BUREAU INTERNATIONAL DES POIDS ET MESURES

CCRI(I)/11-22
revised

Section I (X and γ rays, electrons)
Comité Consultatif pour les Rayonnements Ionisants
20th Meeting 2011

PROGRESS ON RADIATION DOSIMETRY BEV, AUSTRIA 2009 - 2011

Team Dosimetry Laboratory BEV:

Martin Bauer
Andreas Baumgartner (guest scientist until the end of 2010, EURAMET-project 1021)
Frantisek Gabris (until the end of 2010)
Andreas Steurer
Wilhelm Tiefenboeck

BEV - Bundesamt für Eich- und Vermessungswesen

Bundesamt für Eich- und Vermessungswesen

Re-evaluation of the BEV absorbed dose to water primary standard for ^{60}Co

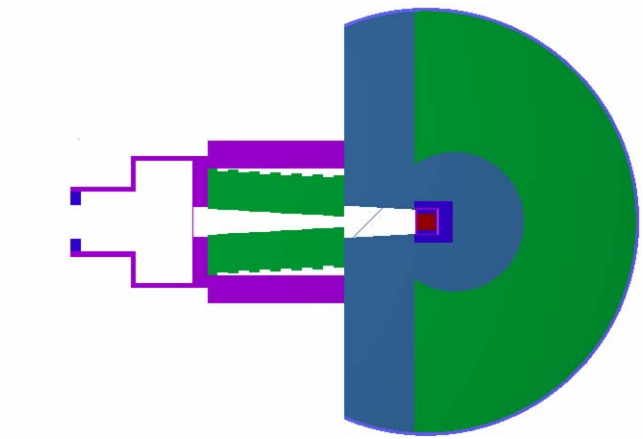
Graphite – calorimeter measurements:

- quasi-adiabatic
- quasi-isothermic

MC simulation with PENELOPE → new correction factors

Conversion graphite → water:

- computing (scaling theorem)
- experimental / ionization chamber measurements



Absorbed dose to water for reference date 31.12.2004

New value: 6,064 mGy/s with U = 0,74 % (k = 2)

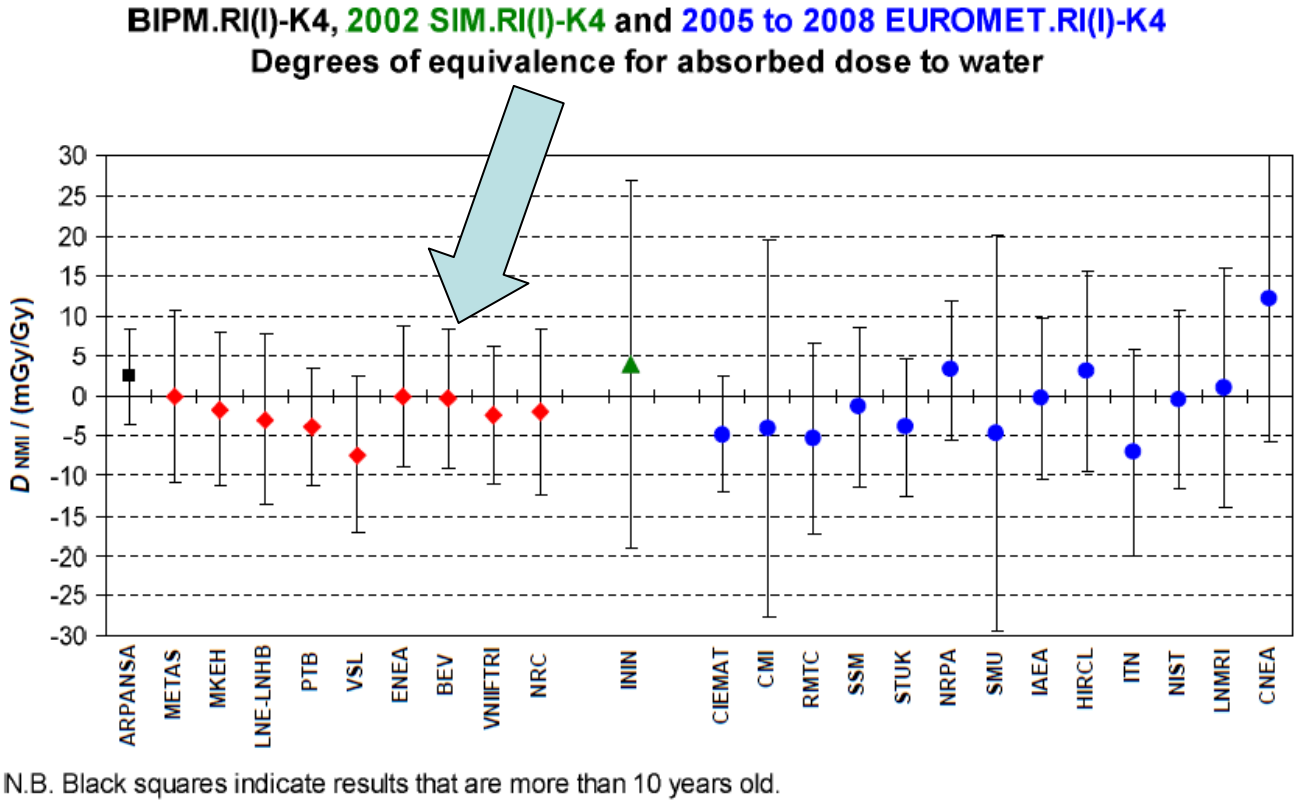
(value before: 6,060 mGy/s)

Change to new reference date 31.12.2008:

3,584 mGy/s with U = 0,74 % (k = 2)

BIPM.RI(I)-K4: Measurement of Absorbed Dose to Water for Cobalt 60

2009



N.B. Black squares indicate results that are more than 10 years old.

Transfer standards:

Ionization chambers

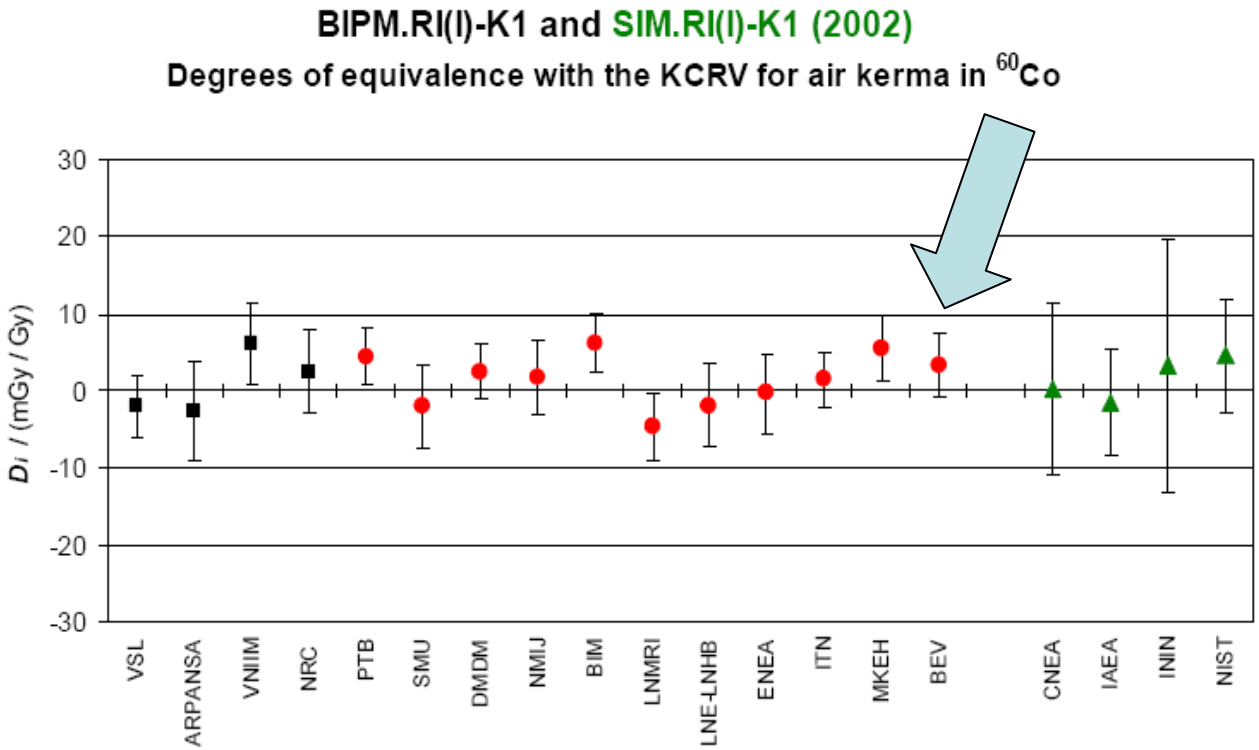
NE 2571-1050

NE 2561 - 276

Final Report April 2010: C. Kessler, P.J. Allisy-Roberts, A. Steurer, A Baumgartner, W. Tiefenböck, F. Gabris "Comparison of the standards for absorbed dose to water of the BEV and the BIPM for ^{60}Co gamma radiation"

BIPM.RI(I)-K1: Measurement of Air Kerma for Cobalt 60

2009



N.B. Black squares indicate results that are more than 10 years old.

Primary standards:

Ionization chambers

CC01-125

CC01-132

Final Report January 2010: C. Kessler, P.J. Allisy-Roberts, A. Steurer, W. Tiefenböck, F. Gabris "Comparison of the standards for air kerma of the BEV and the BIPM for ^{60}Co gamma radiation"

BIPM.RI(I)-K5: Measurement of Air Kerma for Cesium 137

2009

Results:

$\dot{K}_{BEV}$ / µGy s^{-1}	$\dot{K}_{BIPM}$ / µGy s^{-1}	R_K	u_c
16.163	16.097	1.0041	0.0031

Primary standards:

Ionization chambers

CC01-125

CC01-132

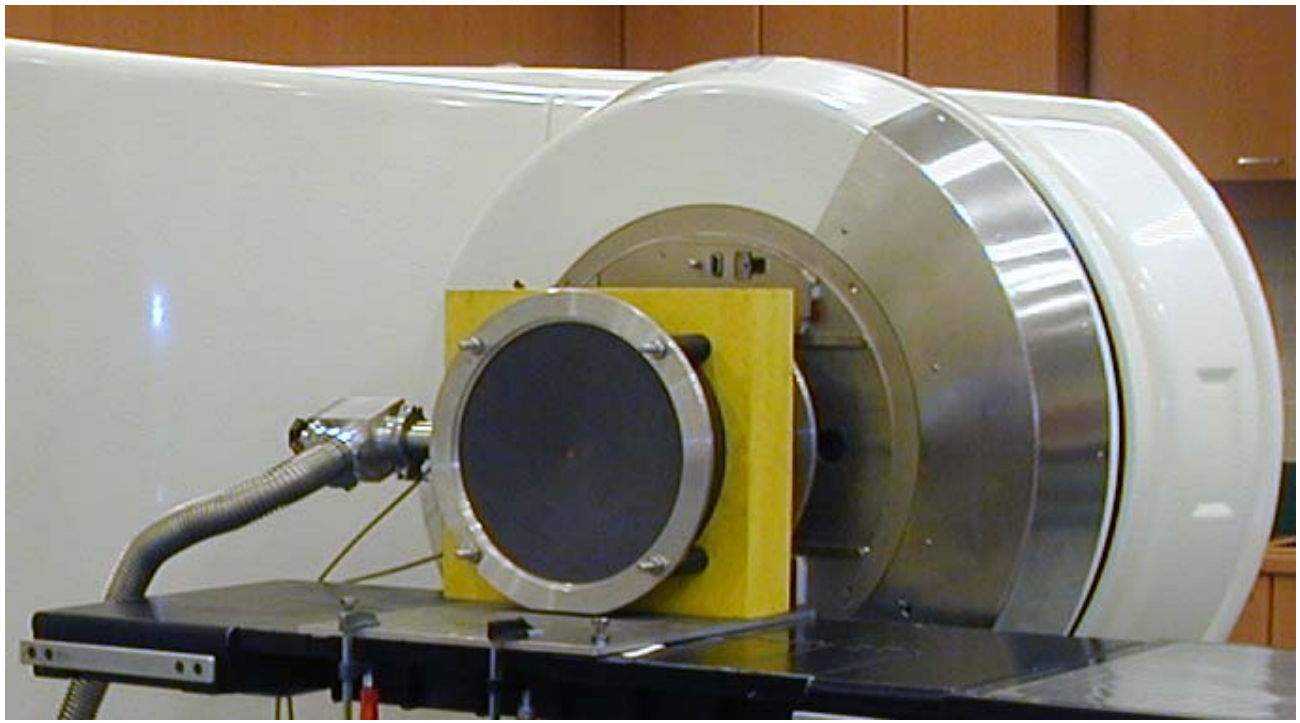
Transfer standard:

Ionization chamber

TK30-103

Final Report January 2010: Kessler, P.J. Allisy-Roberts, A. Steurer, W. Tiefenboeck, F. Gabris "Comparison of the standards for air kerma of the BEV and the BIPM for ^{137}Cs gamma radiation"

ACCELERATOR DOSIMETRY BY GRAPHITE CALORIMETRY – EURAMET PROJECT 1021



ACCELERATOR DOSIMETRY BY GRAPHITE CALORIMETRY – EURAMET PROJECT 1021

- Refurbishment of the BEV calorimeter
  - Revision and replacement of hardware components
  - Development of a new evaluation program with automatic non-linear drift extrapolations, created in LabView®
  - Verification of the calorimeter response for the complete temperature working range
  - Simulation studies for the BEV ^{60}Co teletherapy unit→ new correction factors
  - Measurements in the beam of the new reloaded BEV ^{60}Co teletherapy unit
  - Re-evaluation reference value absorbed dose rate to water BEV ^{60}Co teletherapy unit
- Enhancement of the calorimeter for dosimetry of high energy photon and electron radiation fields (Ph.D. Thesis of Andreas Baumgartner “Primary standard dosimetry of high-energy photon and electron beams”)
  - Simulation studies
  - Measurements at a Varian Clinac® accelerator in an Austrian hospital using the graphite-calorimeter and various secondary standards
  - Calculation of application specific correction factors
  - Correction for the effect of the vacuum gaps around the core
  - Correction for the deviation of the graphite phantom dimensions from the scaling requirements
- EURAMET Project 1021 (BEV, PTB, METAS)
  - Verification
  - Direct comparison of primary standards of absorbed dose to water in Co-60 and high energy photon beams

EURAMET 1021 - Participants and timetable

- Participants
  - BEV (Austria) – pilot laboratory: A. Steurer & A. Baumgartner
  - METAS (Switzerland): G. Stucki
  - PTB (Germany): R.-P. Kapsch
- Timetable
  - Start: 03/2008
  - Measurements with the BEV graphite calorimeter at PTB: 09/2008
  - Measurements with the BEV graphite calorimeter at METAS: 11/ 2008
  - Completion of evaluations: 12/2009
  - Report: 06/2010 (extended report of the participants, in German language)
  - Closing: 10/2010 (presentation at TC-IR Meeting)
  - Presentation at IAEA-Symposium: 11/2010
  - Final report on EURAMET-Website: 02/2011 (access to the report: http://www.euramet.org/index.php?id=tc-ir-projects)

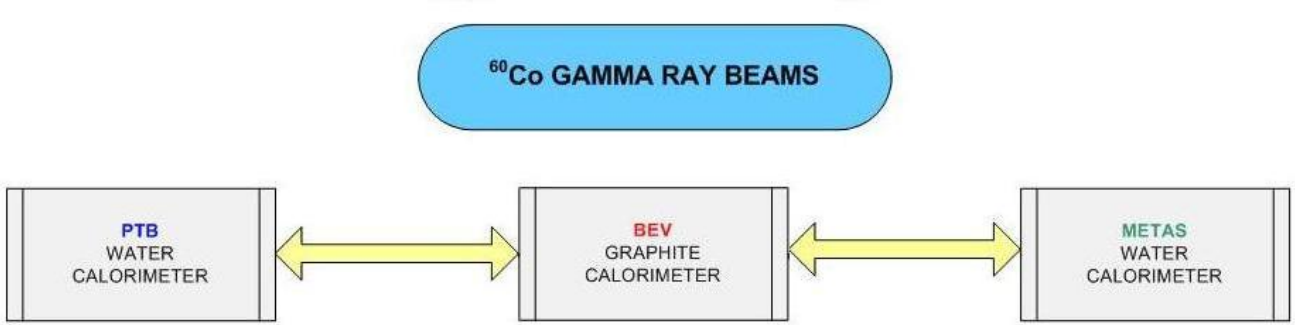
EURAMET 1021 - Description

This project was proposed for the direct comparison of primary standards for absorbed dose to water of BEV, METAS and PTB in ^{60}Co and high-energy photon beams. The primary standards for application in this comparison are one graphite calorimeter (BEV) and two water calorimeters (METAS, PTB).

The measurement were carried out in the ^{60}Co and high-energy photon beams of METAS and PTB. The BEV transported the graphite calorimeter primary standard to METAS and PTB for operation in the accelerator fields. The proposed photon beam qualities were generated by electrons with energies in the range from 4 MeV to 15 MeV. Additionally measurements and calibration of different secondary transfer ionization chambers at the same field conditions were carried out.

Detailed uncertainty budgets and traceability descriptions of participants were arranged.

^{60}Co measurements 1



- Determination of the reference absorbed dose rate to water
- Comparison with the reference absorbed dose rate to water given by PTB / METAS

^{60}Co measurements 2

PTB

METAS

^{60}Co source	nominaler distance to focus SCD (water) R_w [mm]	scaled distance to focus SCD (Graphit) R_g [mm]
PTB	1000,0	639,8
METAS	1000,0	639,8

^{60}Co measurements 3

Results

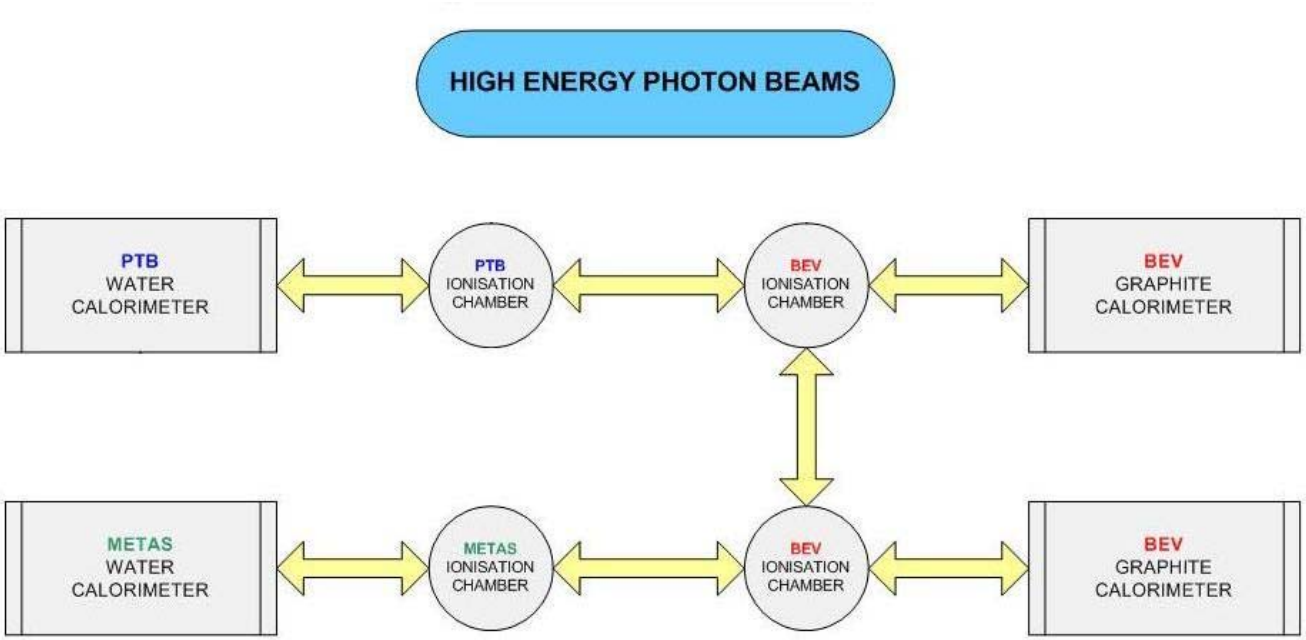
	reference date: 30.07.2004	reference date: 18.11.2008
Measurement BEV	1,257 60 Gy/min	0,681 36 Gy/min
Value given by PTB / METAS	1,261 24 Gy/min	0,680 00 Gy/min
Deviation	–0,3 %	0,2 %

Uncertainties

Institution	BEV	PTB	METAS
Primary standard	Graphit calorimeter	Water calorimeter	Water calorimeter
Standard uncertainty *u*	0,37 % [1)]	0,20 %	0,41 %
	0,69 % [2)]		

1) Valid for measurements at the BEV ^{60}Co Source.
2) Measurements at different ^{60}Co sources are affected by an additional uncertainty regarding the measuring positions.

Accelerator measurements 1

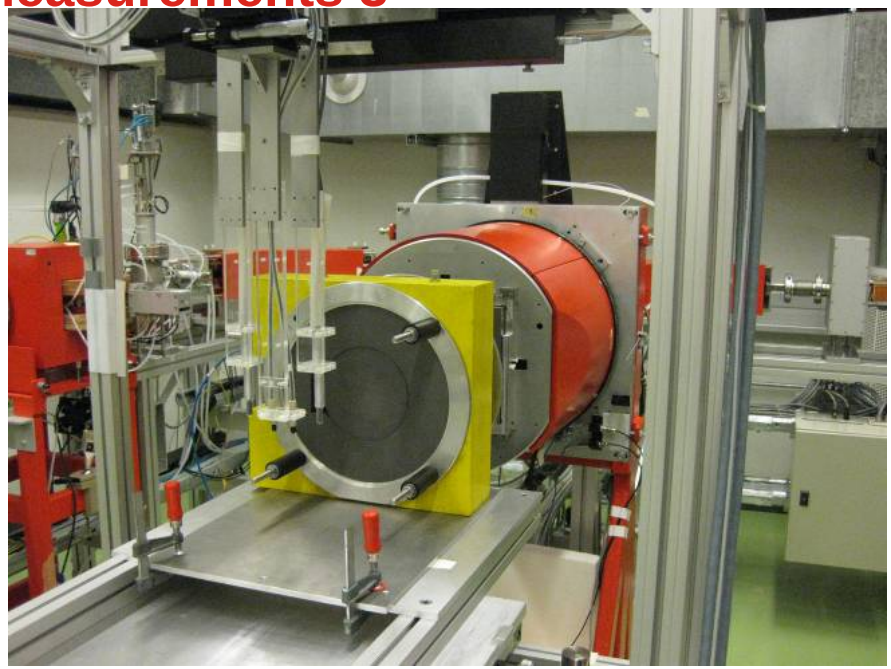


Accelerator measurements 2

- Determination of the absorbed dose rate to water in reference to the monitor chamber
- Calibration of the ionization chamber PTW 30012-27
- Calibration of the same ionization by PTB / METAS
  - NOTE: In September 2008 the experimentel determination of the correction factors k_Q at the new PTB-accelerators wasn‘t finished. Therefore the PTB-BEV-comparison was carried out with a chamber calibrated at ^{60}Co and the factors k_Q given by DIN 6800-2. Later measurements of the factors k_Q at PTB are showing a little shift.
- Comparison of the calibration factors $N_{w,Q}$

Accelerator measurements 3

PTB



METAS

Accelerator	nominaler distance to focus SCD (water) R_w [mm]	scaled distance to focus SCD (Graphit) R_g [mm]
PTB (Linac 107 + 108)	1100,0	699,8
METAS (depending on energy)	986,5 – 995,5	727,5 – 633,3

Accelerator measurements 4

Results comparison PTB-BEV

Quality Q	$TPR_{20,10}$	$N_{w,Q,PTB}/N_{w,Q,BEV}$
4 MV	0,637 6	0,978
6 MV	0,682 8	0,984
10 MV	0,732 9	0,985
15 MV	0,760 0	0,984

Results comparison METAS-BEV

Quality Q	$TPR_{20,10}$	$N_{w,Q,METAS}/N_{w,Q,BEV}$ [1)]	$N_{w,Q,METAS}/N_{w,Q,BEV}$ [1)]
4 MV	0,639 2	1,005	0,999
6 MV	0,674 1	1,007	1,001
10 MV	0,747 8	1,007	1,036 [2)]
15 MV	0,762 7	1,000	0,993

[1)] Using of two different monitor chambers (internal chamber and additional external chamber).
[2)] Presumably caused by a shift of the external monitor chamber during handling.

Accelerator measurements 5

Results indirect comparison PTB-METAS

Quality Q	$TPR_{20,10}$	$N_{w,Q,PTB}/N_{w,Q,METAS}$ [1)]	$N_{w,Q,PTB}/N_{w,Q,METAS}$ [2)]
4 MV	0,637 6	0,990	-
6 MV	0,682 8	0,998	0,992
10 MV	0,732 9	1,004	0,998
15 MV	0,760 0	1,001	-

[1)] METAS-values are fitted to the PTB-$TPR_{20,10}$-values.
[2)] Corrected results after determination of the PTB k_Q-factors for 2 radiation qualities.

Supporting CMCs of PTB and METAS

Uncertainty

Institution	BEV	PTB	METAS
Primary standard	Graphit calorimeter	Water calorimeter	Water calorimeter
Standard uncertainty u	0,75 % [1)]	1,04 % [2)] / 0,50 % [3)]	0,70 %

[1)] Standard uncertainty of graphit calorimeter which is 0,52 % plus a type B contribution caused by different geometric conditions at different accelerators
[2)] Standard uncertainty including the uncertainty of the the chamber calibrated at ^{60}Co and of the factors k_Q.
[3)] Standard uncertainty of the realization of D_w at 6 MV and 10 MV (measurements were done later).

New Diagnostic Radiation Qualities

- 160 kV X-ray generator Seifert Isovolt HS 160
- X-Ray tube 160 kV Comet MRX-161 with W-anode
- Supplemented with two new X-ray tubes:
  - Mo-Anode, 100 kV (Panalytic PW-2185/00)
  - Rh-Anode, 100 kV (Panalytic PW-2182/00)
- New X-ray radiation qualities:
  - Radiation qualities for Mammography
    - RQR-M-Series and RQA-MSeries (IEC 61267) (= PTB-Code MMV and MMH)
    - Other mammography radiation qualities according to PTB
  - Radiation qualities for Fluoroscopy with automatic brightness control system
    - RQC-Series (IEC 61267)
  - Radiation qualities for Computertomography
    - RQT-Series (IEC 61267)

New Diagnostic Radiation Qualities

Mammography Radiation Qualities

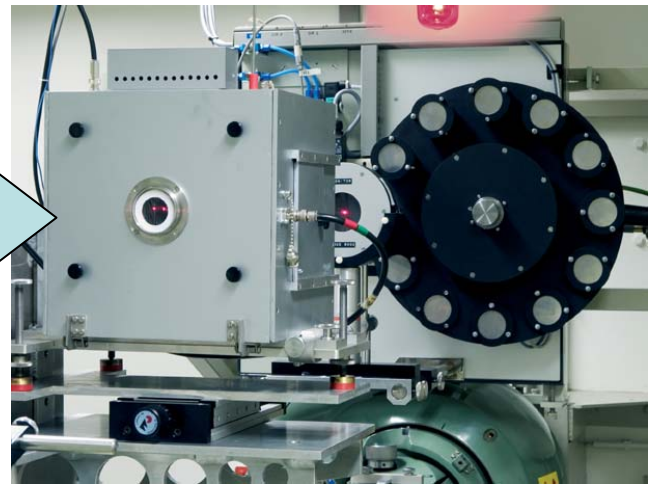
IEC 61267 code	PTB code	anode	filtration	tracibility
RQR M1 – M4 RQA M1 – M4	MMV 25 – 35 MMH 25 – 35	Mo Mo	30 µm Mo 30 µm Mo + 2,0 mm Al	**Secondary standard:** Ionization chamber **PTW 6 cm³ SFD** **TN34069-2,5-0018** (PTB-calibration) **Primary standard:** BEV Parallel plate chamber **PKM** (in developement mammography radiation qualities)
- -	MRV 25 – 35 MRH 25 – 35	Mo Mo	25 µm Rh 25 µm Rh + 2,0 mm Al	
- -	MAV 25 – 50 MAH 25 – 50	Mo Mo	1,0 mm Al 3,0 mm Al	
- -	RRV 25 – 35 RRH 25 – 35	Rh Rh	25 µm Rh 25 µm Rh + 2,0 mm Al	
- -	RAV 25 – 50 RAH 25 – 50	Rh Rh	1,0 mm Al 3,0 mm Al	
- -	WMV 25 – 35 WMH 25 – 35	W W	60 µm Mo 60 µm Mo + 2,0 mm Al	
	WRV 25 – 35 WRH 25 – 35	W W	50 µm Rh 50 µm Rh + 2,0 mm Al	
- -	WAV 25 – 50 WAH 25 – 50	W W	0,5 mm Al 2,5 mm Al	
- -	WPV 25 – 35 WPH 25 – 35	W W	40 µm Pd 40 µm Pd + 2,0 mm Al	
- -	WSV 25 – 35 WSH 25 – 35	W W	50 µm Ag 50 µm Ag + 2,0 mm Al	

New Diagnostic Radiation Qualities

Fluoroscopy and Computertomography Radiation Qualities			
IEC 61267 code	anode	filtration	tracibility
RQC 3 RQC 5 RQC 8	W W W	2,5 mm Al + 0,5 mm Cu 2,8 mm Al + 1,5 mm Cu 3,4 mm Al + 2,5 mm Cu	**Secondary standard:** Ionization chamber **PTW 6 cm³ SFD TN34069-2,5-0018** (PTB-calibration) **Primary standard:** BEV Parallel plate chamber **PKM** (in developement for these radiation qualities)
RQT 8 RQT 9 RQT 10	W W W	3,4 mm Al + 0,2 mm Cu 3,7 mm Al + 0,25 mm Cu 4,4 mm Al + 0,3 mm Cu	

BEV Parallel plate chamber **PKM**

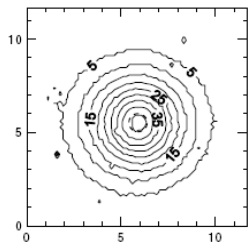
(Measuring volume: 17,7 cm³)

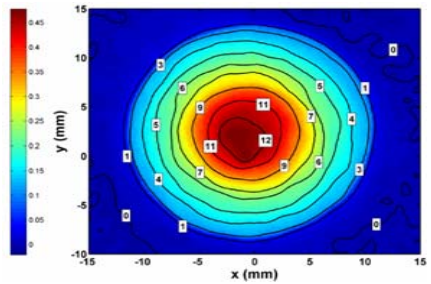


European Metrology Research Programm (EMRP)
Joint Research Project (JRP) T2.J06:
"INCREASING CANCER TREATMENT EFFICACY USING 3D BRACHYTHERAPY"

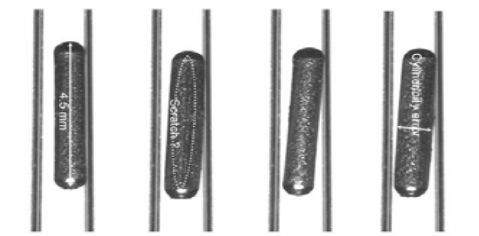
Contributor BEV: Frantisek Gabris

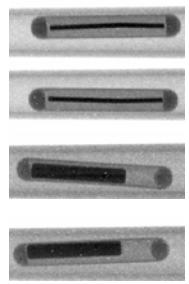
- WP4: Absorbed dose to water metrology chain – Secondary Standard development
- WP5 : 3D-Distribution of real brachytherapy sources - D_w





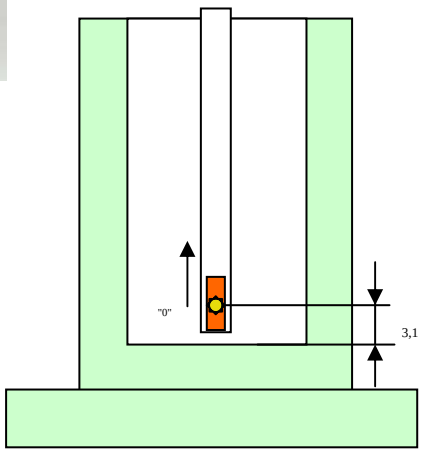
and their position inside a catheter

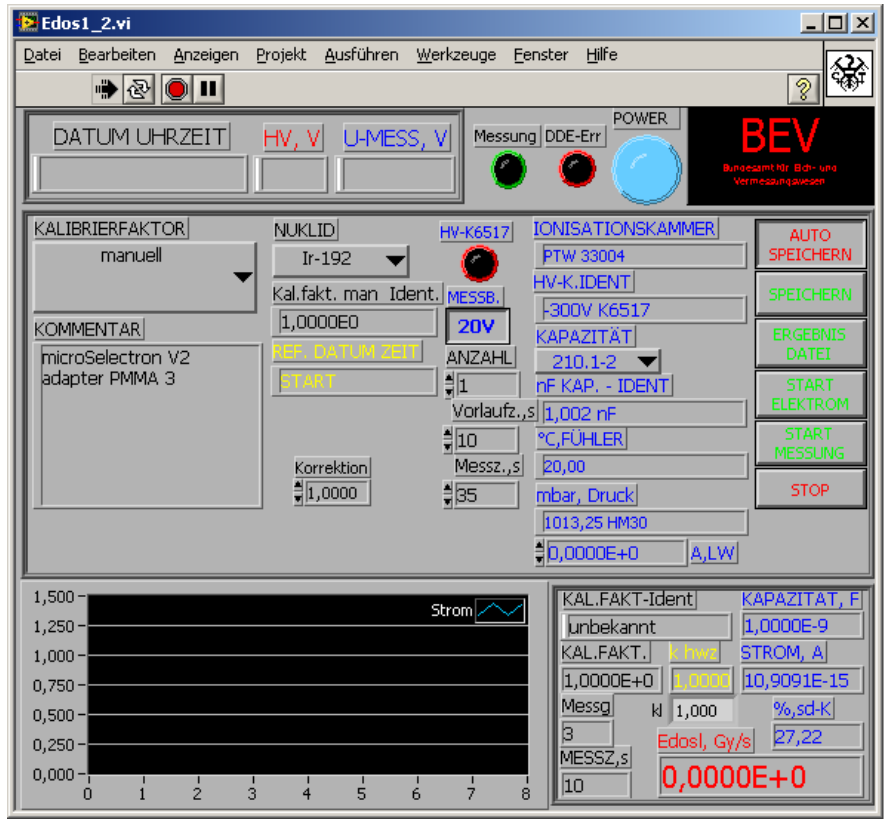




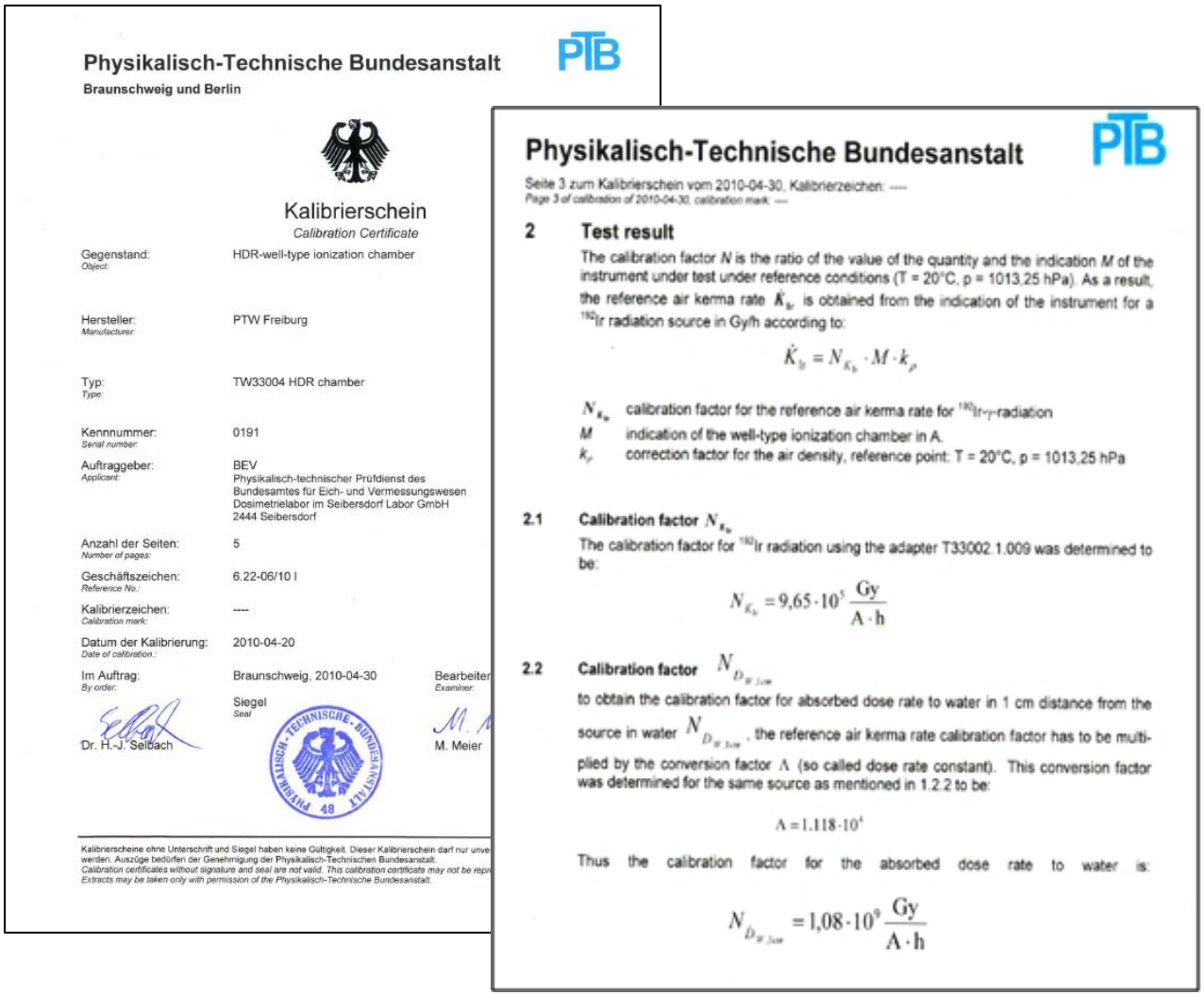
WP4: Secondary Standard development 1

PTW TM33004 well chamber based
BEV standard calibrated





WP4: Secondary Standard development 2



Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

PTB

Kalibrierschein
Calibration Certificate

Gegenstand: *Object:*	HDR-well-type ionization chamber
Hersteller: *Manufacturer:*	PTW Freiburg
Typ: *Type:*	TW33004 HDR chamber
Kennnummer: *Serial number:*	0191
Auftraggeber: *Applicant:*	BEV Physikalisch-technischer Prüfdienst des Bundesamtes für Eich- und Vermessungswesen Dosimetrielabor im Seibersdorf Labor GmbH 2444 Seibersdorf
Anzahl der Seiten: *Number of pages:*	5
Geschäftszeichen: *Reference No.:*	6.22-06/10 I
Kalibrierzeichen: *Calibration mark:*	----
Datum der Kalibrierung: *Date of calibration:*	2010-04-20
Im Auftrag: *By order:*	Braunschweig, 2010-04-30
Bearbeiter: *Examiner:*	M. Meier

Siegel
Seal

Dr. H.-J. Selbach

Kalibrierscheine ohne Unterschrift und Siegel haben keine Gültigkeit. Dieser Kalibrierschein darf nur unve
werden. Auszüge bedürfen der Genehmigung der Physikalisch-Technischen Bundesanstalt.
Calibration certificates without signature and seal are not valid. This calibration certificate may not be repr
Extracts may be taken only with permission of the Physikalisch-Technische Bundesanstalt.

Physikalisch-Technische Bundesanstalt

PTB

Seite 3 zum Kalibrierschein vom 2010-04-30, Kalibrierzeichen: ----
Page 3 of calibration of 2010-04-30, calibration mark: ----

2 Test result

The calibration factor N is the ratio of the value of the quantity and the indication M of the instrument under test under reference conditions (T = 20°C, p = 1013,25 hPa). As a result, the reference air kerma rate $\dot{K}_{air}$ is obtained from the indication of the instrument for a ^{192}Ir radiation source in Gy/h according to:

$$\dot{K}_{air} = N_{K_{air}} \cdot M \cdot k_{\rho}$$

$N_{K_{air}}$ calibration factor for the reference air kerma rate for ^{192}Ir-γ-radiation
M indication of the well-type ionization chamber in A.
k_{ρ} correction factor for the air density, reference point: T = 20°C, p = 1013,25 hPa

2.1 Calibration factor $N_{K_{air}}$

The calibration factor for ^{192}Ir radiation using the adapter T33002.1.009 was determined to be:

$$N_{K_{air}} = 9{,}65 \cdot 10^{5} \frac{\mathrm{Gy}}{\mathrm{A \cdot h}}$$

2.2 Calibration factor $N_{D_{w,Low}}$

to obtain the calibration factor for absorbed dose rate to water in 1 cm distance from the source in water $N_{D_{w,Low}}$, the reference air kerma rate calibration factor has to be multiplied by the conversion factor Λ (so called dose rate constant). This conversion factor was determined for the same source as mentioned in 1.2.2 to be:

$$\Lambda = 1.118 \cdot 10^{4}$$

Thus the calibration factor for the absorbed dose rate to water is:

$$N_{D_{w,Low}} = 1{,}08 \cdot 10^{9} \frac{\mathrm{Gy}}{\mathrm{A \cdot h}}$$

BEV secondary standard for absorbed dose to water quantity for brachytherapy sources was calibrated at the PTB (using Gammamed 12i source)

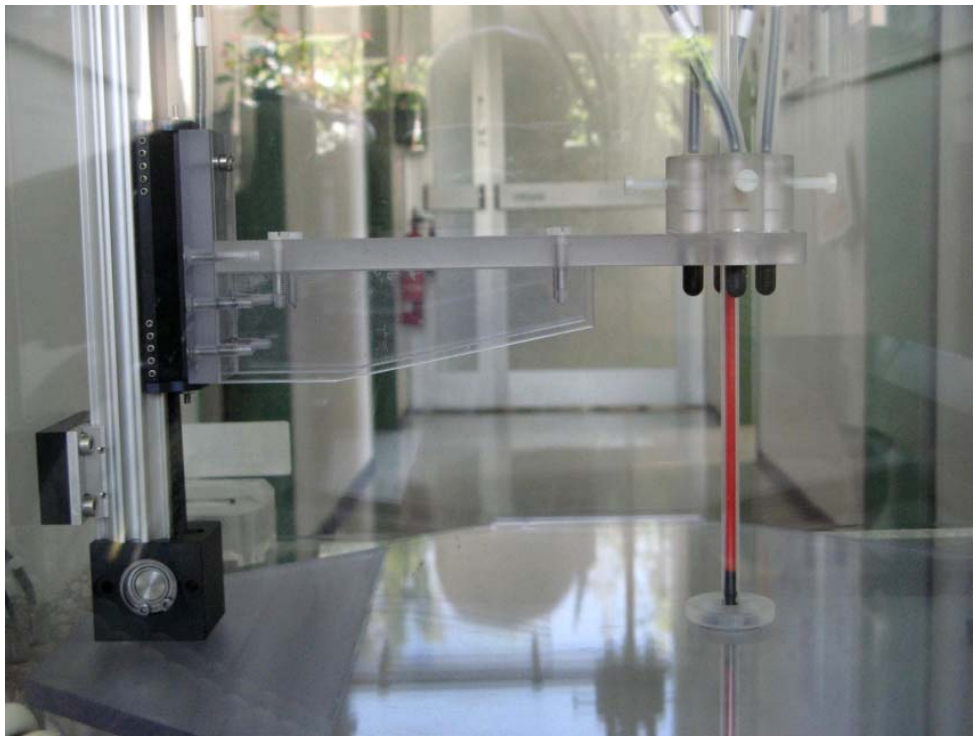
Calibration sheet was issued also for N_{Dw} quantity with source relevant Λ conversion factor

WP5: 3D-Distribution of real brachytherapy sources 1

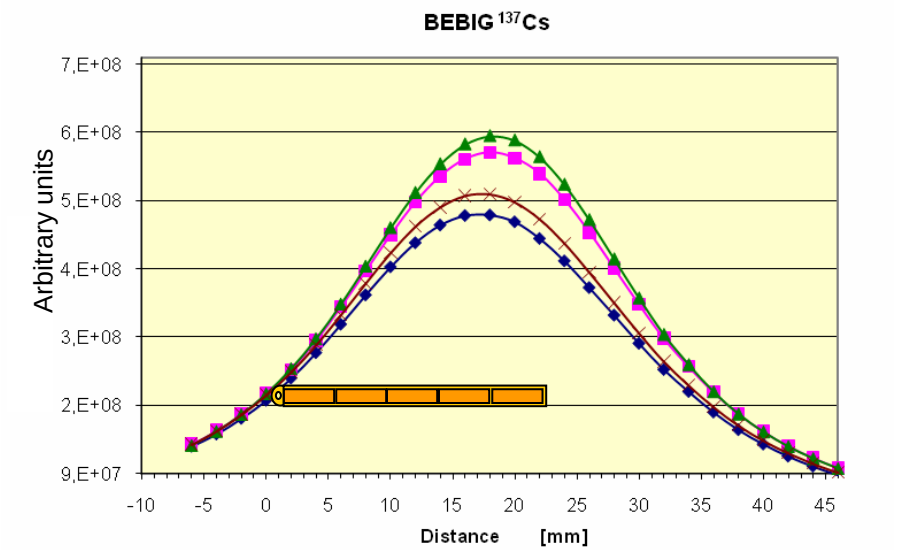
Source scanning system with 0,01 – 0,08 cm^3 ionizing chambers

Scanning was done at the source detector distance 12,5 mm, 20 mm and 30 mm inside the water phantom along the source inside the catheter

WP5: 3D-Distribution of real brachytherapy sources 2



Example: Real measurement in water phantom with - BEBIG ^{137}Cs **LDR** source



IAEA/WHO SSDL Postal dose quality audit by BEV

RESULTS OF TLD MEASUREMENTS FOR Co-60 AND HIGH-ENERGY PHOTONS; REFERENCE IRRADIATIONS

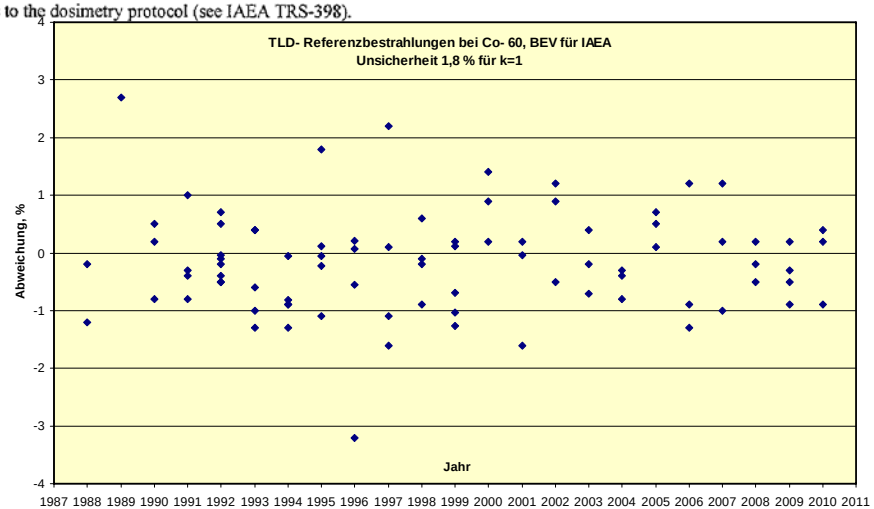
Beam	TLD set #	TLD capsule #	PSDL (stated) dose [Gy]	IAEA (measured)* dose [Gy]	% deviation relative** to PSDL	Mean % deviation
Co-60	*218P01*	*I*	*2.00*	*2.00*	*-0.2*	*-0.9*
		II	*2.00*	*1.98*	*-1.1*	
		III	*2.00*	*1.98*	*-1.2*	

* mean dose evaluated from 4 samples drawn from the individual capsule

** % deviation relative to PSDL stated dose = 100 x (IAEA measured dose - PSDL stated dose)/ PSDL stated dose

The uncertainty in the TLD measurement of the dose is 1.8% (1 standard deviation); this does not include the uncertainty intrinsic to the dosimetry protocol (see IAEA TRS-398).

^{60}Co, Therapy Level,
Uncertainty 1,8 % for *k*=1



RESULTS OF TLD AIR KERMA MEASUREMENTS FOR ^{137}Cs and ^{60}Co, REFERENCE IRRADIATIONS

Radiation Unit	Beam	TLD set #	TLD capsule #	PSDL (stated) air kerma [mGy]	IAEA (measured)* air kerma [mGy]	% deviation relative** to PSDL	Mean % deviation
Source CSC212A (LMRI)	*^{137}Cs*	*Run1_10_BEV*	*I*	*5.00*	*4.98*	*-0.5*	*-0.6*
			II	*5.00*	*4.96*	*-0.8*	

* mean air kerma evaluated from 5 samples drawn from the individual capsule

** % deviation relative to PSDL stated air kerma = 100 x (IAEA measured air kerma - PSDL stated air kerma)/ PSDL stated air kerma

The uncertainty in the TLD measurement of the air kerma is 1.8% (1 standard deviation)

^{137}Cs, Radiation Protection Level,
Uncertainty 2,0 % for *k*=1

Danke schön!