide $^{90}\text{Sr}/^{90}\text{Y}$. The $H_p(0.07)$ and $H_p(3)$ values are marked on the graph.
Secondary beta dosimetry: Dissemination

**Dissemination of the Gray:** $D_t$, and

**Sievert:** $H_p(0.07)$, $H'(0.07)$, $H_p(3)$ and $H'(3)$ (operational quantities)

**Irradiation facility:** **Beta Secondary Standard 2** (commercially available, EZN)

**Main characteristics**
- Developed at PTB
- Traceable to PTB
- Quality assured
- All parameters controlled (single-board computer)
- Dose corrected for radioact. decay and amb. cond.
- Safe source handling
- Beam flattening filter for homog. radiation fields
- Rod and slab phantom included
- Sources: $^{147}$Pm, $^{85}$Kr, $^{90}$Sr/$^{90}$Y (standard) and $^{106}$Ru/$^{106}$Rh (implemented in software)
- Quantities: $H_p(0.07)$, $H'(0.07)$, $H_p(3)$ and $H'(3)$

BSS2 in general: *J. Instrum., 2, P11002 (2007)*

extensions: *J. Instrum., 6, P11007 (2011)*
Secondary beta dosimetry: Dissemination

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extensions: J. Instrum. 6, P11007 (2011)

**Distributed worldwide:** more than 140 exemplars
Secondary beta dosimetry: Dissemination

Dissemination of the Gray: $D_t$, and
Sievert: $H_p(0.07)$, $H'(0.07)$, $H_p(3)$ and $H'(3)$ (operational quantities)

Irradiation facility: Beta Secondary Standard 2 (commercially available, EZN)

Beam profile at different depths in material
without and with beam-flattening filter

J. Instrum. 8, P02019 (2013)
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Revision of ISO 6980 ↔ correction factors for beta dosimetry

Newly proposed operational quantities (ICRU 95)
Beta comparison 2018-2023
- $H_p(0.07)$ and $H_p(3)$, the latter for the first time
- Circulation of PTB’s secondary ionization chamber and measuring stand
- 16 participants: BIPM EURAMET.RI(I)-S16
- Several delays due to Covid-19 and issues with the measuring stand: ~1 year
- Current status: most participants finished; CU on the way; report in 2023
Contents

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Revision of ISO 6980 ⇔ correction factors for beta dosimetry

Newly proposed operational quantities (ICRU 95)
Nearly all correction factors based on measurements using Böhm chamber (BPS1)
ISO 6980: Points of revision since 2019 in TC85 SC2 WG2

ISO 6980: Reference beta fields: *minor / editorial changes*
ISO 6980: Points of revision: ISO 29661 reference

ISO 6980: Reference beta fields: minor / editorial changes
- Alignment to ISO 29661:2012 and its Amd 1:2015:
  ➔ general definitions (quantities, phantoms...), terms and procedure
ISO 6980: Points of revision: spectra included

ISO 6980: Reference beta fields: *minor / editorial changes*

- Alignment to ISO 29661:2012 and its Amd 1:2015:
  ➔ general definitions (quantities, phantoms...), terms and procedure

- Inclusion of electron and photon spectra ➔ *detailed graphs follow*
ISO 6980: Reference beta fields: minor / editorial changes

- Alignment to ISO 29661:2012 and its Amd 1:2015:
  ➔ general definitions (quantities, phantoms...), terms and procedure

- Inclusion of electron and photon spectra ➔ detailed graphs

- Harmonization of the substitute for the ISO water slab and cylinder phantom ➔ 20 cm × 20 cm × 2 cm PMMA in all three parts
ISO 6980: Points of revision: photon contribution

- Alignment to ISO 29661:2012 and its Amd 1:2015:
  ➔ general definitions (quantities, phantoms...), terms and procedure

- Inclusion of electron and photon spectra ➔ detailed graphs

- Harmonization of the substitute for the ISO water slab and cylinder phantom ➔ 20 cm x 20 cm x 2 cm PMMA in all three parts

- Inclusion of photon contribution to total reference dose ➔ $k_{br} = \frac{(I - I_{br})}{I}$ and $D_R = \frac{D_{Rbr}}{k_{br}}$

Photon contribution: $1 - k_{br}$ (0.01% ... 0.55%)

Photon spectrometry: J. Instrum. 6, P09006 (2011)
Photon contribution to dose: J. Instrum. 6, P11007 (2011)
ISO 6980: Points of revision: nuclide $^{14}$C removed

ISO 6980: Reference beta fields: *minor / editorial changes*

- Alignment to ISO 29661:2012 and its Amd 1:2015:
  ➔ *general definitions (quantities, phantoms...), terms and procedure*

- Inclusion of electron and photon spectra ➔ *detailed graphs*

- Harmonization of the substitute for the ISO water slab and cylinder phantom ➔ 20 cm $\times$ 20 cm $\times$ 2 cm PMMA in all three parts

- Inclusion of photon contribution to total reference dose
  ➔ $k_{br} = \frac{(I-I_{br})}{I}$ and $D_R = \frac{D_{Rg}}{k_{br}}$

- Removal of $^{14}$C ($E_{\text{beta,mean}} = 0.04$ MeV)
  ➔ *as not in use in any institute*
ISO 6980: Reference beta fields: *major / technical changes*
ISO 6980: Reference beta fields: *major / technical changes: correction factors for phantoms / quantities* (EGSnrc)

Validation (1/2): measured (symbols) and simulated (lines) depth dose curves agree

Simulation of the radiation sources of the BSS2

Primary extrapolation chamber in a PMMA slab phantom
→ absorbed dose to tissue, $D_t(0.07)$, i.e., $H_p(0.07)$ in a slab phantom

J. Instrum. 8, P02019 (2013)
Validation (2/2): measured (symbols) and simulated (lines) depth dose curves agree

ISO 6980: Reference beta fields: major / technical changes: correction factors for phantoms / quantities (EGSnrc)

Simulation of the radiation sources of the BSS2

Primary extrapolation chamber in a PMMA slab phantom → absorbed dose to tissue, $D_t(0.07)$, i.e., $H_p(0.07)$ in a slab phantom

ISO 6980: Points of revision: correction factors by simulations

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J. Instrum. 8, P02019 (2013)
ISO 6980: Points of revision: correction factors by simulations

ISO 6980: Reference beta fields: major / technical changes: correction factors for phantoms / quantities (EGSnrc)

\[ H_{p}(0.07)_{\text{slab}} \]

Simulation of the radiation sources of the BSS2

... replaced by an ICRU tissue slab

\[ D_t(0.07), \text{ i.e., } H_{p}(0.07) \text{ in a slab phantom} \]
ISO 6980: Reference beta fields: *major / technical changes: correction factors for phantoms / quantities* (EGSnrc)

Validation (1/2): measured (closed symbols) and simulated (open symbols) angular dependence factors agree ...

... for $H_p(0.07)$

$H_p(0.07)_{\text{slab}}$

Enhance simulation efficiency by phase space files


Validation (1/2): measured (closed symbols) and simulated (open symbols) angular dependence factors agree ...

\[
\frac{H_p(0.07)}{H_p(0.07)_{\text{slab}}} = \frac{R(0.07; \text{source}; \alpha)_{\text{slab}}}{R(0.07; \text{source}; 0^\circ)_{\text{slab}}}
\]

ISO 6980: Points of revision: correction factors by simulations

Enhance simulation efficiency by phase space files


Validation (1/2): measured (closed symbols) and simulated (open symbols) angular dependence factors agree ...

\[
\frac{H_p(0.07)}{H_p(0.07)_{\text{slab}}} = \frac{R(0.07; \text{source}; \alpha)_{\text{slab}}}{R(0.07; \text{source}; 0^\circ)_{\text{slab}}}
\]

ISO 6980: Reference beta fields: *major / technical changes: correction factors for phantoms / quantities* (EGSnrc)
ISO 6980: Points of revision: correction factors by simulations

ISO 6980: Reference beta fields: major / technical changes: correction factors for phantoms / quantities (EGSnrc)

Validation (2/2): measured (closed symbols) and simulated (open symbols) angular dependence factors agree ...

... and $H_p(3)$

Enhance simulation efficiency by phase space files


$H_p(0.07)_{\text{slab}}$

$H_p(0.07)_{\text{rod}}$

$H'_p(0.07)_{\text{rod}}$

$\text{corr} = H_p(d) / H_p(0.07)_{\text{slab}}$


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National Metrology Institute
ISO 6980: Reference beta fields: major / technical changes: correction factors for phantoms / quantities (EGSnrc)

Differentiate $H_p(0.07)_{\text{slab}}$, $H_p(0.07)_{\text{rod}}$ and $H'(0.07)$

$\Rightarrow k_{\text{corr}} = \frac{H(d)}{H_p(0.07)_{\text{slab}}}$

Enhance simulation efficiency by phase space files

Files (spectra) freely available:


ISO 6980: Points of revision: addition of quantities

ISO 6980: Reference beta fields: major / technical changes: correction factors for phantoms / quantities (EGSnrc)
Differentiate $H_p(0.07)_{\text{slab}}$, $H_p(0.07)_{\text{rod}}$ and $H(0.07)$ and inclusion of $H_p(3)$ and $H'(3)$

$\Rightarrow k_{\text{corr}} = H(d) / H_p(0.07)_{\text{slab}}$

Enhance simulation efficiency by phase space files


ISO 6980: Reference beta fields: *major / technical changes*

- Sources and geometries in the 2004/2006 version

### ISO 6980: Points of revision: addition of radiation fields

<table>
<thead>
<tr>
<th>Radionuclide (source)</th>
<th>10 cm, without filter</th>
<th>11 cm, without filter</th>
<th>20 cm, without filter</th>
<th>20 cm, with filter</th>
<th>30 cm, without filter</th>
<th>30 cm, with filter</th>
<th>50 cm, without filter</th>
<th>50 cm, with filter</th>
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</thead>
<tbody>
<tr>
<td>$^{14}$C</td>
<td>x</td>
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<tr>
<td>$^{147}$Pm</td>
<td></td>
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<td></td>
<td></td>
<td>x</td>
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<tr>
<td>$^{85}$Kr</td>
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<td></td>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td>$^{90}$Sr/$^{90}$Y</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>$^{106}$Ru/$^{106}$Rh</td>
<td>x</td>
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</table>

Actual fields, simulations: *J. Instrum. 8, P02019 (2013)*
and addendum *J. Instrum. 14, A07001 (2019)*

BSS2 in general: *J. Instrum. 2, P11002 (2007)*
extensions: *J. Instrum. 6, P11007 (2011)*
ISO 6980: Reference beta fields: *major / technical changes*

- Inclusion of *additional* distances and filter geometries
  (removal of $^{14}$C and $^{106}$Ru/$^{106}$Rh at 10 cm)

<table>
<thead>
<tr>
<th>Radionuclide (source)</th>
<th>10 cm, without filter</th>
<th>11 cm, without filter</th>
<th>20 cm, without filter</th>
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<th>30 cm, without filter</th>
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<th>50 cm, without filter</th>
<th>50 cm, with filter</th>
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<tbody>
<tr>
<td>$^{14}$C</td>
<td>X</td>
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<tr>
<td>$^{147}$Pm</td>
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<td>X</td>
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<tr>
<td>$^{85}$Kr</td>
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<td></td>
<td>$\times$</td>
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<td>$\times$</td>
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<tr>
<td>$^{90}$Sr/$^{90}$Y</td>
<td>$\times$</td>
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<tr>
<td>$^{106}$Ru/$^{106}$Rh</td>
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</tr>
</tbody>
</table>

Actual fields, simulations: *J. Instrum. 8, P02019 (2013)*
and addendum *J. Instrum. 14, A07001 (2019)*

New fields: *J. Instrum. 15, P05015 (2020)*

BSS2 in general: *J. Instrum. 2, P11002 (2007)*
extensions: *J. Instrum. 6, P11007 (2011)*
ISO 6980: Reference beta fields: *major / technical changes*

- **Inclusion of new fields** with mean energy between $^{85}\text{Kr}$ and $^{90}\text{Sr}/^{90}\text{Y}$

  ➔ add absorber in front of a $^{90}\text{Sr}/^{90}\text{Y}$ source: 3 mm or 4 mm PMMA at 4 cm distance
  ➔ two more radiation fields

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### ISO 6980: Points of revision: addition of radiation fields

#### Radionuclide (source) | 10 cm, without filter | 11 cm, without filter | 20 cm, without filter | 20 cm, with filter | 30 cm, without filter | 30 cm, with filter | 40 cm, without filter | 40 cm, with filter | 50 cm, without filter | 50 cm, with filter
---|---|---|---|---|---|---|---|---|---|---
$^{14}\text{C}$ | | | | | | | | | | |
$^{147}\text{Pm}$ | | | | | | | | | | |
$^{85}\text{Kr}$ | | | | | | | | | | |
$^{90}\text{Sr}/^{90}\text{Y}$ | | | | | 3 mm, 4 mm | | | | | |
$^{106}\text{Ru}/^{106}\text{Rh}$ | | | | | | | | | | |


**New fields:** *J. Instrum. 15*, P05015 (2020)
ISO 6980: Points of revision: addition of radiation fields

ISO 6980: Reference beta fields: major / technical changes
- Dose rate and energy ranges in ISO 6980: 2004/2006 version

![Energy and dose rate ranges (ISO 6980: 2004/2006)](image)

- **85Kr; 3.7 GBq**
  - 30 cm; with filter

- **90Sr/90Y; 0.46 GBq**
  - 11 cm; w/o filter
  - 20 cm; w/o filter

- **106Ru/106Rh; 0.02 GBq**
  - 11 cm; w/o filter
  - 20 cm; with filter
  - 30 cm; w/o filter
  - 30 cm; with filter
  - 50 cm; w/o filter
  - 10 cm; w/o filter

- **147Pm; 3.7 GBq**
  - 20 cm; with filter

- **14C; 0.01 GBq**
  - 10 cm; w/o filter


ISO 6980: Points of revision: addition of radiation fields

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ISO 6980: Points of revision: addition of radiation fields

ISO 6980: Reference beta fields: *major / technical changes*
- Dose rate and energy ranges in ISO 6980: new 202x version

**Energy and dose rate ranges (ISO 6980: 202x)**

- **85Kr; 3.7 GBq**
  - 30 cm; with filter
  - 50 cm; with filter

- **90Sr/90Y; 0.46 GBq**
  - 11 cm; w/o filter
  - 20 cm; w/o filter
  - 30 cm; w/o filter
  - 50 cm; w/o filter

- **147Pm; 3.7 GBq**
  - 20 cm; with filter

- **106Ru/106Rh; 0.02 GBq**
  - 11 cm; w/o filter
  - 20 cm; w/o filter
  - 30 cm; with filter
  - 50 cm; with filter

- **90Sr/90Y; 0.46 GBq**
  - 20 cm; 3 mm PMMA

**BSS2 in general:** *J. Instrum. 2, P11002 (2007)*
**extensions:** *J. Instrum. 6, P11007 (2011)*

- Actual fields, simulations: *J. Instrum. 8, P02019 (2013)*
- and addendum *J. Instrum. 14, A07001 (2019)*
- New fields: *J. Instrum. 15, P05015 (2020)*
ISO 6980: Points of revision: spectra included

ISO 6980: Reference beta fields: major / technical changes
- Electron and photon spectra in ISO 6980: new 202x version: free in air (without backscatter)

Actual fields, simulations: J. Instrum. 8, P02019 (2013)

ISO 6980: Points of revision: spectra included

ISO 6980: Reference beta fields: *major / technical changes*

- Electron and photon spectra in ISO 6980: new 202x version: **free in air** (without backscatter)


ISO 6980: Reference beta fields: **major / technical changes**

- Electron and photon spectra in ISO 6980: new 202x version:
  - in front of a tissue phantom (including backscatter)
  - many low energy backscatter particles

Electron spectra at 0 mm depth (with backscatter)

Photon spectra at 0 mm depth (with backscatter)

Fluence per $H_p(0.07) = 1 \text{ mSv}$ (MC: EGSnrc)


New fields: *J. Instrum. 15, P05015 (2020)*
ISO 6980: Points of revision: spectra included

ISO 6980: Reference beta fields: major / technical changes

- Electron and photon spectra in ISO 6980: new 202x version:
  - at 0.07 mm tissue depth (including backscatter)
  - significant absorption of low energy electrons; photons not significantly attenuated

Photon energy

Electron spectra at 0.07 mm depth (with backscatter)

Photon spectra at 0.07 mm depth (with backscatter)


ISO 6980: Points of revision: spectra included

ISO 6980: Reference beta fields: major / technical changes
- Electron and photon spectra in ISO 6980: new 202x version:
  at 0.07 mm tissue depth (including backscatter)
  ➔ significant absorption of low energy electrons; photons not significantly attenuated

Electron spectra at 0.07 mm depth (with backscatter)

Phonon spectra at 0.07 mm depth (with backscat.)

Electron fluence per 1 mSv = $H_p(0.07)$

Fluence per $H_p(0.07) = 1$ mSv (MC: EGSnrc)

ISO 6980: Reference beta fields: *major / technical changes*

- Electron and photon spectra in ISO 6980: new 202x version:
  - at 3 mm tissue depth (including backscatter)
    - $^{147}$Pm and $^{85}$Kr totally absorbed; $^{90}$Sr/$^{90}$Y and $^{106}$Ru/$^{106}$Rh fluence and energy reduced; low energy photons attenuated

**New fields:** *J. Instrum*. 15, P05015 (2020)

**Actual fields, simulations:** *J. Instrum*. 8, P02019 (2013) and addendum *J. Instrum*. 14, A07001 (2019)
ISO 6980: Reference beta fields: *major / technical changes: correction factors for primary dosimetry* (EGSnrc)

- for radiation fields of the BSS2:

<table>
<thead>
<tr>
<th>Radionuclide (source)</th>
<th>10 cm, without filter</th>
<th>11 cm, without filter</th>
<th>20 cm, without filter</th>
<th>20 cm, with filter</th>
<th>30 cm, without filter</th>
<th>30 cm, with filter</th>
<th>50 cm, without filter</th>
<th>50 cm, with filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{14}$C</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{147}$Pm</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{85}$Kr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>$^{90}$Sr/$^{90}$Y</td>
<td></td>
<td>x</td>
<td>x</td>
<td>3 mm, 4 mm</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>$^{106}$Ru/$^{106}$Rh</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

*Metrologia 57, 065022 (2020)*
*Metrologia 57, 065005 (2020)*
ISO 6980: Reference beta fields: *major / technical changes: correction factors for primary dosimetry* (EGSnrc)

- for radiation fields of the BSS2:

  ➔ Calculation for Beta Primary Standards of PTB: BPS1 (current, Böhm chamber) and BPS2 (new, PTB made):

Photographs of the Böhm extrapolation chamber (left, BPS1) and the newly developed (right, BPS2)
ISO 6980: Reference beta fields: major / technical changes: correction factors for primary dosimetry (EGSnrc)

- for radiation fields of the BSS2:
  ➔ Calculation for Beta Primary Standards of PTB: BPS1 (current, Böhm chamber) and BPS2 (new, PTB made):

Model of new PTB primary standard (BPS2)

Active air volume: \( \varnothing = 3 \text{ cm}; l = 250 \mu\text{m} \ldots 2500 \mu\text{m} \)

Files (spectra) freely available:


ISO 6980: Points of revision: calculated correction factors

- Points of revision: calculated correction factors

- for radiation fields of the BSS2:

- Calculation for Beta Primary Standards of PTB: BPS1 (current, Böhm chamber) and BPS2 (new, PTB made):

Model of new PTB primary standard (BPS2)

Active air volume: \( \varnothing = 3 \text{ cm}; l = 250 \mu\text{m} \ldots 2500 \mu\text{m} \)

Files (spectra) freely available:

ISO 6980: Reference beta fields: *major / technical changes: correction factors for primary dosimetry* (EGSnrc)

- for radiation fields of the BSS2 for the Böhm chamber (in ISO 6980):
  
  **Backscatter:** $k_{ba}$
  
  **Sidewall perturbation:** $k_{pe}$
  
  **Inhomogeneity in active volume:** $k_{ih}$

**Files (spectra) freely available:**


**Model of new PTB primary standard (BPS2)**

- Active air volume: $\phi = 3$ cm; $l = \text{250 \mu m} \ldots \text{2500 \mu m}$

**Files (spectra) freely available:**

- *Metrologia 57, 065022 (2020) & Metrologia 57, 065005 (2020)*

**Materials:**

- Air
- PolyEther Ether Ketone (PEEK)
- Electrically cond. PEEK (PEEK_ELS)
- Polycarbonate (Makrolon)
ISO 6980: Reference beta fields: *major / technical changes: correction factors for primary dosimetry* (EGSnrc)

- for radiation fields of the BSS2 for the Böhm chamber (in ISO 6980):

  **Backscatter:** $k_{ba} = \frac{D_{\text{tissue\_back}}}{D_{\text{real\_chamber}}}$

  **Sidewall perturbation:** $k_{pe}$

  **Inhomogeneity in active volume:** $k_{ih}$

**Model of new PTB primary standard (BPS2)**

**ISO 6980: Points of revision: calculated correction factors**

Files (spectra) freely available:


*Metrologia 57, 065022 (2020)*

*Metrologia 57, 065005 (2020)*
ISO 6980: Reference beta fields: major / technical changes: correction factors for primary dosimetry (EGSnrc)

- for radiation fields of the BSS2 for the Böhm chamber (in ISO 6980):

  \[
  k_{ba} = \frac{D_{\text{tissue\_back}}}{D_{\text{real\_chamber}}}
  \]

  Backscatter:

  Sidewall perturbation: \( k_{pe} \)

  Inhomogeneity in active volume: \( k_{ih} \)

Model of new PTB primary standard (BPS2)

ISO 6980: Points of revision: calculated correction factors

Files (spectra) freely available:

- J. Instrum. 8, P02019 (2013)

\[
\begin{align*}
\text{Active air volume: } & \phi = 3 \text{ cm;} \\
& l = 250 \mu\text{m }... \text{ 2500 }\mu\text{m}
\end{align*}
\]
ISO 6980: Points of revision: calculated correction factors

ISO 6980: Reference beta fields: major / technical changes: correction factors for primary dosimetry (EGSnrc)
- for radiation fields of the BSS2 for the Böhm chamber (in ISO 6980):

  Backscatter: \( k_{ba} = \frac{D_{\text{tissue\_back}}}{D_{\text{real\_chamber}}} \)

  Sidewall perturbation: \( k_{pe} = \frac{D_{\text{chamber\_without\_side\_walls}}}{D_{\text{real\_chamber}}} \)

  Inhomogeneity in active volume: \( k_{ih} \)

Model of new PTB primary standard (BPS2)

Files (spectra) freely available:
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- Metrologia 57, 065005 (2020)
ISO 6980: Reference beta fields: *major / technical changes*

- for radiation fields of the BSS2 for the Böhm chamber (in ISO 6980):
  
  Backscatter:  \( k_{\text{ba}} = \frac{D_{\text{tissue\_back}}}{D_{\text{real\_chamber}}} \)
  
  Sidewall perturbation:  \( k_{\text{pe}} = \frac{D_{\text{chamber\_without\_side\_walls}}}{D_{\text{real\_chamber}}} \)
  
  Inhomogeneity in active volume:  \( k_{\text{ih}} = \frac{D_{\text{small\_volume}}}{D_{\text{real\_volume}}} \)

### Calculated correction factors:

- ISO 6980: Points of revision: calculated correction factors

### Reference

- **ISO 6980:**
  - Reference beta fields: major / technical changes

### Files (spectra) freely available:

- **Metrologia 57, 065022 (2020)**
- **Metrologia 57, 065005 (2020)**

---

**Small “point” volume:**
- \( \varnothing = 0.5 \text{ cm}; \ h = 100 \mu\text{m} \)
  - (too small to see)

**Active air volume:**
- \( \varnothing = 3 \text{ cm}; \ l = 250 \mu\text{m} \ldots 2500 \mu\text{m} \)

- **Active air volume:**
  - \( \varnothing = 3 \text{ cm}; \ l = 250 \mu\text{m} \ldots 2500 \mu\text{m} \)

- **Files (spectra) freely available:**
  - *J. Instrum.* 8, P02019 (2013) &
ISO 6980: Reference beta fields: major / technical changes
- for radiation fields of the BSS2 for the Böhm chamber (in ISO 6980):

  Backscatter: \( k_{\text{ba}} = \frac{D_{\text{tissue\_back}}}{D_{\text{real\_chamber}}} \)

  Sidewall perturbation: \( k_{\text{pe}} = \frac{D_{\text{chamber\_without\_side\_walls}}}{D_{\text{real\_chamber}}} \)

  Inhomogeneity in active volume: \( k_{\text{ih}} = \frac{D_{\text{small\_volume}}}{D_{\text{real\_volume}}} \)

ISO 6980: Points of revision: calculated correction factors

- Active air volume: \( \phi = 3 \text{ cm}; \ l = 250 \mu m \ldots 2500 \mu m \)
- Small “point” volume: \( \phi = 0.5 \text{ cm}; \ h = 100 \mu m \)

Files (spectra) freely available:
- Metrologia 57, 065022 (2020)
- Metrologia 57, 065005 (2020)
ISO 6980: Reference beta fields: major / technical changes

- Optional Spencer-Attix (SA) instead of Bragg-Gray (BG) theory (MC: EGSnrc):

  ➔ Spencer-Attix stopping power ratios consider the air cavity dimensions:

  \[ k_{SA} = \frac{s_{t,a}(l)_{SA}}{s_{t,a,BG}} \]

Monte Carlo-based Spencer–Attix and Bragg–Gray Tissue-to-Air Stopping Power Ratios for ISO Beta Sources

T. Palani Selvam, S. Vandana*, A. K. Bukshi and D. A. R. Babu
Radiological Physics and Advisory Division, Health, Safety and Environment Group, Bhabha Atomic Research Centre, Trombay, Mumbai 400 085, India
J. Instrum. 16, P03006 (2021)

Active air volume:
\( \phi = 3 \text{ cm}; \)
\( l = 250 \mu\text{m} \ldots 2500 \mu\text{m} \)

\( \Delta_{\text{cutoff}} = 4 \ldots 14 \text{ keV} \)

Scoring volume in tissue:
\( \phi = 3 \text{ cm}; \ l = 1 \mu\text{m} \)

Files (spectra) freely available:
Application of new correction factors to extrapolation curves: for both: normal incidence, i.e. 0° ...

Residuals for $^{85}$Kr at 30 cm with filter at $\alpha = 0^\circ$ measured with BPS1

- i) ISO 6980-2:2004
- ii) $k_{ba}$ & $k_{pe}$ via EGSnrc
- iii) $k_{ba}$ & $k_{pe}$ & $k_{ih}$ via EGSnrc
- iv) As iii) & $k_{SA}$, i.e. Spencer-Attix theory

$D_x / D_{ISO}$

Metrologia 57, 065022 (2020)
Metrologia 57, 065005 (2020)
Application of new correction factors to extrapolation curves: for both: normal incidence, i.e. 0° and especially oblique (e.g., 60°).

Residuals for $^{90}$Sr/$^{90}$Y at 30 cm with filter at $\alpha = 60°$ measured with BPS1

- i) ISO 6980:2004: 1.000
- ii) $k_{ba}$ & $k_{pe}$ via EGSnrc: 0.981
- iii) $k_{ba}$ & $k_{pe}$ & $k_{ih}$ via EGSnrc: 0.977
- iv) As iii) & $k_{SA}$, i.e. Spencer-Attix theory: 0.982

Extrapolation curve

Deviation from linearity enlarged by a factor of 10 for illustration purposes.

Metrologia 57, 065022 (2020)
Metrologia 57, 065005 (2020)
Nearly all correction factors based on measurements using Böhm chamber (BPS1)
ISO 6980: Reference beta fields (202x), in revision ➔ Ed.2

Important correction factors based on simulations for Böhm chamber (BPS1)

Current status: FDIS for vote circulated in August 2022
The author wishes to thank the members of 
ISO TC85 SC2 WG2 SG0 (Betas):

May 2019 (Okayama, Japan)

October 2020

March 2021

September 2021

May 2022

References:


R. Behrens, 2020 *Correction factors for primary beta dosimetry*: *Metrologia* 57, 065022 (2020)

R. Behrens, 2020 *Energy reduced beta radiation fields from $^{90}$Sr/$^{90}$Y for the BSS 2*: *J. Instrum.* 15, P05015 (2020)

R. Behrens, 2020 *Correction factors for two new reference beta radiation fields*: *Metrologia* 57, 065005 (2020)


List of standards:

Contents

Introduction

Primary and secondary beta dosimetry

International comparison BIPM EURAMET.RI(I)-S16

Revision of ISO 6980 ⇔ correction factors for beta dosimetry

Newly proposed operational quantities (ICRU 95)
Newly proposed operational quantities (ICRU 95)

ICRU Report 95: 
Operational Quantities for External Radiation Exposure
What Changes for Radiation Protection?

Thomas Otto, ICRU and CERN
CCRI Webinar, 12. 10. 2021

Calibrations and irradiations in terms of the newly proposed ICRU operational quantities for radiation protection in photon and beta reference radiation fields

Rolf Behrens
Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

IM2022 contribution
April 26, 2022 (PDF and video):
### Protection quantities vs. current operational quantities (ICRU 51 / 57)

<table>
<thead>
<tr>
<th>Protection quantities (ICRP 116)</th>
<th>Whole body</th>
<th>Lens of the eye</th>
<th>Local skin</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ICRP reference voxel phantoms:</strong></td>
<td>$E_{\text{eff}} = \sum_T w_T \sum_R w_R D_{T,R}$</td>
<td>Stylized eye model; whole lens (ICRP 116, Annex F):</td>
<td>Tissue-equivalent cube (10x10x10 cm³); 1 cm² area at 50 – 100 μm depth (ICRP 116, Annex G):</td>
</tr>
<tr>
<td><strong>Simulations:</strong></td>
<td>$h_{\text{eff}} = E_{\text{eff}} \Phi$</td>
<td>$H_{\text{lens}} = \sum_R w_R D_{\text{lens,R}}$</td>
<td>$H_{\text{local skin}} = \sum_R w_R D_{\text{local skin,R}}$</td>
</tr>
</tbody>
</table>

#### Sievert

**Operational quantities: definition:** $H = Q(L) \cdot D$

<table>
<thead>
<tr>
<th>Operational quantities (ICRU 51/57)</th>
<th>Area</th>
<th>Individual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ICRU 4-element tissue sphere:</strong></td>
<td>( \Theta = 30 \text{ cm} ): $H'(10) = Q \cdot D(10)_{\text{sph}}$</td>
<td>$H_p(10) = Q \cdot D(10)_{\text{pers}}$</td>
</tr>
<tr>
<td><strong>ICRU 4-element tissue sphere:</strong></td>
<td>( \Theta = 30 \text{ cm} ): $H'(3;\Omega) = Q \cdot D(3;\Omega)_{\text{sph}}$</td>
<td>$H_p(3) = Q \cdot D(3)_{\text{pers}}$</td>
</tr>
<tr>
<td><strong>ICRU 4-element tissue sphere:</strong></td>
<td>( \Theta = 30 \text{ cm} ): $H'(0.07;\Omega) = Q \cdot D(0.07;\Omega)_{\text{sph}}$</td>
<td>$H_p(0.07) = Q \cdot D(0.07)_{\text{pers}}$</td>
</tr>
</tbody>
</table>

For calibration: ICRU 4-element tissue slab: 30x30x15 cm³; $H_p(10) = Q \cdot D(10)_{\text{slab}}$

For calibration: ICRU 4-element cylinder: \( \Theta = h = 20 \text{ cm} \): $H_p(3) = Q \cdot D(3)_{\text{cylinder}}$

For calibration: ICRU 4-el. tissue slab, pillar, rod (\( \Theta = 73, 19 \text{ mm} \)): $H_p(0.07) = Q \cdot D(0.07)_{\text{slab, pillar, rod}}$
<table>
<thead>
<tr>
<th>Protection quantities (ICRP 116)</th>
<th>Lens of the eye</th>
<th>Local skin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole body</td>
<td>Stylized eye model; whole lens (ICRP 116, Annex F): $H_{\text{lens}} = \sum R_w R_{\text{lens},R}$</td>
<td>Tissue-equivalent cube (10x10x10 cm$^3$); 1 cm$^2$ area at 50 – 100 µm depth (ICRP 116, Annex G): $H_{\text{local skin}} = \sum R_w R_{\text{local skin},R}$</td>
</tr>
<tr>
<td>ICRP reference voxel phantoms:</td>
<td>$h_{\text{Eff}} = E_{\text{eff}} \Phi$</td>
<td></td>
</tr>
<tr>
<td>$E_{\text{eff}} = \sum T_w \sum R_{T,R}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simulations:</td>
<td>$d_{\text{lens}}(\Omega) = D_{\text{lens}}(\Omega) / \Phi$</td>
<td></td>
</tr>
</tbody>
</table>

**Operational quantities: definition:** $H = h \cdot \Phi$; $D = d \cdot \Phi$

<table>
<thead>
<tr>
<th>Area</th>
<th>Stylized eye model; whole lens (ICRP 116, Annex F): $D'<em>{\text{lens}}(\Omega) = d</em>{\text{lens}}(\Omega) \cdot \Phi$</th>
<th>ICRU 4-element tiss. slab, pillar, rod; 2 mm skin cover; 1 cm$^2$ area at 50 - 100 µm: $D'<em>{\text{local skin}}(\Omega) = d</em>{\text{local skin}}(\Omega) \cdot \Phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICRP reference voxel phantoms:</td>
<td>$H^* = h_{E,\text{max}} \cdot \Phi$</td>
<td></td>
</tr>
<tr>
<td>$h_{\text{E,\text{max}}} = h_{\text{max}} \cdot \Phi$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Individual</th>
<th>Stylized eye model; whole lens (ICRP 116, Annex F): $D'<em>{\text{lens}}(\Omega) = d</em>{\text{lens}}(\Omega) \cdot \Phi$</th>
<th>ICRU 4-element tiss. slab (30 x 30 x 15 cm$^3$) with 2 mm skin cover over 1 cm$^2$ at 50-100 µm: $D'<em>{\text{local skin}}(\Omega) = d</em>{\text{local skin}}(\Omega) \cdot \Phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICRP reference voxel phantoms:</td>
<td>$H_p = h_E \cdot \Phi$</td>
<td></td>
</tr>
<tr>
<td>$h_E = h_{\text{max}} \cdot \Phi$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Primary dosimetry of operational quantities [Sv]: neutrons

<table>
<thead>
<tr>
<th>Basic quantity</th>
<th>Radiation field</th>
<th>Method to determine the operational quantities $H &amp; D$</th>
</tr>
</thead>
</table>
| Neutron        | Neutron spectrometry and / or Monte Carlo transport $\Rightarrow (\Phi_E / \Phi)$ | Fold spectrum with conversion coefficients for mono-energetic neutrons, $h_\phi(E) & d_\phi(E)$ from ICRU 57 / ICRU 95:  
  
  $H = \left\{ \left[ \int \left( \frac{\Phi_E}{\Phi} \right) \cdot h_\phi(E) \cdot dE \right] \right\} \cdot \Phi$  
  
  $D = \left\{ \left[ \int \left( \frac{\Phi_E}{\Phi} \right) \cdot d_\phi(E) \cdot dE \right] \right\} \cdot \Phi$ |

*AP (associated particle) method

\[ \int \left( \frac{\Phi_E}{\Phi} \right) \cdot \Phi \Rightarrow H & D \]
<table>
<thead>
<tr>
<th>Basic quantity</th>
<th>Radiation field</th>
<th>Method to determine the operational quantities $H$ &amp; $D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_{a,IC}$ via free air or cavity chamber</td>
<td>Photon spectrometry $\Rightarrow (\Phi_E/\Phi) &amp; K_{a,spc}$</td>
<td>Fold spectrum with conversion coefficients for mono-energetic photons, $h_K(E)$, $d_K(E) &amp; (K_{a}/\Phi)<em>E$ from ICRU 57 / ICRU 95: $H = \left{ \left[ (\Phi_E/\Phi) \cdot (K</em>{a}/\Phi)<em>E \cdot h_K(E) \cdot dE \right] / K</em>{a,spc} \right} \cdot K_{a,IC}$ $D = \left{ \left[ (\Phi_E/\Phi) \cdot (K_{a}/\Phi)<em>E \cdot d_K(E) \cdot dE \right] / K</em>{a,spc} \right} \cdot K_{a,IC}$</td>
</tr>
</tbody>
</table>
### Particle tracks in air: photons vs. electrons

<table>
<thead>
<tr>
<th>Air cube of 1 m x 1 m x 1 m</th>
<th>1 MeV</th>
<th>300 keV</th>
<th>100 keV</th>
<th>30 keV</th>
<th>at beam center</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 Photons</td>
<td><img src="image1.png" alt="Image of 1000 Photons 1 MeV" /></td>
<td><img src="image2.png" alt="Image of 1000 Photons 300 keV" /></td>
<td><img src="image3.png" alt="Image of 1000 Photons 100 keV" /></td>
<td><img src="image4.png" alt="Image of 1000 Photons 30 keV" /></td>
<td>practically mono-directional</td>
</tr>
<tr>
<td>1000 Electrons</td>
<td><img src="image5.png" alt="Image of 1000 Electrons 1 MeV" /></td>
<td><img src="image6.png" alt="Image of 1000 Electrons 300 keV" /></td>
<td><img src="image7.png" alt="Image of 1000 Electrons 100 keV" /></td>
<td><img src="image8.png" alt="Image of 1000 Electrons 30 keV" /></td>
<td>far from being mono-directional</td>
</tr>
</tbody>
</table>
# Primary dosimetry of operational quantities [Sv]: betas

<table>
<thead>
<tr>
<th>Basic quantity</th>
<th>Radiation field</th>
<th>Method to determine the operational quantities $H$ &amp; $D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta $D_{t,meas}$ via extrapolation chamber</td>
<td>Monte Carlo transport $\Rightarrow k_{sim} = H_{sim} / D_{t,sim}$ ($= D_{sim} / D_{t,sim}$)</td>
<td>Multiply absorbed dose to tissue with correction factor to account for the respective phantom $\Rightarrow H = D_{t,meas} \cdot k_{sim}$ with the phantoms from ICRU 57 / ICRU 95</td>
</tr>
</tbody>
</table>

**Correction factors:** *J. Instrum. 10, P03014 (2015)*

**ICRU tissue**

$H_{p}(0.07)_{slab}$ & $H_{p}(3)_{slab}$

$H_{p}(0.07)_{rod}$

$H_{p}(3)_{cylinder}$

$H'(0.07)$

$H'(3)$

$\Rightarrow H = D_{t,meas} \cdot k_{sim}$
**Primary dosimetry of operational quantities [Sv]: betas**

<table>
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<tr>
<th>Basic quantity</th>
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<tr>
<td>Beta $D_{t,meas}$ via extrapolation chamber</td>
<td>Monte Carlo transport $\Rightarrow k_{sim} = \frac{H_{sim}}{D_{t,sim}}$ ($= \frac{D_{sim}}{D_{t,sim}}$)</td>
<td>Multiply <strong>absorbed dose to tissue</strong> with correction factor to account for the respective phantom $\Rightarrow D = D_{t,meas} \cdot k_{sim}$ with the phantoms from ICRU 57 / ICRU 95</td>
</tr>
</tbody>
</table>

Correction factors: *J. Radiol. Prot.* 41, 871 (2021)
## Primary dosimetry of operational quantities: summary

<table>
<thead>
<tr>
<th>Basic quantity</th>
<th>Radiation field</th>
<th>Method to determine the operational quantities $H$ &amp; $D$</th>
</tr>
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</table>
| Neutron        | Neutron spectrometry and / or Monte Carlo transport $\Rightarrow (\Phi_E/\Phi)$ | Fold spectrum with conversion coefficients for mono-energetic neutrons, $h_\Phi(E)$ & $d_\Phi(E)$ from ICRU 57 / ICRU 95:  
$H = \left\{ \left[ \left( \Phi_E/\Phi \right) \cdot h_\Phi(E) \cdot dE \right] \cdot \Phi \right\}$  
$D = \left\{ \left[ (\Phi_E/\Phi) \cdot d_\Phi(E) \cdot dE \right] \cdot \Phi \right\}$ |
| Photon         | Photon spectrometry $\Rightarrow (\Phi_E/\Phi) & K_{a,spc}$ | Fold spectrum with conversion coefficients for mono-energetic photons, $h_K(E)$, $d_K(E)$ & $(K_a/\Phi)_E$ from ICRU 57 / ICRU 95:  
$H = \left\{ \left[ (\Phi_E/\Phi) \cdot (K_a/\Phi)_E \cdot h_K(E) \cdot dE \right] / K_{a,spc} \right\} \cdot K_{a,IC}$  
$D = \left\{ \left[ (\Phi_E/\Phi) \cdot (K_a/\Phi)_E \cdot d_K(E) \cdot dE \right] / K_{a,spc} \right\} \cdot K_{a,IC}$ |
| Beta           | Monte Carlo transport $\Rightarrow k_{sim} = H_{sim} / D_{sim}$  
$\left(= D_{sim} / D_{t,meas} \right)$ | Multiply absorbed dose to tissue with correction factor to account for the respective phantom:  
$H = D_{t,meas} \cdot k_{sim}$  
$D = D_{t,meas} \cdot k_{sim}$ with the phantoms from ICRU 57 / ICRU 95 |

**Take home:** Procedures unchanged - “only” new conversion coefficients / correction factors  
$\Rightarrow$ Response of dosemeters can be re-calculated; BUT calibration coefficient and energy dependence change!
Impact to beta quantities / beta dosemeters:
Assume a perfect dosemeter for the current quantities

For betas: *J. Radiol. Prot.* 41, 871 (2021)  
For photons: *J. Radiol. Prot.* 42, 011519 (2022)
Only minor changes above 10 keV photon energy
Assume a perfect dosemeter for the current quantities

Dotted red lines: response limits 0.71 ... 1.67 according to IEC 61526 (active) and IEC 62387 (passive) dosemeters

Journey to implementation ...
International and national requirements and legislation

- Basic Safety Standards of the IAEA
- Basic Safety Standards of the European Union
- National radiation protection law & ordinance, directives and subordinate documents

➔ implementation of new quantities: 5...10 years
Dr. R. Behrens, PTB 6.3: Latest developments in beta-radiation metrology

Photons: ISO 4037: 2019
Recently revised ➔ $H_p(3)$ and $H'(3)$ implemented

Betas: ISO 6980: 2004/06
In revision since 2019 ➔ implementation of $H_p(3)$ & $H'(3)$

In revision since 2019 ➔ general update

➔ implementation of new quantities and conversion coefficients: another 5...10 years
Standards for procedures:
* ISO 14146: Routine test for dosemeters (2018)

Standards for dosemeter requirements:

<table>
<thead>
<tr>
<th>Type of radiation</th>
<th>Area dosemeters</th>
<th>Personal dosemeters</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Active</td>
<td>passive</td>
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<tr>
<td>Photon</td>
<td>PTB-A 23.3, 2018</td>
<td>DIN 25483, 2000 (TLD, only env.)</td>
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<td>PTB-A 23.2, 2018</td>
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<td>IEC 61017, 2016-02 (environmental dosem.)</td>
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<td>IEC 60532, 2010 (fixed installed in nuclear facilities)</td>
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<tr>
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<td>IEC 60846-1, 2009 (portable dosem.)</td>
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<td>IEC 60846-2, 2015 (emergency dosem.)</td>
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<td>IEC 62387, 2020 (all passive dosemeters)</td>
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<tr>
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<td>IEC 61526, 2010 (all active dosemeters)</td>
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<td>IEC 62387, 2020 (all passive dosemeters)</td>
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<tr>
<td>Beta</td>
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<td>Neutron</td>
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<td>IEC 61005, 2014</td>
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<td>IEC 61322, 2020 (fixed installed)</td>
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<td>ISO 21909-1, 2021 (all passive neutron detectors)</td>
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<td>ISO 21909-2, 2021 (requirements in workplaces)</td>
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<td>DIN 6802-4, 1998 (Albedo)</td>
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</table>

➤ implementation of new quantities and reference to updated ISO 4037, ISO 6980 and ISO 8529
Proposed operational quantities: implementation

Implementation, if at all, will take several years, if not decades!
Introduction

Primary and secondary beta dosimetry

International comparison BIPM EURAMET.RI(I)-S16

Revision of ISO 6980 ⟷ correction factors for beta dosimetry

Newly proposed operational quantities (ICRU 95)

Finally, we are done 😊 
nearly …
Latest developments in beta-radiation metrology
(primary dosimetry, ISO 6980 revision, and ICRU 95 impact)

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