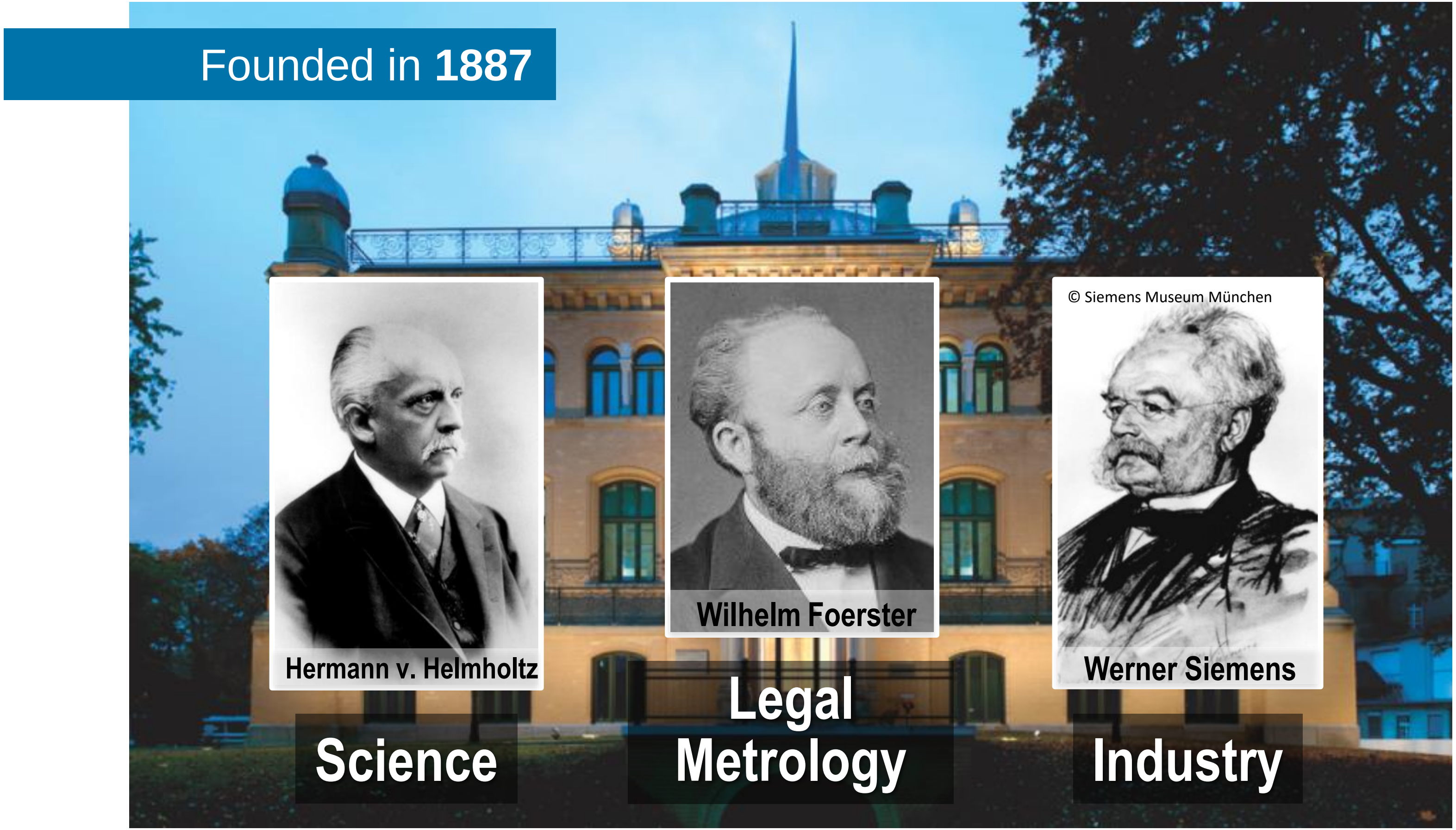
Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

X-Ray Detector Calibrations

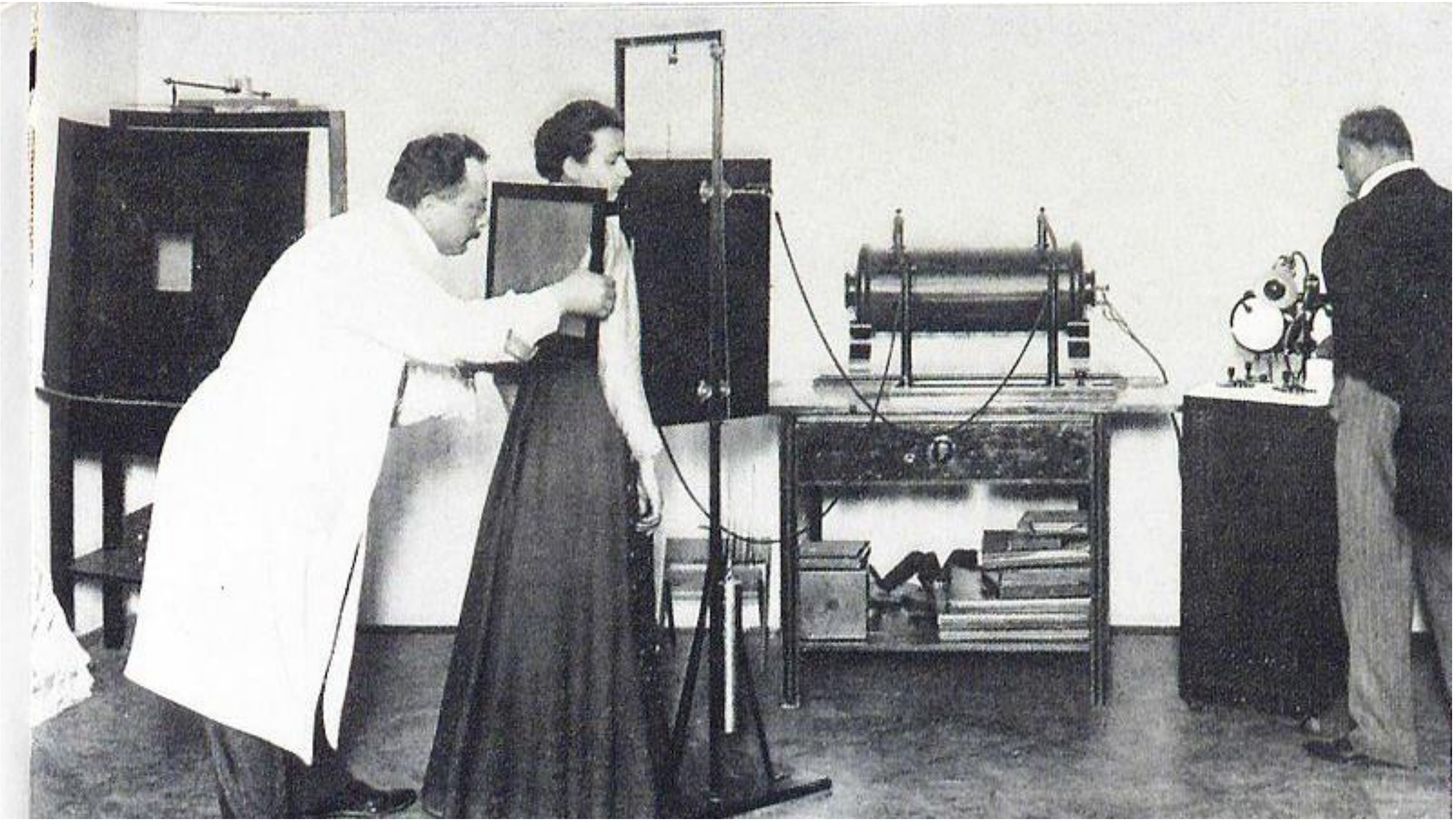
at the PTB

Dr. Stefan Pojtinger

National Metrology Institute of Germany



Radiology 1904



Egon Larsen: Kleine Geschichte der Technik für die Jugend. Berlin : Weiss, 1961

The Working Group 6.25

Personell
- 4 R&D
- 7 technical

Primary Standards
- 8 primary standards
- more than 300 radiation qualities
- 50-80 calibrations

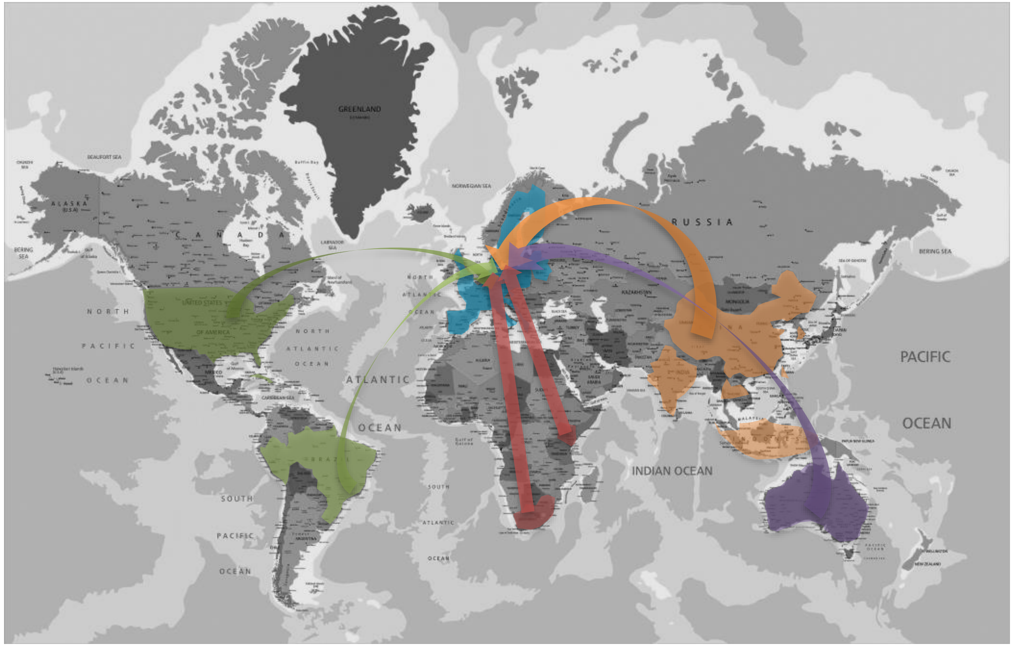

Traceability for X-ray Dosimetry



Research and Development
- Personalized CT dosimetry

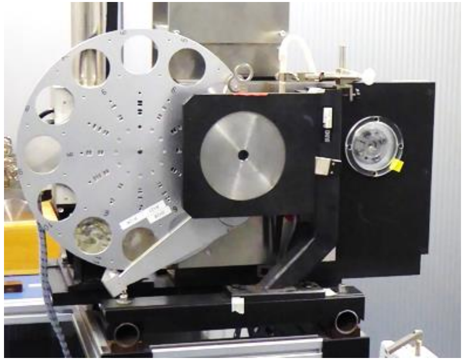
Type Testing and Committee Work
- IEC standards
- Testing of diagnostic dosimeters


Calibrations 2023



- customers from more than 32 countries
- ~100 detectors
- ~1000 calibration coefficients

X-ray Facilities



Facility	Tube	Anode	Anode angle	Inherent filtration [mm Be]	Max. ppV [kV]
Rö 124	Y.TU 160-D02	W	20°	0.8	160
Rö 127	ISOVOLT 320M2/4,5-13	W	20°	3	320
Rö 127	PW-2185/00	Mo	26°	1	100
Rö 127	MCD 100H-3	Rh	24°	1	100
Rö 128	MB450-1H450	W	21°	7	450
Rö 128	MXR 165	W	30°	4	160
Rö 128	PW-2182	Rh	18°	0.15	100

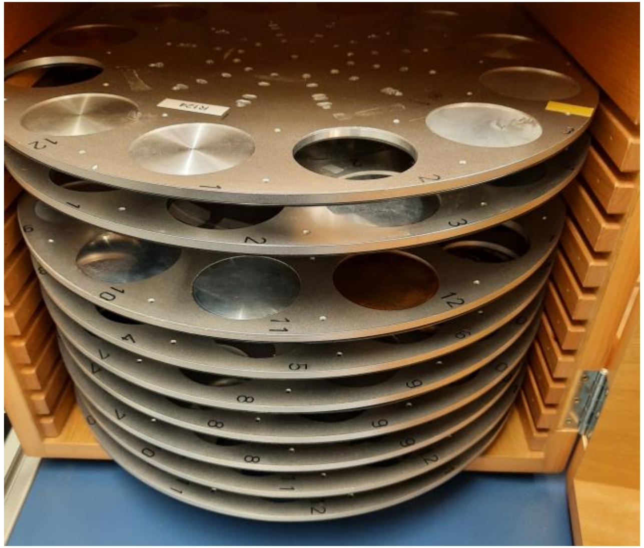
Radiation Conditions

- **IEC 61267**
  - Testing of medical diagnostic x-ray equipment

- **ISO 4037**
  - Radiological protection [...]

- **BIPM reference radiation conditions**
  - Key-Comparisons K1, K2, K3, K5, K7, K9

- **DIN 6809-4 (dose to water)**



Available filtrations: Al, Cu, Sn, Pb, Mo, Rh, Pd, Ag

IEC 61267: Radiation Conditions

Radiation conditions typically used by SSDLs and manufacturers of dosimetric equipment

TABLE 6.1. RADIATION QUALITIES FOR CALIBRATIONS OF DIAGNOSTIC DOSIMETERS

Radiation quality	Radiation origin	Material of an additional filter	Application
RQR	Radiation beam emerging from X ray assembly	No phantom	General radiography, fluoroscopy and dental applications (measurements free in air)
RQA	Radiation beam with an added filter	Aluminium	Measurements behind the patient (on the image intensifier)
RQT	Radiation beam with an added filter	Copper	CT applications (measurements free in air)
RQR-M	Radiation beam emerging from X ray assembly	No phantom	Mammography applications (measurements free in air)
RQA-M	Radiation beam with an added filter	Aluminium	Mammography studies

taken from TRS-457

IEC 61267: Radiation Conditions

Radiation Protection Dosimetry, 2024, 1–8
https://doi.org/10.1093/rpd/ncae029
Paper

OXFORD

On the robustness of detective quantum efficiency within the limits of IEC 61267 RQA standard radiation qualities

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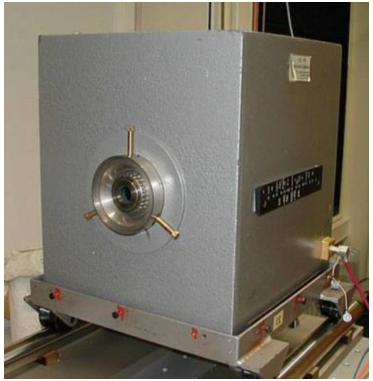
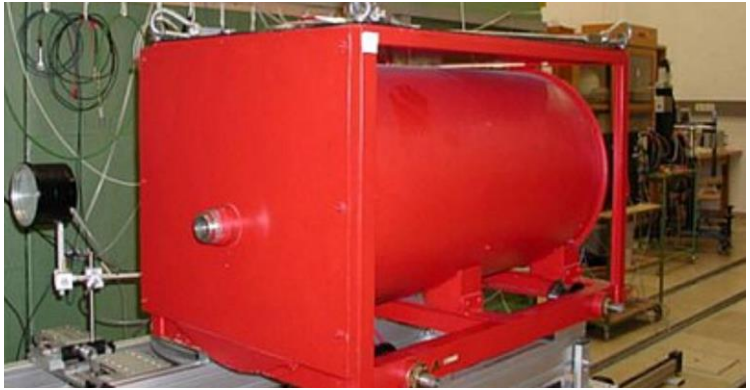
Abstract

IEC 61267 allows a certain leeway regarding the establishment of radiation qualities in order to enable the use of X-ray tubes having different anode angles and inherent filtrations. This allowance has a direct impact on the calculation of the detective quantum efficiency and may potentially complicate any comparison of different imaging detectors based on this quantity. This work investigates this effect by applying computational methods. To this end, an algorithm was implemented to calculate the variation of the squared signal-to-noise ratio per air kerma for RQA standard radiation qualities and to deduce corresponding uncertainties based on GUM Supplement 2. For RQA standard radiation qualities, the results show standard uncertainties for the squared signal-to-noise ratio per air kerma of between 0.05 and 2.1%. Comparing imaging detectors based on detective quantum efficiency is associated with substantial uncertainty for some radiation qualities. This is due to the different photon fluences with respect to energy that are allowed by IEC 61267 for identical standard radiation qualities.

Primary Standards for Air Kerma

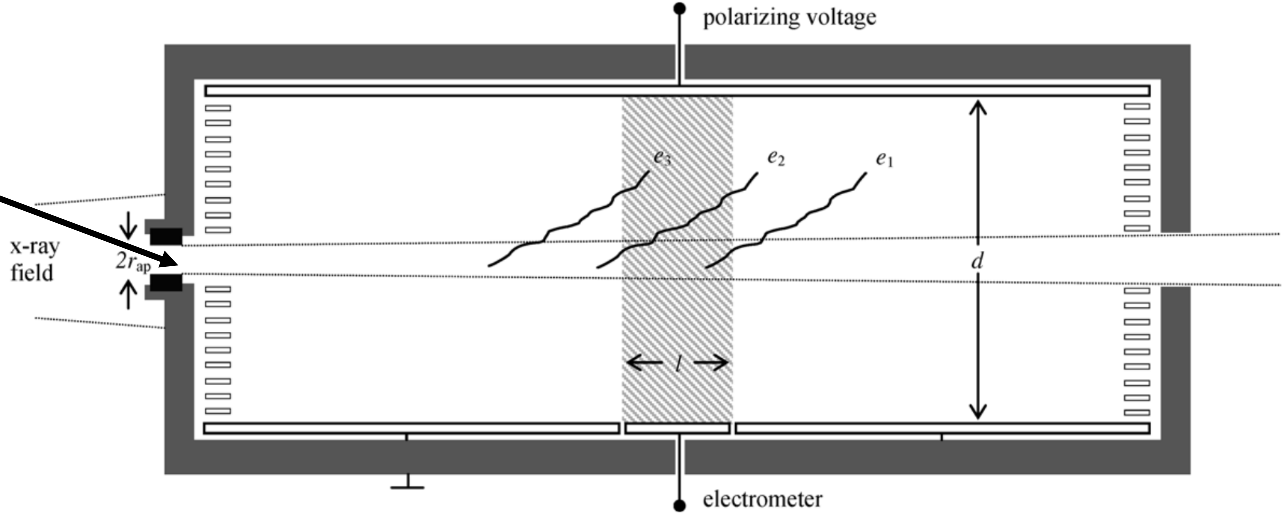
Name	Type	Energy Range [kV]
PK 100	Parallel-plate ionization chamber	7.5 – 150
FK	Cylindrical ionization chamber	30 - 300
PK 400	Parallel-plate ionization chamber	50 – 400





Primary Standards for Air Kerma

reference point



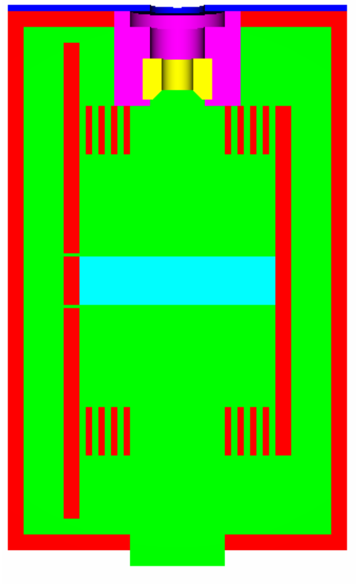
$$K_{air} = (W_{air}/e)\frac{q_{net}}{m_{air}(1-\bar{g}_{air})}\prod_i k_i = (W_{air}/e)\frac{q_{net}}{\rho_{air}V_{eff}(1-\bar{g}_{air})}\prod_i k_i$$

q_{net}: measured charge corrected for ambient (and system-generated background)

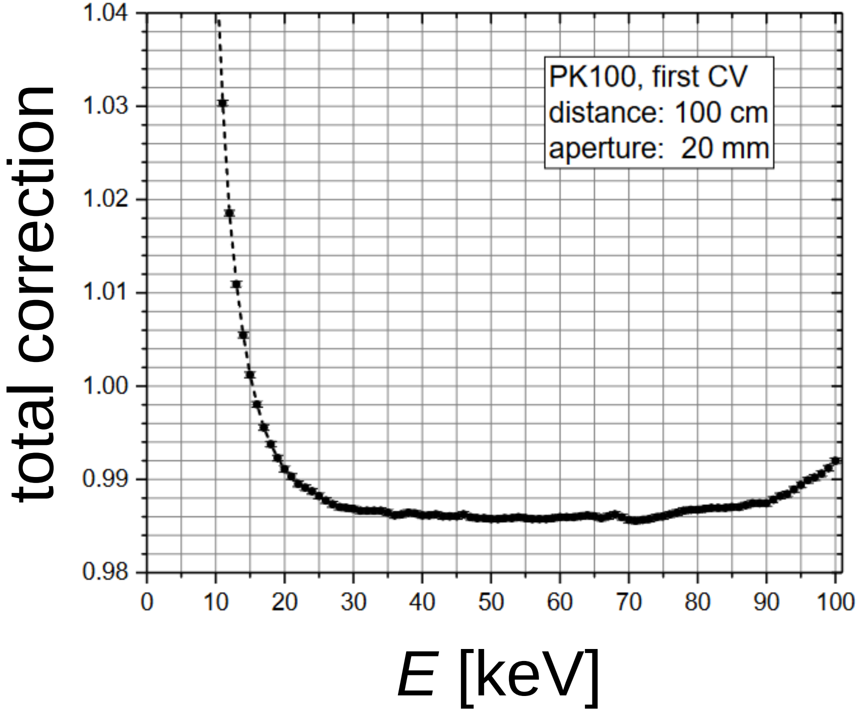
taken from ICRU 90

Correction Factors

MC simulations
(EGSnrc)

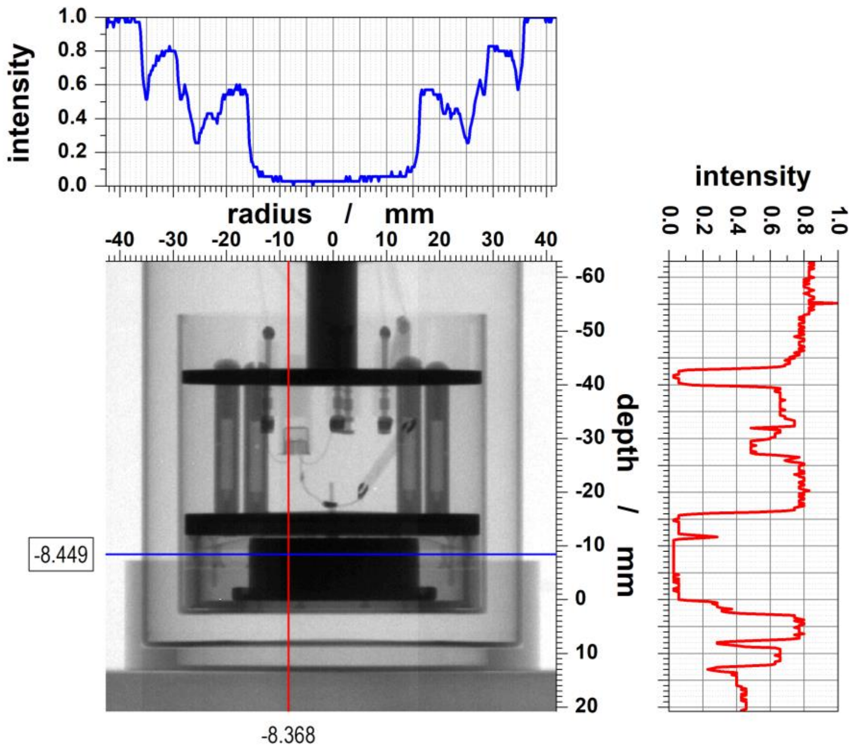


Monoenergetic
Correction Factors



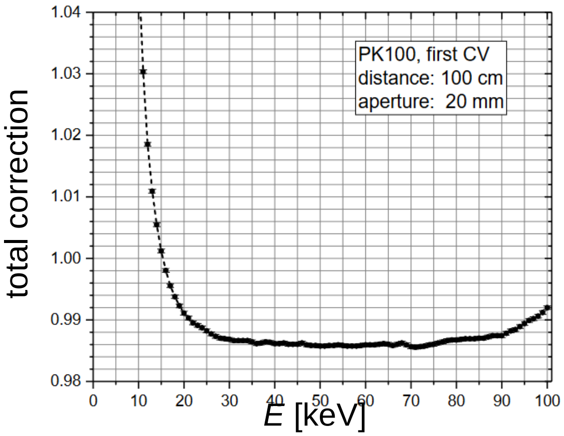
Spectrometry

- High purity germanium spectrometer (ORTEC 51-TF164)
- Crystal diameter 32 mm
- Crystal length 13 mm
- FWHM at 5.9 keV 0.54 keV
- FWHM at 122 keV 0.69 keV
- Bayesian deconvolution (J. Instrum. 7 P03003)

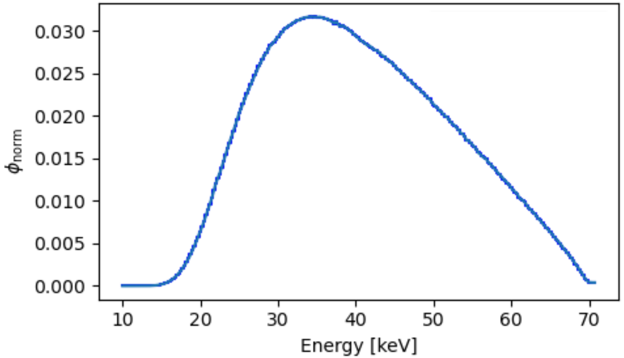


Correction Factors for Calibrations

Monoenergetic Correction Factors



X-Ray Spectrum (IEC RQA 5)



$$K_{\mathrm{air}} = (W_{\mathrm{air}}/\mathrm{e}) \frac{q_{\mathrm{net}}}{m_{\mathrm{air}}(1-\bar{g}_{\mathrm{air}})} \prod_i k_i$$

Uncertainties

The largest uncertainty component is caused by the uncertainty of the value of $\boldsymbol{W_{\mathrm{air}}/e}$ without which the remaining uncertainties add up to 0.27%.

Parameter	Description	Value	u_{iA} (%)	u_{iB} (%)	u_i (%)
W_{air}/e	Mean energy (eV)	33.97		0.35	0.35
I	Ionization current	-	0.10	0.06	0.12
ρ_{air}	Air density (kg m^{-3})	1.2048		0.01	0.01
V	Collecting volume (mm^3)	1575	0.06		0.06
$1/(1-\bar{g})$	Radiative loss correction	1.0000		0.01	0.01
k_h	Humidity	0.9980		0.03	0.03
k_{iw}	$= k_{ii}k_W$ (section 3.2)	0.9968		0.11	0.11
k_{pol}	Polarity	1.0000	0.05	0.05	0.07
k_s[1)]	Saturation	1.0022	0.05	0.05	0.07
k_d	Field distortion	0.9910	0.10		0.10
k_p	Wall penetration	1.0000	0.05		0.05
k_ρ	Air density correction	1.0000	0.036		0.036
k_{att}	Air attenuation	1.0310	0.05	0.05	0.07
k_{ap}	Guard strip attenuation	1.0060	0.05		0.05
k_{dia}	Diaphragm effects	0.9996		0.05	0.05
k_{sc}	Scattered radiation	0.9902		0.05	0.05
k_e	Electron loss	1.0000		0.05	0.05
$\dot{K}_{\mathrm{air}}$	Air kerma rate (result)	-	0.19	0.39	0.44

[1)] Calculated for the air kerma rate 1 mGy/s

Spectrometry

CrossMark

OPEN ACCESS

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PAPER

Catalog of x-ray spectra of Mo-, Rh-, and W-anode-based x-ray tubes from 10 to 50 kV

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Keywords: x-ray spectrometry, mammography, high-purity germanium detector

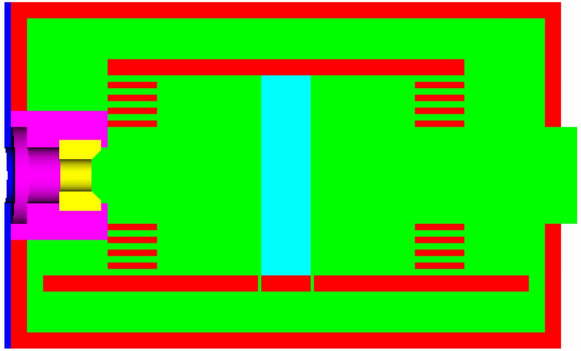
Abstract

This work presents a comprehensive catalog of x-ray spectra measured from x-ray tubes with tungsten, molybdenum, and rhodium anodes generated at tube potentials between 10 and 50 kV in steps of 1 kV. They can serve as an input for dose calculations, image quality calculations, investigations of detector features, and validations of computational spectral models, among other things. The measurements are performed by means of a high-purity germanium detector-based spectrometer 1 m from the x-ray sources without any added filtration. The x-ray tubes are characterized by thin beryllium exit windows (0.15—4 mm); thus, for energies above 15 keV, the spectra recorded can be considered approximately unfiltered. This allows potential users of the catalog to computationally add any filter to the spectra in order to create special radiation qualities of their choice. To validate this

New Primary Standard for Air Kerma

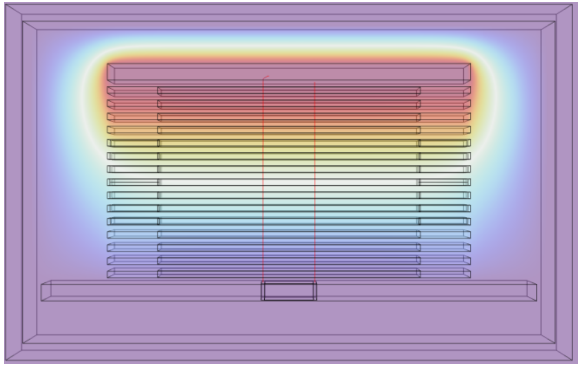
Monte-Carlo-Simulations with EGSnrc (egs_fac) for sizing the chamber

- Monoenergetic simulations (5 – 50 keV)
- Correction factors for air attenuation, scattering, electron loss, diaphragm effects



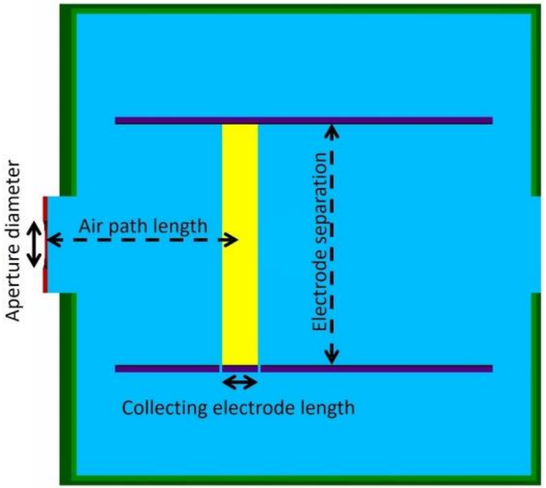
FEM simulations with Comsol for studying the electric field

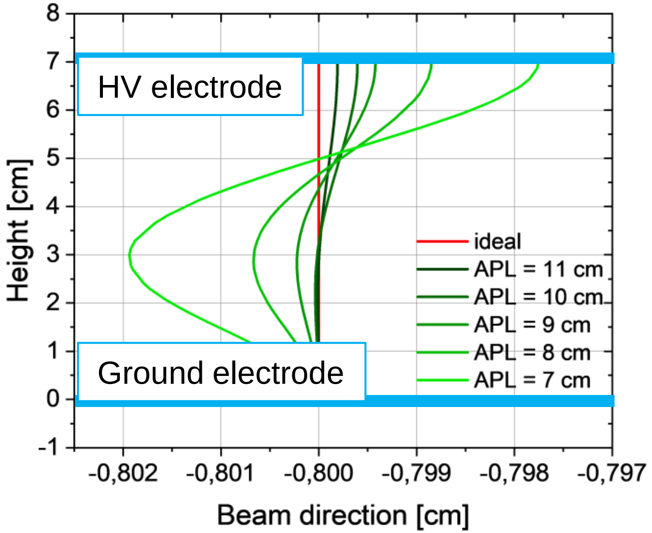
- Effect of different structures on the field lines
- Correction factor for field distortion

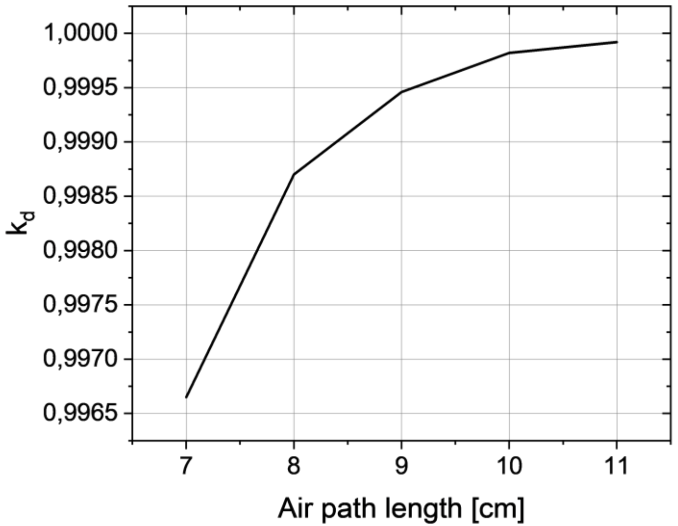


Jessica Gschweng, PTB

New Primary Standard for Air Kerma







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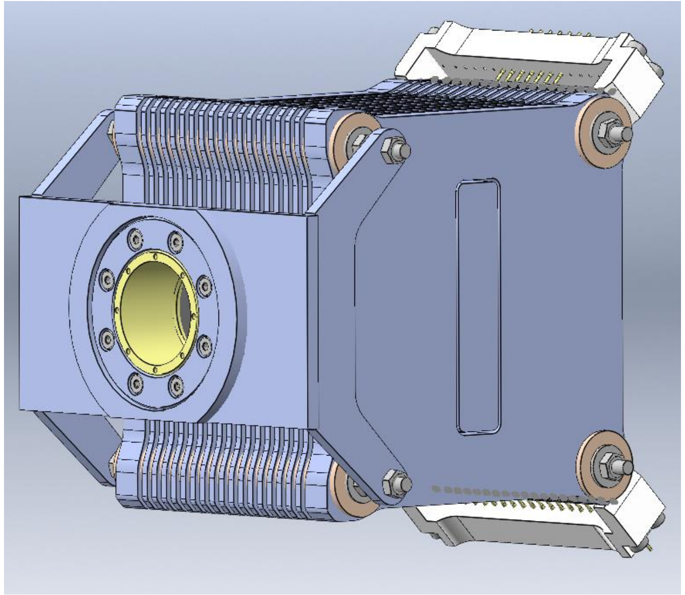

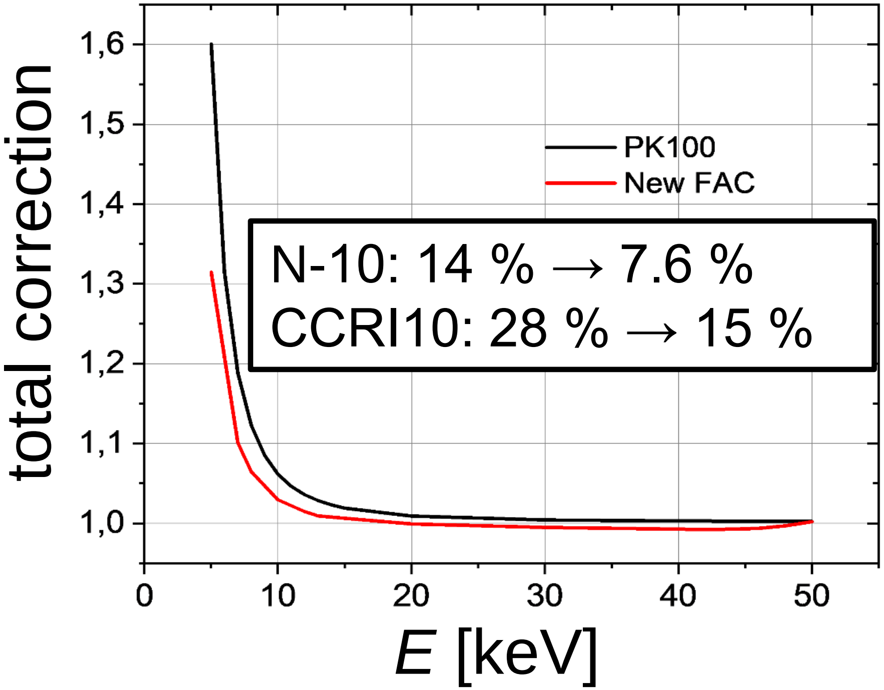

Jessica Gschweng, PTB

Conclusions

- PTB offers X-ray detector calibrations
- Radiation conditions are based on international standards (IEC, ISO)
- PTB primary standards are characterized by Monte Carlo and FEM simulations
- Based on this simulations, traceability for new radiation conditions can be established easily

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