Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

Latest developments in beta-radiation metrology

(primary dosimetry, ISO 6980 revision, and ICRU 95 impact)

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PTB, Department "Radiation protection dosimetry" (6.3)

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

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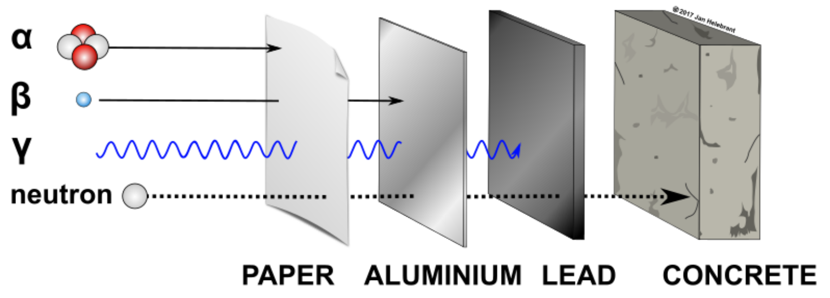
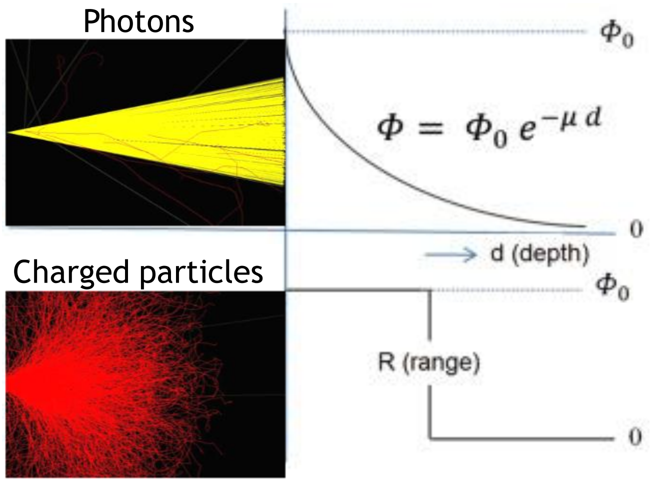
Types of radiation and their characteristics

Penetrating power of different types of radiation



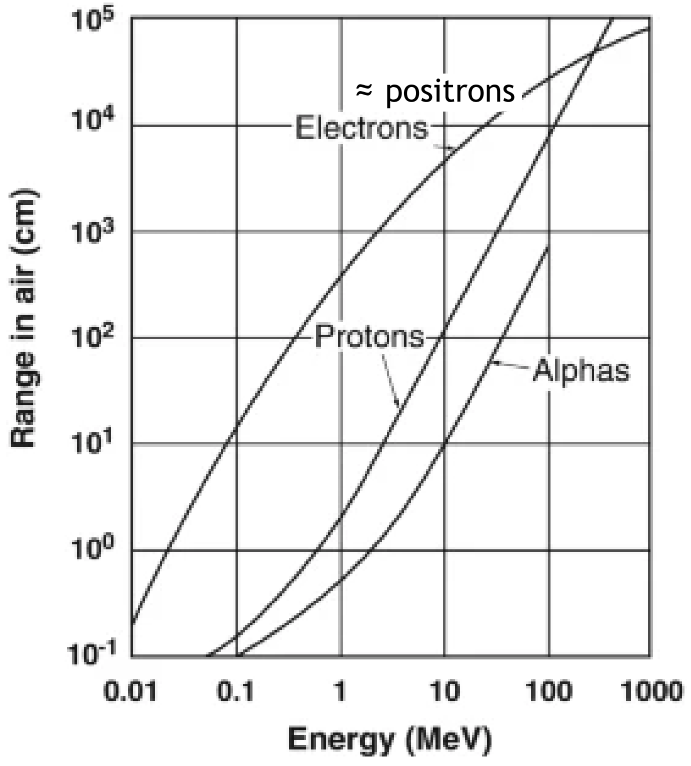
https://www.osha.gov/ionizing-radiation/background

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



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

Ranges of charged particles in air

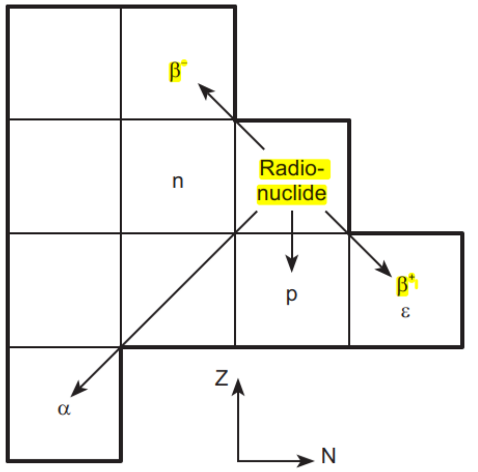


https://link.springer.com/chapter/10.1007/978-3-319-73398-2_14 (Figure 3)

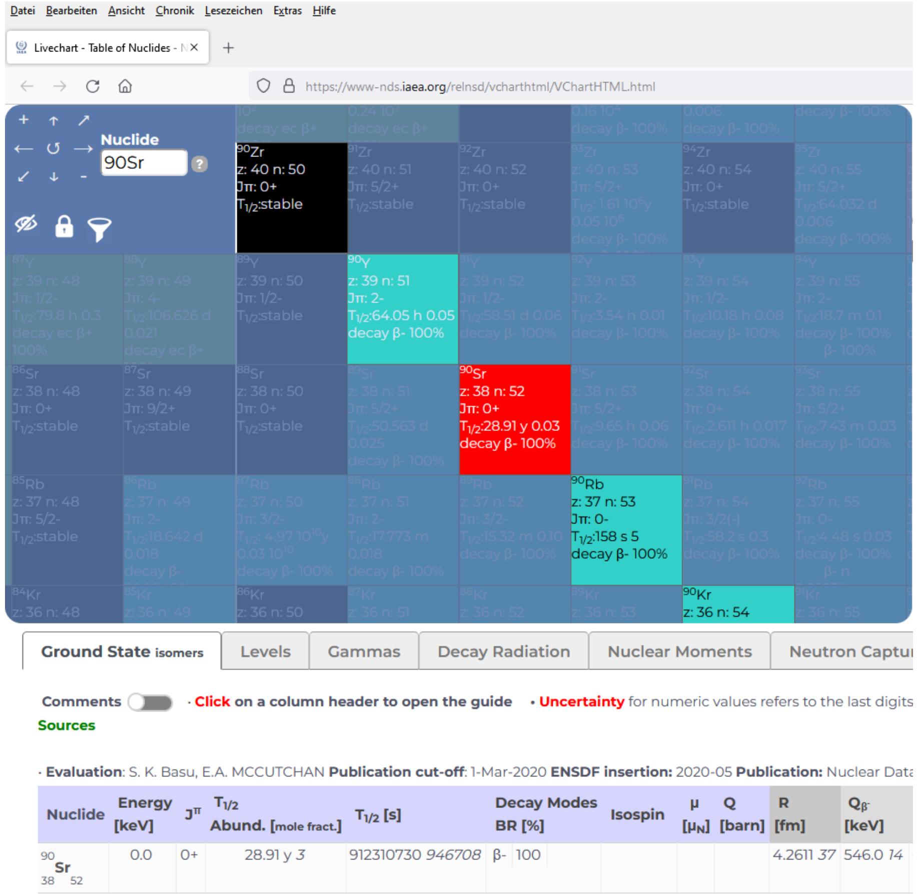
Beta radiation: what's that?

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

Beta minus decay ⇒ electron
Beta plus decay ⇒ positron



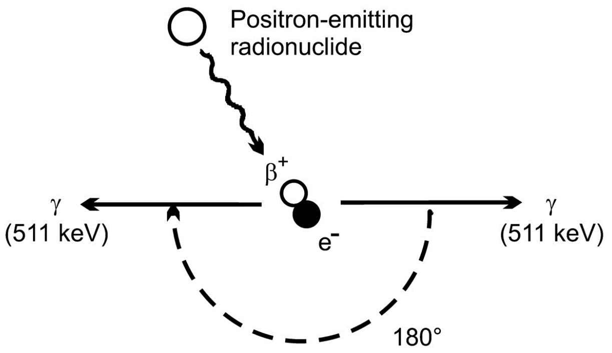
https://doi.org/10.1051/epjn/2019004



https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html

Electrons and positrons:

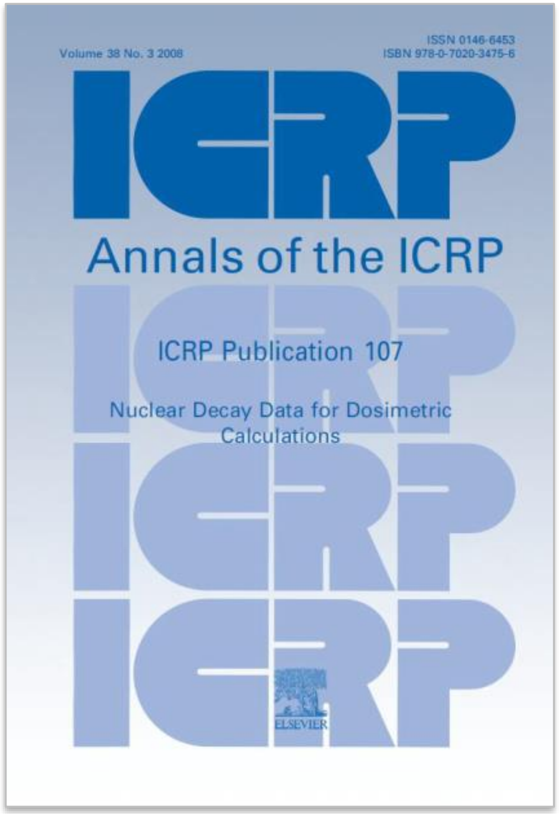
Practically the same interaction – apart from the positron's end...

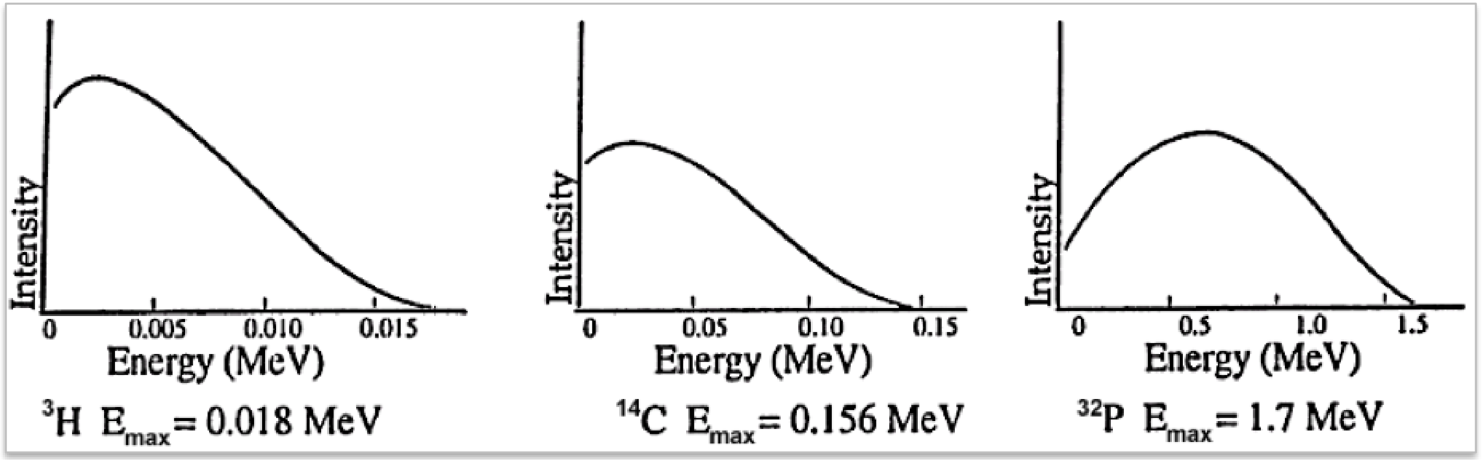


https://www.radiation-dosimetry.org/what-is-positron-annihilation-definition/

Beta radiation: spectrum emission

Beta particle spectra in ICRP 107



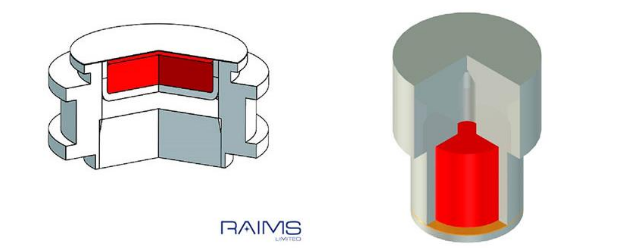


https://ehs.stanford.edu/manual/radiation-safety-manual/radioactivity

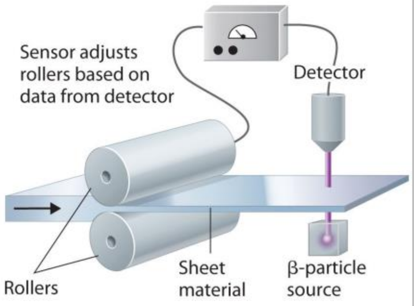
Beta dosimetry for radiation protection: why?

Beta radiation in medicine, industry and research

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



https://raims.co.uk/product-category/sealed-sources/



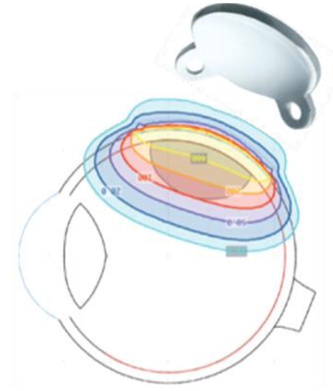
http://mrtremblaycambridge.weebly.com/p15-radioactivity.html

Radiosynoviorthesis using
^{90}Y for pain therapy

http://www.radiologie-bad-neuenahr.de/leistungen/rso/rso.phpt

Ru-106 Eye Applicators

Beta Radiation for Eye Tumor Treatment



https://medical.ezag.com/en/products/ru-106-eye-applicators/

0.0 0.2 0.4 0.6 0.8 MeV 1.2

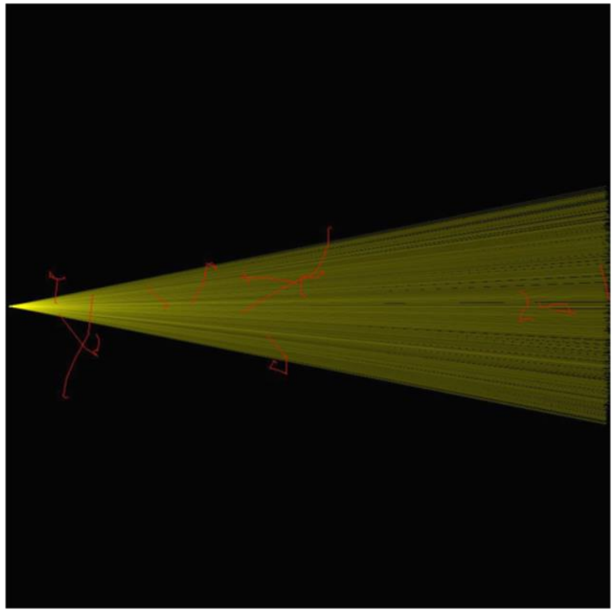
Mean beta energy

Contents

Particle tracks in air: photons vs. electrons

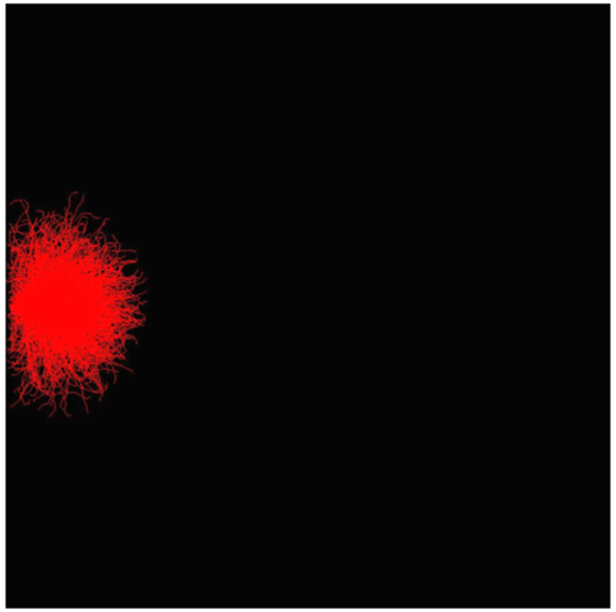
Beta radiation: Significant absorption and scattering of betas in rather small air volumes

Air cube of 1 cm x 1 cm x 1 cm



10 keV photons

Collimated beam
(from left to right):
opening angle α = ±11°

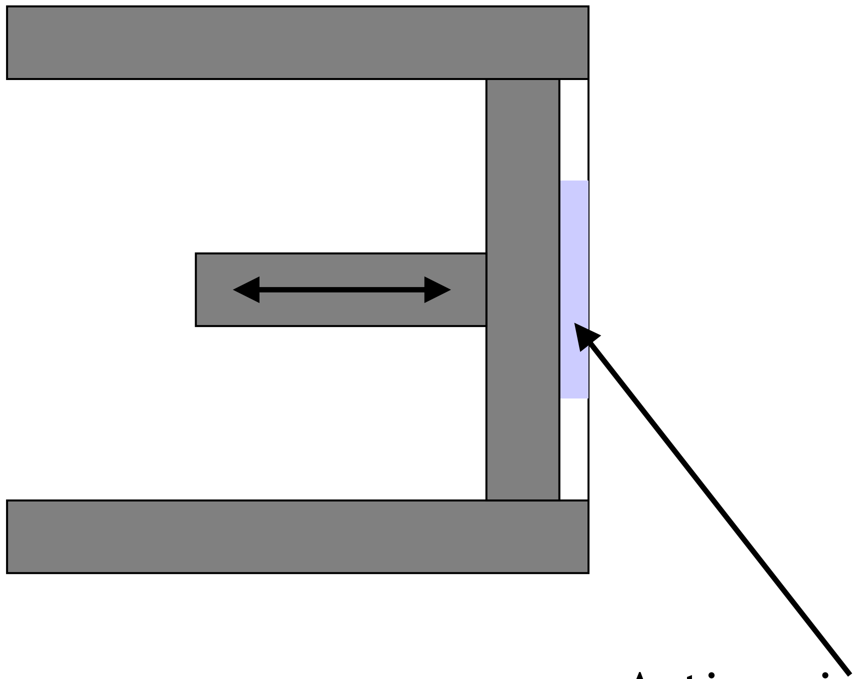


10 keV electrons

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



Active air volume

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

(developed at PTB)

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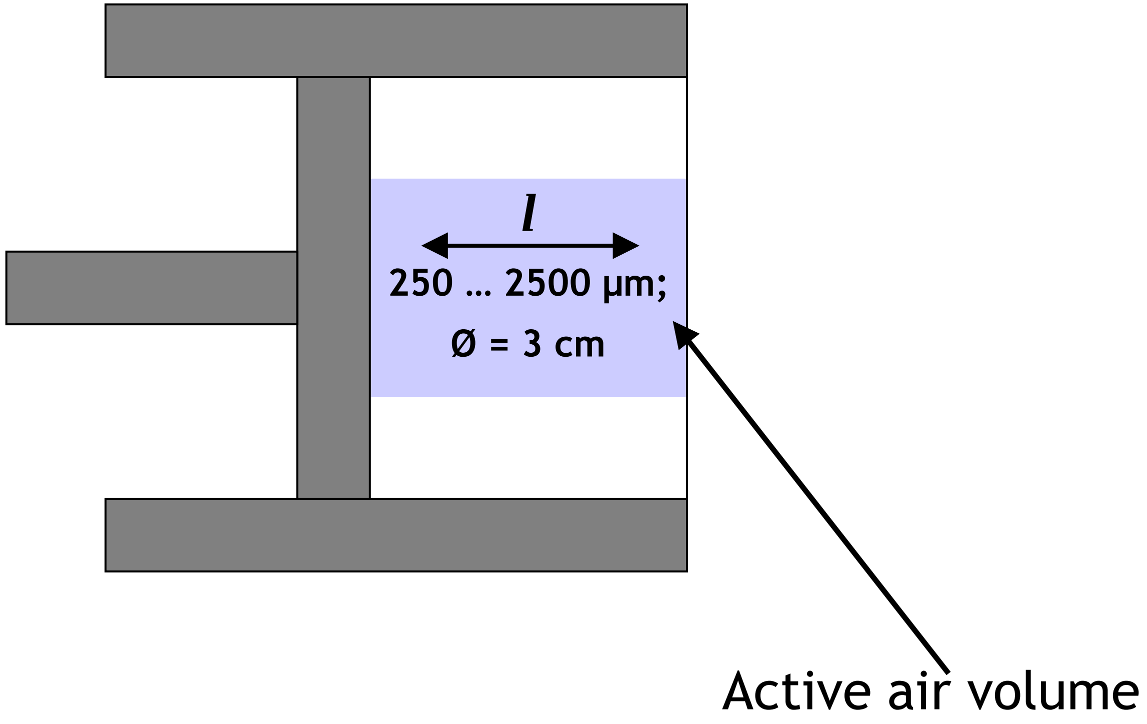

Beta Primary Standards of PTB: BPS1, *Böhm chamber*
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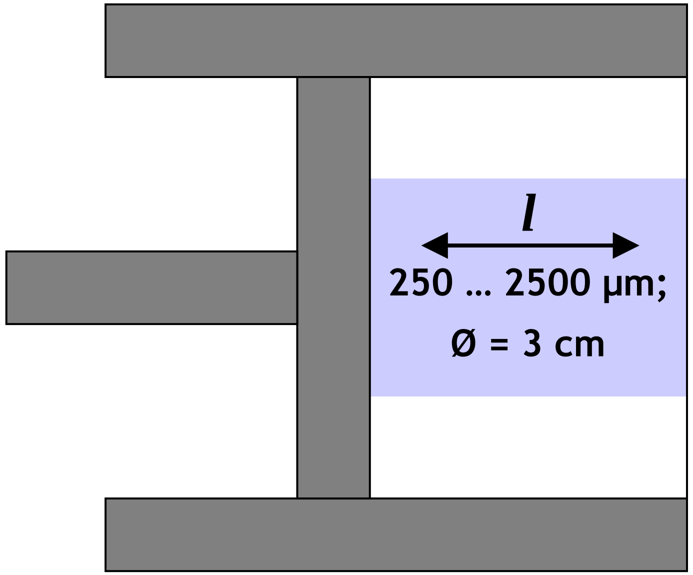
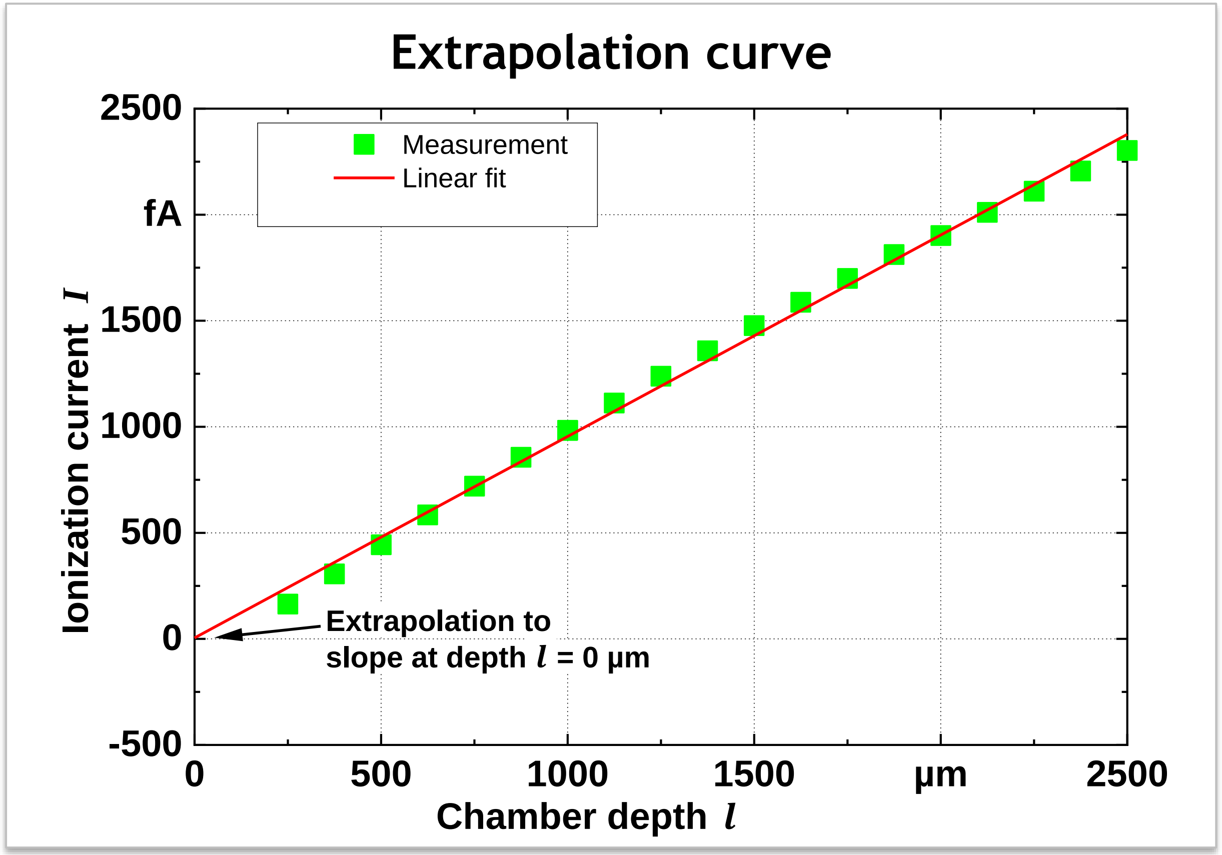
Principles of primary beta dosimetry: Realization

Realization of the Gray: Principle of extrapolation chamber

Ionization chamber with variable volume:
Extrapolation chamber





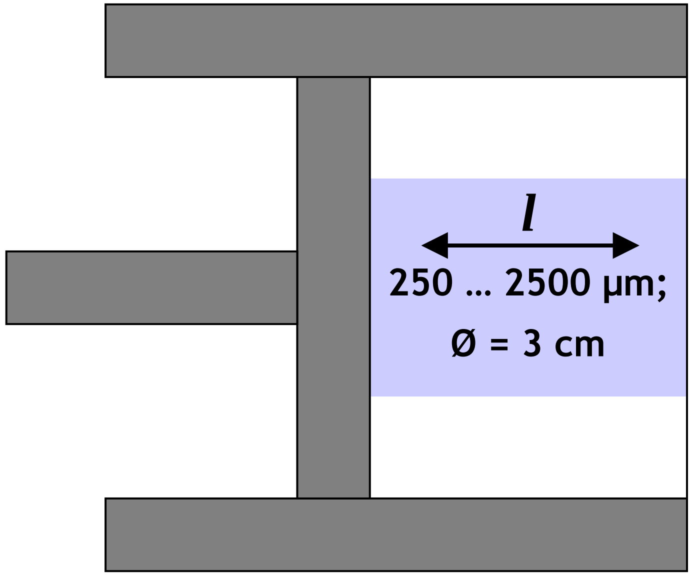
ISO 6980-2:2004:

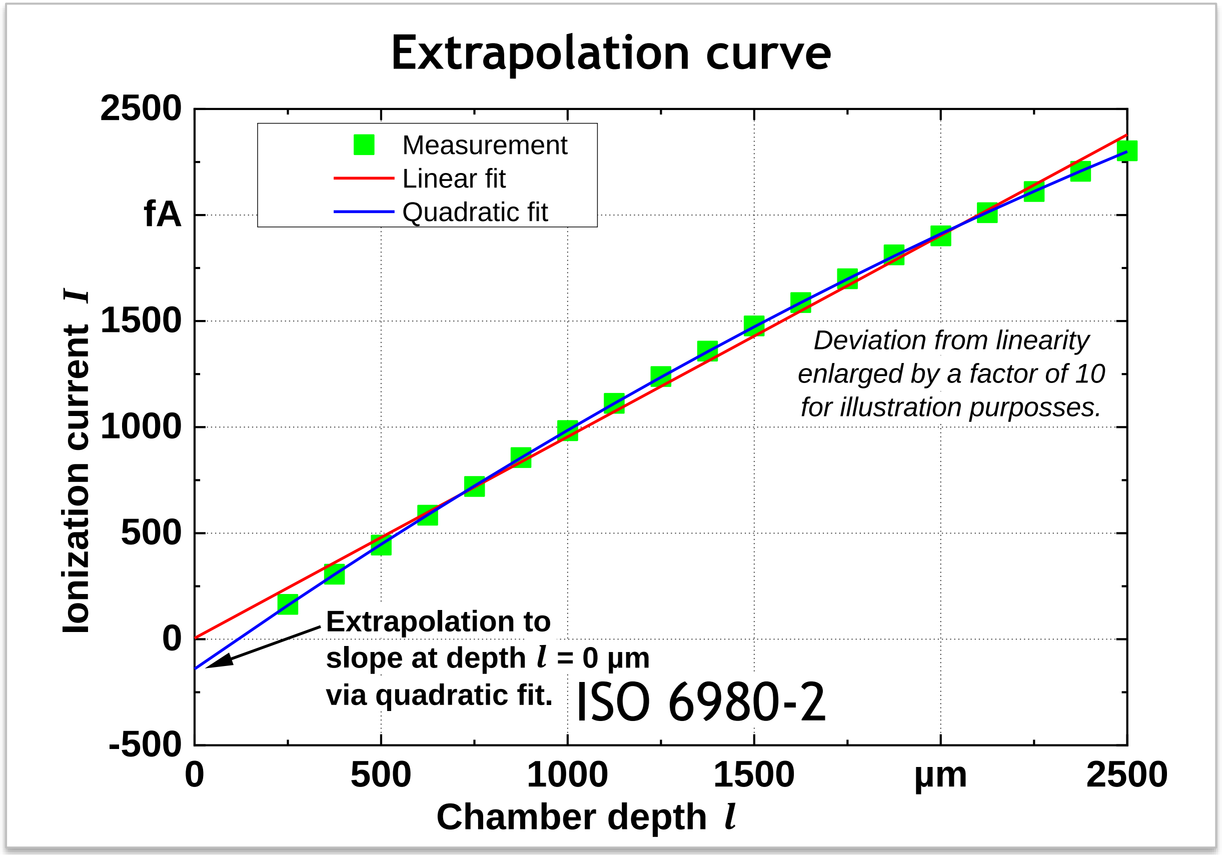
Absorbed dose rate to tissue: $\dot{D}_{\mathrm{R}\beta} = \frac{(\bar{W}_0/e)\cdot s_{\mathrm{t,a}}}{\rho_{a0}\cdot a}\left[\frac{\mathrm{d}}{\mathrm{d}l}\{k\cdot k'\cdot I(l)\}\right]_{l=0}$

Principles of primary beta dosimetry: Realization

Realization of the Gray: Principle of extrapolation chamber

Ionization chamber with variable volume:
Extrapolation chamber





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Principles of primary beta dosimetry: Realization

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

Table 3 — Correction factors which are constant for the entire extrapolation curve measurements

Symbol	Description	Influencing parameters related to: Extrapolation chamber	Condition of use	Source	Irradiation conditions
k_{ba}	Correction factor for the difference in backscatter between tissue and the material of the collecting electrode	+		+	+
k_{br}	Correction factor for the effect of bremsstrahlung from the beta-particle source			+	
k_{el}	Correction factor for the 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 the average energy required to produce an ion pair		+		
k_{in}	Correction factor for interface effects between the air in the collecting volume and the adjacent entrance window and collecting electrode	+			
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_{Sta}	Correction factor for the change of the stopping power ratio at different phantom depth		+	+	+

ISO 6980-2

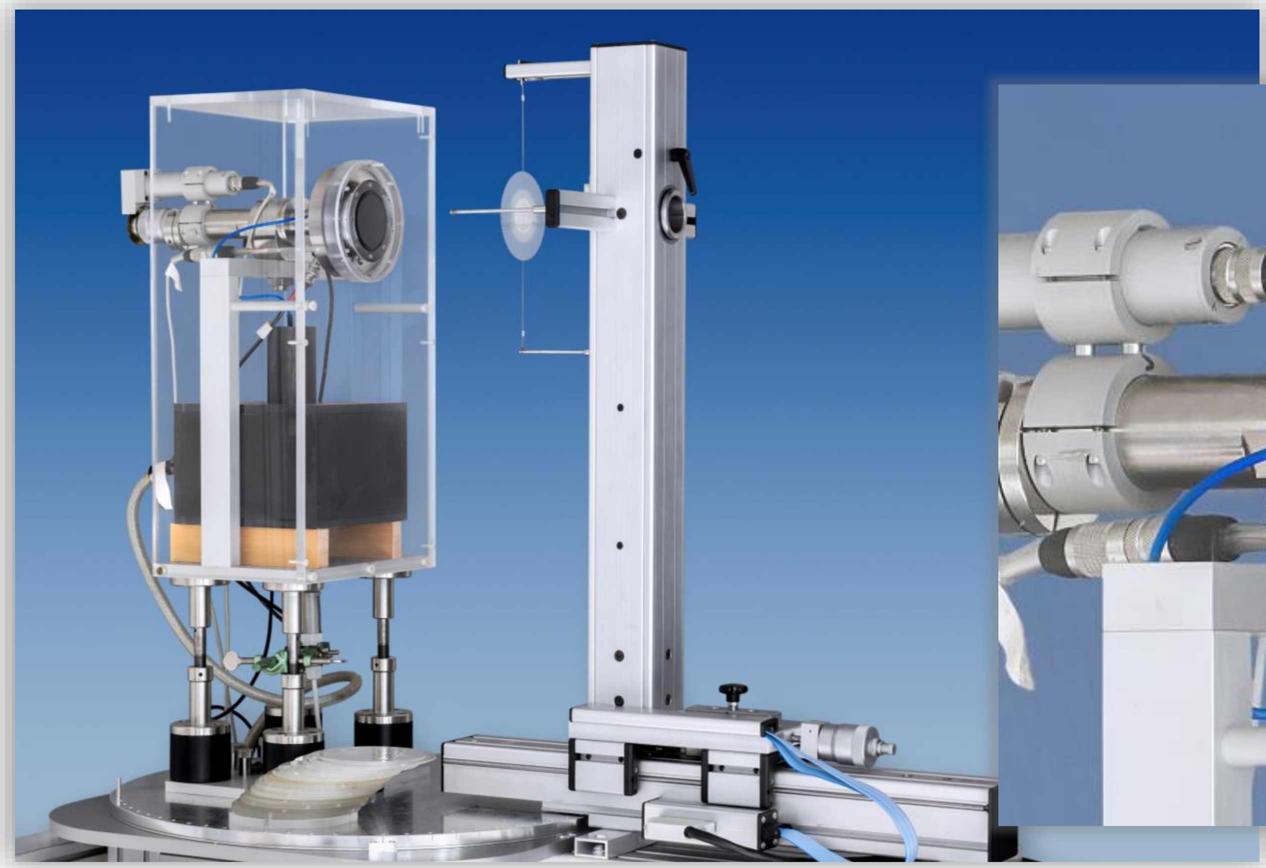
Table 4 — Correction factors which can vary during the extrapolation curve measurements

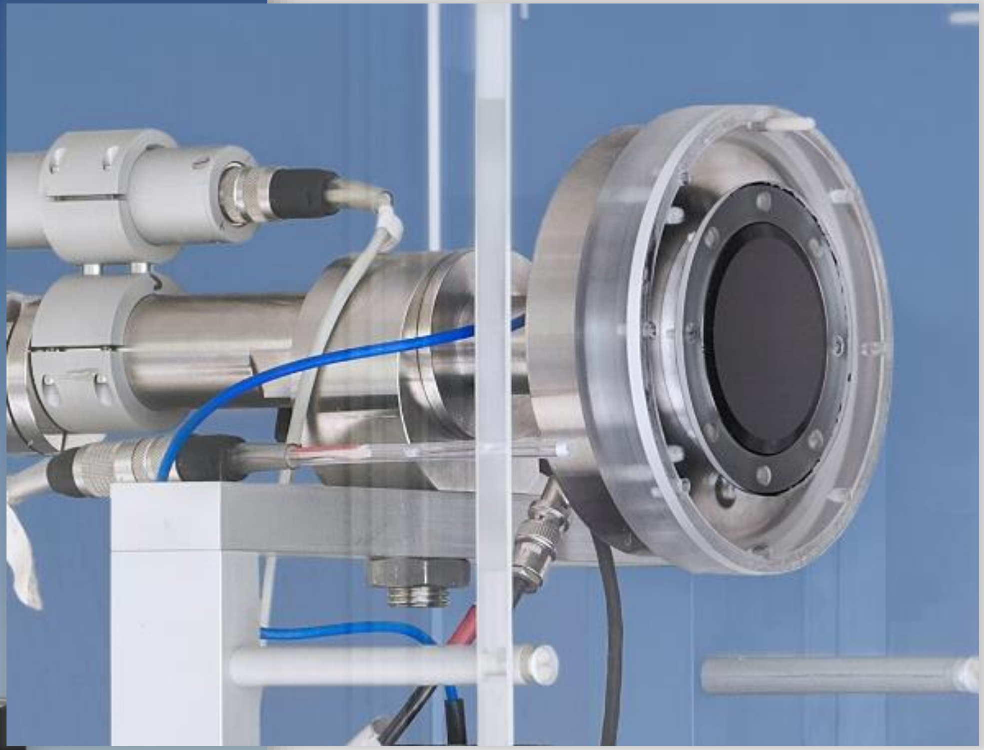
Symbol	Description	Influencing parameters relating to: Extrapolation chamber	Condition of use	Source	Irradiation conditions
k_{abs}	Correction factor for variations in the attenuation and scattering of beta particles between the source and the collecting volume and inside the collection volume due to variations from reference conditions and for differences of the entrance window to a tissue-equivalent thickness of 007 mm	+	+	+	+
k_{ad}	Correction factor for the variations of the air density in the collecting volume from reference conditions		+		
k_{de}	Correction factor for the radioactive decay of the beta-particle source			+	
k_{ih}	Correction factor for the inhomogeneity of the absorbed dose rate inside the collecting volume	+		+	+
k_{pe}	Correction factor for the perturbation of the beta-particle flux density by the side walls of the extrapolation chamber	+		+	+
k_{SA}	Correction factor for the stopping power ratio to use the Spencer-Attix theory instead of the Bragg-Gray theory			+	+
k_{sat}	Correction factor for ionization losses due to ionic recombination	+	+		+

Absorbed dose rate to tissue: $\dot{D}_{\mathrm{R}\beta} = \frac{(\bar{W}_0/e)\cdot s_{\mathrm{t,a}}}{\rho_{a0}\cdot a}\left[\frac{\mathrm{d}}{\mathrm{d}l}\{k\cdot k'\cdot I(l)\}\right]_{l=0}$ **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





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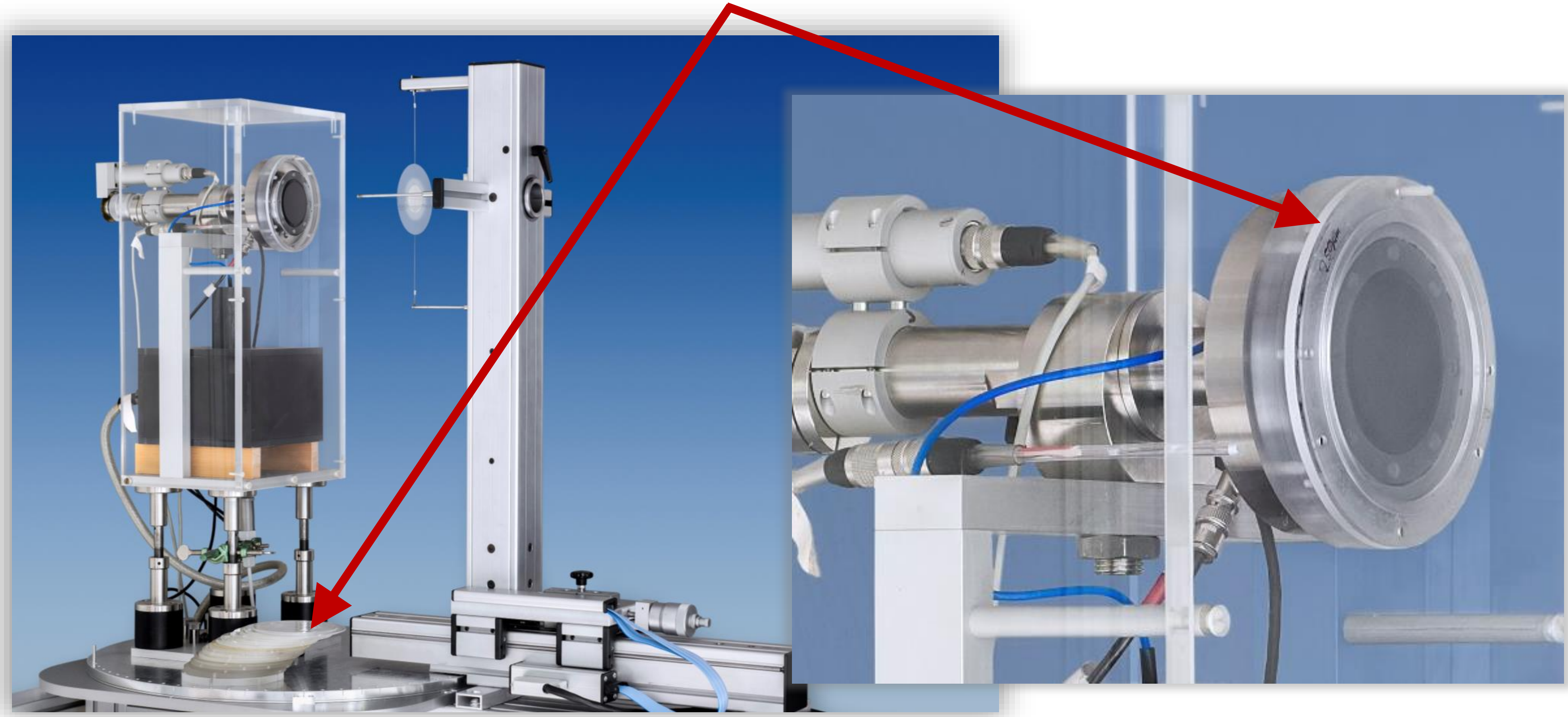

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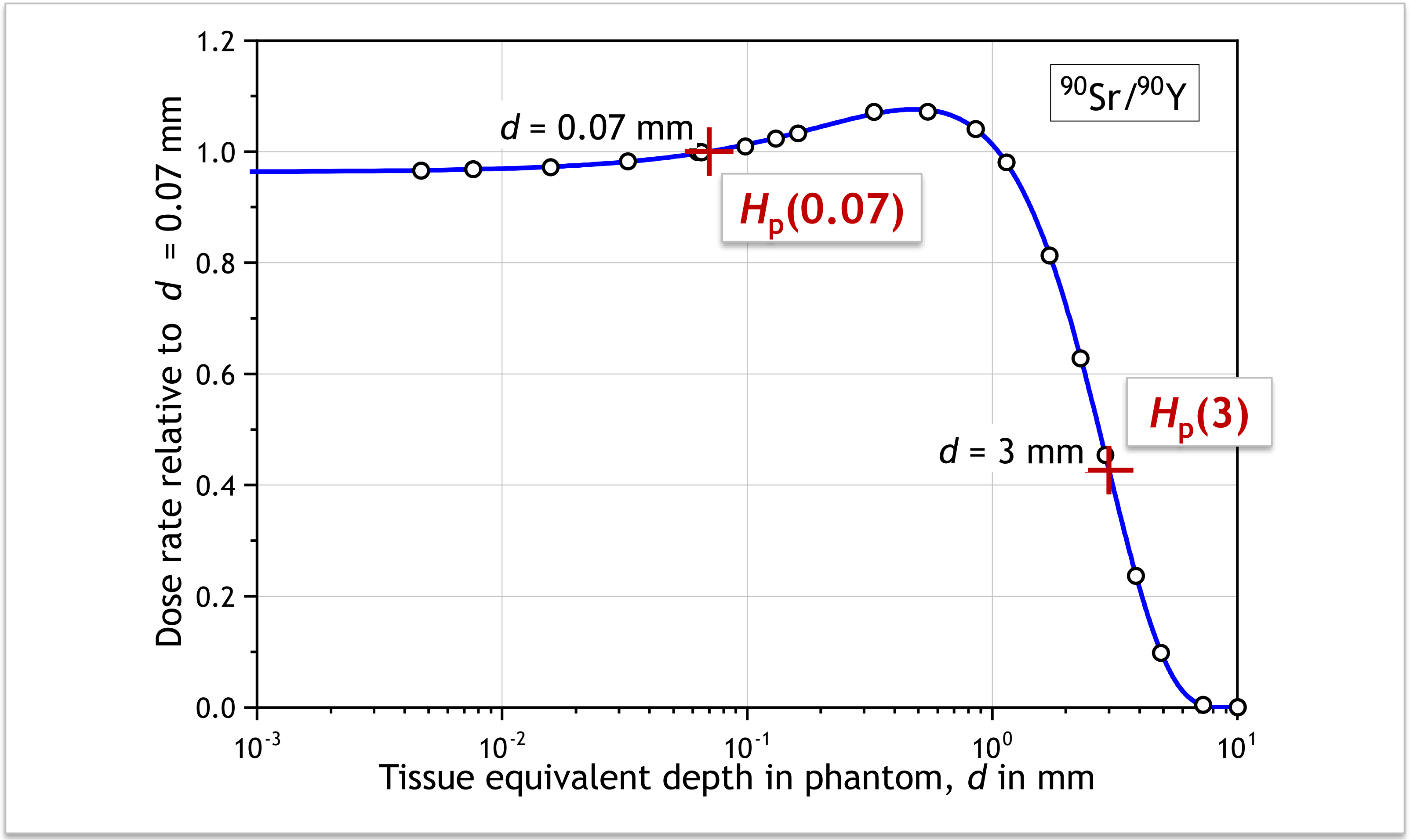

Secondary beta dosimetry: Dissemination

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

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

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 $H'(3)$

Secondary beta dosimetry: Dissemination

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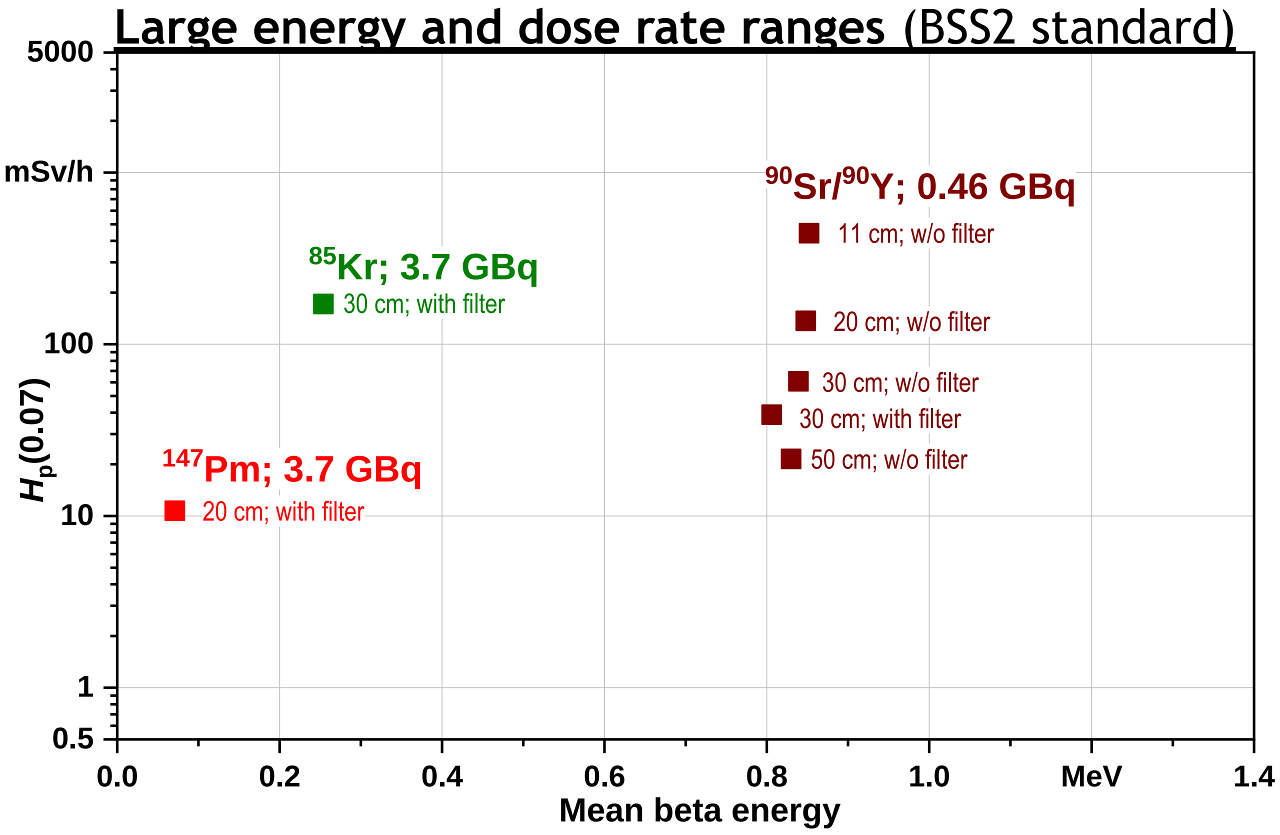

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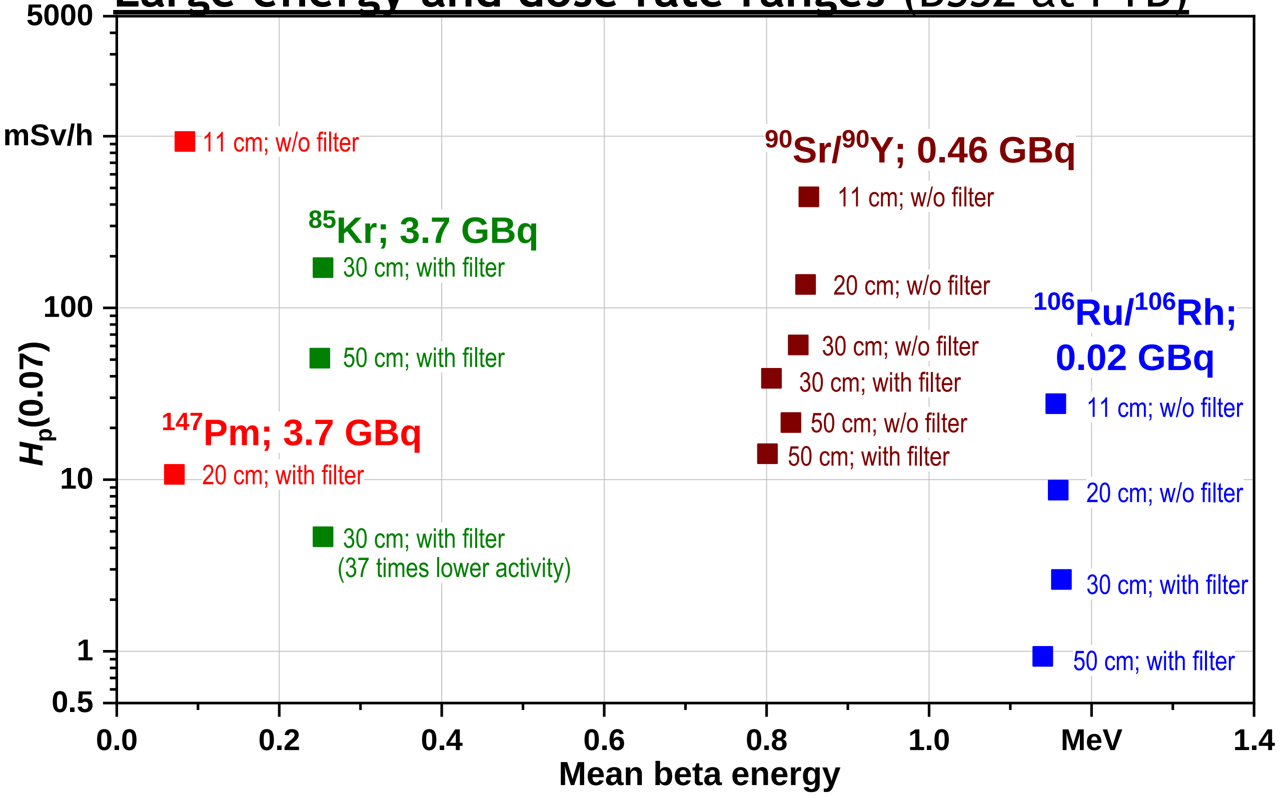
BSS2 in general: *J. Instrum. 2, P11002 (2007)*
extensions: *J. Instrum. 6, P11007 (2011)*

Large energy and dose rate ranges (BSS2 at PTB)



Secondary beta dosimetry: Dissemination

Dissemination of the Gray: D_t, and

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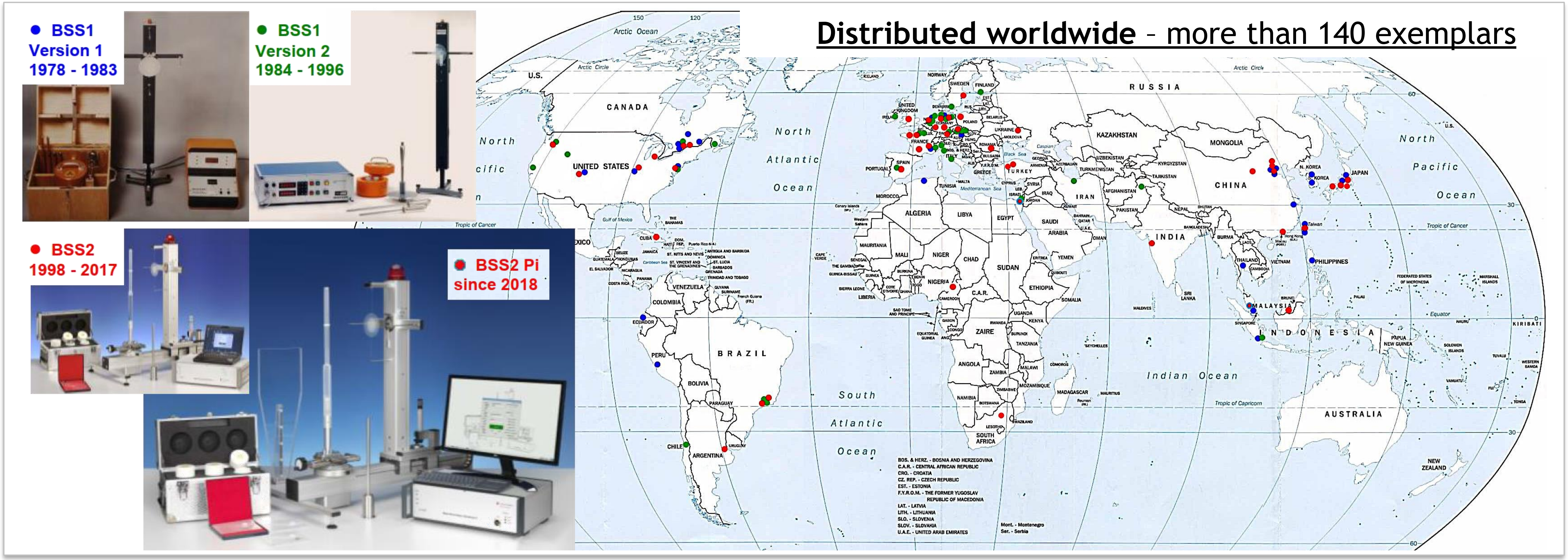
extensions: [J. Instrum. 6, P11007 (2011)]

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



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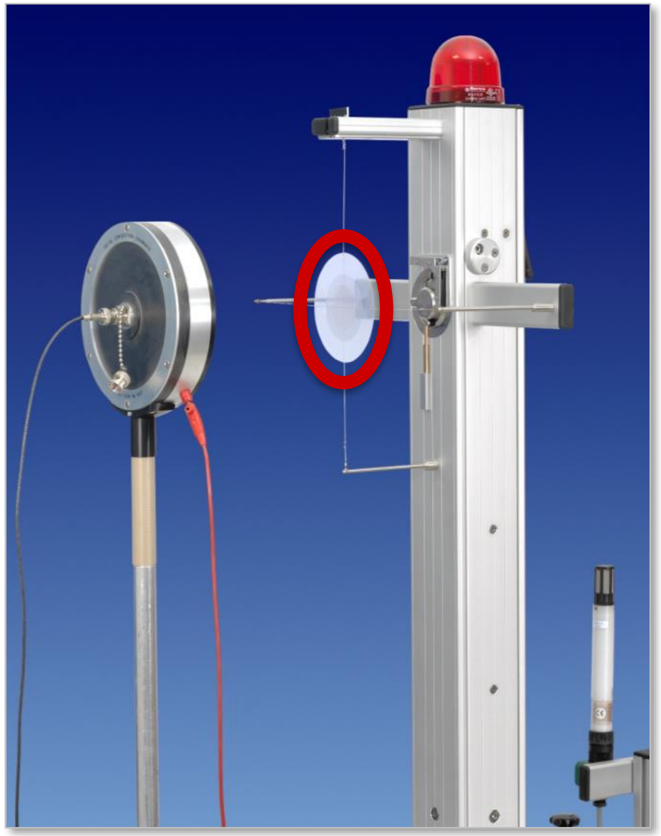
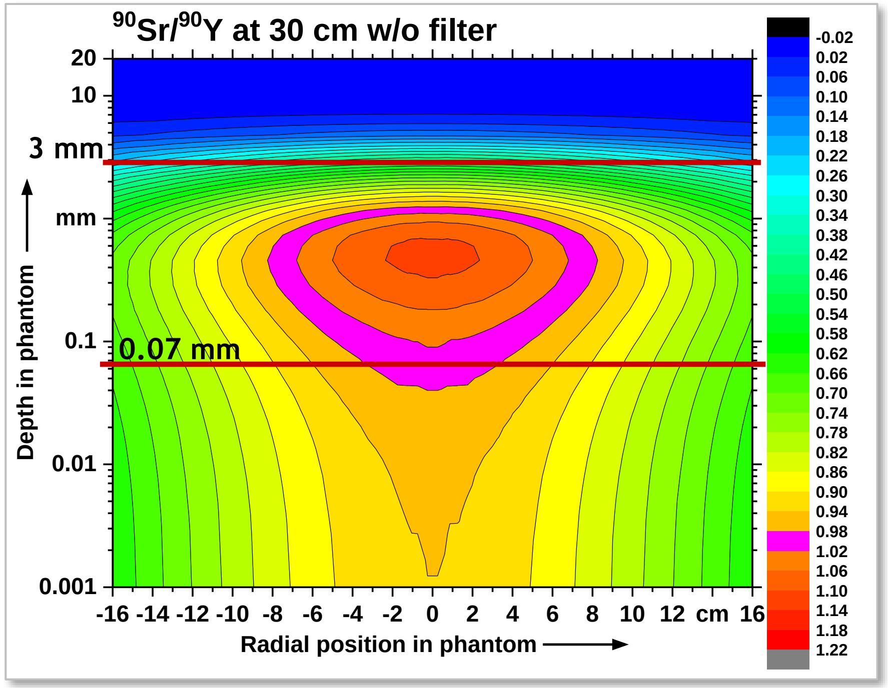
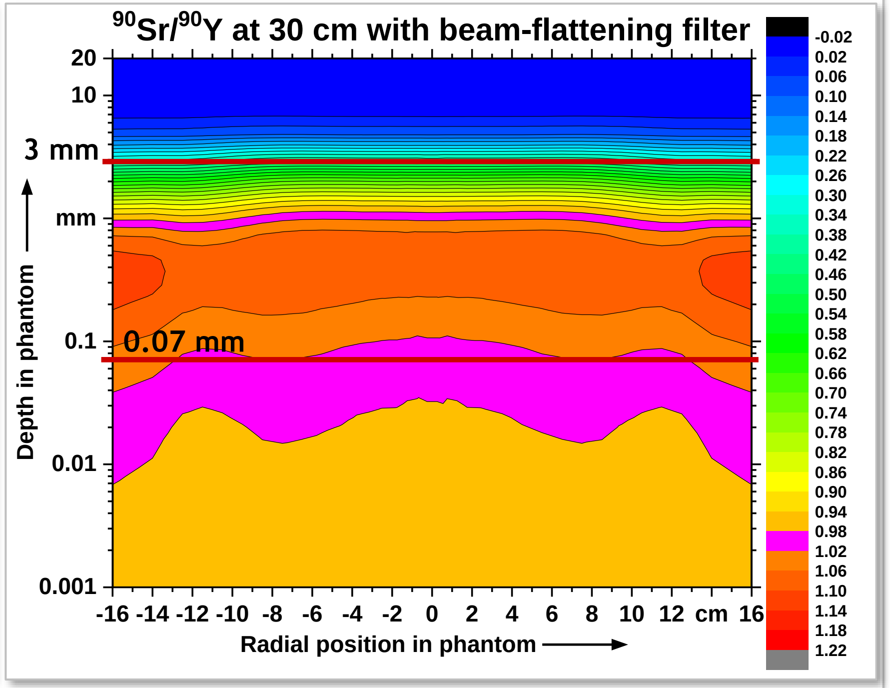


Beam profile at different depths in material
without and **with beam-flattening filter**





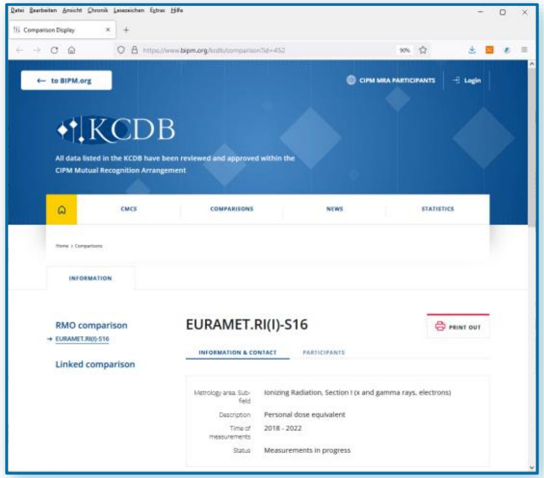
J. Instrum. 8, P02019 (2013)

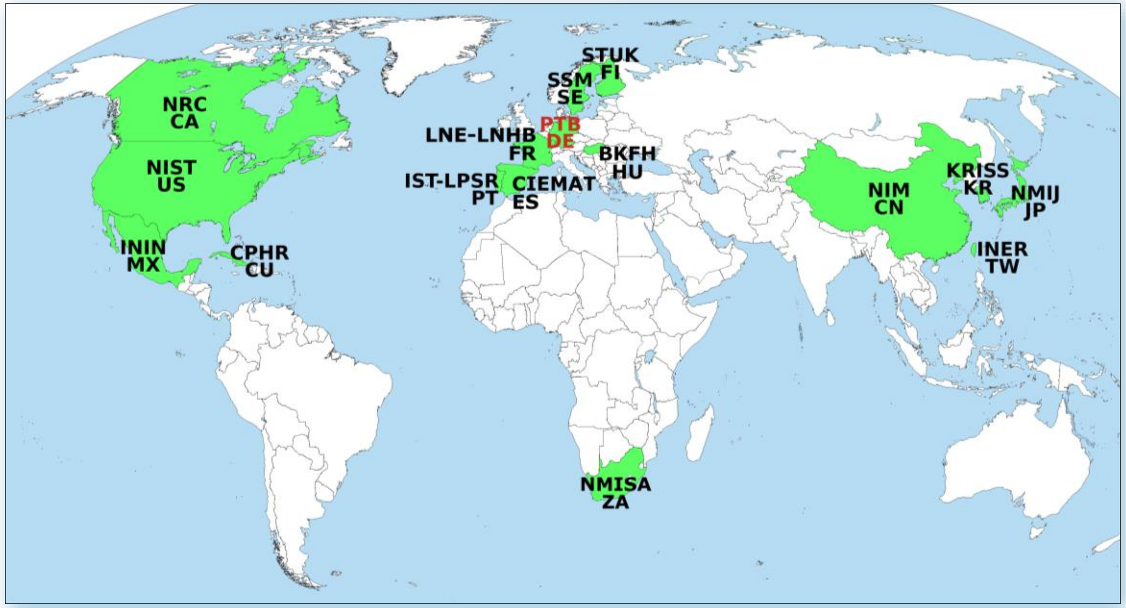
Contents

International comparison BIPM EURAMET.RI(I)-S16

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

Beta standards at ISO TC85 SC2 WG2

ISO 6980: Reference beta fields (2004 .. 2006), Ed.1

Nearly all correction factors based on measurements using Böhm chamber (BPS1)

INTERNATIONAL STANDARD **ISO 6980-1**

First edition
2006-08-01

Nuclear energy — Reference beta-particle radiation —

Part 1:
Methods of production

Énergie nucléaire — Rayonnement bêta de référence —

Partie 1: Méthodes de production

INTERNATIONAL STANDARD **ISO 6980-2**

Première edition
2004-10-15

Nuclear energy — Reference beta-particle radiation —

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

Énergie nucléaire — Rayonnements bêta de référence —

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

INTERNATIONAL STANDARD **ISO 6980-3**

First edition
01

Nuclear energy — Reference beta-particle radiation —

Part 3:
Calibration of area and personal dosemeters and the determination of their response as a function of beta radiation energy and angle of incidence

Énergie nucléaire — Rayonnement bêta de référence —

Partie 3: Étalonnage des dosimètres individuels et des dosimètres de zone et détermination de leur réponse en fonction de l'énergie et de l'angle d'incidence du rayonnement bêta

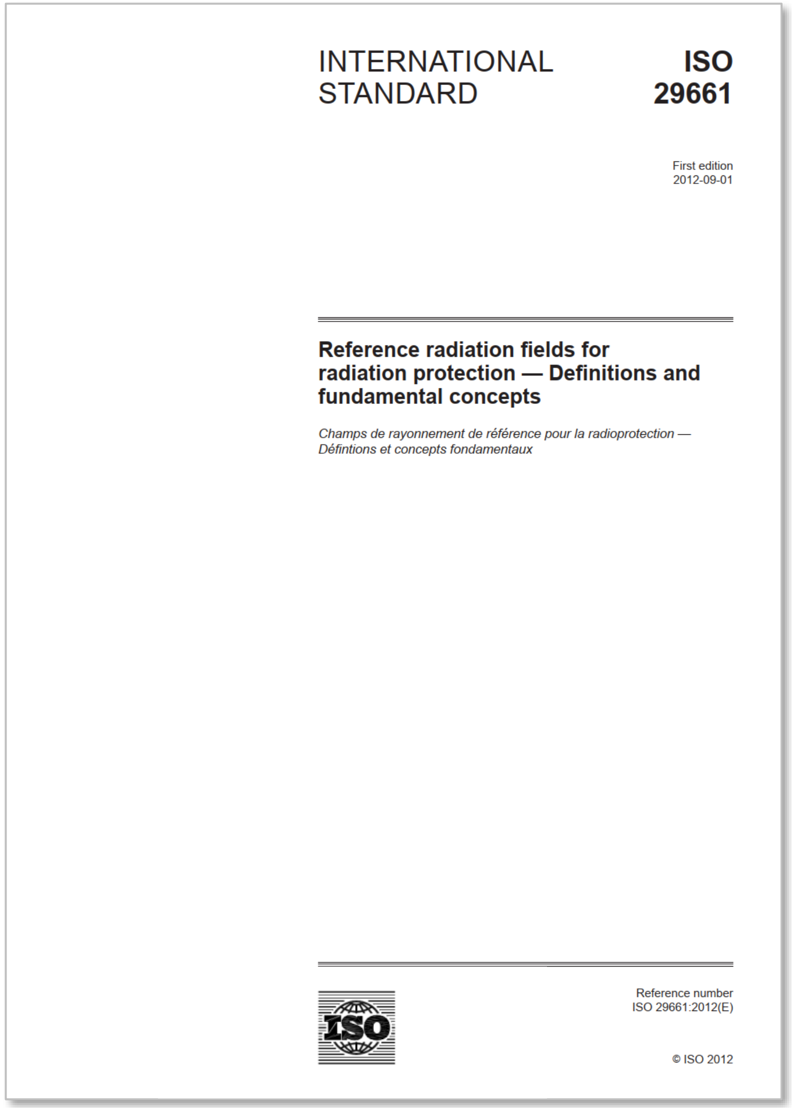
ISO 6980: Points of revision since 2019 in TC85 SC2 WG2

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*



INTERNATIONAL STANDARD

ISO 29661

First edition
2012-09-01

Reference radiation fields for radiation protection — Definitions and fundamental concepts

Champs de rayonnement de référence pour la radioprotection — Défintions et concepts fondamentaux

ISO

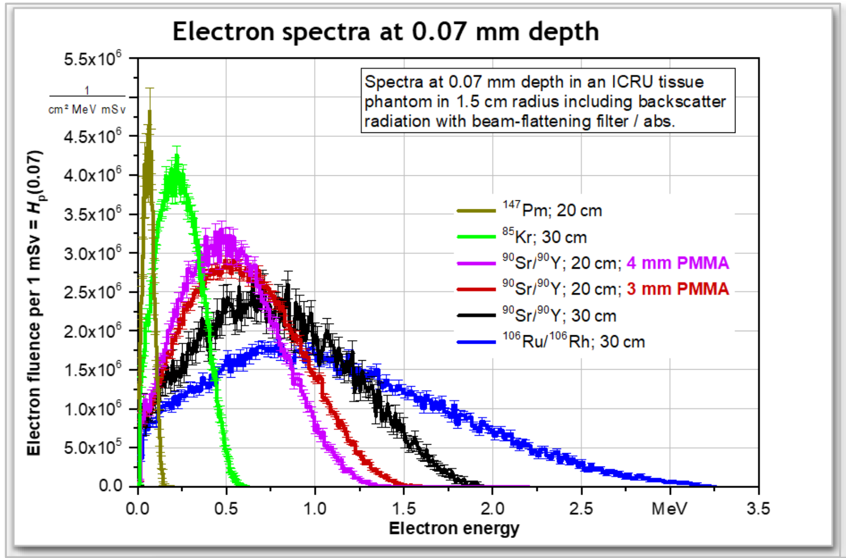
Reference number
ISO 29661:2012(E)

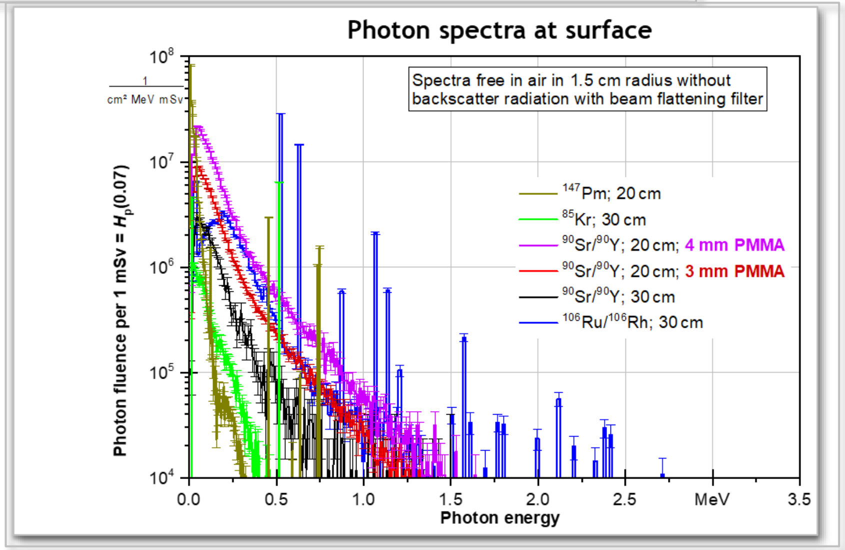
© ISO 2012

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*

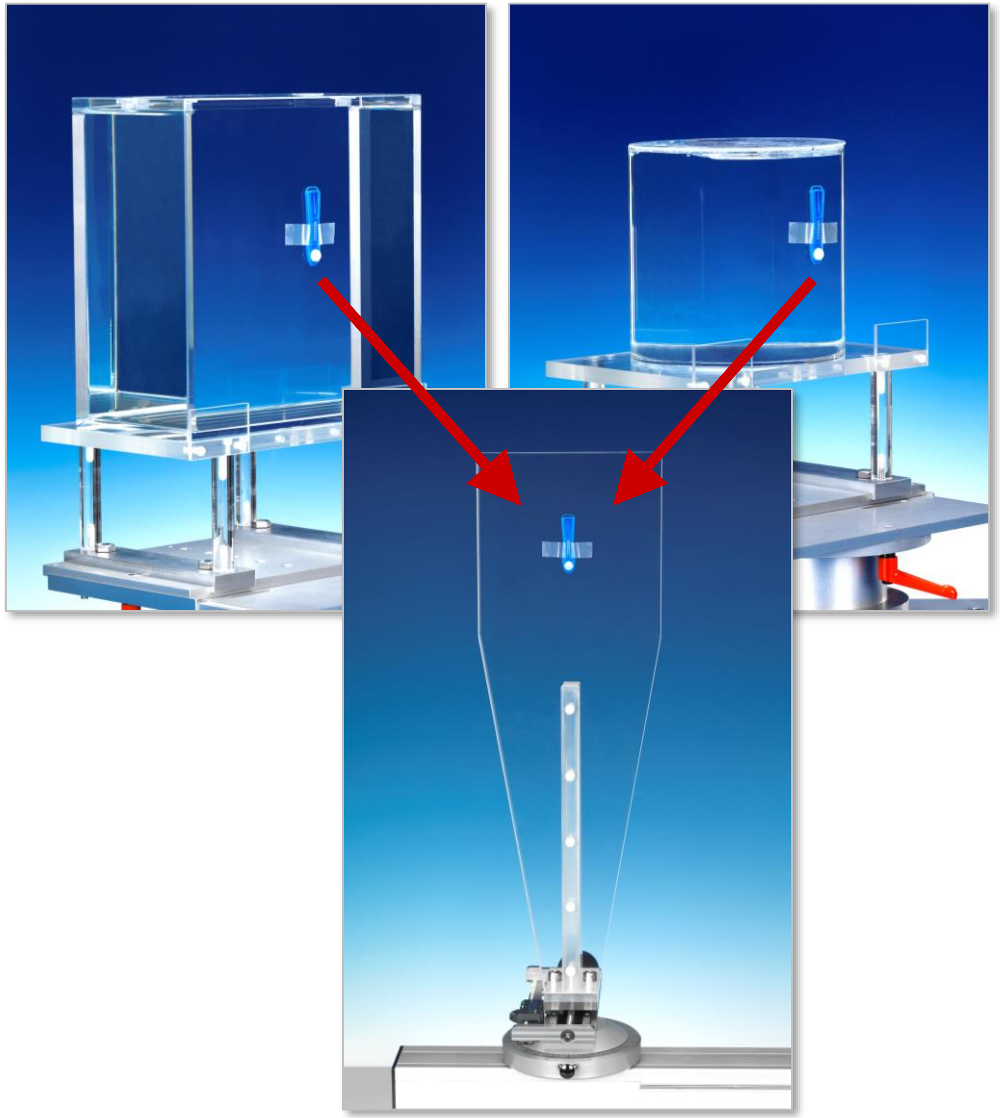




ISO 6980: Points of revision: phantom harmonized

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 x 20 cm x 2 cm PMMA* in all three parts



ISO 6980: Points of revision: photon contribution

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*
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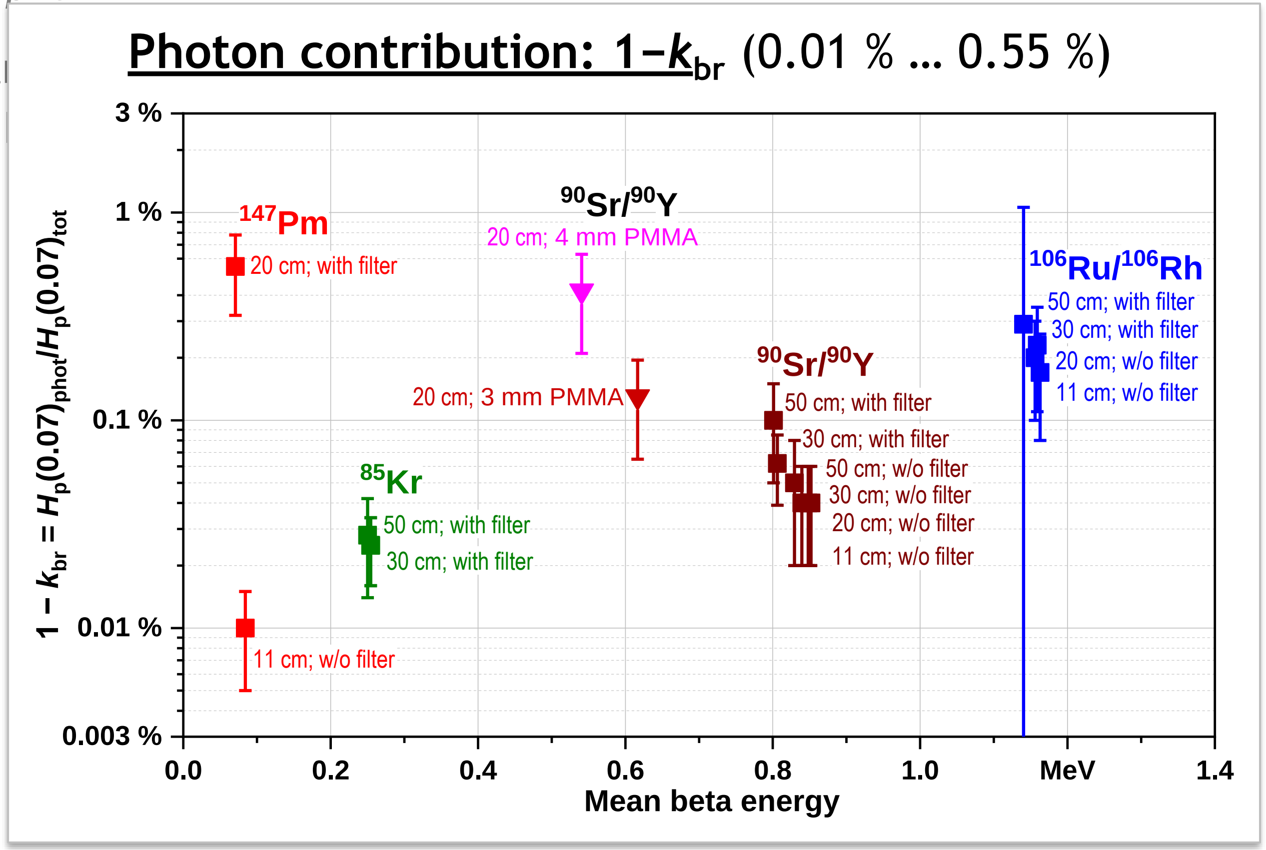
- Harmonization of the substitute for the ISO water slab a[…]
  phantom ➔ *20 cm x 20 cm x 2 cm PMMA* in all three […]
- Inclusion of photon contribution to total reference dose
  ➔ $k_{\mathrm{br}} = \frac{(I - I_{\mathrm{br}})}{I}$ and $D_{\mathrm{R}} = \frac{D_{\mathrm{R}ß}}{k_{\mathrm{br}}}$

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 x 20 cm x 2 cm PMMA* in all three parts
- Inclusion of photon contribution to total reference dose
  ➔ $k_{\mathrm{br}} = \frac{(I - I_{\mathrm{br}})}{I}$ and $D_{\mathrm{R}} = \frac{D_{\mathrm{Rß}}}{k_{\mathrm{br}}}$
- Removal of ^{14}C ($E_{\mathrm{beta,mean}}$ = 0.04 MeV)
  ➔ *as not in use in any institute*

ISO 6980: Points of revision: correction factors by simulations

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

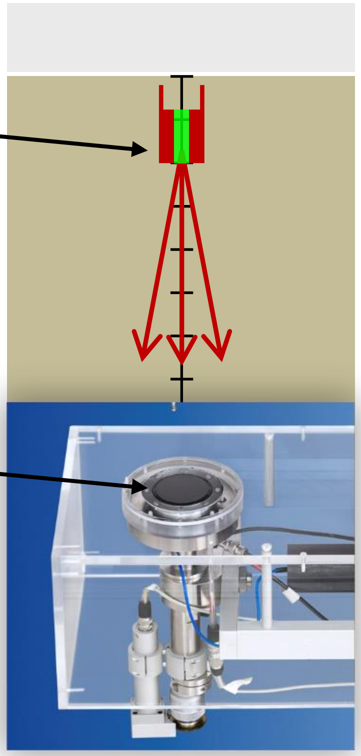
ISO 6980: Points of revision: correction factors by simulations

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

Simulation of the radiation sources of the BSS2

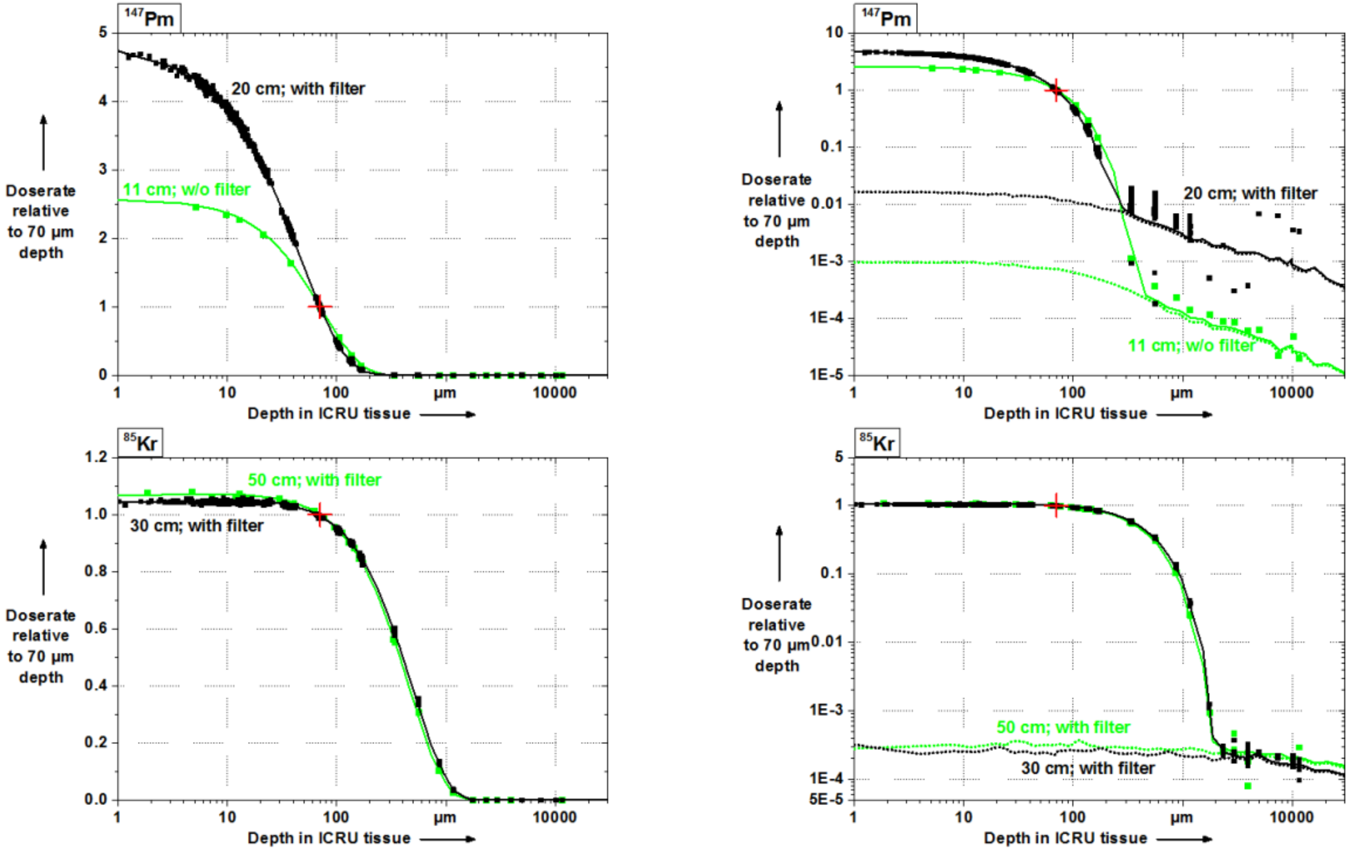
Primary extrapolation chamber in a PMMA slab phantom

➔ absorbed dose to tissue, $D_t(0.07)$, i.e., $H_p(0.07)$ in a slab phantom



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

J. Instrum. 8, P02019 (2013)



linear scale

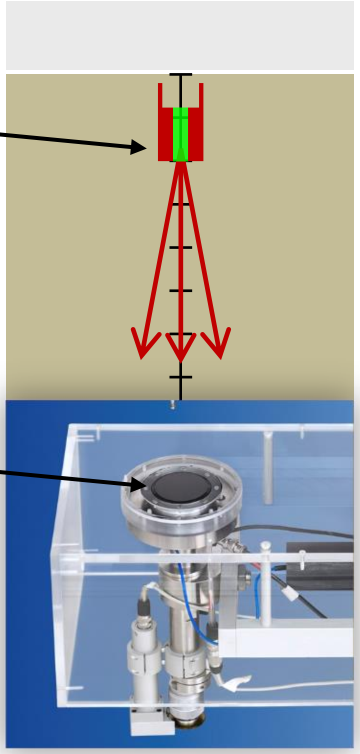
logarithmic scale

ISO 6980: Points of revision: correction factors by simulations

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

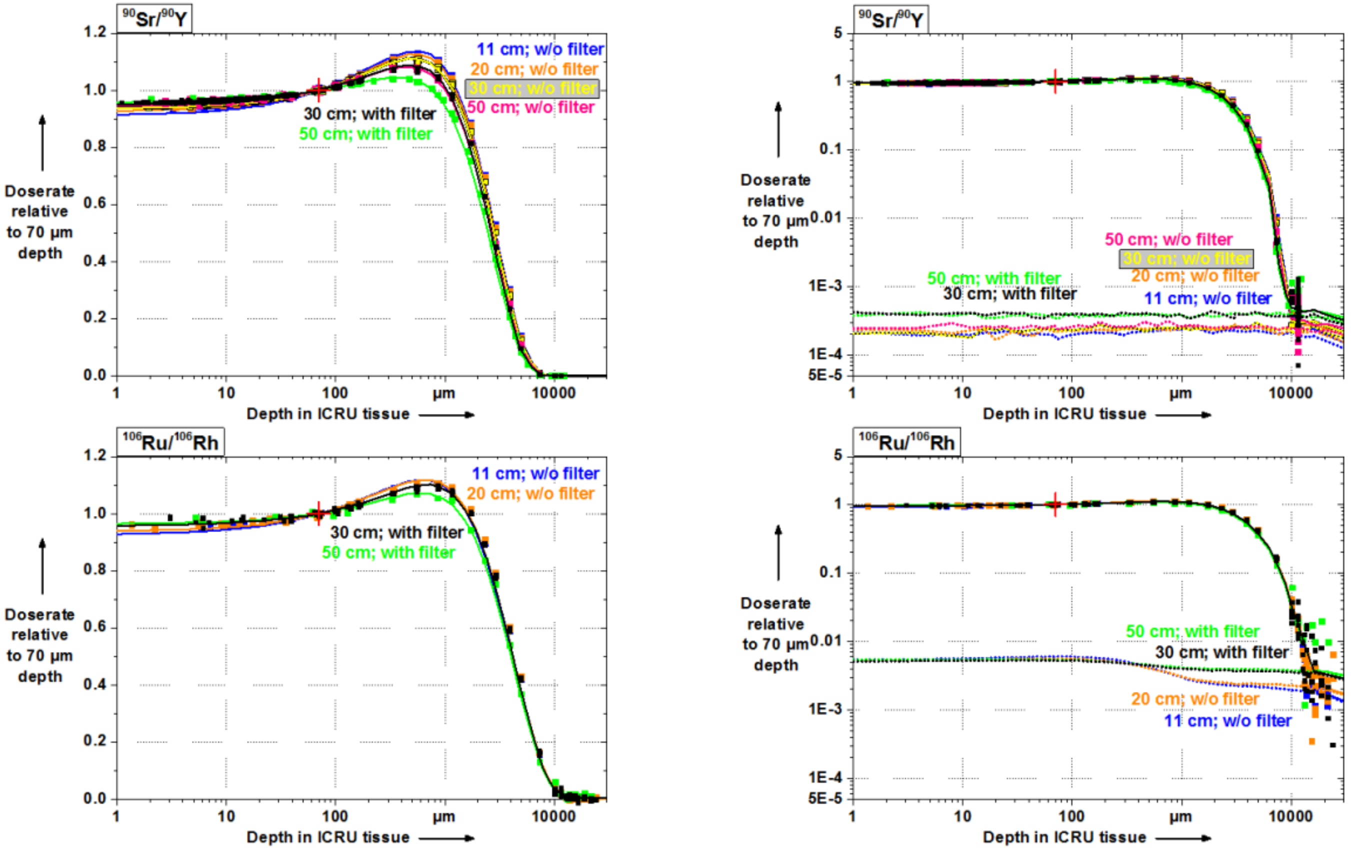
Simulation of the radiation sources of the BSS2

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



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

J. Instrum. 8, P02019 (2013)



linear scale

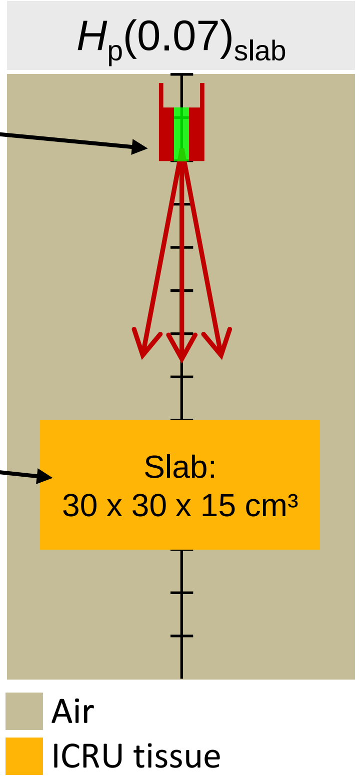
logarithmic scale

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

$H_p(0.07)_{slab}$

Simulation of the radiation sources of the BSS2

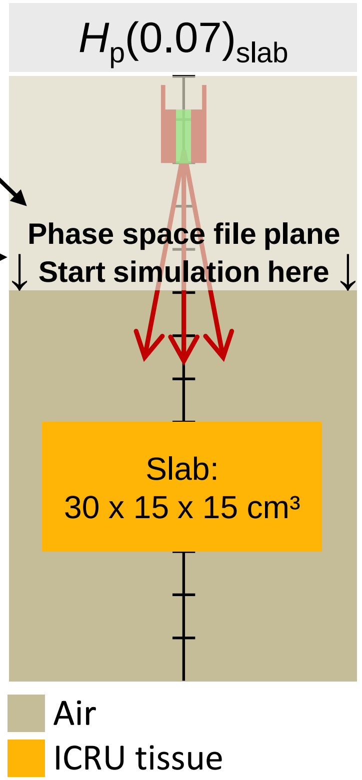
… replaced by an ICRU tissue slab
➔ absorbed dose to tissue, $D_t(0.07)$, i.e., $H_p(0.07)$ in a slab phantom



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

$H_p(0.07)_{slab}$

Enhance simulation efficiency by phase space files

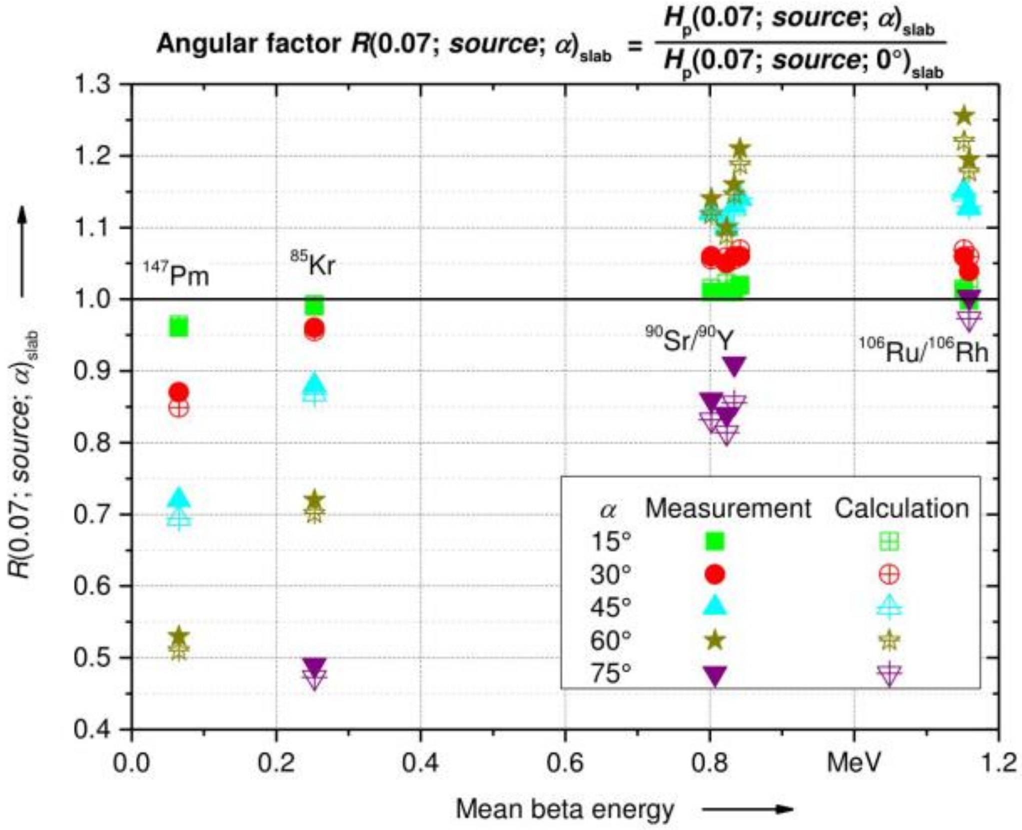


Files (spectra) freely available:

J. Instrum. 8, P02019 (2013) &
J. Instrum. 14, A07001 (2019)

Validation (1/2): measured (closed symbols) and simulated (open symbols) angular dependence factors agree … *J. Instrum. 10, P03014 (2015)*

… for $H_p(0.07)$

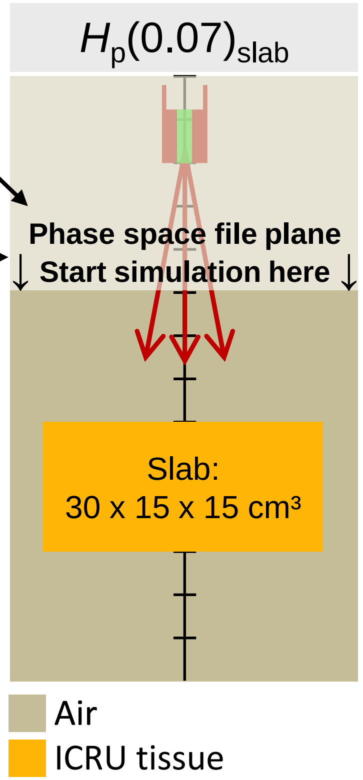


ISO 6980: Points of revision: correction factors by simulations

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

$H_p(0.07)_{slab}$

Enhance simulation efficiency by phase space files



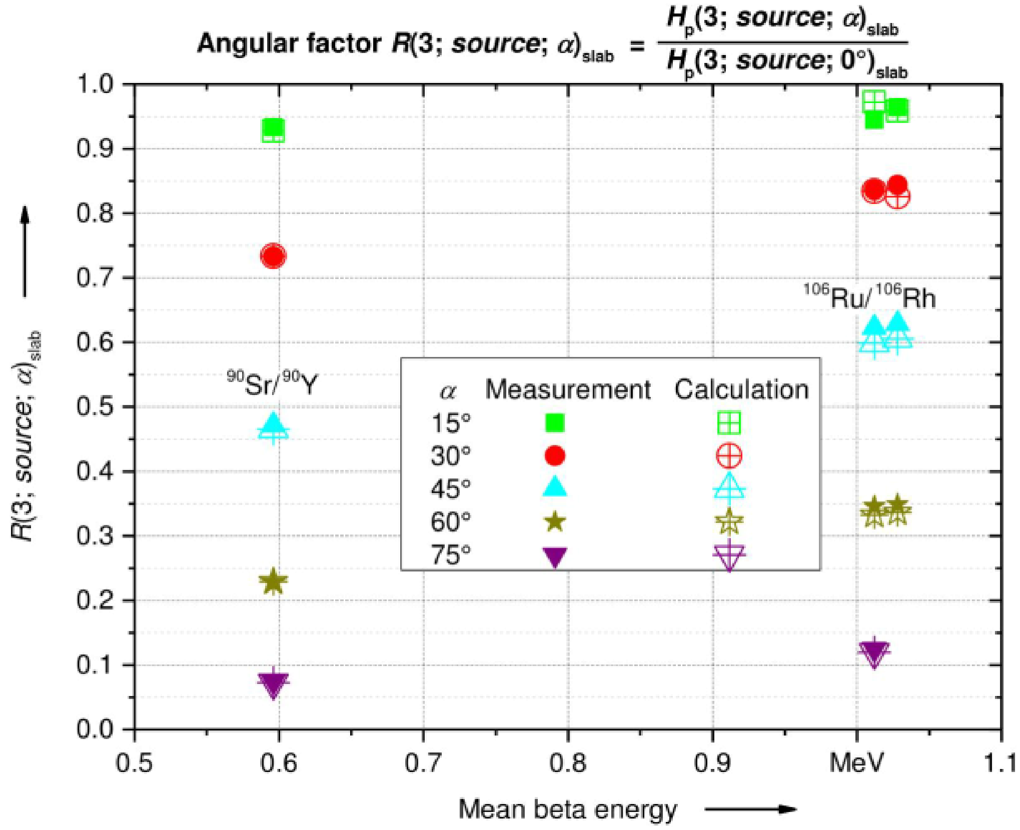
Files (spectra) freely available:

J. Instrum. 8, P02019 (2013) &

J. Instrum. 14, A07001 (2019)

Validation (2/2): measured (closed symbols) and simulated (open symbols) angular dependence factors agree … J. Instrum. 10, P03014 (2015)

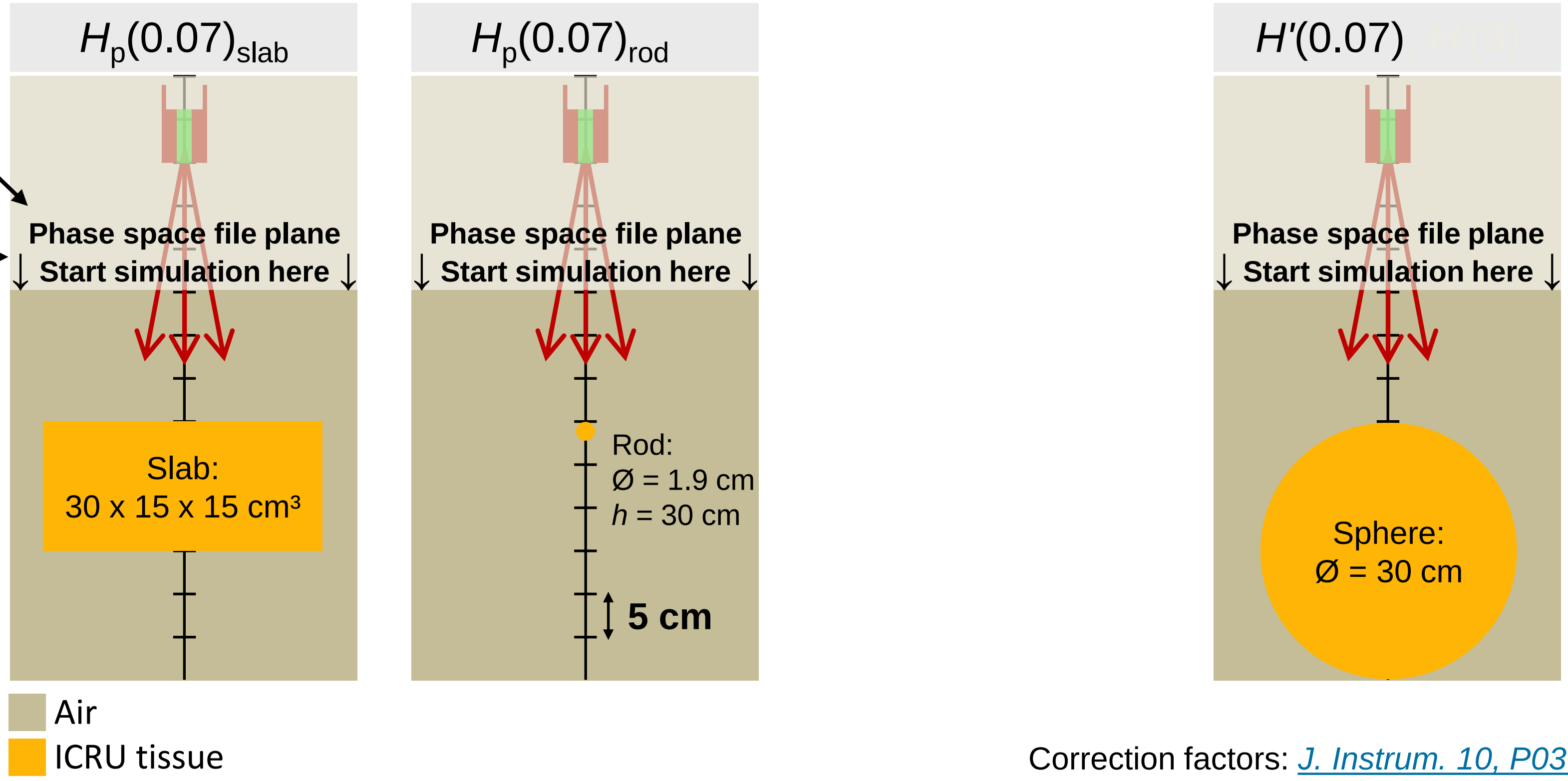
… and $H_p(3)$



ISO 6980: Points of revision: addition of quantities

ISO 6980: Reference beta fields: *major / technical changes:* **correction factors for phantoms / quantities** (EGSnrc)
Differentiate $H_p(0.07)_{slab}$, $H_p(0.07)_{rod}$ and $H'(0.07)$
➔ $k_{corr} = H(d) / H_p(0.07)_{slab}$

Enhance simulation efficiency by phase space files



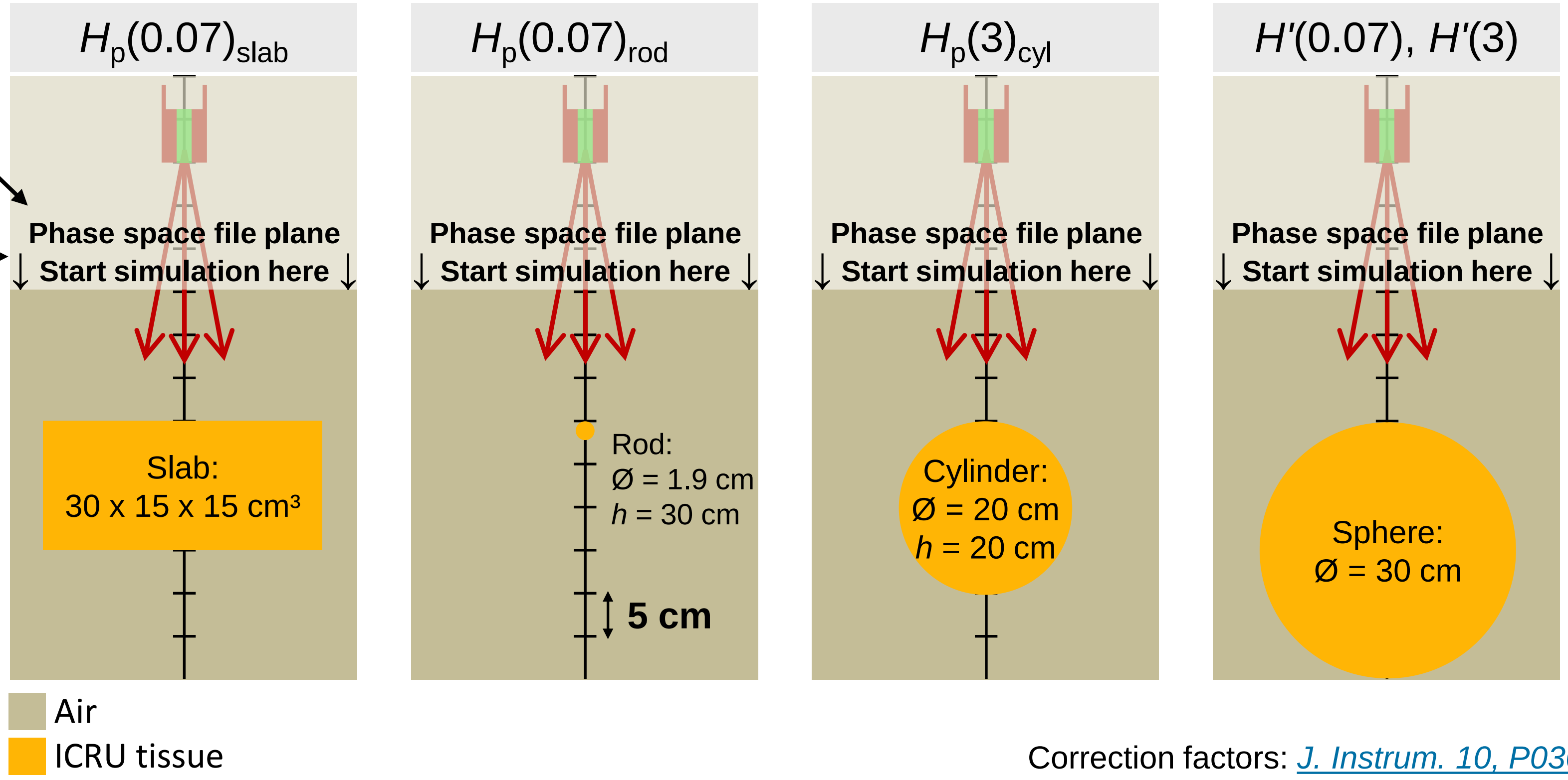
Files (spectra) freely available:
J. Instrum. 8, P02019 (2013) &
J. Instrum. 14, A07001 (2019)

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

ISO 6980: Points of revision: addition of quantities

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

Enhance simulation efficiency by phase space files



Files (spectra) freely available:
J. Instrum. 8, P02019 (2013) &
J. Instrum. 14, A07001 (2019)

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

ISO 6980: Points of revision: addition of radiation fields

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

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

- Sources and geometries in the 2004/2006 version

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	50 cm, without filter	50 cm, with filter
^{14}C	x							
^{147}Pm				x				
^{85}Kr						x		
$^{90}Sr/^{90}Y$		x	x		x	x	x	
$^{106}Ru/^{106}Rh$	x							

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

ISO 6980: Points of revision: addition of radiation fields

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

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

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)

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	50 cm, without filter	50 cm, with filter
^{14}C	x							
^{147}Pm		x		x				
^{85}Kr						x		x
$^{90}Sr/^{90}Y$		x	x		x	x	x	x
$^{106}Ru/^{106}Rh$	x	x	x			x		x

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

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

ISO 6980: Points of revision: addition of radiation fields

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

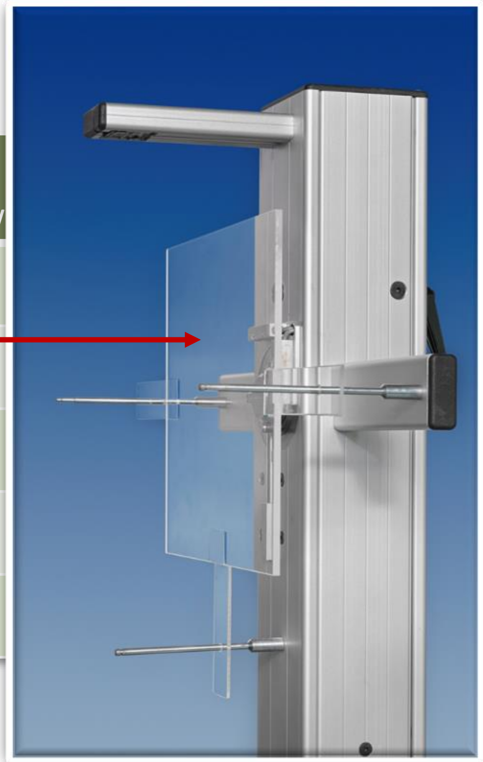
Actual fields, simulations: *J. Instrum. 8, P02019 (2013)*
and addendum J. Instrum. 14, A07001 (2019)

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

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

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

Radionuclide (source)	10 cm, without filter	11 cm, without filter	20 cm, without filter	20 cm, with filter	w		0 cm, hout filter	50 cm, with filter
^{14}C	x							
^{147}Pm		x		x				
^{85}Kr								x
^{90}Sr/^{90}Y		x	x	3 mm, 4 mm			x	x
^{106}Ru/^{106}Rh	x	x	x					x



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

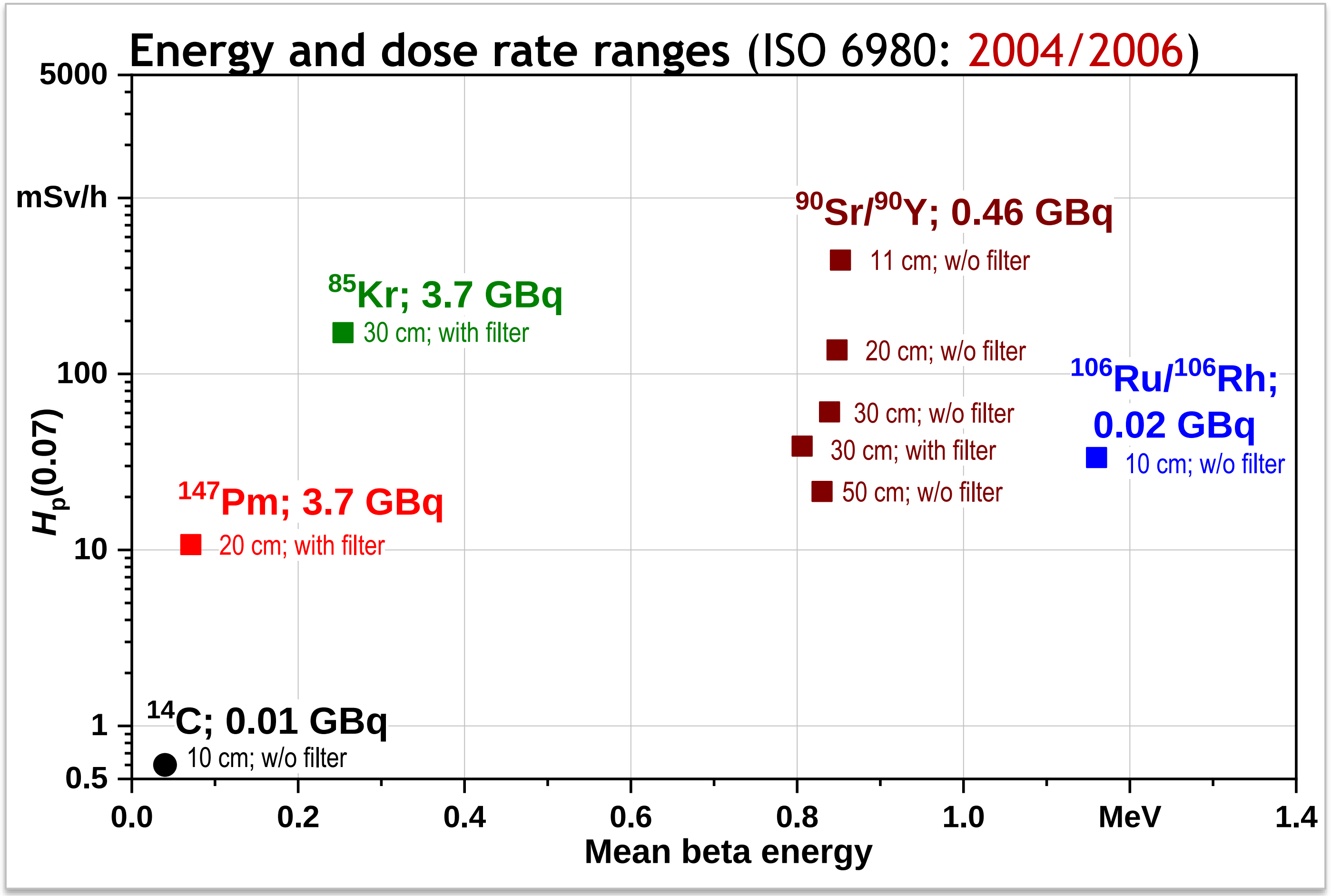
ISO 6980: Points of revision: addition of radiation fields

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

- Dose rate and energy ranges in ISO 6980: 2004/2006 version

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)*

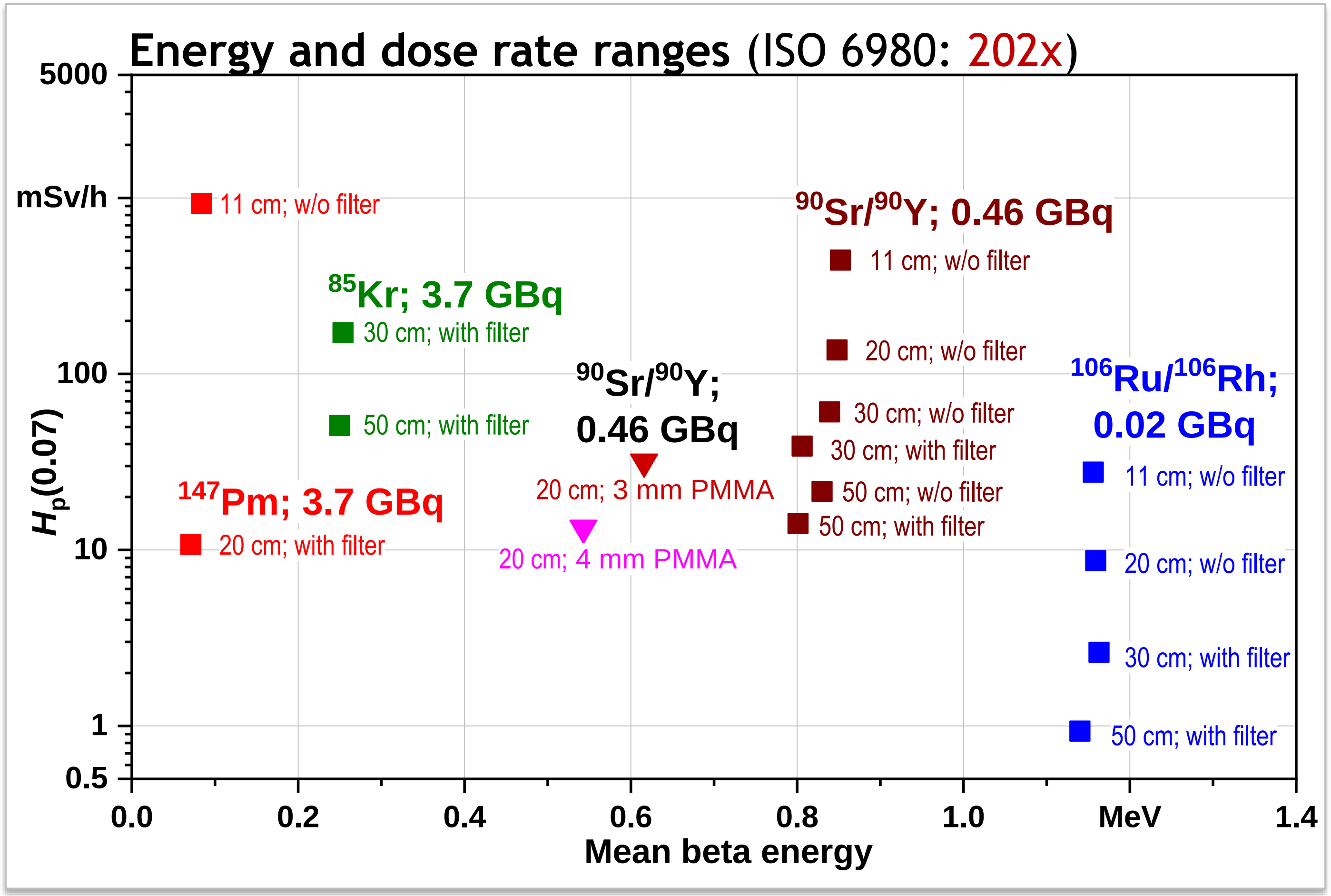
ISO 6980: Points of revision: addition of radiation fields

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

- Dose rate and energy ranges in ISO 6980: new 202x version

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)*

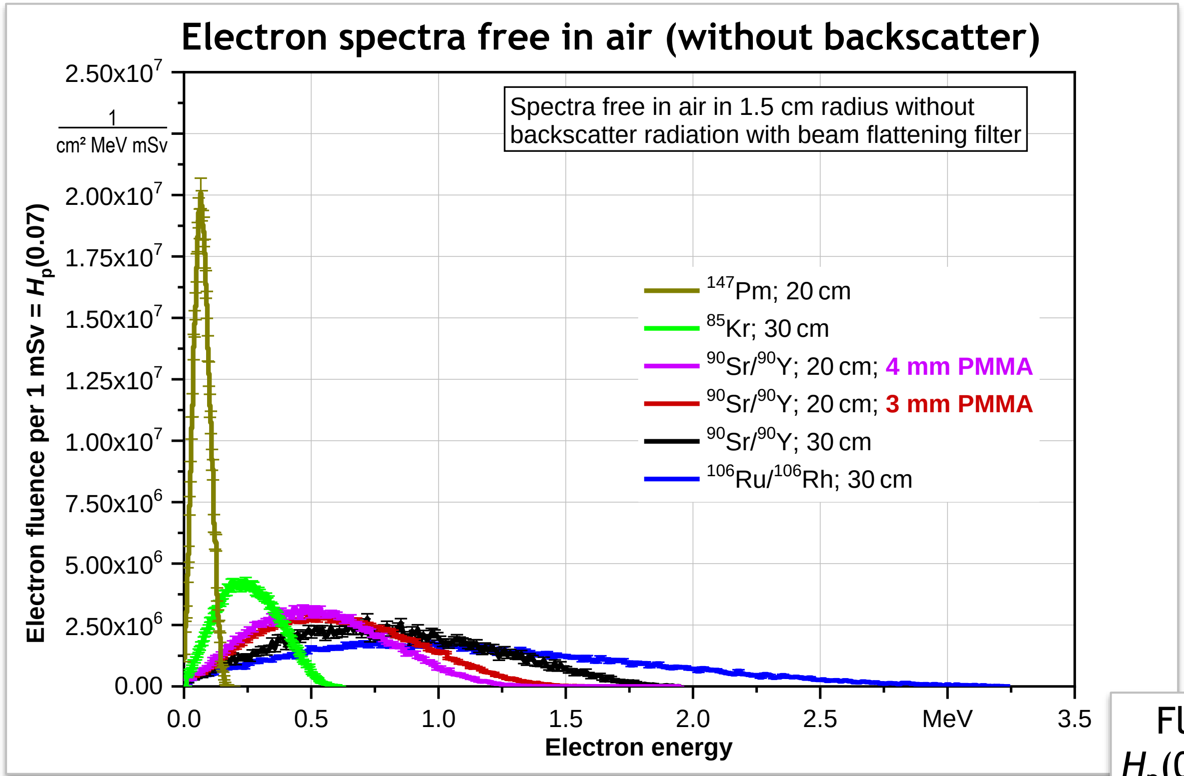
ISO 6980: Points of revision: spectra included

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

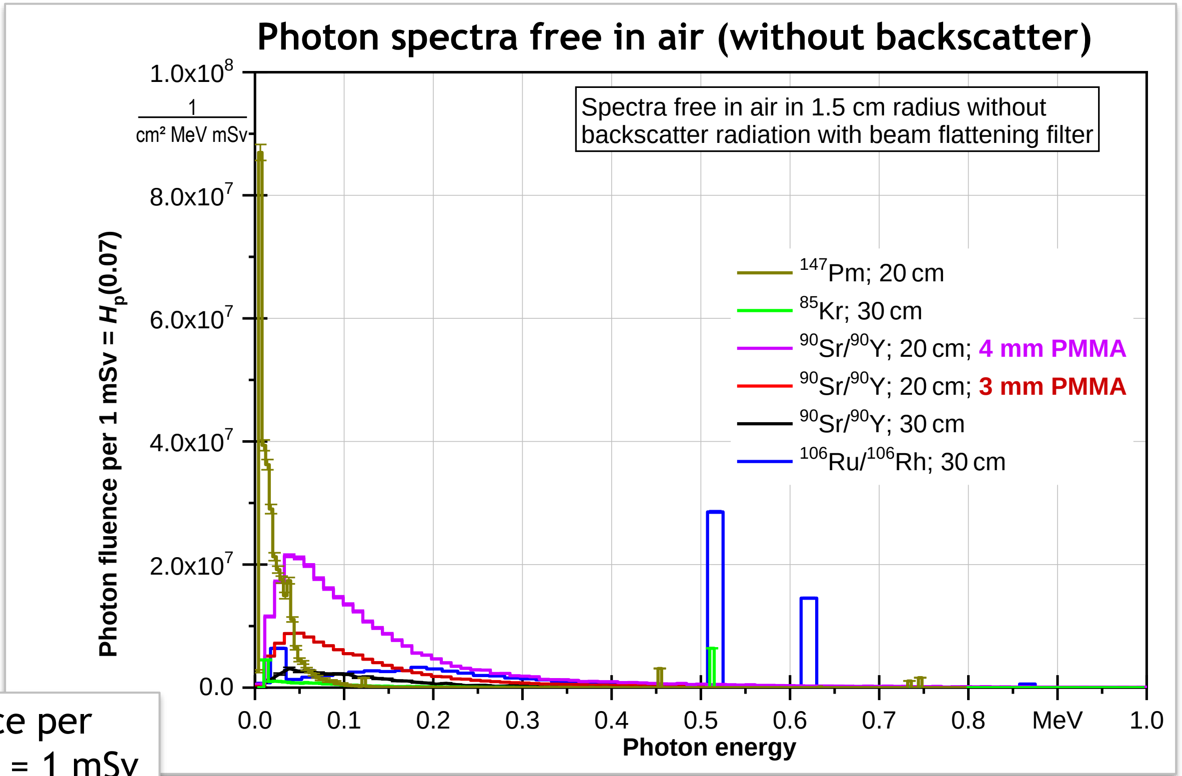
- **Electron and photon spectra** in ISO 6980: new 202x version: **free in air** (without backscatter)

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

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



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



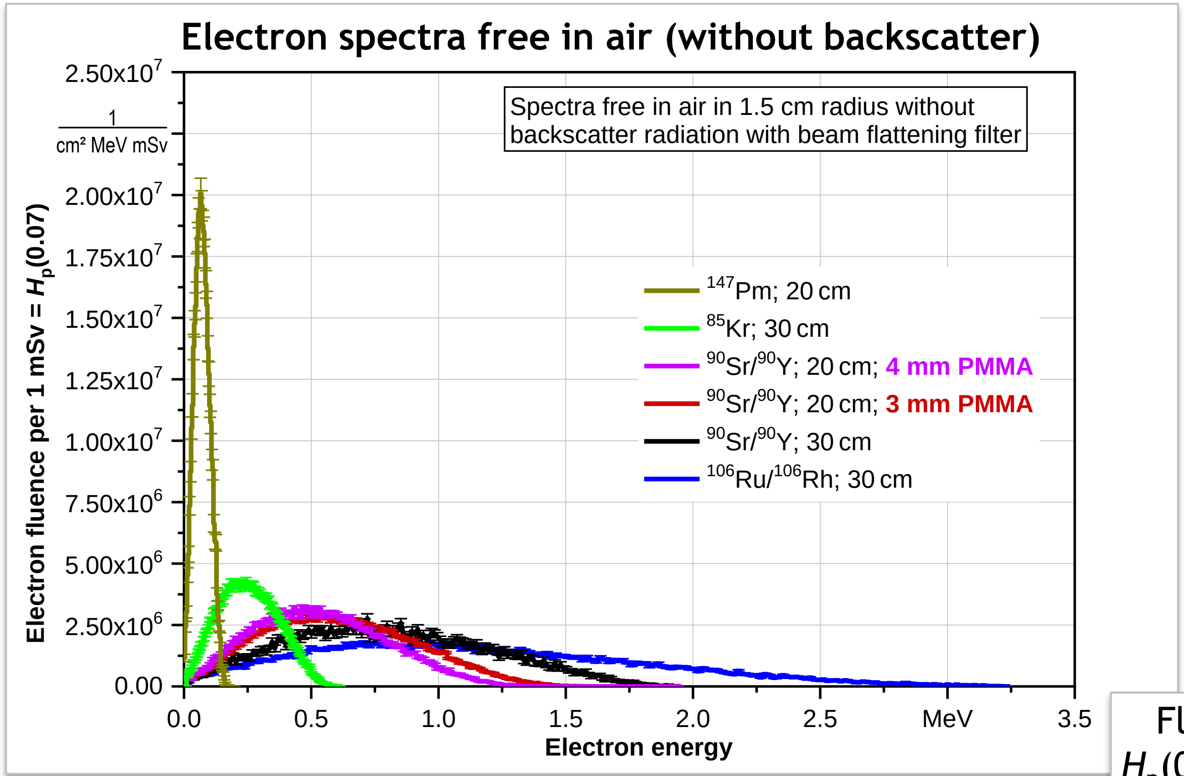
ISO 6980: Points of revision: spectra included

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

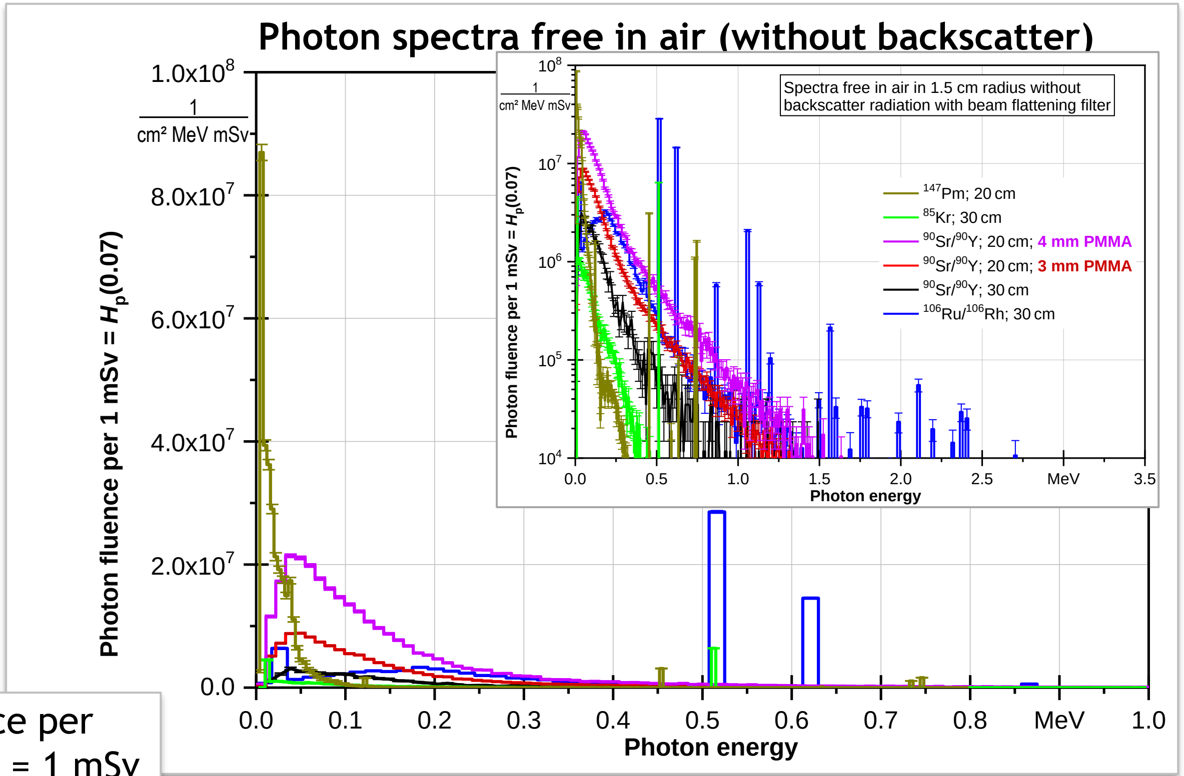
New fields: *J. Instrum. 15, P05015 (2020)*

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

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



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

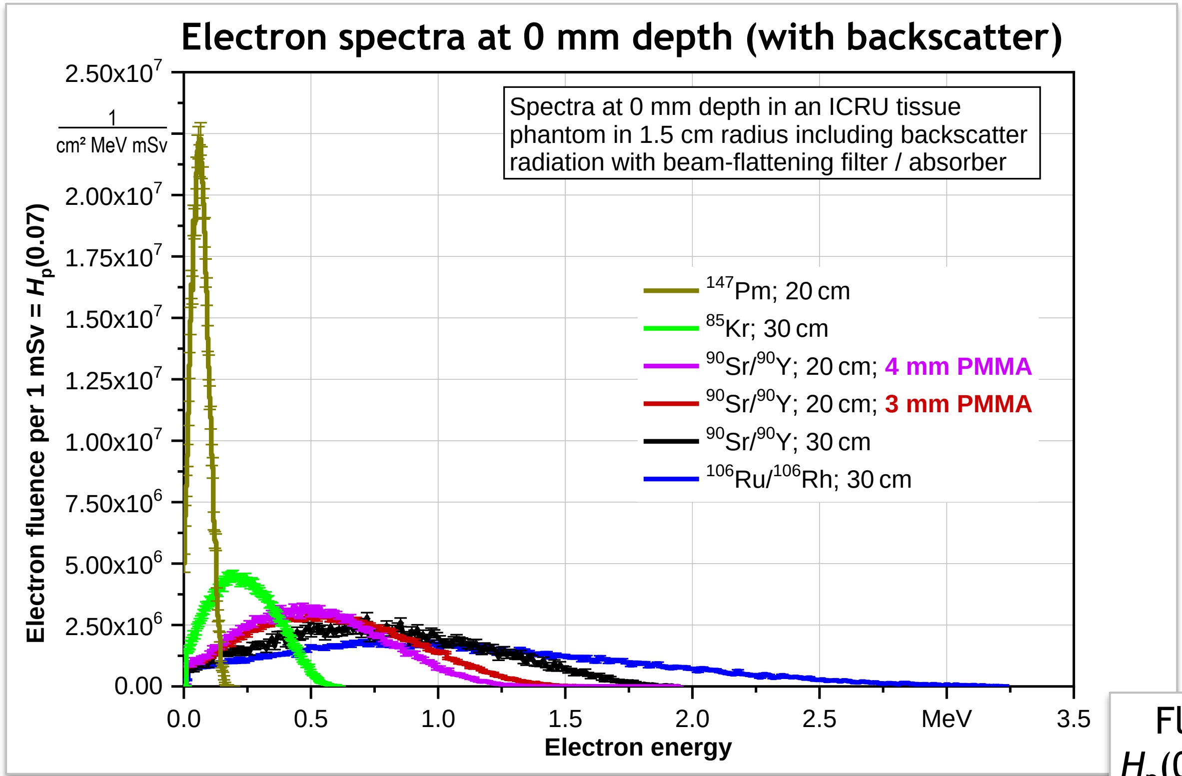


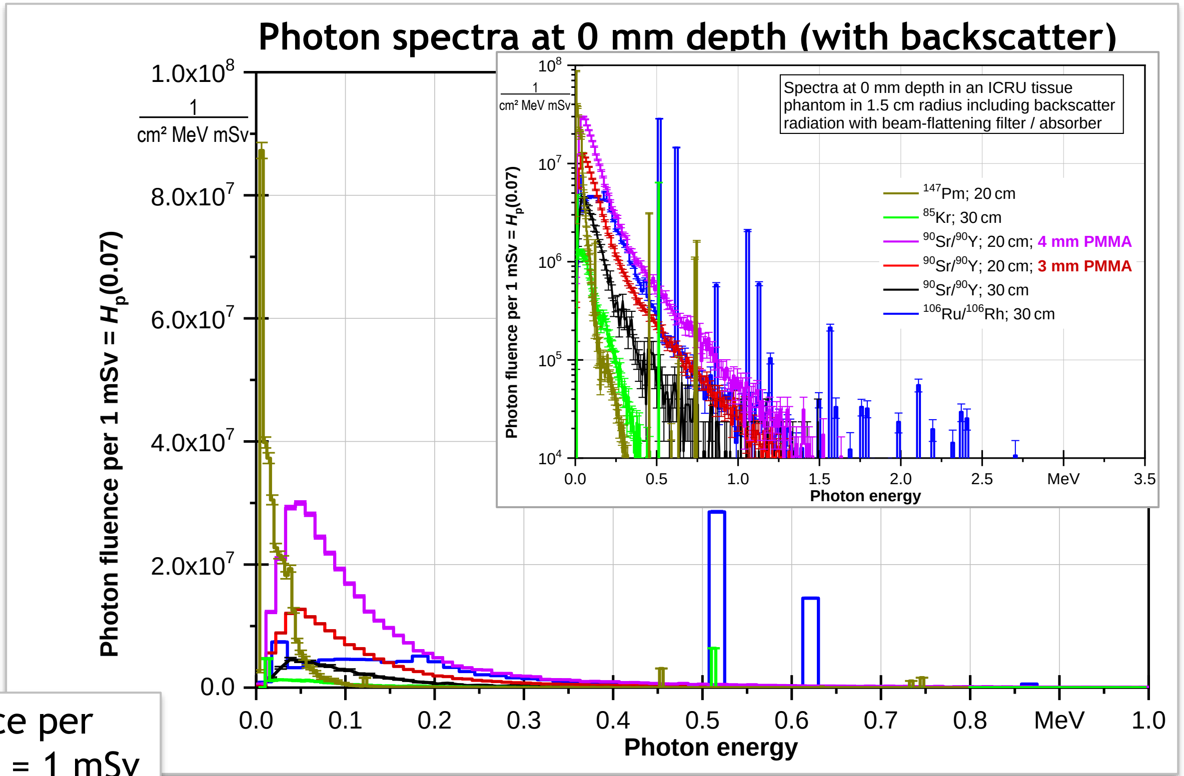
Actual fields, simulations: *J. Instrum. 8, P02019 (2013)*
and addendum J. Instrum. 14, A07001 (2019)

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

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





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

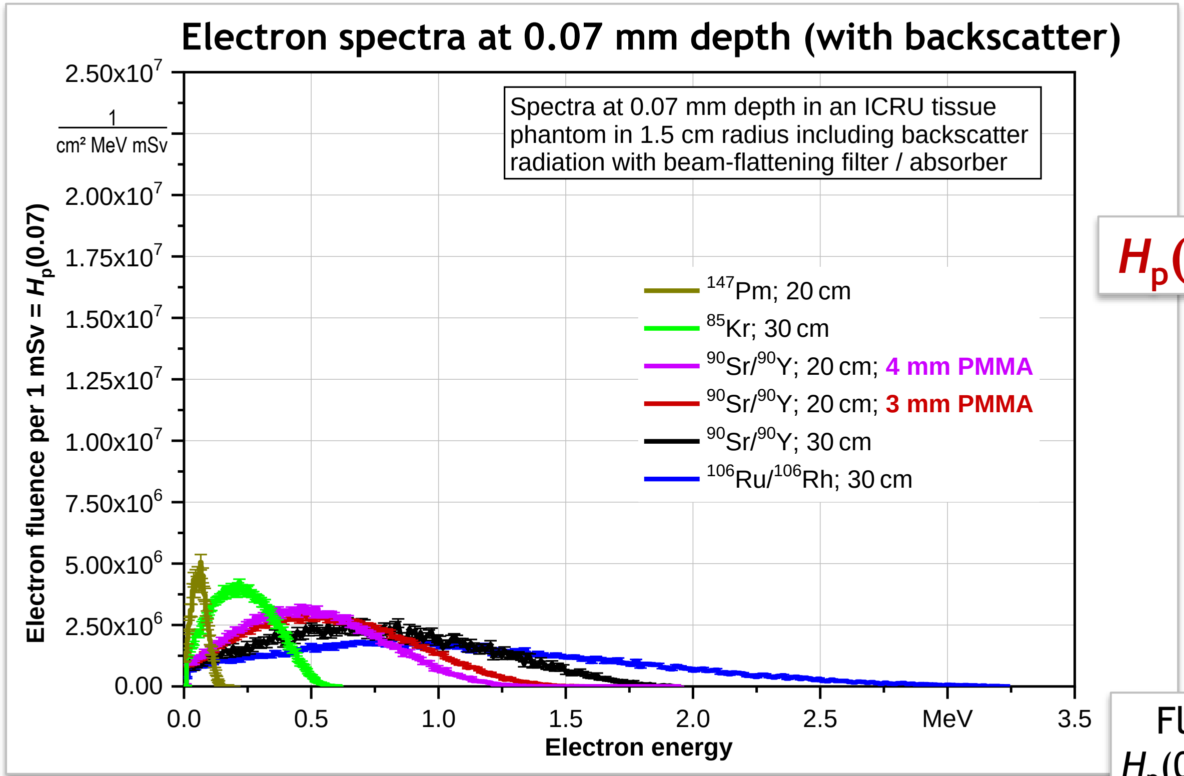
ISO 6980: Points of revision: spectra included

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

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

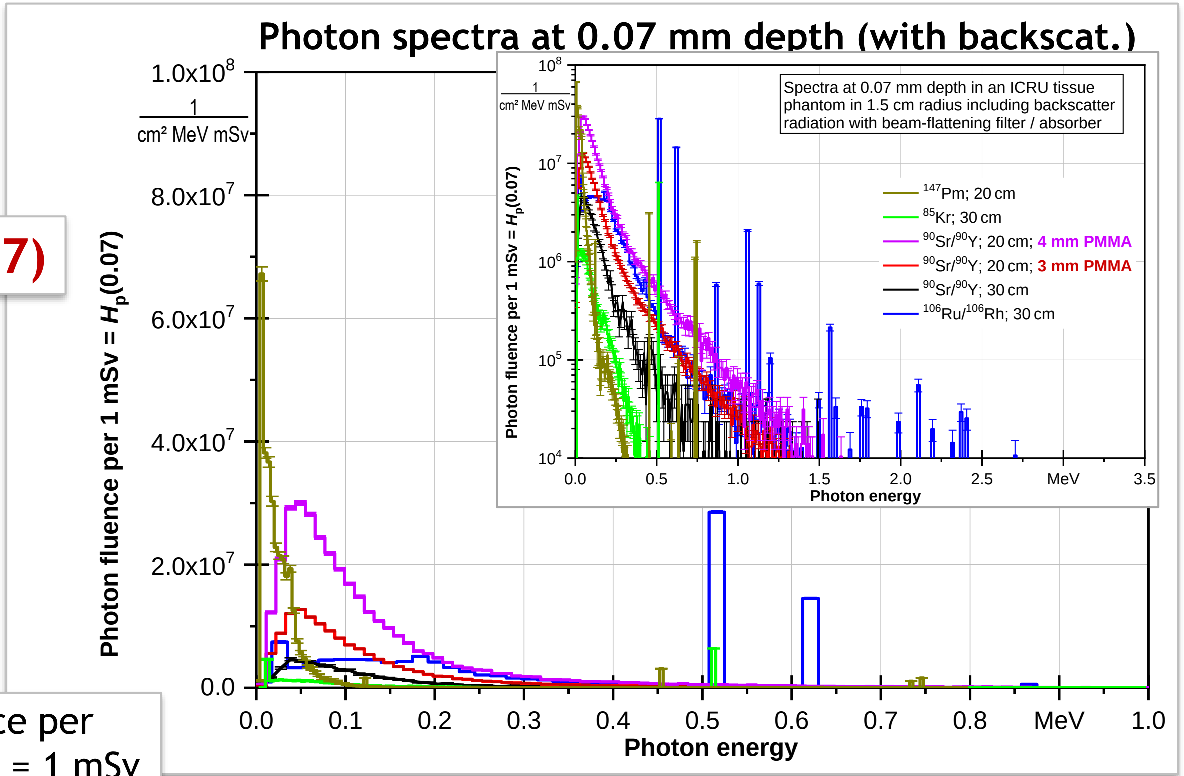
ISO 6980: Reference beta fields: *major / technical changes*

- **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



$H_p(0.07)$

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



ISO 6980: Points of revision: spectra included

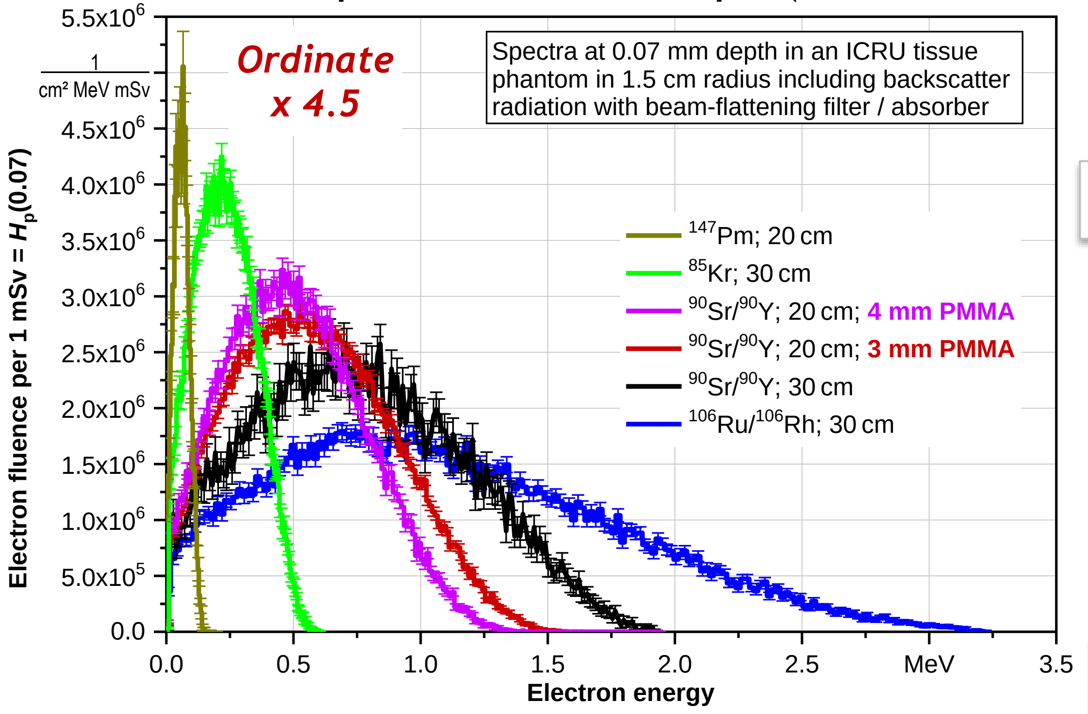
Actual fields, simulations: *J. Instrum. 8, P02019 (2013)*
and addendum J. Instrum. 14, A07001 (2019)

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

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

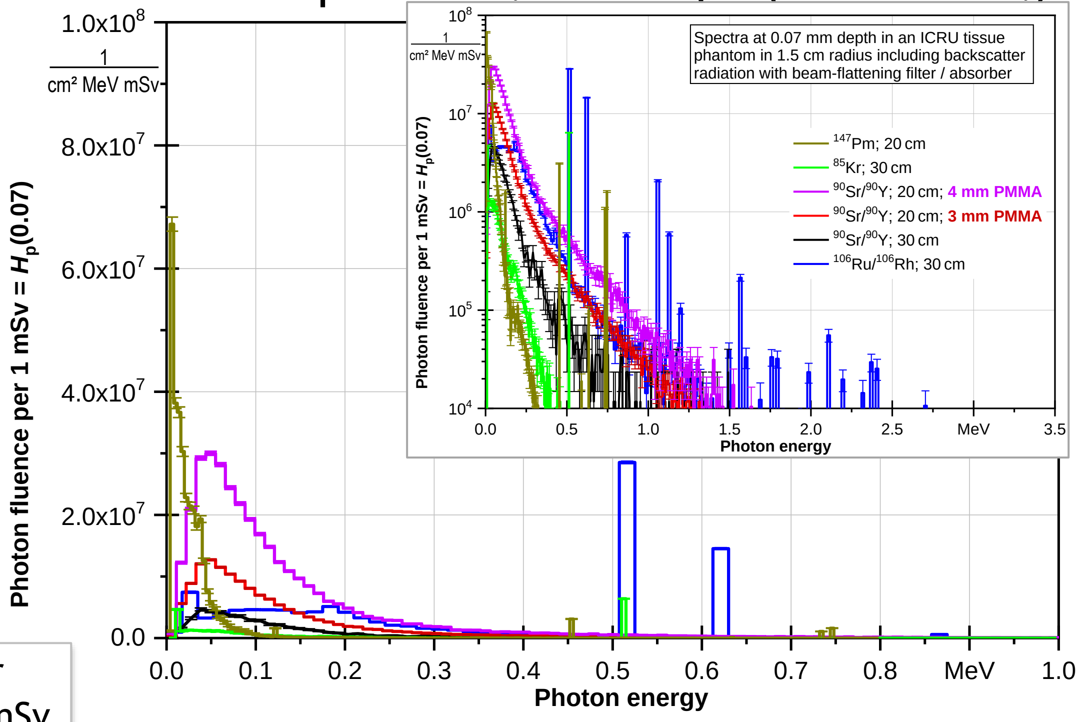
- Electron and photon spectra in ISO 6980: new 202x version:
  at 0.07 mm tissue depth (including backscatter)
  ➔ significant **absorption of low energy** electrons; photons not significantly attenuated

Electron spectra at 0.07 mm depth (with backscatter)



$H_p(0.07)$

Photon spectra at 0.07 mm depth (with backscat.)



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

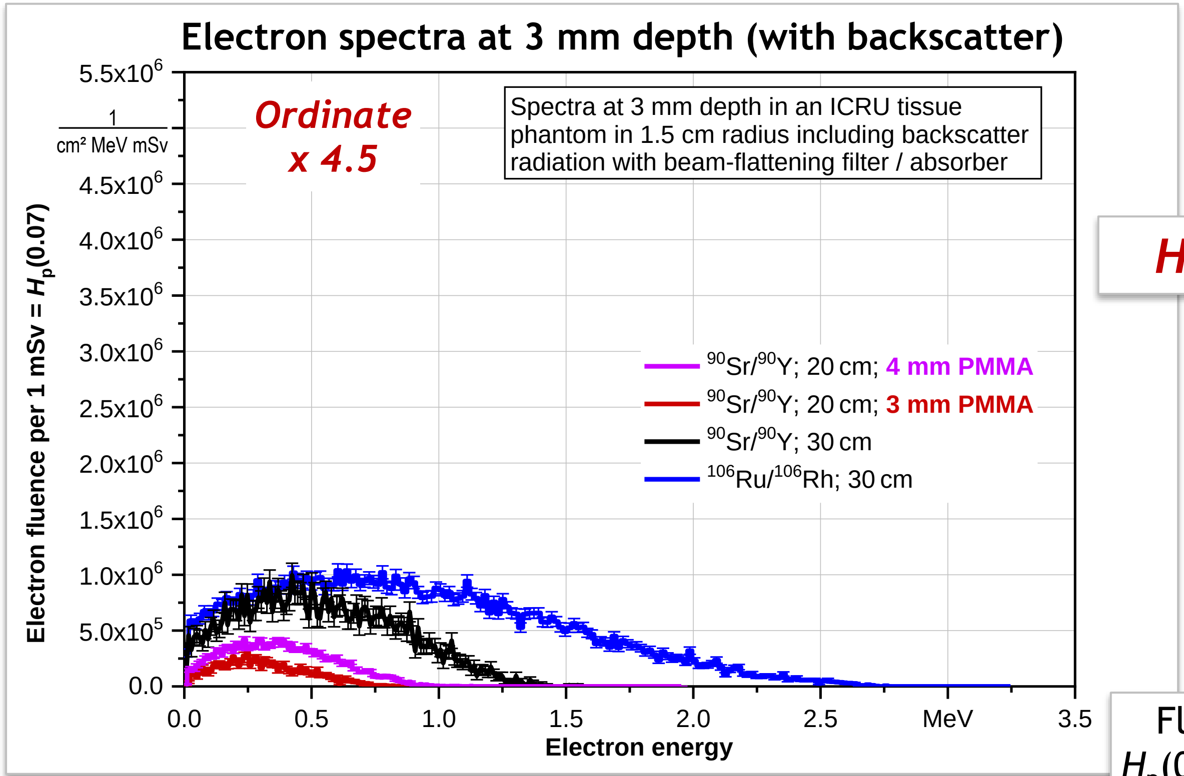
ISO 6980: Points of revision: spectra included

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

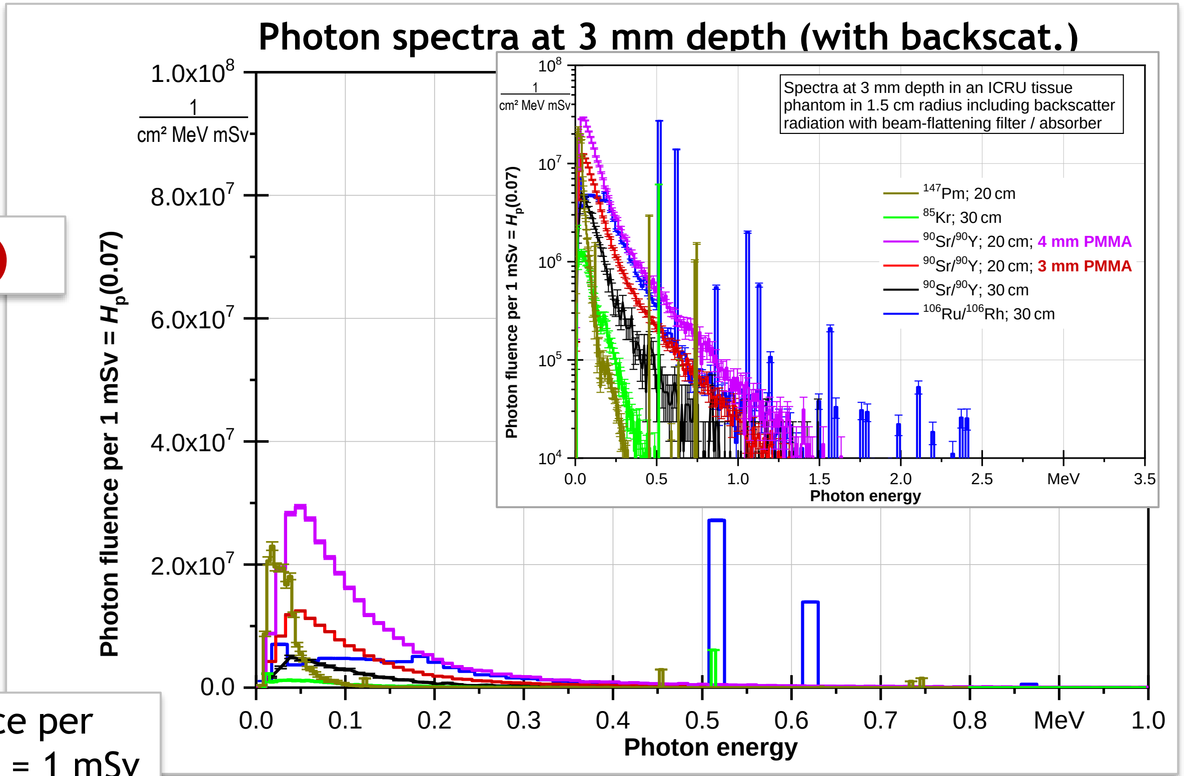
Actual fields, simulations: *J. Instrum. 8, P02019 (2013)*
and addendum J. Instrum. 14, A07001 (2019)

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

- 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



H$_p$(3)



Fluence per *H*$_p$(0.07) = 1 mSv (MC: EGSnrc)

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:

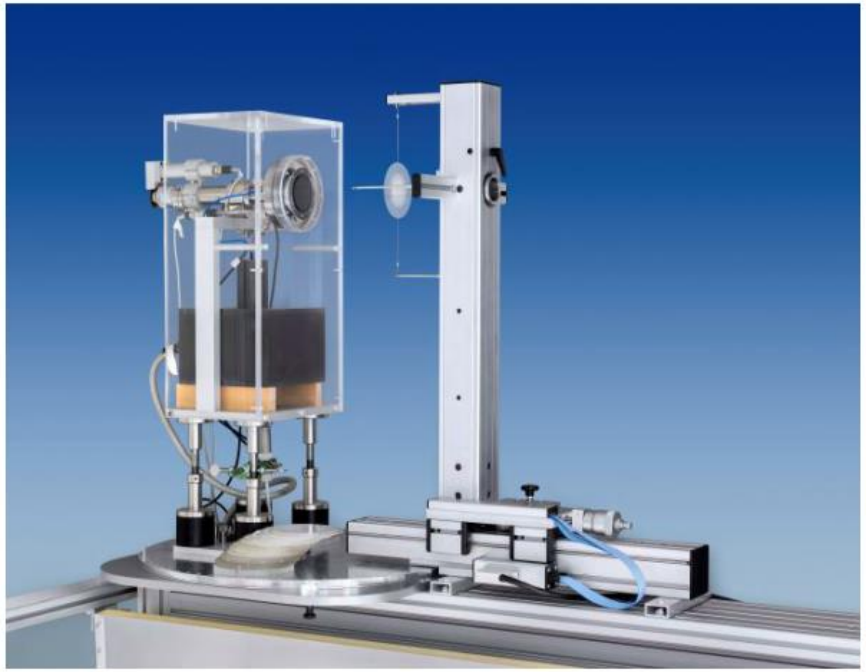
Radionuclide (source)	10 cm, without filter	11 cm, without filter	20 cm, without filter	20 cm, with filter	30 cm, without filter	30 cm, with filter	50 cm, without filter	50 cm, with filter
^{14}C	x							
^{147}Pm		**x**		**x**				
^{85}Kr						**x**		**x**
$^{90}Sr/^{90}Y$		**x**	**x**	**3 mm, 4 mm**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

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

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:
  - ➔ 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)

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

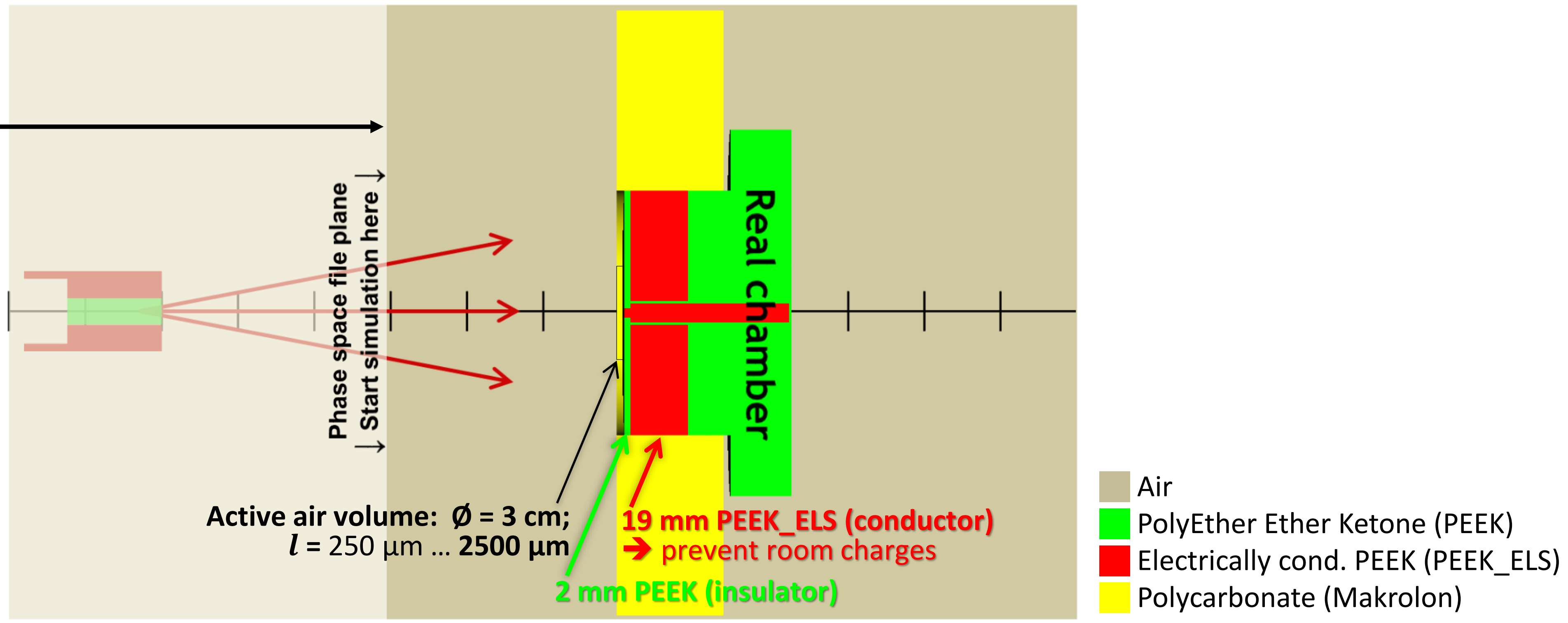
ISO 6980: Points of revision: calculated correction factors

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

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

Model of new PTB primary standard (BPS2)

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



Files (spectra) freely available:
J. Instrum. 8, P02019 (2013) &
J. Instrum. 14, A07001 (2019)

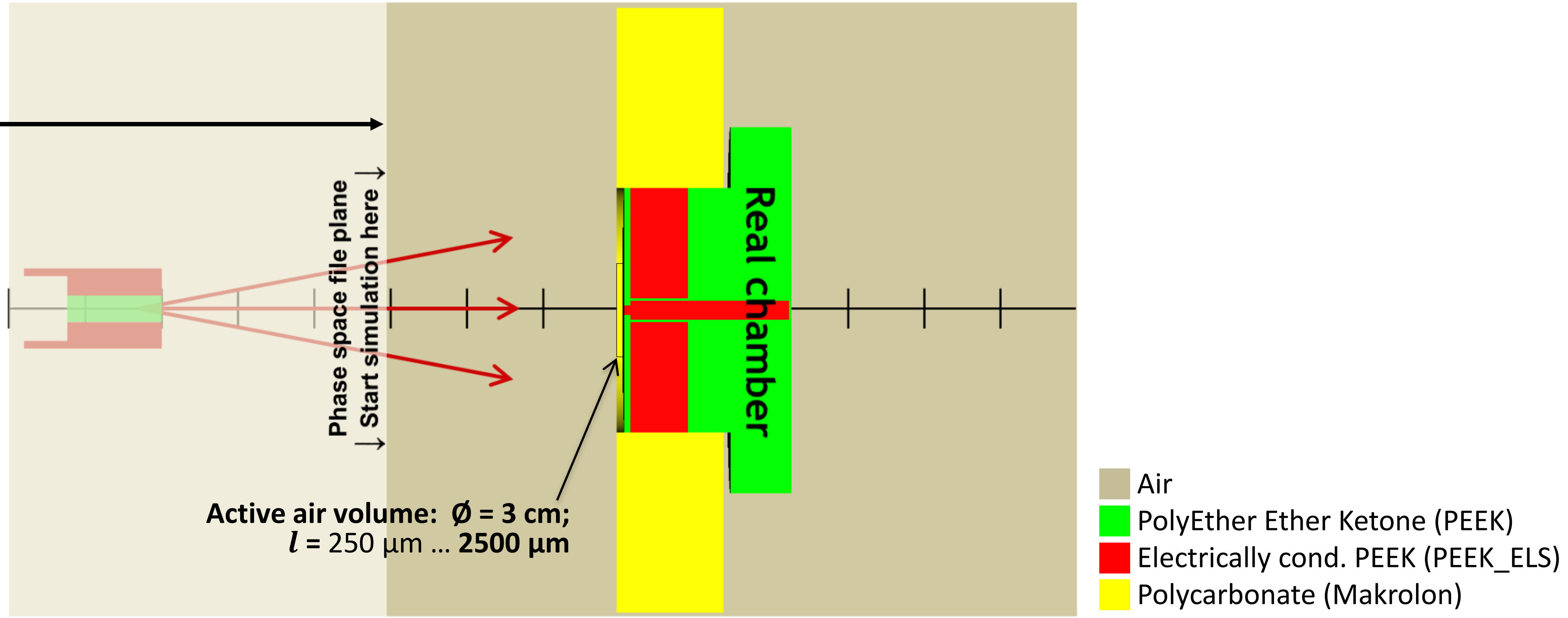
ISO 6980: Reference beta fields: *major / technical changes:* **correction factors for primary dosimetry** (EGSnrc)

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

Backscatter: k_{ba}
Sidewall perturbation: k_{pe}
Inhomogeneity in active volume: k_{ih}

Model of new PTB primary standard (BPS2)

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



Files (spectra) freely available:
J. Instrum. 8, P02019 (2013) &
J. Instrum. 14, A07001 (2019)

ISO 6980: Points of revision: calculated correction factors

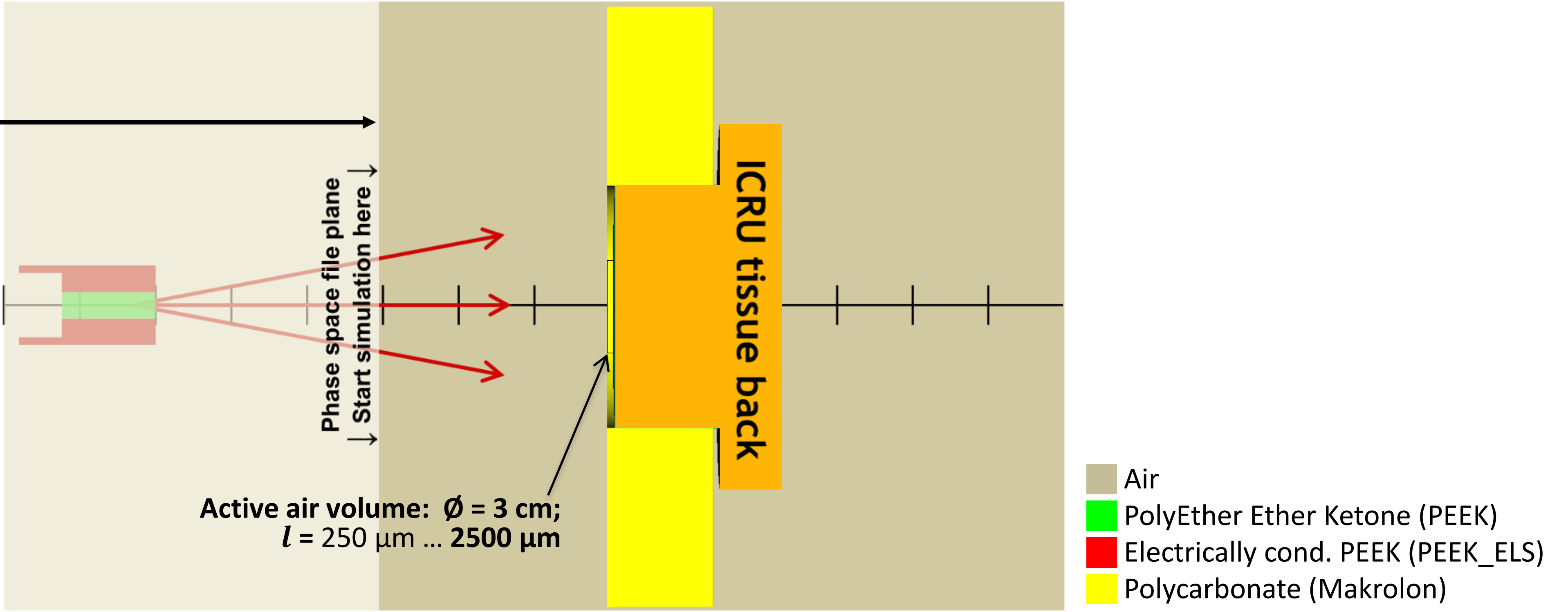
ISO 6980: Reference beta fields: *major / technical changes:* **correction factors for primary dosimetry** (EGSnrc)

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

Backscatter: $k_{ba} = D_{tissue\_back} / D_{real\_chamber}$
Sidewall perturbation: k_{pe}
Inhomogeneity in active volume: k_{ih}

Model of new PTB primary standard (BPS2)

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



Files (spectra) freely available:
J. Instrum. 8, P02019 (2013) &
J. Instrum. 14, A07001 (2019)

ISO 6980: Points of revision: calculated correction factors

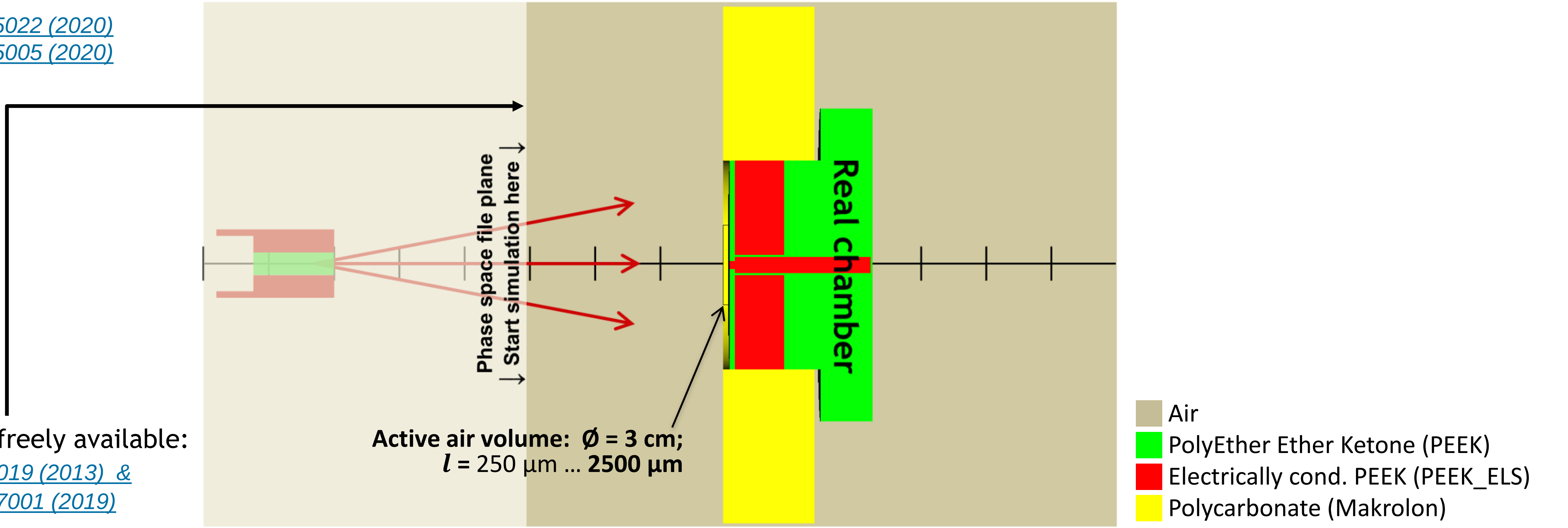
ISO 6980: Reference beta fields: *major / technical changes:* **correction factors for primary dosimetry** (EGSnrc)

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

Backscatter: $k_{ba} = D_{tissue\_back} / D_{real\_chamber}$
Sidewall perturbation: k_{pe}
Inhomogeneity in active volume: k_{ih}

Model of new PTB primary standard (BPS2)

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



Files (spectra) freely available:
J. Instrum. 8, P02019 (2013) &
J. Instrum. 14, A07001 (2019)

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):

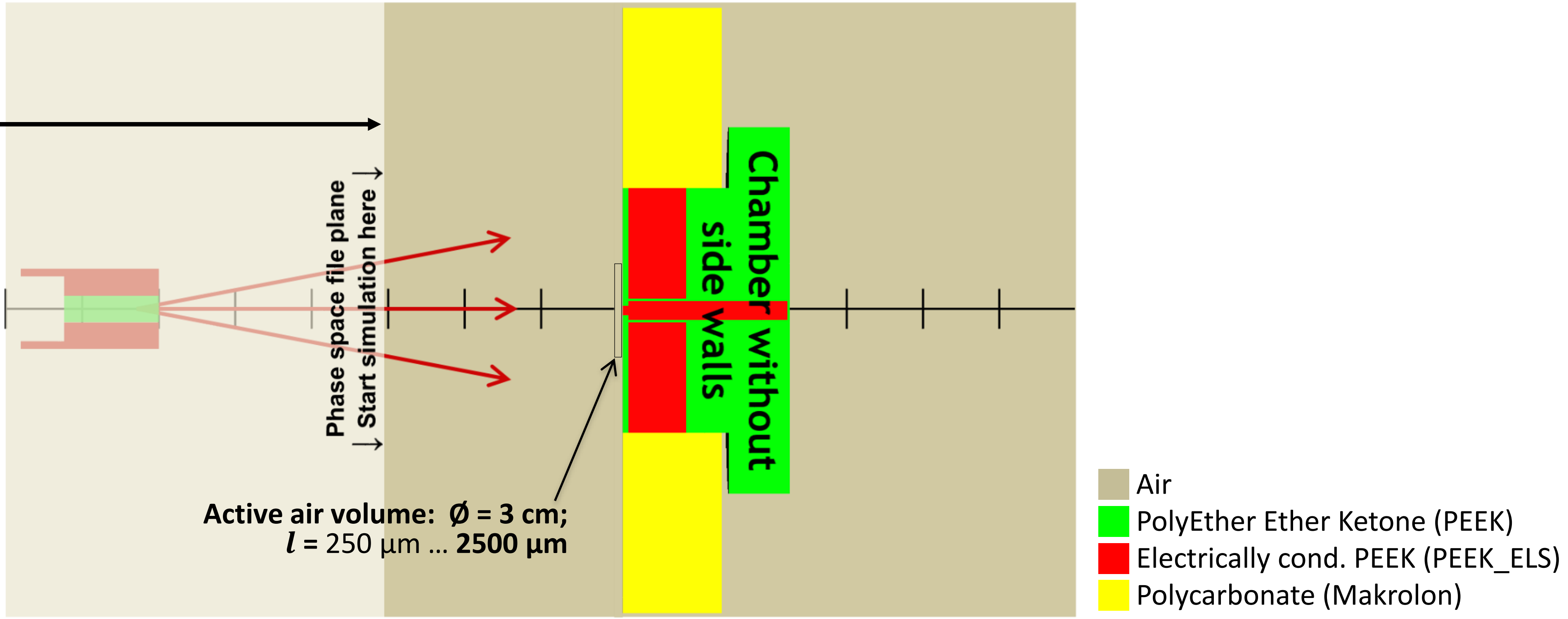
Backscatter: $k_{ba} = D_{tissue\_back} / D_{real\_chamber}$

Sidewall perturbation: $k_{pe} = D_{chamber\_without\_side\_walls} / D_{real\_chamber}$

Inhomogeneity in active volume: k_{ih}

Model of new PTB primary standard (BPS2)

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



Files (spectra) freely available:
J. Instrum. 8, P02019 (2013) &
J. Instrum. 14, A07001 (2019)

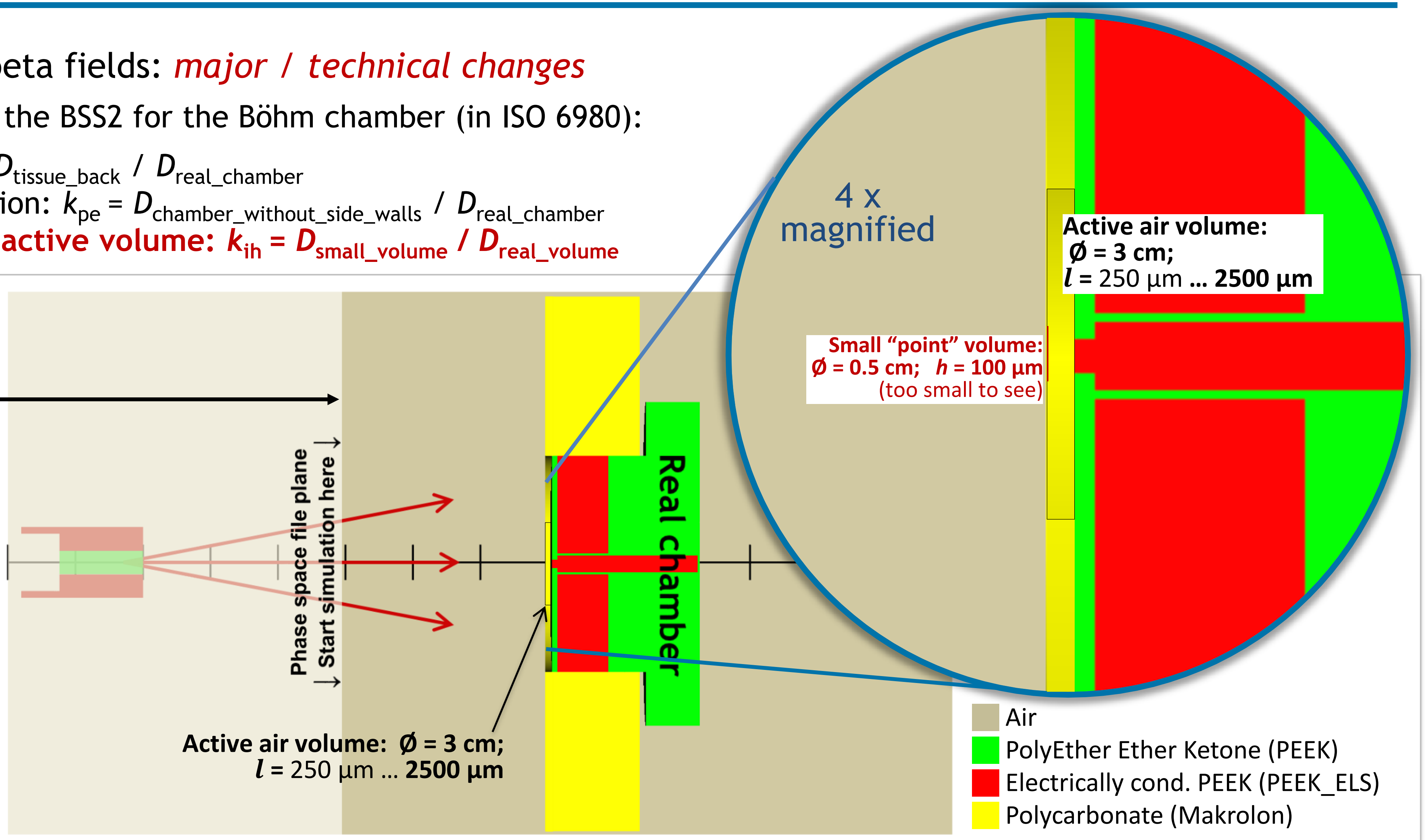
ISO 6980: Points of revision: calculated correction factors

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

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

Backscatter: $k_{ba} = D_{tissue\_back} / D_{real\_chamber}$
Sidewall perturbation: $k_{pe} = D_{chamber\_without\_side\_walls} / D_{real\_chamber}$
Inhomogeneity in active volume: $k_{ih} = D_{small\_volume} / D_{real\_volume}$

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



Files (spectra) freely available:
J. Instrum. 8, P02019 (2013) &
J. Instrum. 14, A07001 (2019)

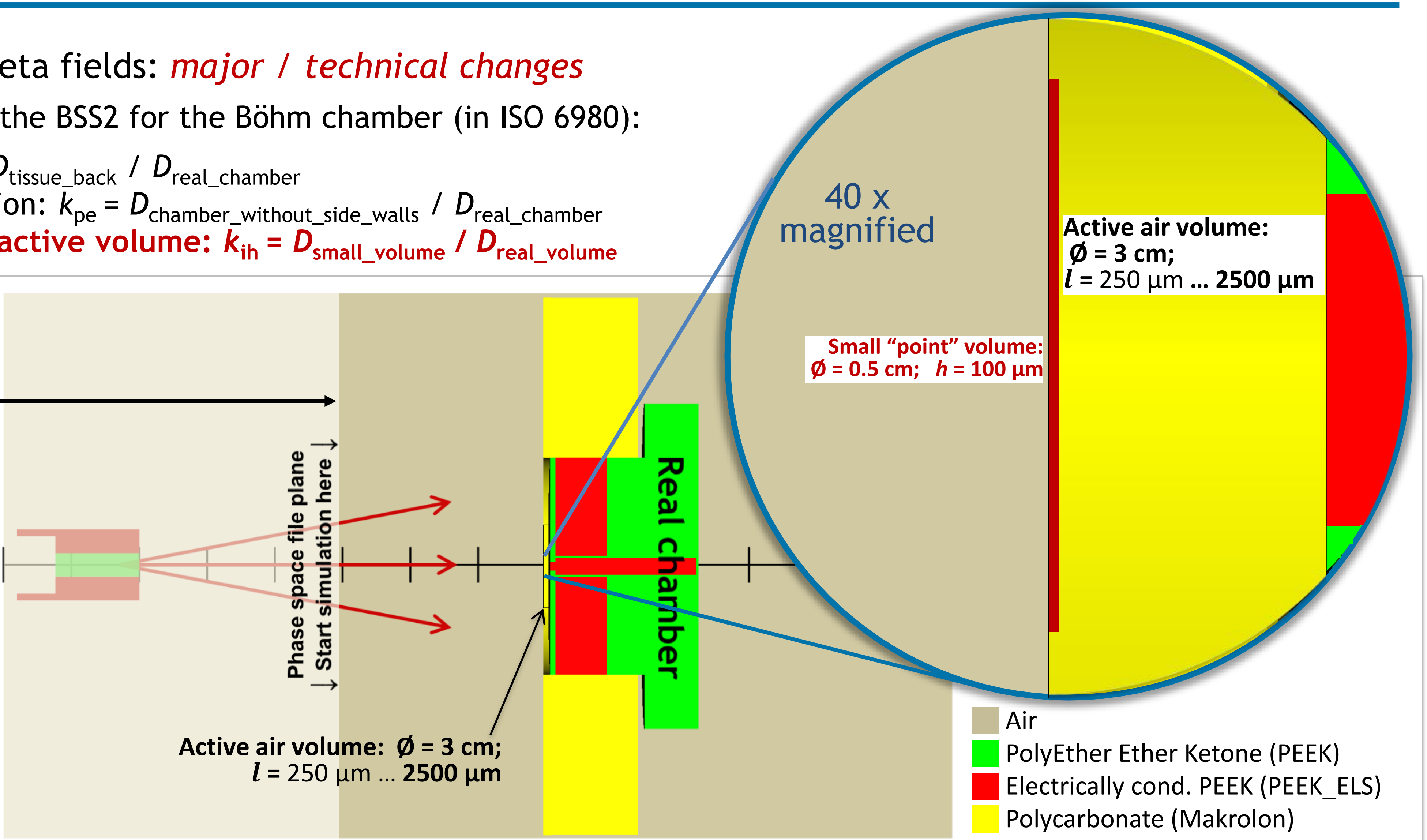
ISO 6980: Points of revision: calculated correction factors

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

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

Backscatter: $k_{ba} = D_{tissue\_back} / D_{real\_chamber}$
Sidewall perturbation: $k_{pe} = D_{chamber\_without\_side\_walls} / D_{real\_chamber}$
Inhomogeneity in active volume: $k_{ih} = D_{small\_volume} / D_{real\_volume}$

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



Files (spectra) freely available:
J. Instrum. 8, P02019 (2013) &
J. Instrum. 14, A07001 (2019)

ISO 6980: Points of revision: Spencer-Attix theory

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**:

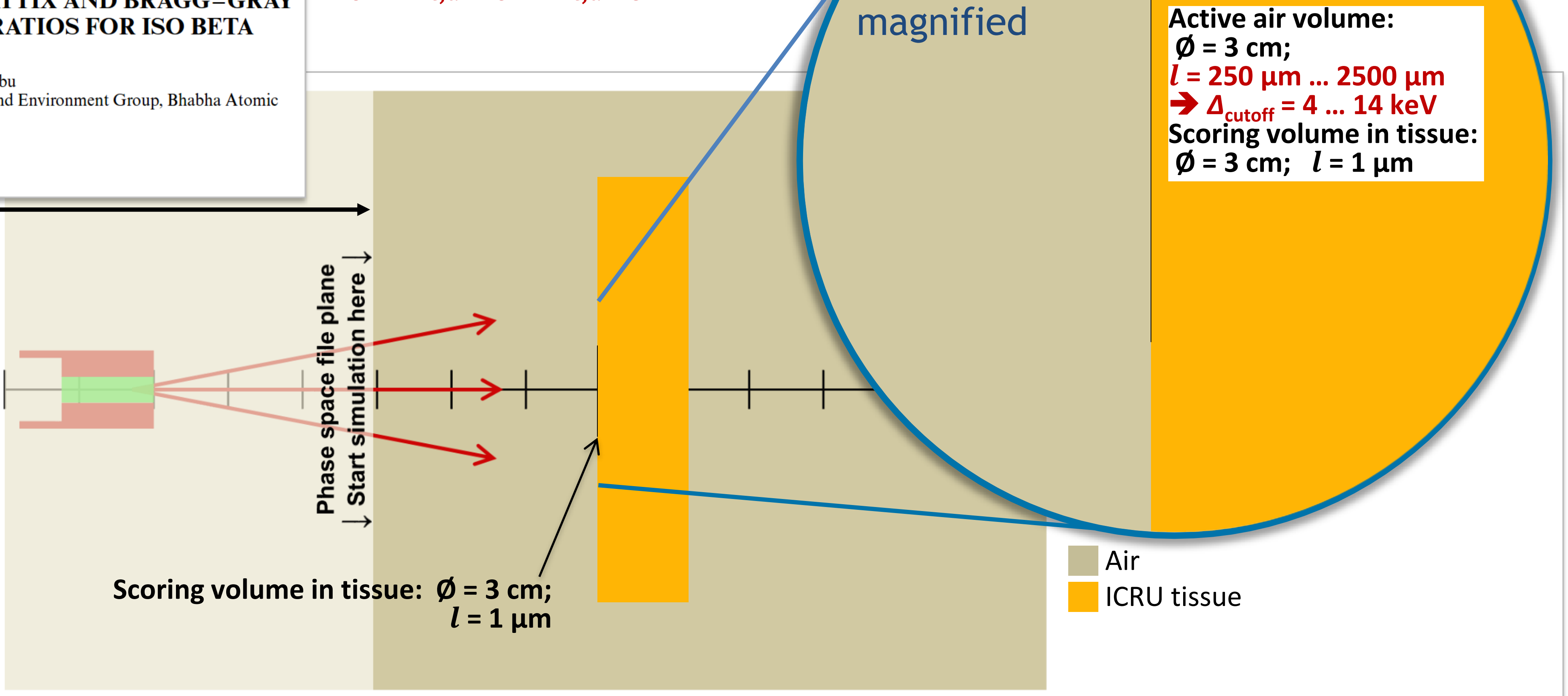
$$\dot{D}_{R\beta} = \frac{(\bar{W}_0/e)\cdot s_{t,a}}{\rho_{a0}\cdot a}\left[\frac{\mathrm{d}}{\mathrm{d}l}\{k\cdot k'\cdot I(l)\}\right]_{l=0}$$

$k_{SA} = s_{t,a}(l)_{SA} \,/\, s_{t,a,BG}$

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. Bakshi and D. A. R. Babu
Radiological Physics and Advisory Division, Health, Safety and Environment Group, Bhabha Atomic Research Centre, Trombay, Mumbai 400 085, India

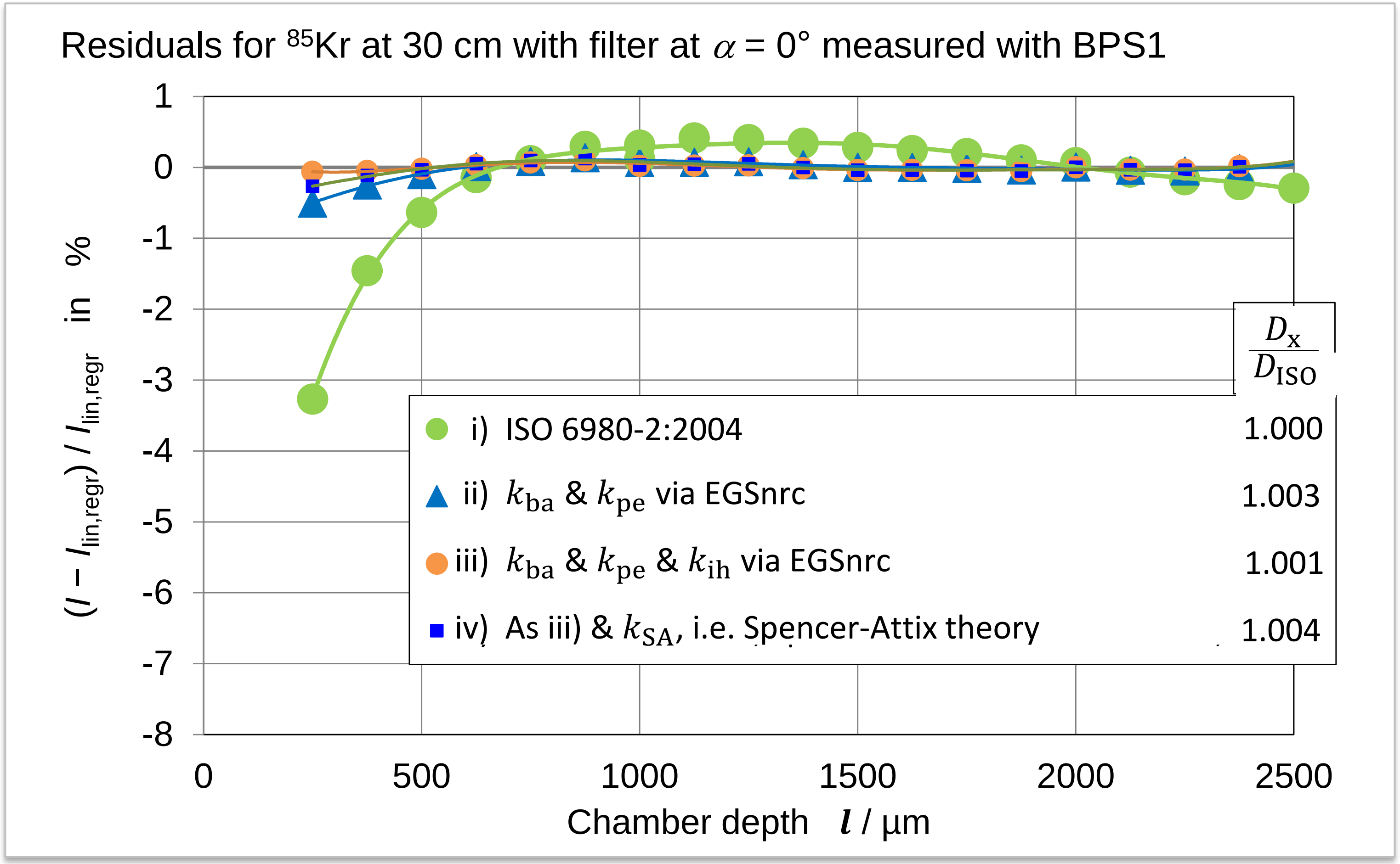
Radiat. Prot. Dosim. 168, 184 (2016)
J. Instrum. 16, P03006 (2021)

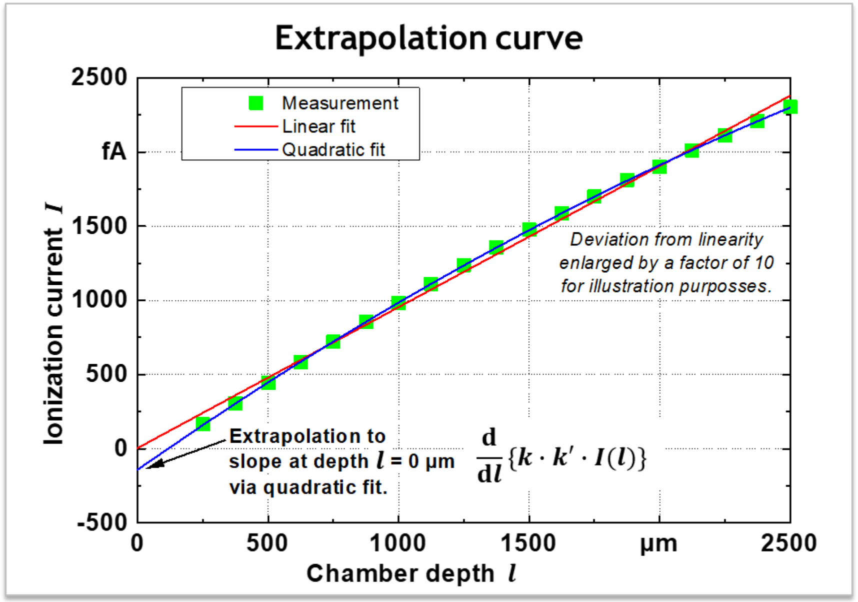


Files (spectra) freely available:
J. Instrum. 8, P02019 (2013) &
J. Instrum. 14, A07001 (2019)

ISO 6980: Points of revision: application of new corr. factors

Application of new correction factors to extrapolation curves:
for both: normal incidence, i.e. 0° …

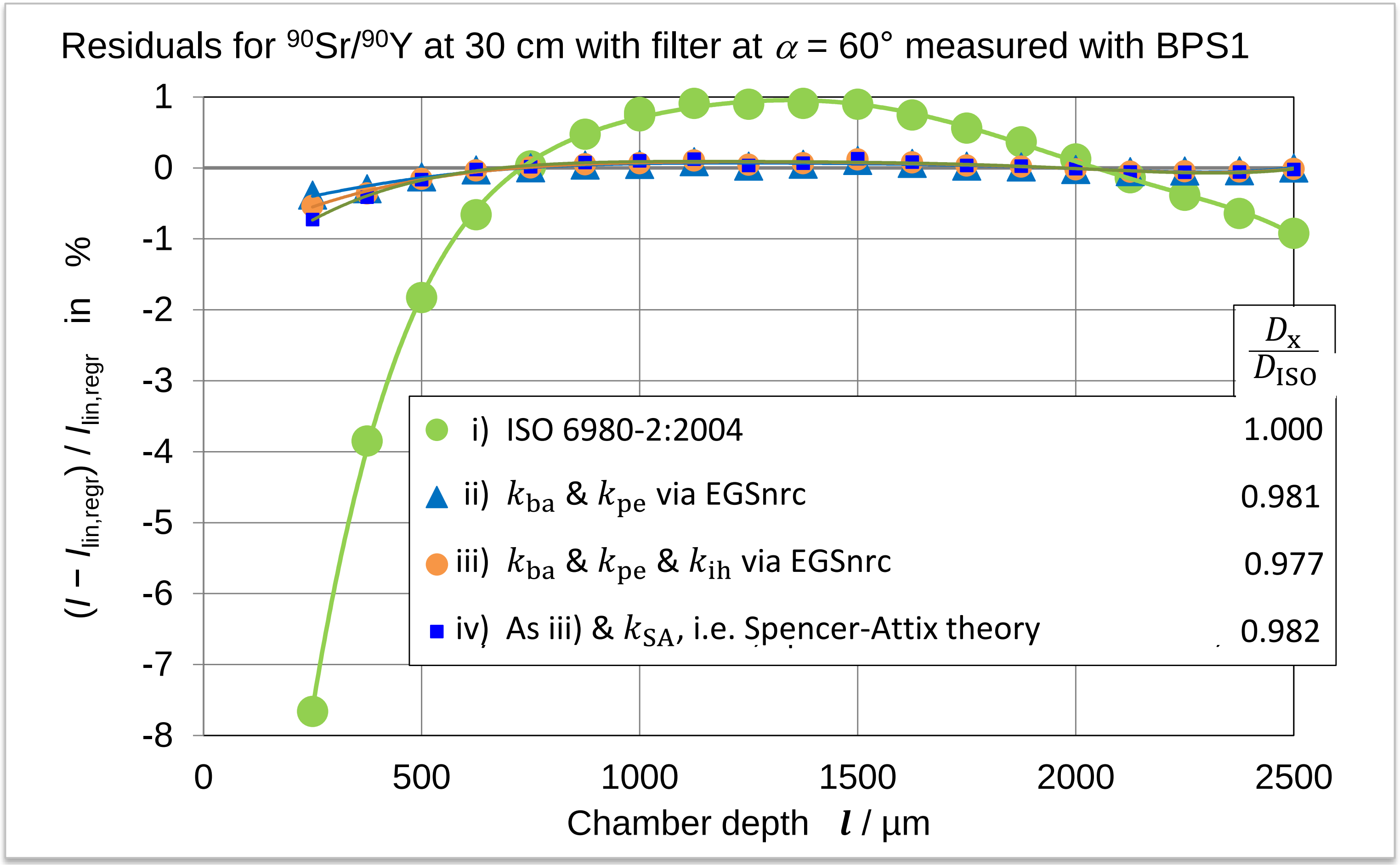


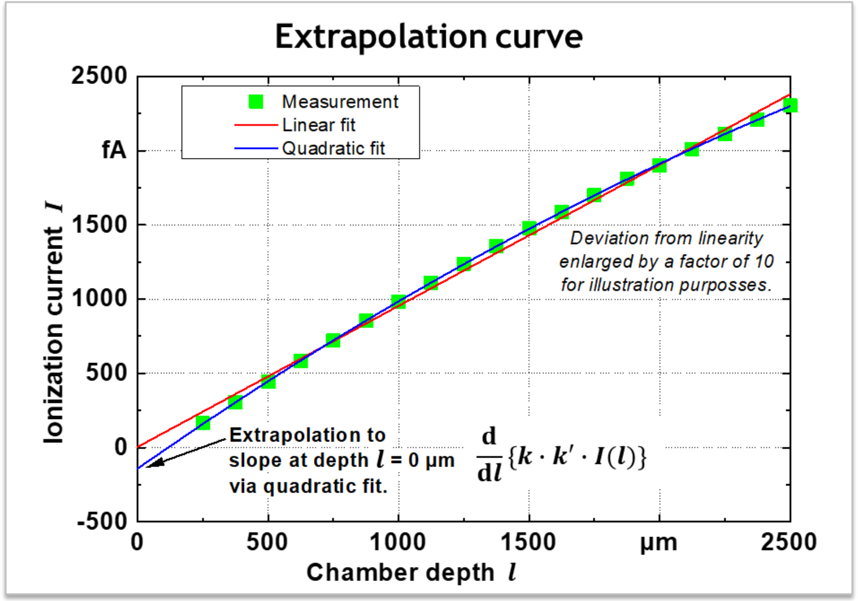


Metrologia 57, 065022 (2020)
Metrologia 57, 065005 (2020)

ISO 6980: Points of revision: application of new corr. factors

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





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

Beta standards at ISO TC85 SC2 WG2

ISO 6980: Reference beta fields (2004 .. 2006), Ed.1

Nearly all correction factors based on measurements using Böhm chamber (BPS1)

INTERNATIONAL STANDARD **ISO 6980-1**

First edition
2006-08-01

Nuclear energy — Reference beta-particle radiation —

Part 1:
Methods of production

Énergie nucléaire — Rayonnement bêta de référence —

Partie 1: Méthodes de production

INTERNATIONAL STANDARD **ISO 6980-2**

Première edition
2004-10-15

Nuclear energy — Reference beta-particle radiation —

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

Énergie nucléaire — Rayonnements bêta de référence —

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

INTERNATIONAL STANDARD **ISO 6980-3**

First edition
01

Nuclear energy — Reference beta-particle radiation —

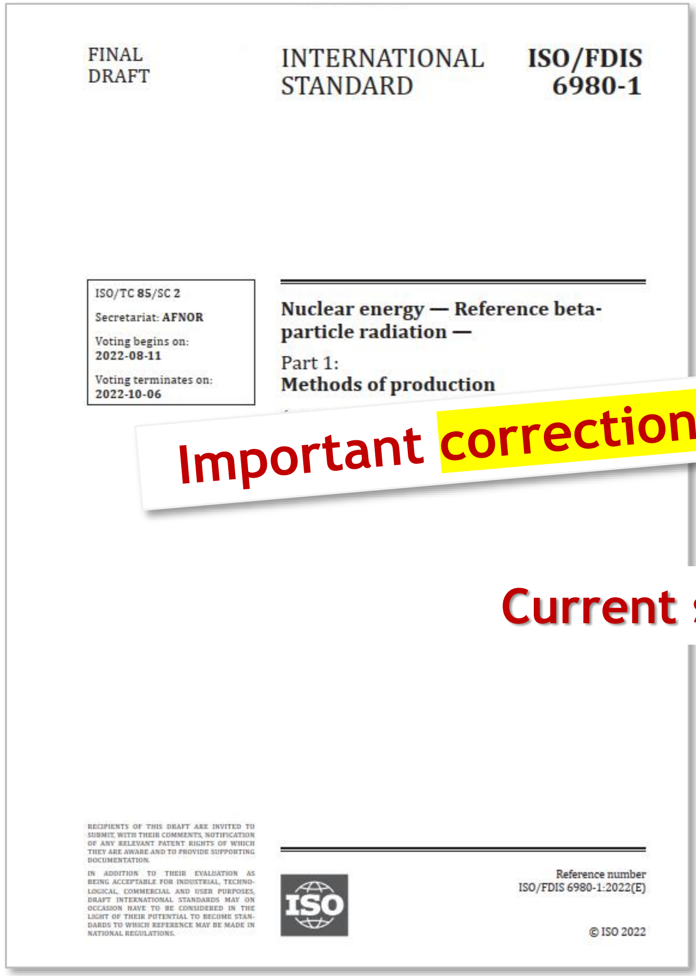
Part 3:
Calibration of area and personal dosemeters and the determination of their response as a function of beta radiation energy and angle of incidence

Énergie nucléaire — Rayonnement bêta de référence —

Partie 3: Étalonnage des dosimètres individuels et des dosimètres de zone et détermination de leur réponse en fonction de l'énergie et de l'angle d'incidence du rayonnement bêta

Beta standards at ISO TC85 SC2 WG2

ISO 6980: Reference beta fields (202x), in revision ➔ Ed.2


FINAL DRAFT

INTERNATIONAL STANDARD

ISO/FDIS 6980-1

ISO/TC 85/SC 2

Secretariat: AFNOR

Voting begins on: 2022-08-11

Voting terminates on: 2022-10-06

Nuclear energy — Reference beta-particle radiation —

Part 1: Methods of production

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Reference number ISO/FDIS 6980-1:2022(E)

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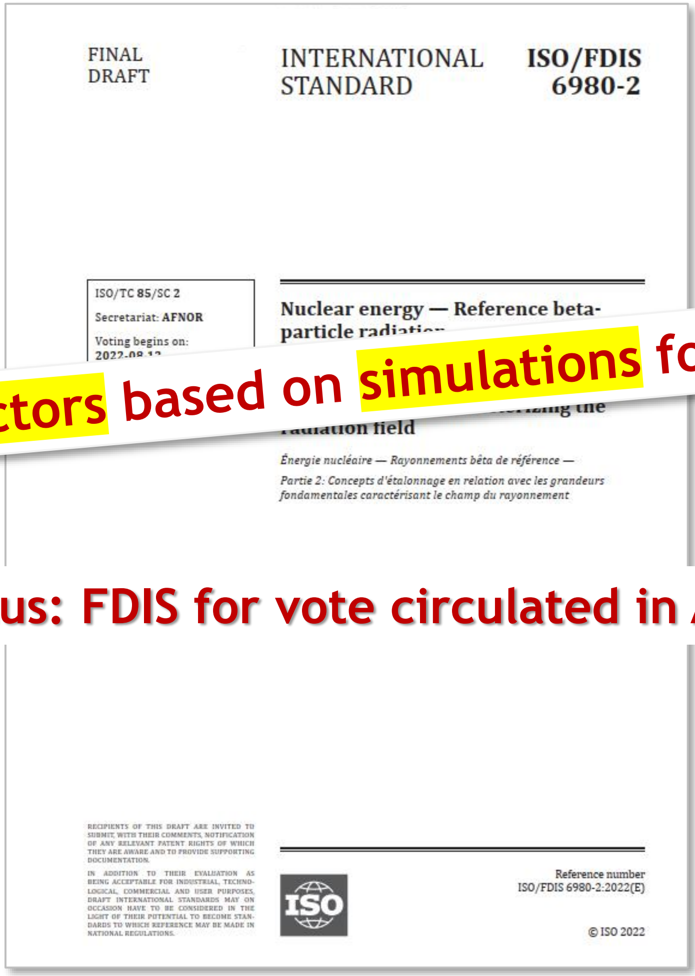
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INTERNATIONAL STANDARD

ISO/FDIS 6980-2

ISO/TC 85/SC 2

Secretariat: AFNOR

Voting begins on:

Nuclear energy — Reference beta-particle radiati…

…rizing the radiation field

Énergie nucléaire — Rayonnements bêta de référence —

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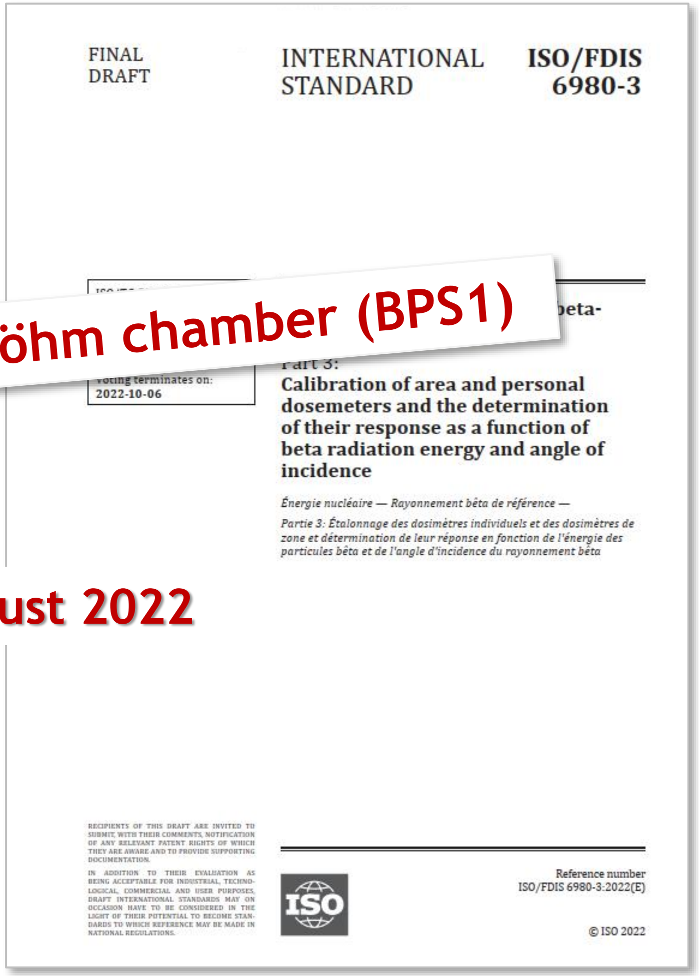
FINAL DRAFT

INTERNATIONAL STANDARD

ISO/FDIS 6980-3

Voting terminates on: 2022-10-06

…beta-

Part 3:

Calibration of area and personal dosemeters and the determination of their response as a function of beta radiation energy and angle of incidence

Énergie nucléaire — Rayonnement bêta de référence —

Partie 3: Étalonnage des dosimètres individuels et des dosimètres de zone et détermination de leur réponse en fonction de l'énergie des particules bêta et de l'angle d'incidence du rayonnement bêta

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Reference number ISO/FDIS 6980-3:2022(E)

© ISO 2022

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

Current status: FDIS for vote circulated in August 2022

Revision of the series ISO 6980

References:

R. Behrens, 2011 *Extensions to the Beta Secondary Standard BSS 2*: J. Instrum. **6**, P11007 (2012) and Erratum J. Instrum. **7**, E04001 (2012) and Addendum J. Instrum. **7**, A05001 (2012)

R. Behrens, 2011 & 2019 *Simulation of the radiation fields of the Beta Secondary Standard BSS 2*: J. Instrum. **8**, P02019 (2013) & Addendum J. Instrum. **14**, A07001 (2019)

R. Behrens, 2015 *Correction factors for the ISO rod phantom, a cylinder phantom, and the ICRU sphere for reference beta radiation fields of the BSS 2*: J. Instrum. **10**, P03014 (2015)

T.P. Selvam et al., 2016 *Monte Carlo-based Spencer-Attix and Bragg-Gray tissue-to-air stopping power ratios for ISO beta sources*: Radiat. Prot. Dosim. **168**, 184-189 (2016)

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)

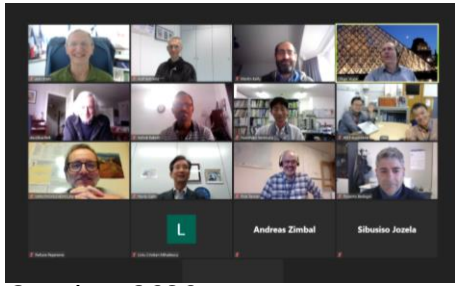
R. Behrens, 2020 *Correction factors for two new reference beta radiation fields*: Metrologia **57**, 065005 (2020)

T. Palani Selvam, V. Shrivastava and A.K. Bakshi, 2021 *Monte Carlo calculation of Spencer-Attix and Bragg-Gray stopping-power ratios of tissue-to-air for ISO reference beta sources – an EGSnrc study*: J. Instrum. **16**, P03006 (2021)

List of standards:
www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung_6/6.3/information/norm_lst.pdf

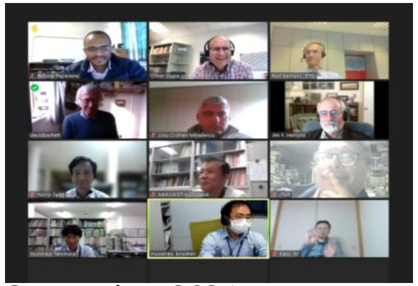
The author wishes to thank the members of ISO TC85 SC2 WG2 SG0 (Betas):

May 2019 (Okayama, Japan)



October 2020

March 2021



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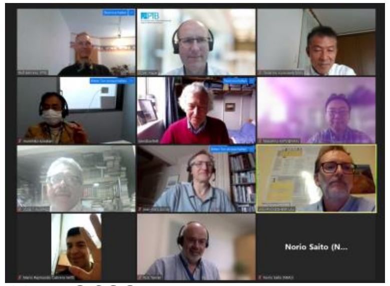


May 2022

Contents

Newly proposed operational quantities (ICRU 95)


Volume 20 • Number 1 • 2020

Journal of the ICRU

ICRU REPORT 95

Operational Quantities for External Radiation Exposure

ICRP

INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS

CCRI webinar by Thomas Otto
October 12, 2021 (PDF and video):

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

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

IM2022 contribution
April 26, 2022 (PDF and video):

PTB Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

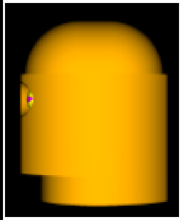
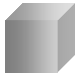
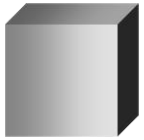
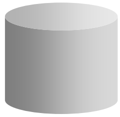
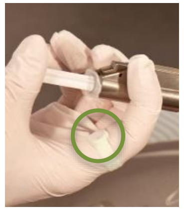
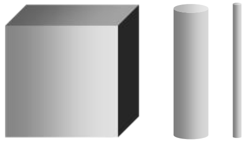
Calibrations and irradiations in terms of the newly proposed ICRU operational quantities for radiation protection in photon and beta reference radiation fields
Or
Newly proposed ICRU/ICRP operational quantities: conversion coefficients for photon and beta reference radiation fields (ISO 4037 and ISO 6980)

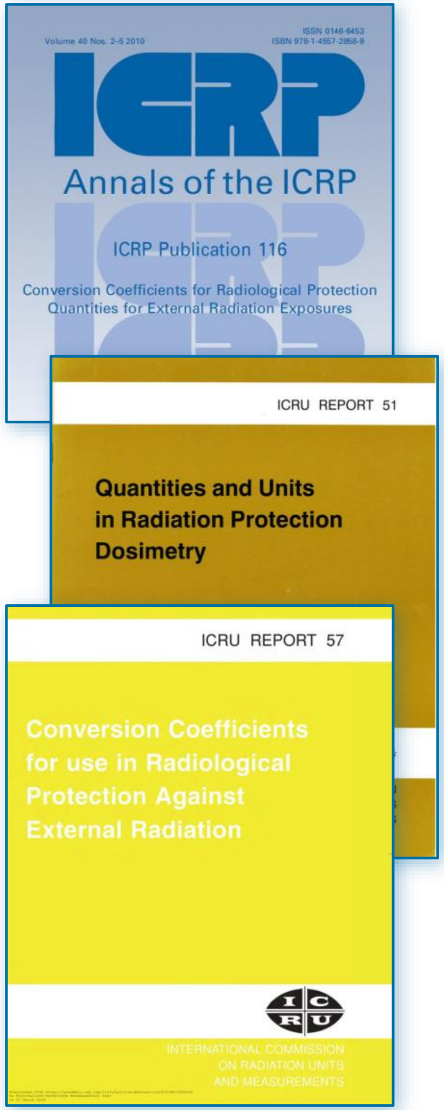
Rolf Behrens
ORCiD: 0000-0002-4905-7791
PTB, Department "Radiation protection dosimetry" (6.3)

IM 2022 NEUDOS 14

Protection quantities vs. current operational quantities (ICRU 51 / 57)

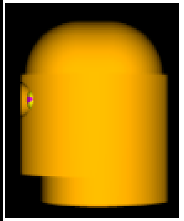
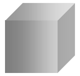
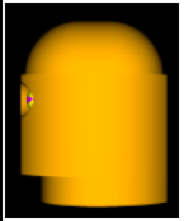
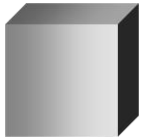
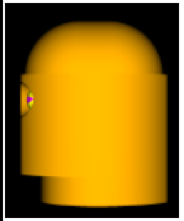
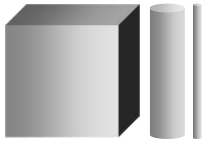
Sievert

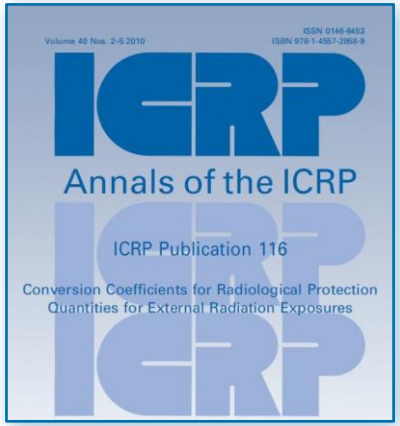
	Whole body	Lens of the eye	Local skin
Protection quantities (ICRP 116)	 ICRP reference voxel phantoms: $E_{eff} = \sum_T w_T \sum_R w_R D_{T,R}$ Simulations: $\boldsymbol{h_{Eeff} = E_{eff}\, \Phi}$	 Stylized eye model; whole lens (ICRP 116, Annex F): $H_{lens} = \sum_R w_R D_{lens,R}$ $\boldsymbol{d_{lens}(\Omega) = D_{lens}(\Omega) / \Phi}$	 Tissue-equivalent cube ($10x10x10\ cm^3$); $1\ cm^2$ area at 50 – 100 µm depth (ICRP 116, Annex G): $\boldsymbol{H_{local\ skin} = \sum_R w_R D_{local\ skin,R}}$
Operational quantities: definition: $H = Q(L) \cdot D$			
Operational quantities for monitoring (ICRU 51/57) — Area	 ICRU 4-element tissue sphere: Ø = 30 cm: $H^*(10) = Q \cdot D(10)_{sph}$	 ICRU 4-element tissue sphere: Ø = 30 cm: $H'(3;\Omega) = Q \cdot D(3;\Omega)_{sph}$	 ICRU 4-element tissue sphere: Ø = 30 cm: $H'(0.07;\Omega) = Q \cdot D(0.07;\Omega)_{sph}$
Individual	 $H_p(10) = Q \cdot D(10)_{pers}$  For calibration: ICRU 4-element tissue slab: $30x30x15\ cm^3$: $H_p(10) = Q \cdot D(10)_{slab}$	 $H_p(3) = Q \cdot D(3)_{pers.}$  For calibration: ICRU 4-element cylinder: Ø = h = 20 cm: $H_p(3) = Q \cdot D(3)_{cylinder}$	 $H_p(0.07) = Q \cdot D(0.07)_{pers.}$  For calibration: ICRU 4-el. tissue slab, pillar, rod (Ø = 73, 19 mm): $H_p(0.07) = Q \cdot D(0.07)_{slab,\ pillar,\ rod}$



Protection quantities vs. proposed operational quantities (ICRU 95)

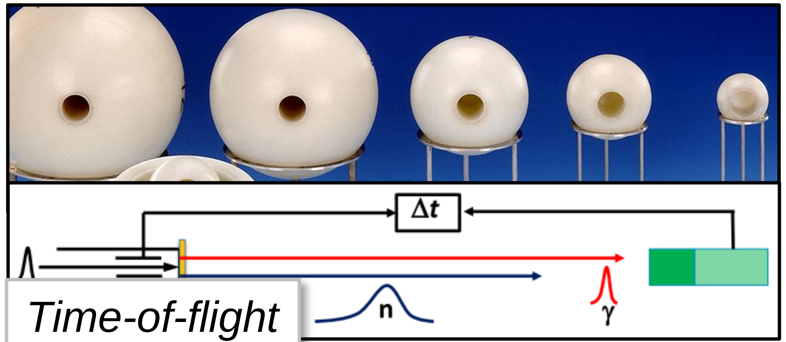
Sievert

	Whole body	Lens of the eye	Local skin
Protection quantities (ICRP 116)	 ICRP reference voxel phantoms: $E_{eff} = \sum_T w_T \sum_R w_R D_{T,R}$ Simulations: $\mathbf{h_{Eeff} = E_{eff}\,\Phi}$	 Stylized eye model; whole lens (ICRP 116, Annex F): $H_{lens} = \sum_R w_R D_{lens,R}$ $\mathbf{d_{lens}(\Omega) = D_{lens}(\Omega) / \Phi}$	 Tissue-equivalent cube (10x10x10 cm^3); 1 cm^2 area at 50 – 100 µm depth (ICRP 116, Annex G): $\mathbf{H_{local\ skin} = \sum_R w_R D_{local\ skin,R}}$
Operational quantities: definition: $\mathbf{H = h \cdot \Phi;\quad D = d \cdot \Phi}$			
Operational quantities for monitoring (ICRU 95) – **Area**	 ICRP reference voxel phantoms: $H^* = h_{E,max} \cdot \Phi$	 Stylized eye model; whole lens (ICRP 116, Annex F): $D'_{lens}(\Omega) = d_{lens}(\Omega) \cdot \Phi$	 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 $D'_{local\ skin}(\Omega) = d_{local\ skin}(\Omega) \cdot \Phi$
Operational quantities for monitoring (ICRU 95) – **Individual**	 ICRP reference voxel phantoms: $H_p = h_E \cdot \Phi$	 Stylized eye model; whole lens (ICRP 116, Annex F): $D'_{lens}(\Omega) = d_{lens}(\Omega) \cdot \Phi$	 ICRU 4-element tiss. slab, pillar, rod; 2 mm skin cover; 1 cm^2 area at 50 - 100 µm: $D_{p\ local\ skin} = d_{local\ skin} \cdot \Phi$

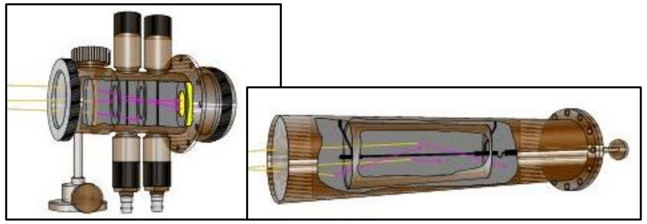


Primary dosimetry of operational quantities [Sv]: neutrons

	Basic quantity	Radiation field	Method to determine the operational quantities *H* & *D*
Neutron	**Φ** via Mn-bath, p-recoil det., or others*)	Neutron spectrometry and / or Monte Carlo transport ➔ (Φ_E/Φ)	Fold spectrum with conversion coefficients for mono-energetic neutrons, $h_\Phi(E)$ & $d_\Phi(E)$ from **ICRU 57 / ICRU 95**: $H = \{ [\int(\Phi_E/\Phi) \cdot \mathbf{h_\Phi(E)} \cdot dE] \} \cdot \mathbf{\Phi}$ $D = \{ [\int(\Phi_E/\Phi) \cdot \mathbf{d_\Phi(E)} \cdot dE] \} \cdot \mathbf{\Phi}$



Time-of-flight



*) AP (associated particle) method

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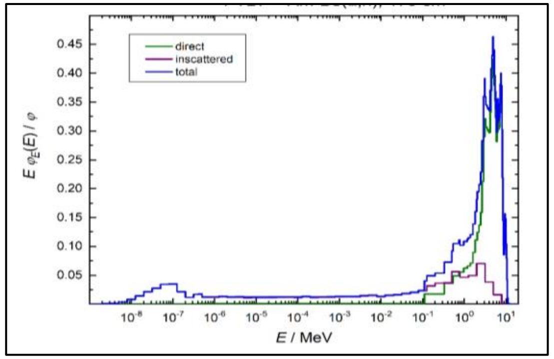

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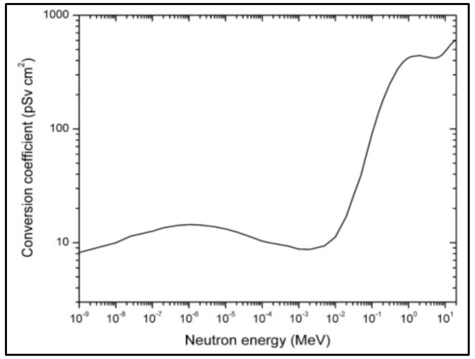
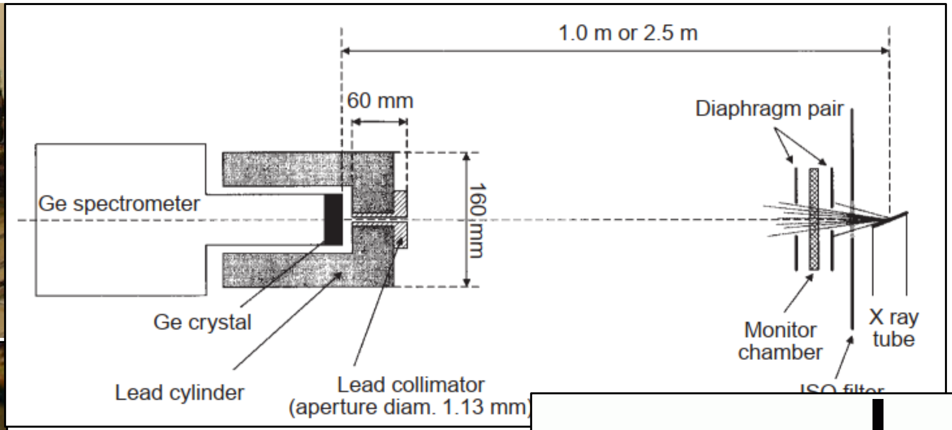


$\Big) \Rightarrow H \,\&\, D$

Primary dosimetry of operational quantities [Sv]: photons

	Basic quantity	Radiation field	Method to determine the operational quantities H & D
Photon	$K_{a,IC}$ via free air or cavity chamber	Photon spectrometry ➔ (Φ_E/Φ) & $K_{a,spc}$	Fold spectrum with conversion coefficients for mono-energetic photons, $h_K(E)$, $d_K(E)$ & $(K_a/\Phi)_E$ from **ICRU 57 / ICRU 95**: $H = \{ [\int(\Phi_E/\Phi) \cdot \mathbf{(K_a/\Phi)_E \cdot h_K(E)} \cdot dE] / K_{a,spc} \} \cdot K_{a,IC}$ $D = \{ [\int(\Phi_E/\Phi) \cdot \mathbf{(K_a/\Phi)_E \cdot d_K(E)} \cdot dE] / K_{a,spc} \} \cdot K_{a,IC}$



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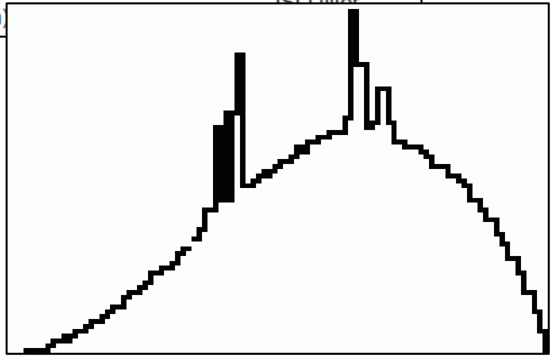

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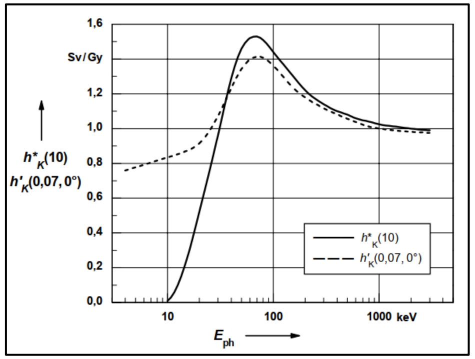
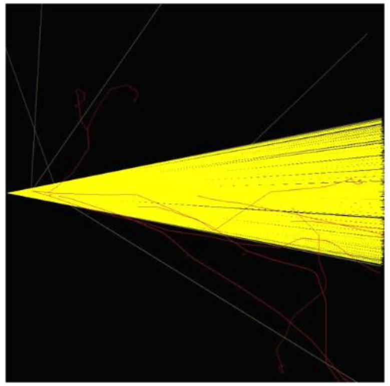
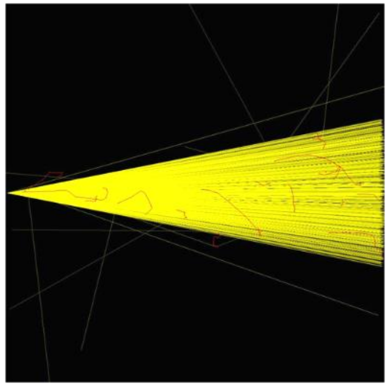
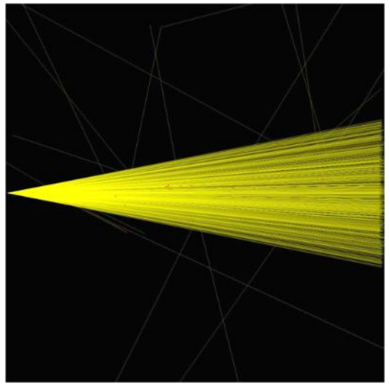
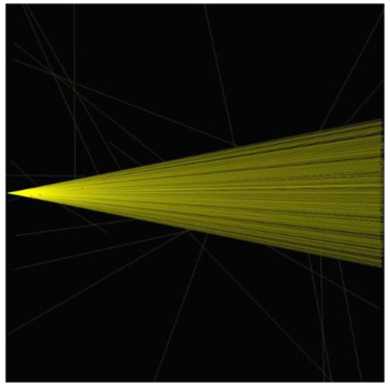
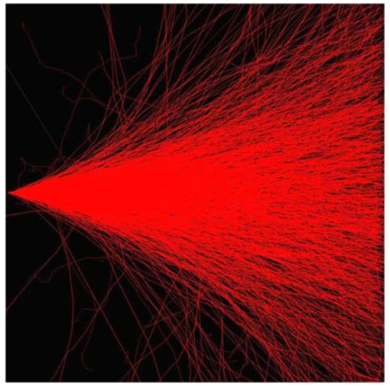
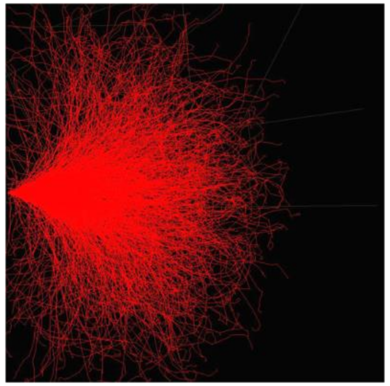
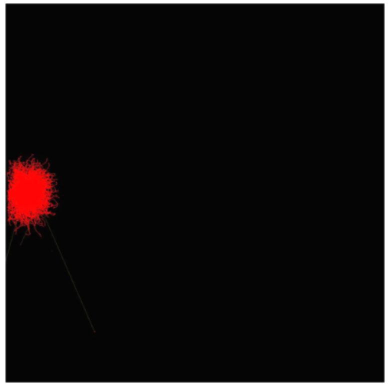


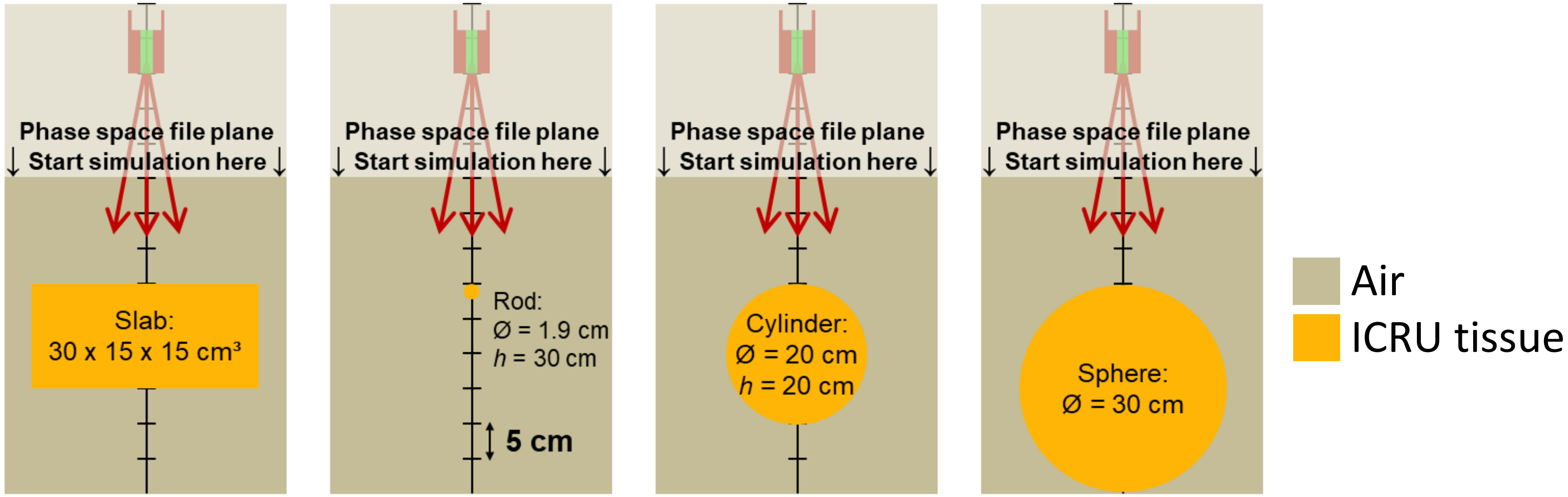
$) \Rightarrow H \,\&\, D$

Particle tracks in air: photons vs. electrons

Air cube of 1 m x 1 m x 1 m	1 MeV	300 keV	100 keV	30 keV	at beam center
1000 Photons					practically mono-directional
1000 Electrons					far from being mono-directional

Primary dosimetry of operational quantities [Sv]: betas

	Basic quantity	Radiation field	Method to determine the operational quantities H & D
Beta	$D_{t,meas}$ via extrapolation chamber	Monte Carlo transport ➔ $k_{sim} = H_{sim} / D_{t,sim}$ (= $D_{sim} / D_{t,sim}$)	Multiply **absorbed dose to tissue** with correction factor to account for the respective phantom ⇒ $H = D_{t,meas} \cdot k_{sim}$ with the phantoms from **ICRU 57** / ICRU 95



ICRU 57

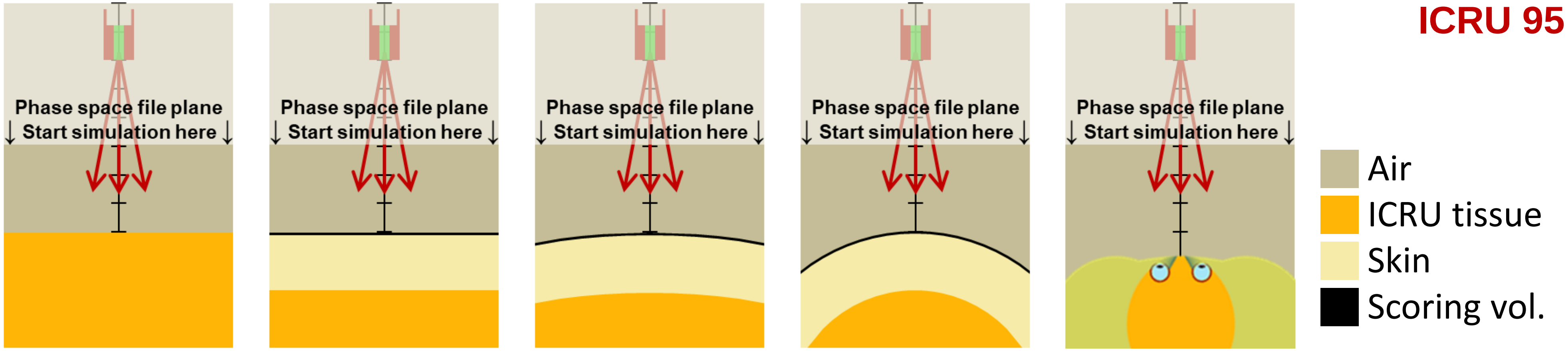
slab	rod	cylinder	sphere
$D_{t,sim}$			$H'(0.07)$
$H_p(0.07)_{slab}$ & $H_p(3)_{slab}$	$H_p(0.07)_{rod}$	$H_p(3)_{cylinder}$	$H'(3)$

$\Rightarrow H = D_{t,meas} \cdot k_{sim}$

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

Primary dosimetry of operational quantities [Sv]: betas

	Basic quantity	Radiation field	Method to determine the operational quantities *H* & *D*
Beta	$D_{t,meas}$ via extrapolation chamber	Monte Carlo transport ➔ $k_{sim} = H_{sim} / D_{t,sim}$ (= $D_{sim} / D_{t,sim}$)	Multiply **absorbed dose to tissue** with correction factor to account for the respective phantom ⇒ $D = D_{t,meas} \cdot k_{sim}$ with the phantoms from ICRU 57 / **ICRU 95**



ICRU 95

slab	slab	pillar	rod	eye
$D_{t,sim}$	$D'_{local\ skin}$			D'_{lens}
$H_p(0.07)_{slab}$ & $H_p(3)_{slab}$	$D_{p\ local\ skin,\ slab}$	$D_{p\ local\ skin,\ pillar}$	$D_{p\ local\ skin,\ rod}$	$D_{p\ lens}$

$\Rightarrow D = D_{t,meas} \cdot k_{sim}$

Correction factors: *J. Radiol. Prot. 41, 871 (2021)*

Primary dosimetry of operational quantities: summary

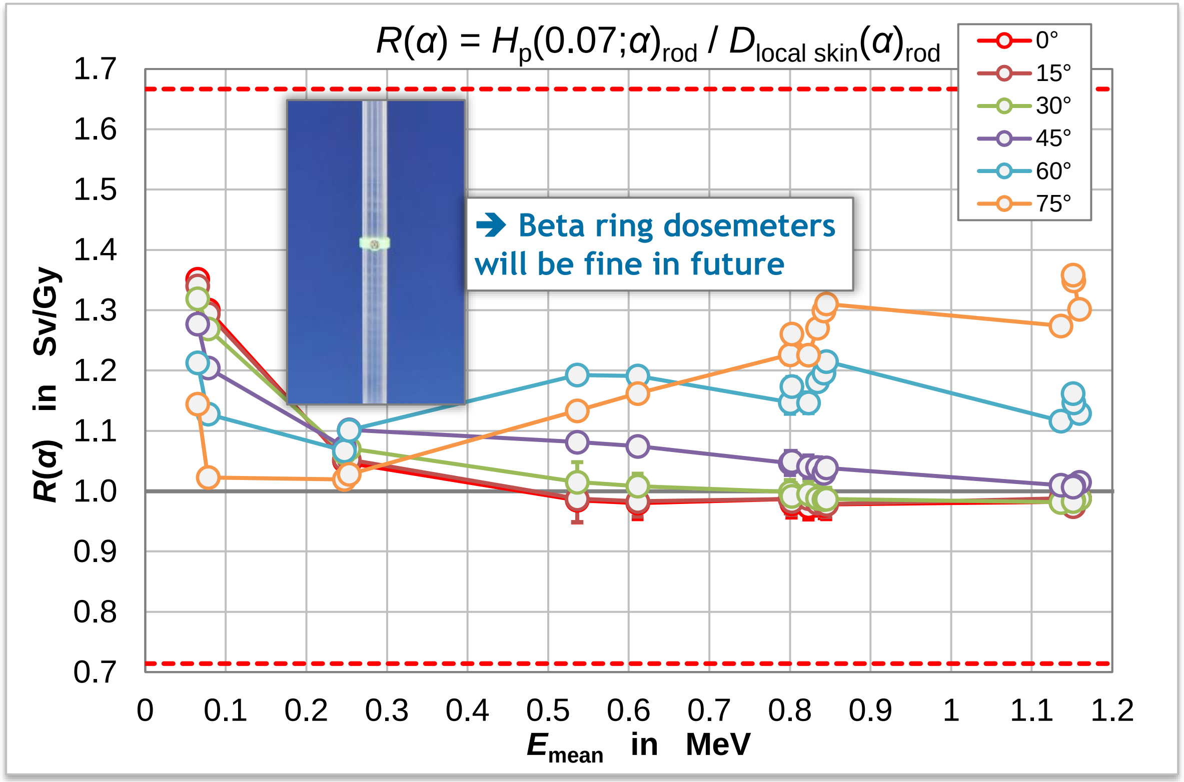
	Basic quantity	Radiation field	Method to determine the operational quantities *H* & *D*
Neutron	**Φ** via Mn-bath, p-recoil det., or others*)	Neutron spectrometry and / or Monte Carlo transport ➔ (Φ_E/Φ)	Fold spectrum with conversion coefficients for mono-energetic neutrons, $h_\Phi(E)$ & $d_\Phi(E)$ from ICRU 57 / ICRU 95: $H = \{ [\int(\Phi_E/\Phi) \cdot h_\Phi(E) \cdot dE] \} \cdot \boldsymbol{\Phi}$ $D = \{ [\int(\Phi_E/\Phi) \cdot d_\Phi(E) \cdot dE] \} \cdot \boldsymbol{\Phi}$
Photon	**$K_{a,IC}$** via free air or cavity chamber	Photon spectrometry ➔ (Φ_E/Φ) & $K_{a,spc}$	Fold spectrum with conversion coefficients for mono-energetic photons, $h_K(E)$, $d_K(E)$ & $(K_a/\Phi)_E$ from ICRU 57 / ICRU 95: $H = \{ [\int(\Phi_E/\Phi) \cdot (K_a/\Phi)_E \cdot h_K(E) \cdot dE] / K_{a,spc} \} \cdot \boldsymbol{K_{a,IC}}$ $D = \{ [\int(\Phi_E/\Phi) \cdot (K_a/\Phi)_E \cdot d_K(E) \cdot dE] / K_{a,spc} \} \cdot \boldsymbol{K_{a,IC}}$
Beta	**$D_{t,meas}$** via extrapolation chamber	Monte Carlo transport ➔ $k_{sim} = H_{sim} / D_{t,sim}$ $(= D_{sim} / D_{t,sim})$	Multiply **absorbed dose to tissue** with correction factor to account for the respective phantom: $H = \boldsymbol{D_{t,meas}} \cdot k_{sim}$; $D = \boldsymbol{D_{t,meas}} \cdot k_{sim}$ with the phantoms from ICRU 57 / ICRU 95

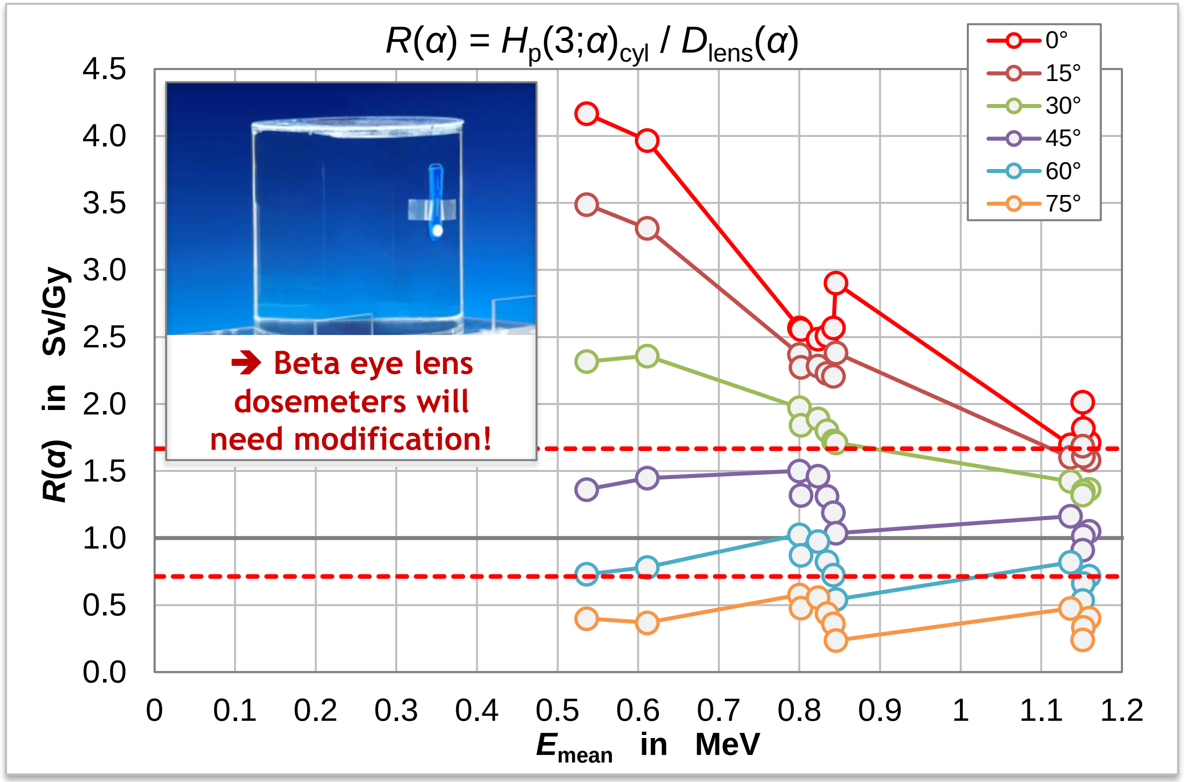
Take home: **Procedures unchanged** – "*only*" **new conversion** coefficients / **correction** factors
➔ Response of dosemeters can be re-calculated; BUT calibration coefficient and energy dependence change!

Conversion coefficients: ICRU 95: impact

Impact to beta quantities / beta dosemeters:

Assume a perfect dosemeter for the current quantities





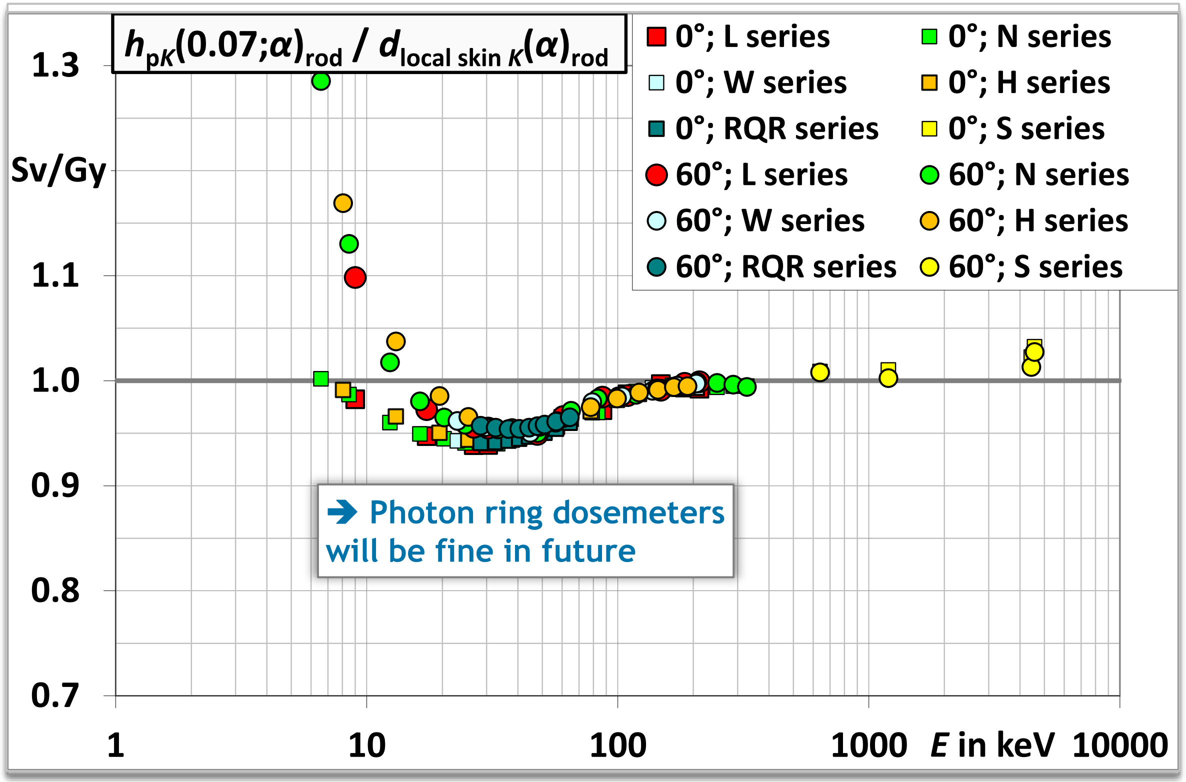
Dotted red lines: response limits 0.71 … 1.67 according to IEC 61526 (active) and IEC 62387 (passive) dosemeters

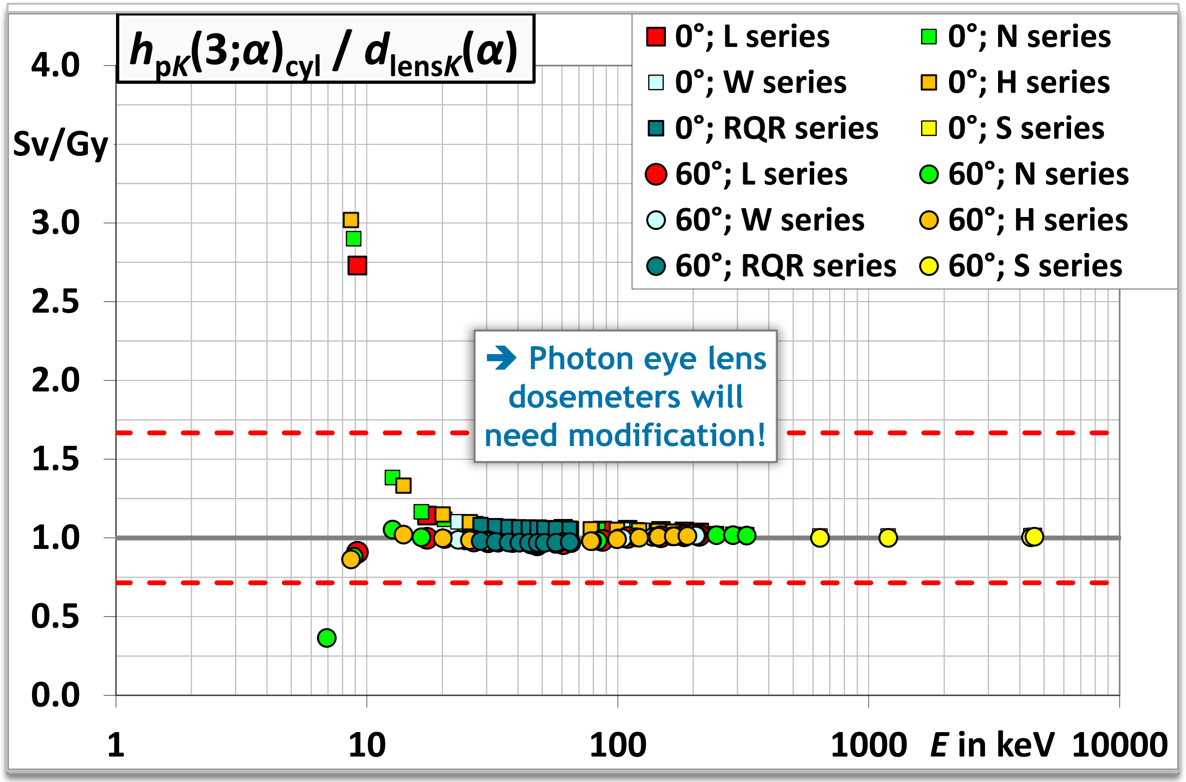
For betas: *J. Radiol. Prot. 41, 871 (2021)* For photons: *J. Radiol. Prot. 42, 011519 (2022)*

Conversion coefficients: ICRU 95: impact

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

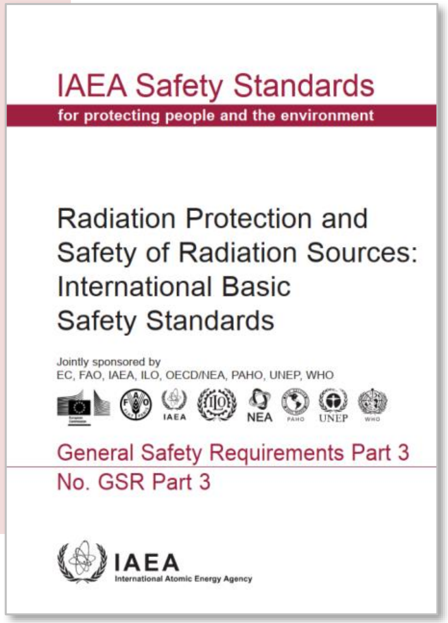
For betas: *J. Radiol. Prot. 41, 871 (2021)* For photons: *J. Radiol. Prot. 42, 011519 (2022)*

Proposed operational quantities: implementation

Journey to implementation …

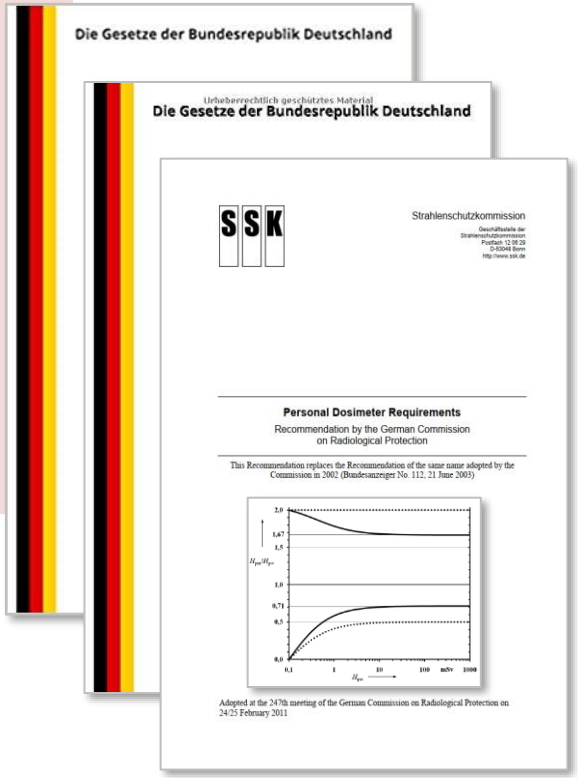
International and national requirements and legislation

Basic Safety Standards
of the IAEA



Basic Safety Standards
of the European Union

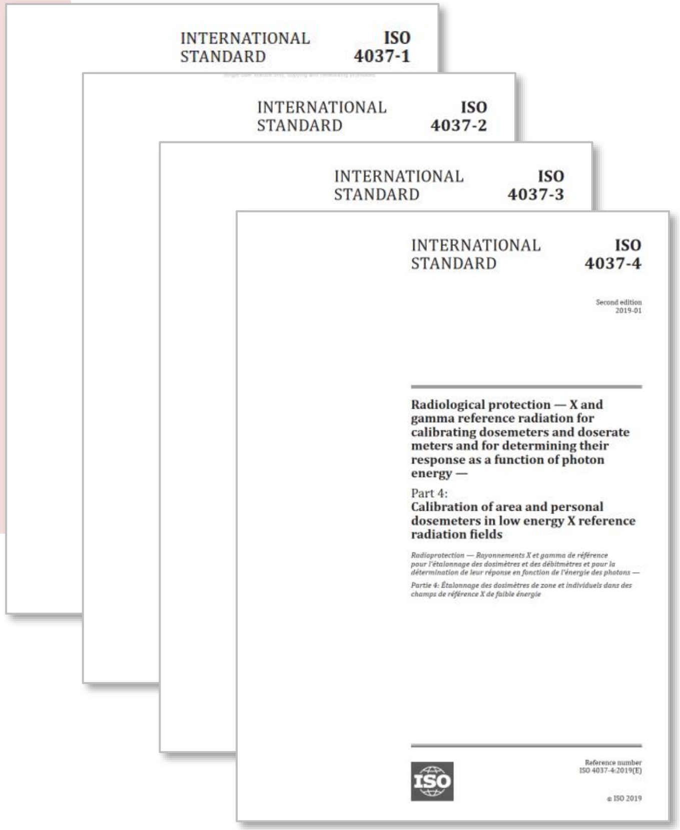
National radiation protection
law & ordinance, directives
and subordinate documents



➔ implementation of new quantities: 5…10 years

Standards for Reference Radiation Qualities

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


INTERNATIONAL STANDARD ISO 4037-1

INTERNATIONAL STANDARD ISO 4037-2

INTERNATIONAL STANDARD ISO 4037-3

INTERNATIONAL STANDARD ISO 4037-4

Second edition 2019-01

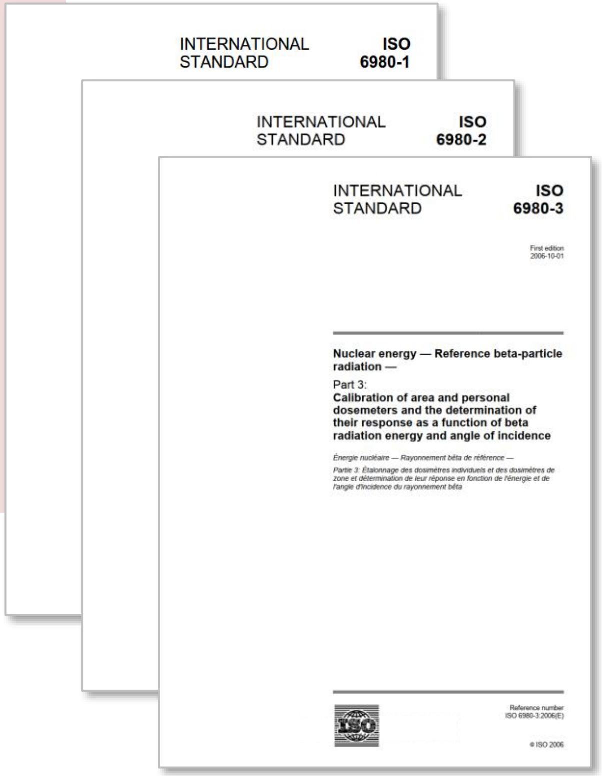
Radiological protection — X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy —

Part 4: Calibration of area and personal dosemeters in low energy X reference radiation fields

Reference number ISO 4037-4:2019(E)

© ISO 2019

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


INTERNATIONAL STANDARD ISO 6980-1

INTERNATIONAL STANDARD ISO 6980-2

INTERNATIONAL STANDARD ISO 6980-3

First edition 2006-10-01

Nuclear energy — Reference beta-particle radiation —

Part 3: Calibration of area and personal dosemeters and the determination of their response as a function of beta radiation energy and angle of incidence

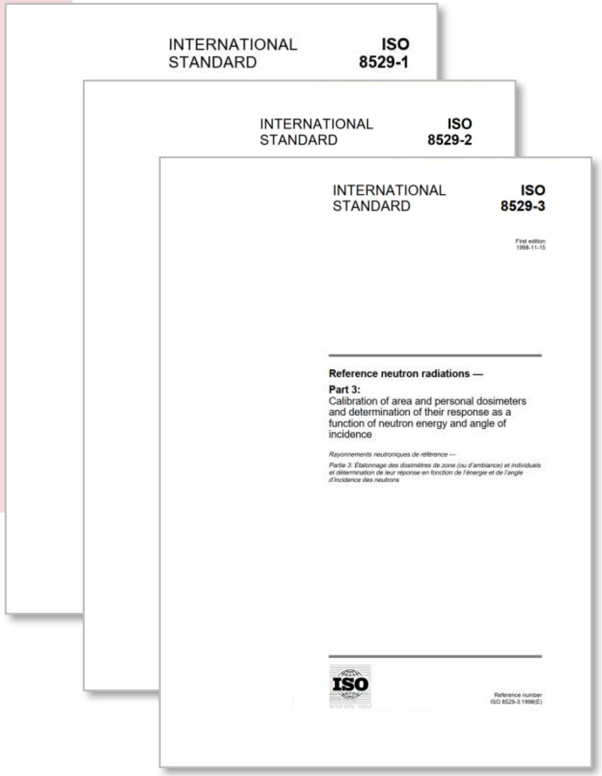
Énergie nucléaire — Rayonnement bêta de référence —

Partie 3: Étalonnage des dosimètres individuels et des dosimètres de zone et détermination de leur réponse en fonction de l'énergie et de l'angle d'incidence du rayonnement bêta

Reference number ISO 6980-3:2006(E)

© ISO 2006

Neutrons: ISO 8529: 1998/2001
In revision since 2019 ➔
general update


INTERNATIONAL STANDARD ISO 8529-1

INTERNATIONAL STANDARD ISO 8529-2

INTERNATIONAL STANDARD ISO 8529-3

First edition 1998-11-15

Reference neutron radiations —

Part 3: Calibration of area and personal dosimeters and determination of their response as a function of neutron energy and angle of incidence

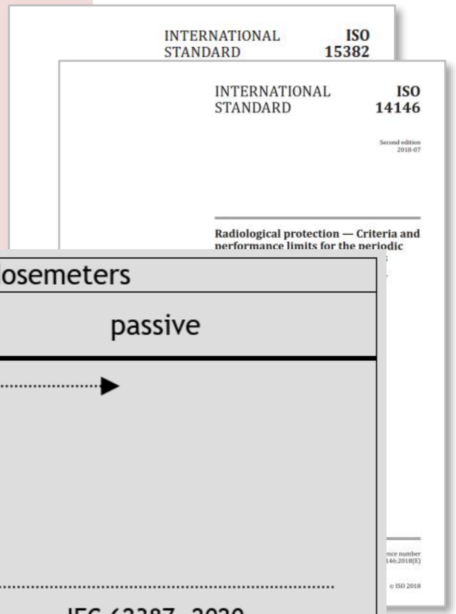
➔ implementation of new quantities and conversion coefficients: another 5…10 years

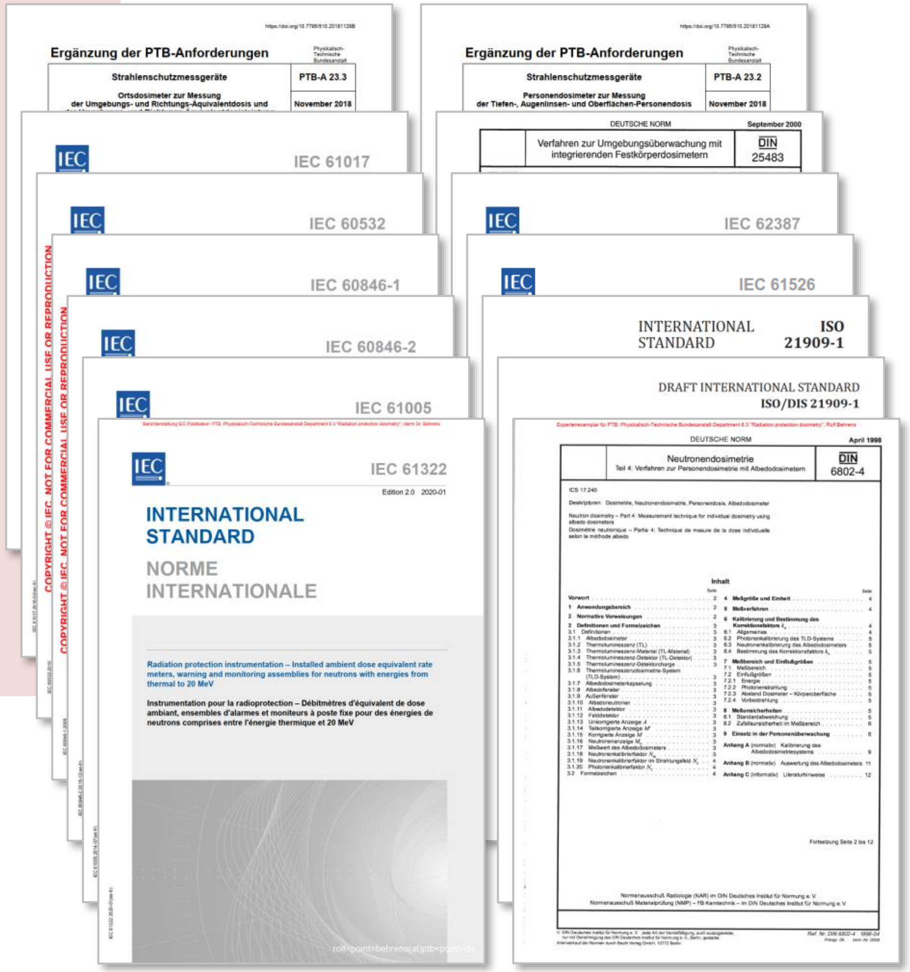
Standards for Procedures and for Dosemeter Requirements

Standards for procedures:
* ISO 15382: Dosimetry in practice (2015)
* ISO 14146: Routine test for dosemeters (2018)

Standards for dosemeter requirements:

Type of radia-tion	Area dosemeters		Personal dosemeters	
	Active	passive	active	passive
Photon	PTB-A 23.3, 2018 → IEC 61017, 2016-02 (environmental dosem.) IEC 60532, 2010 (fixed installed in nuclear facilities) IEC 60846-1, 2009 (portable dosem.) IEC 60846-2, 2015 (emergency dosem.)	→ DIN 25483, 2000 (TLD, only env.) IEC 62387, 2020 (all passive dosemeters)	PTB-A 23.2, 2018 → IEC 61526, 2010 (all active dosemeters)	→ IEC 62387, 2020 (all passive dosemeters)
Beta	↓	↓	↓	↓
Neu-tron	IEC 61005, 2014 IEC 61322, 2020 (fixed installed)	---	↓	ISO 21909-1, 2021 (all passive neutron detectors) ISO 21909-2, 2021 (requirements in workplaces) DIN 6802-4, 1998 (Albedo)





➔ 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!

Summary = 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)

Finally, we are done ☺

nearly …

Latest developments in beta-radiation metrology

(primary dosimetry, ISO 6980 revision, and ICRU 95 impact)

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As of 09/2022

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- **CCRI** for inviting me
- **ISO TC85 SC2 WG2** "Reference radiation fields" preparing ISO 6980
- **ICRU** RC26 preparing ICRU 95
- **PTB** staff:
  Phil Brüggemann
  Jürgen Roth
  Heike Nittmann
  Department 6.3