EURAMET TC-IR Project 1021

Direct comparison of primary standards of absorbed dose to water in ^{60}Co and high-energy photon beams

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1 Description

This project is 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 should be 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 (optional 18 MeV). Additionally measurements and calibration of different secondary transfer ionization chambers at the same field conditions were done.

Detailed uncertainty budgets and traceability descriptions of participants are arranged.

2 Participants

BEV (Austria) – pilote laboratory

METAS (Switzerland)

PTB (Germany)

3 Timetable

Start: March 2008

Measurements with the BEV graphite calorimeter at PTB: September 2008

Measurements with the BEV graphite calorimeter at METAS: November 2008

Completion of evaluations: December 2009

Report: December 2010 (extended report of the participants, in German language)

Paper: Autumn 2010 / 2011 (IAEA-Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry, paper in Radiation Protection Dosimetry, technical note or short communication, presumably in Metrologia)

Closing: October 2010 (presentation at TC-IR Meeting)

4 Report

The BEV graphite calorimeter is in operation since 1983 as an absorbed dose to water primary standard for ^{60}Co radiation fields [1], [2]. After an extended refurbishment process the energy range was enhanced for application in accelerator fields. For this purpose a set of conversion and correction factors was required. They were obtained utilising Monte Carlo simulations and measurements [3].

To verify the results of the refurbishment and the enhancement process a project was proposed for the direct comparison of primary standards for absorbed dose to water of BEV, METAS and PTB, in ^{60}Co gamma ray beams and high-energy photon beams. The primary standards used for this comparison were the BEV graphite calorimeter and two water calorimeters (METAS, PTB).

The measurements were carried out in the ^{60}Co gamma ray beams and in high-energy photon beams (4 MV, 6 MV, 10 MV and 15 MV) of METAS and PTB. The BEV transported the graphite calorimeter primary standard to PTB (in September 2008) and METAS (in November 2008).

This was the first time that an absorbed dose primary standard calorimeter of one National Metrology Institute (NMI) was transported to a different NMI for the purpose of a direct comparison in accelerator high-energy photon beams.

The project was connected with a huge logistic effort (transportation and setup of the calorimeter system including graphite phantom, measurement– and evaluation device, vacuum pump, ionization chamber measurement system etc.) and with a lot of expected and unexpected challenges. The main concept of the comparison is shown in the following figures.

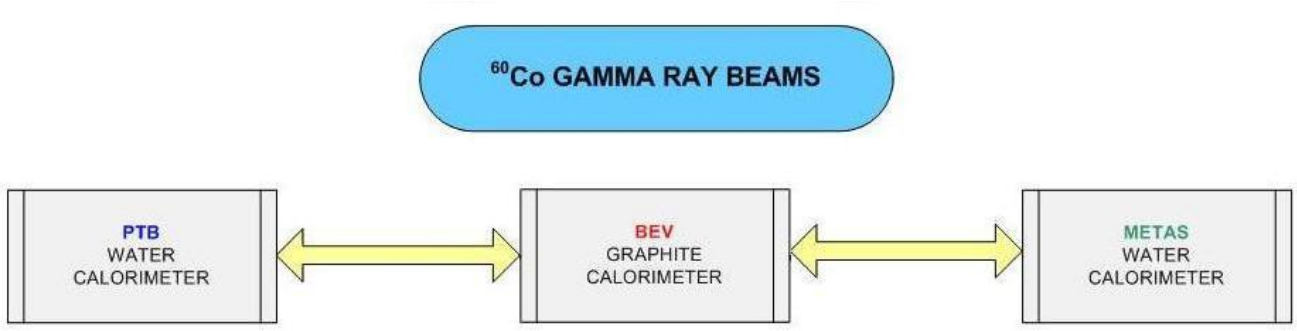


Figure 1 Concept of the comparison for $_{60}$Co gamma ray beams

Measurements in ^{60}Co gamma ray beams:

- Determination of the reference value for absorbed dose to water of the ^{60}Co therapy unit of PTB, respectively METAS with the BEV graphite calorimeter.
- Comparison of this value with the reference value determined with the water calorimeter of PTB, respectively METAS.

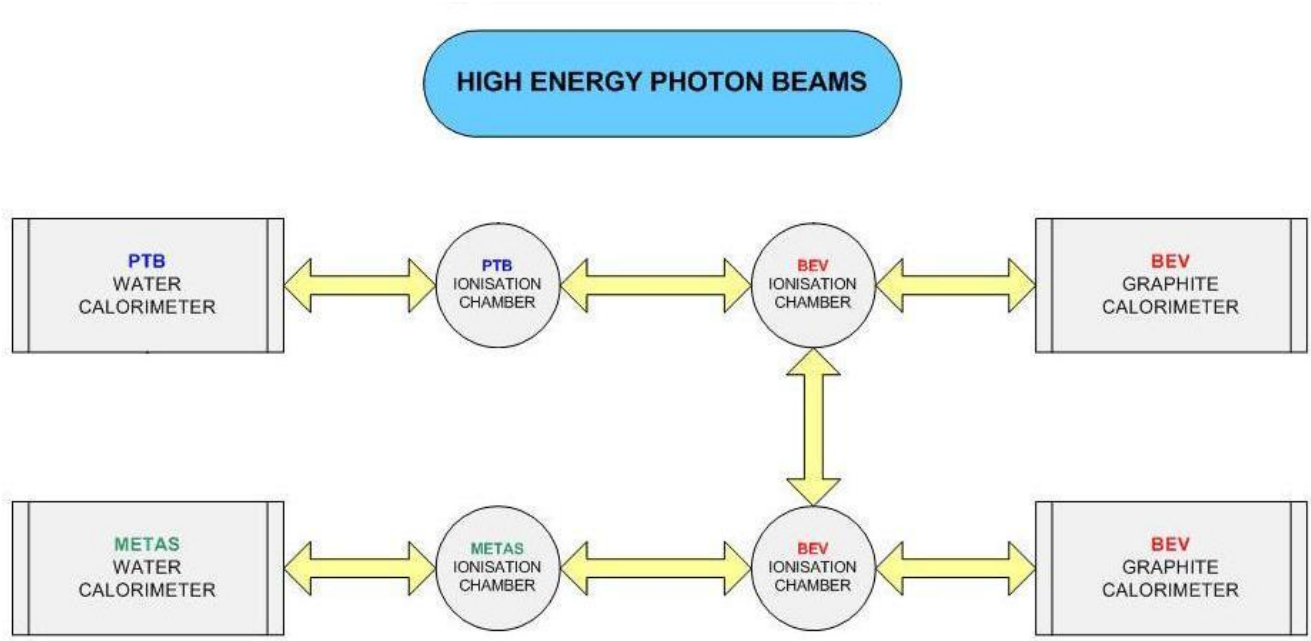


Figure 2 Concept of the comparison in high-energy photon beams

Measurements in high-energy photon beams:

- Determination of absorbed dose to water at the accelerator at PTB, respectively METAS and calibration of an ionization chamber.
- Calibration of the same ionization chamber PTW 30012-27 using an ionization chamber of PTB respectively METAS, calibrated with the water calorimeter of PTB respectively METAS.

The graphite calorimeter was used in the quasi-adiabatic operation mode to obtain the absorbed dose to graphite. The conversion to absorbed dose to water was done by two methods based on the photon fluence scaling theorem [4]: conversion by calculation (applied for 60Co measurements) and conversion with an ionization chamber (applied for accelerator beam measurements). The use of the first method at the accelerator is affected by two problems:

- The effective (virtual) point of source of an accelerator beam is not well known
- There are backscatter influences to the monitor chamber from the graphite phantom as a result of the small distance according to the photon fluence scaling theorem

For ^{60}Co a deviation of -0,3 % (PTB) and 0,2 % (METAS) was obtained (Table 1).

At the METAS accelerator deviations between 0,3 % and 0,7 % for the four energies were obtained (Table 3). Only the results for the PTB accelerators are problematical. Deviations between 1,5 % and 2,2 % were obtained (Table 4). The reason for the discrepancy seems to be clear. The measurements with the ionization chamber in the graphite phantom were made immediately after the graphite calorimeter measurements with a working temperature of 27 °C. Therefore a temperture effect – which influences the ionization current measurement – is assumed. Considering these circumstances one obtains a shift in the right direction. Unfortunatly a retrospective correction is not possible.

Nevertheless, and especially under consideration of the very short measuring time at PTB, respectively at METAS the project was very successful. Only five days were scheduled and necessary for five energies including setups of the graphite calorimeter and calibration of the ionization chambers and of course solving of some of the unexpected problems. The mobile application of the BEV graphite calorimeter was shown impressively. Within a very short time very

satisfactory results can be obtained. The results obtained by the different NMI's are widely in agreement.

Comparing the ionization chamber calibration coefficients of PTB and METAS for the four considered high-energy photon beam qualities deviations between 0,2 % and 0,9 % were obtained (Table 5 and Figure 3).

It has to be noted that in September 2008 the experimental 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 of the PTB (IBA FC65G-1108) 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 (Table 6).

5 References

[1] Leitner A., Witzani J.: The Realization of the Unit of Absorbed Dose at the Austrian Dosimetry Laboratory Seibersdorf, OEFZS–4740, Februar 1995.

[2] Witzani J., Duftschmid K.E., Strachotinsky Ch. & Leitner A.: A Graphite Absorbed-Dose Calorimeter in the Quasi-Isothermal Mode of Operation, Metrologia 20, 73-79 (1983), Springer-Verlag.

[3] Baumgartner A.: Primary standard dosimetry of high-energy photon and electron beams. Ph.D. Thesis in German language (Vienna University of Technology), 2010.

[4] Pruitt J.S., Loevinger R.: The photon-fluence scaling theorem for Compton-scattered radiation. Med Phys 9, 1982.

6 Summary of the results

Radiation quality ^{60}Co	^{60}Co facility PTB	^{60}Co facility METAS
	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 %

Table 1 Determination of the absorbed dose rate to water reference value for ^{60}Co

Institution	BEV	PTB	METAS
Primary standard	Graphite 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.

Table 2 Standard uncertainty for absorbed dose to water reference value for ^{60}Co

Radiation quality	$TPR_{20,10}$	$N_{w,Q,PTB}/ N_{w,Q,BEV}$ [1)]
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

Table 3 Results comparison PTB-BEV for high energy photons

Radiation quality	$TPR_{20,10}$	$N_{w,Q,METAS}/ N_{w,Q,BEV}$ [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.

Table 4 Results comparison METAS-BEV for high energy photons

Radiation quality	$TPR_{20,10}$	$N_{w,Q,PTB}/ N_{w,Q,BEV}$ [1)]
4 MV	0,637 6	0,990
6 MV	0,682 8	0,998
10 MV	0,732 9	1,004
15 MV	0,760 0	1,001

[1)] METAS-values are fitted to the PTB-$TPR_{20,10}$-values.

Table 5 Results indirect comparison PTB-METAS for high energy photons

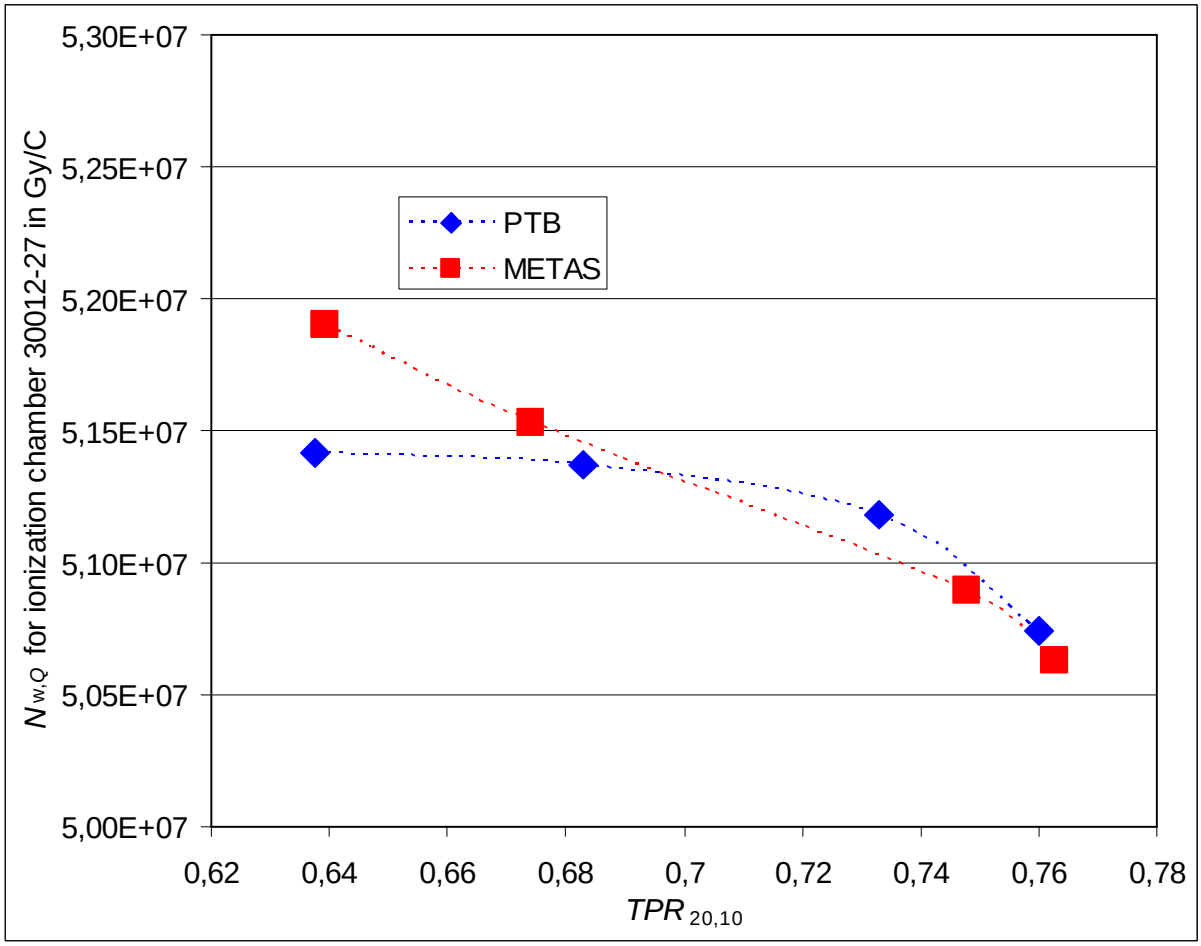


Figure 3 Results indirect comparison PTB-METAS for high energy photons

Radiation quality	$TPR_{20,10}$	$N_{w,Q,PTB}$/ $N_{w,Q,BEV}$ [1)]
4 MV	0,637 6	-
6 MV	0,682 8	0,992
10 MV	0,732 9	0,998
15 MV	0,760 0	-

[1)] METAS-values are fitted to the PTB-$TPR_{20,10}$-values.

Table 6 Corrected results indirect comparison PTB-METAS for high energy photons after determination of the PTB k_Q-factors

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

[1)] Standard uncertainty of the graphite calorimeter which is 0,52 % plus a type B contribution caused by different geometric conditions at different accelerators.

[2)] The standard uncertainty of the later measurements at 6 MV and 10 MV is given by the PTB with 0,5 %.

Table 7 Standard uncertainty for absorbed dose to water reference value for high enerrgy photons

7 Related publications and reports

Baumgartner A, Steurer A, Maringer F-J (2009) "Simulation of photon energy spectra from Varian 2100C and 2300C/D Linacs: simplified estimates with PENELOPE Monte Carlo models" Applied Radiation and Isotopes 67 (2009) 2007–2012

Baumgartner A, Steurer A, Maringer F-J (2008) "Advance of the Austrian Absorbed Dose to Water Primary Standardisation System" IRPA 12, Buenos Aires, 19.-24. October 2008

Baumgartner A, Witzani J, Steurer A, Leitner A, Maringer F-J (2007) "Energy Range and Application Enhancement of the BEV Graphite Calorimeter: First Assignments and Preliminary Results" Workshop proceedings, Absorbed Dose and Air Kerma Primary Standards Workshop, Paris 2007

Baumgartner A (2010) "Primary standard dosimetry of high-energy photon and electron beams" Ph.D. Thesis in German language (Vienna University of Technology)

Baumgartner A, Steurer A, Maringer F-J, Tiefenboeck W, Gabris F, Kapsch R-P, Stucki G (2010) "Correction factors of an absorbed dose primary standard graphite calorimeter in ^{60}Co gamma ray beams" Radiation Protection Dosimetry (2010), pp. 1–10 doi:10.1093/rpd/ncq376

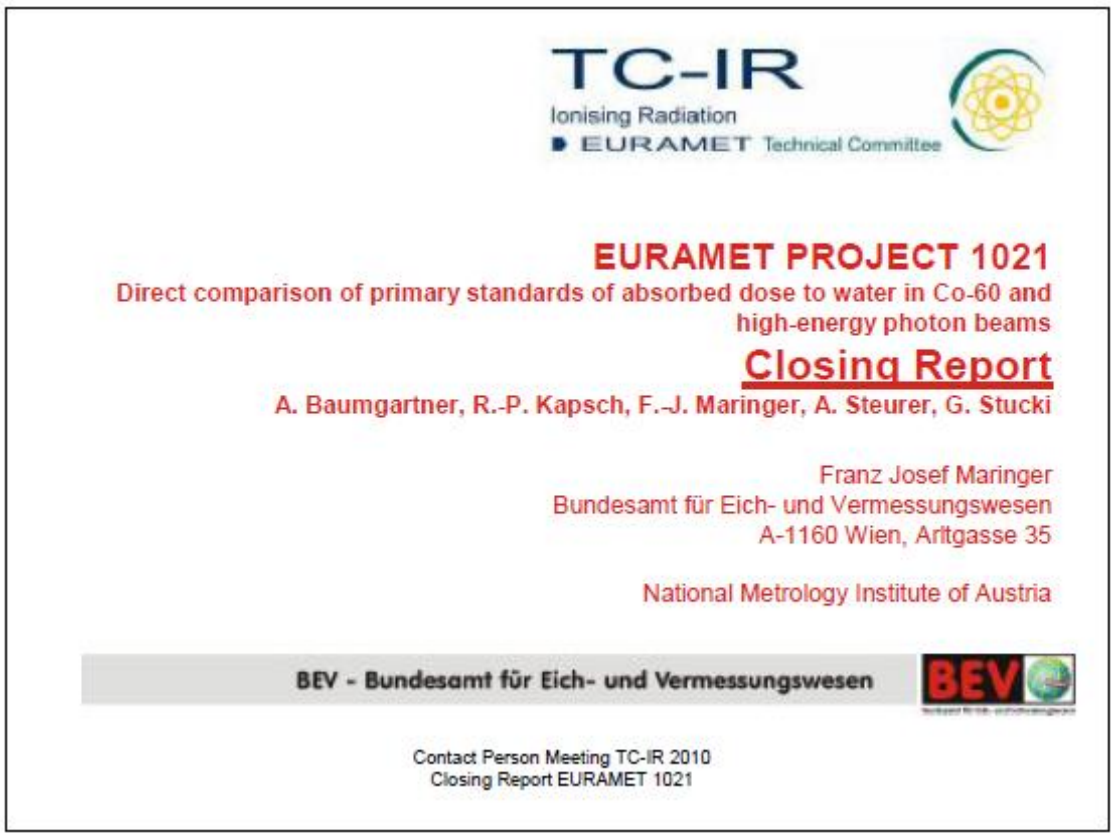
Baumgartner A, Steurer A, Maringer F-J, Kapsch R-P, Stucki G (2010) "Energy range and application enhancement of the BEV absorbed dose graphite calorimeter: Primary standard dosimetry of high-energy photon beams" (under Review)

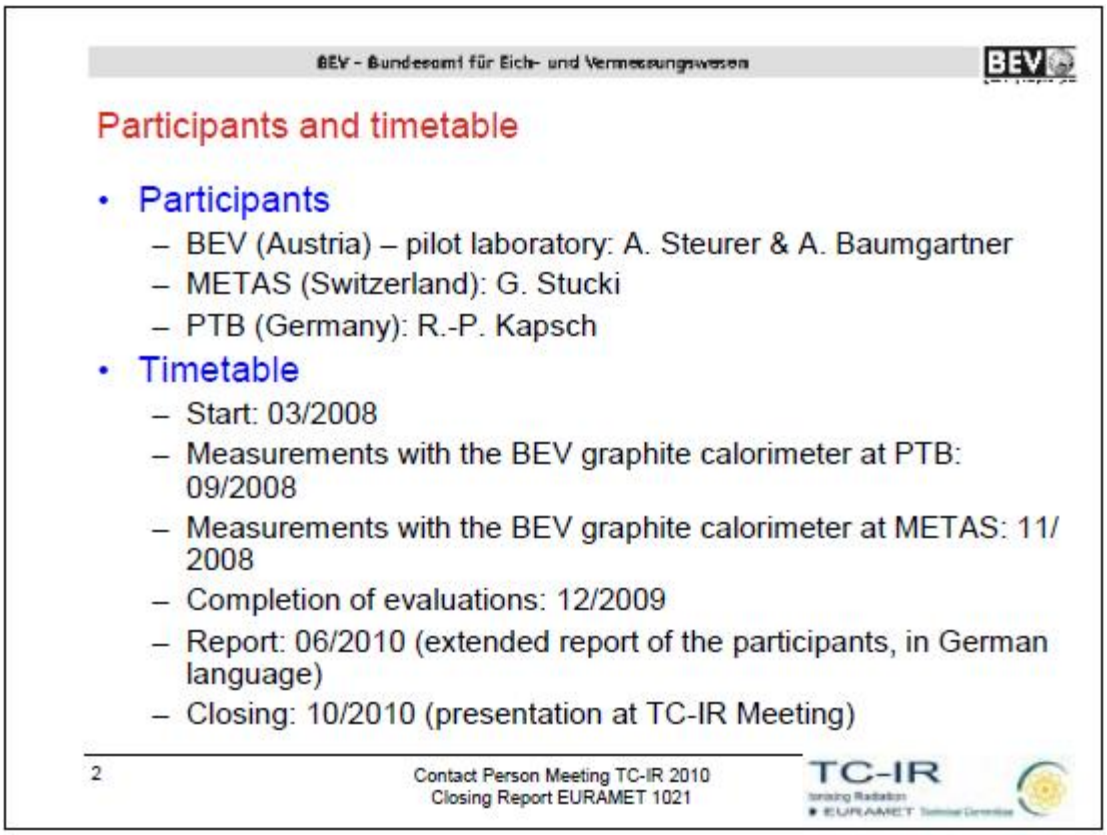
Baumgartner A, Steurer A, Kapsch R-P, Stucki G (2010) "EURAMET TC-IR Project 1021 – Direct comparison of primary standards of absorbed dose to water in ^{60}Co and high-energy photon beams" (internal report in German language)

Baumgartner A, Steurer A, Tiefenboeck W, Gabris F, Maringer F-J (2010) "Radiation protection in radiotherapy: primary standard dosimetry of high-energy photon beams in Austria" Third European IRPA Congress, Helsinki, 14.-June 2010

Steurer A, Baumgartner A, Kapsch R-P, Stucki G, Maringer F-J "Results of the direct comparison of primary standards for absorbed dose to water in ^{60}Co and high-energy photon beams (EURAMET TC-IR Project 1021)" International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry, IAEA, Vienna, Austria, 9-12 November 2010 (access to the presentation: http://nucleus.iaea.org/HHW/MedicalPhysics/IDOS/PS1_Steurer_253.pdf)

8 Annex: Closing Report EURAMET 1021 – Contact Person Meeting TC-IR 2010 Bratislava (presentation)





Description

This project is proposed for the direct comparison of primary standards for absorbed dose to water of BEV, METAS and PTB in Co-60 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 should be carried out in the Co-60 and high-energy photon beams of METAS and PTB. The BEV will transport the graphite calorimeter primary standard to METAS and PTB for operation in the accelerator fields. The proposed photon beam qualities are 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 are planned.

Detailed uncertainty budgets and traceability descriptions of participants are arranged.

Introduction

- BEV primary standard for absorbed dose to water is a graphite calorimeter
- Ph.D. Thesis of A. Baumgartner: refurbishment and re-evaluation for Co-60, extension of the application range to high-energy photon beams.
- Verification: Comparison measurements at Co-60-sources and accelerators of different NMIs

NOTE:

- This type of direct comparison of calorimeters in high-energy photon beams generated with accelerators was carried out worldwide the first time .

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Challenges

- Transport of the calorimeter system from Vienna to Braunschweig / Bern
- Only 5 days to measure 5 photon energies (Co-60, 4 MV, 6 MV, 10 MV, 15 MV)
- Different situations (monitor chamber, geometry, backscatter-effects…)
- Including measurements
  - to evaluate depth dose correction
  - to evaluate backscatter effects (monitor chamber)
  - to evaluate the the effectice source position
  - …
- Ionization chamber measurements (calibration)

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Basics graphit calorimeter

- Measuring of absorbed dose to graphite (quasi-adiabatic mode) – temperature rise of the core is measured over the response of the core thermistor resistances
- Conversion to absorbed dose to water based on the photon fluence scaling theorem
  - Method 1: calculation $\dot{D}_w = \dot{D}_g \cdot \left(\frac{R_g}{R_w}\right)^2 \cdot \ldots$

    R_g: scaled distance to calorimeter, R_w: distance to reference point in water phantom
  - Method 2: experimental $\dot{D}_w = \dot{D}_g \cdot \frac{Q_w}{Q_g} \cdot \ldots$

    Q_g, Q_w : Ionization-chamber measurements in graphite phantom (scaled distance) and in water phantom

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Co-60 measurements 1

- Conversion method 1 (calculation)
- Determination of the reference absorbed dose rate to water
- Comparison with the reference absorbed dose rate to water given by PTB / METAS

7

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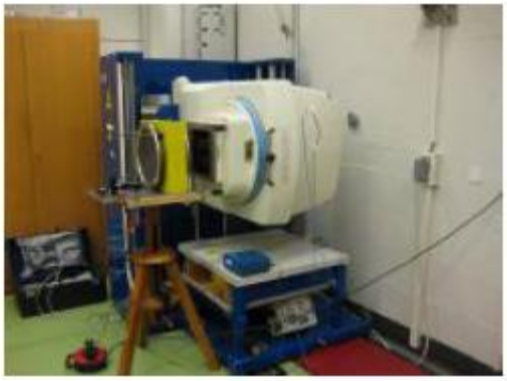
Co-60 measurements 2

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

8

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Co-60 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.

9

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Co-60 measurements 4

Explanation

- The application of method 1 requires the accurate knowledge of the virtual point source position
- In water calorimetry there is no requirement to know the virtual point source position exactly since no scaling is applied.
- In case of limited time it was not possible to determine the position of the virtual point source with the same accuracy as in the home laboratory.
- Therefore graphite calorimeter measurements at different ^{60}Co sources are affected by an additional uncertainty regarding the measuring positions.

10

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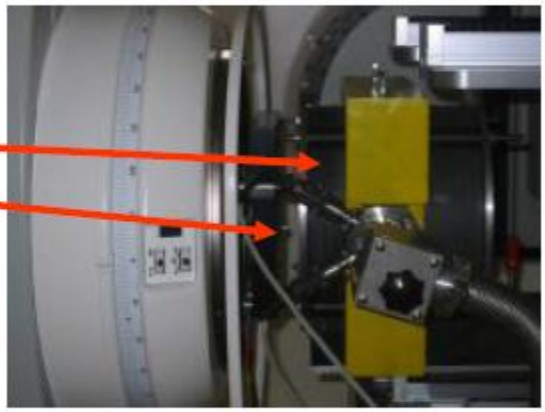
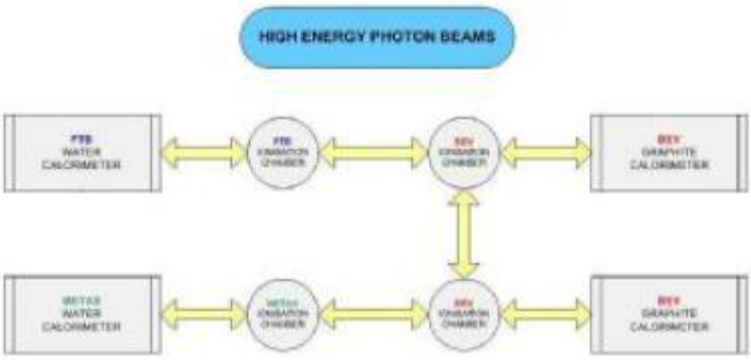
Accelerator measurements 1

- First, the favorite method of conversion was method 1 (calculation)
- → Problems at the accelerator
  - Backscatter effects – backscattering from graphite phantom to monitor chamber because of near distances (scaling)
  - Position of the effective point of source is not known very well – influence on the factor $(R_g/R_w)^2$
- Change to method 2 (experimental)



Accelerator measurements 2



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Accelerator measurements 3

- 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.
- Comparison of the calibration factors $N_{w,Q}$

13

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Accelerator measurements 4

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

14

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Accelerator measurements 5

Results comparison PTB-BEV (BEV → Method 2)

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 (BEV → Method 2)

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 monitor chamber during handling.

15

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Accelerator measurements 6

Results indirect comparison PTB-METAS

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

[1)] METAS-values are fitted to the PTB-$TPR_{20,10}$-values.

Uncertainty

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

16

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Acknowledgements

We wish to thank the collegues who where part of the project.

17

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Related publications and reports 1

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- Baumgartner A (2010) „Primaerstandard-Dosimetrie hochenergetischer Photonen- und Elektronenstrahlung“ Dissertation (Vienna University of Technology)

18

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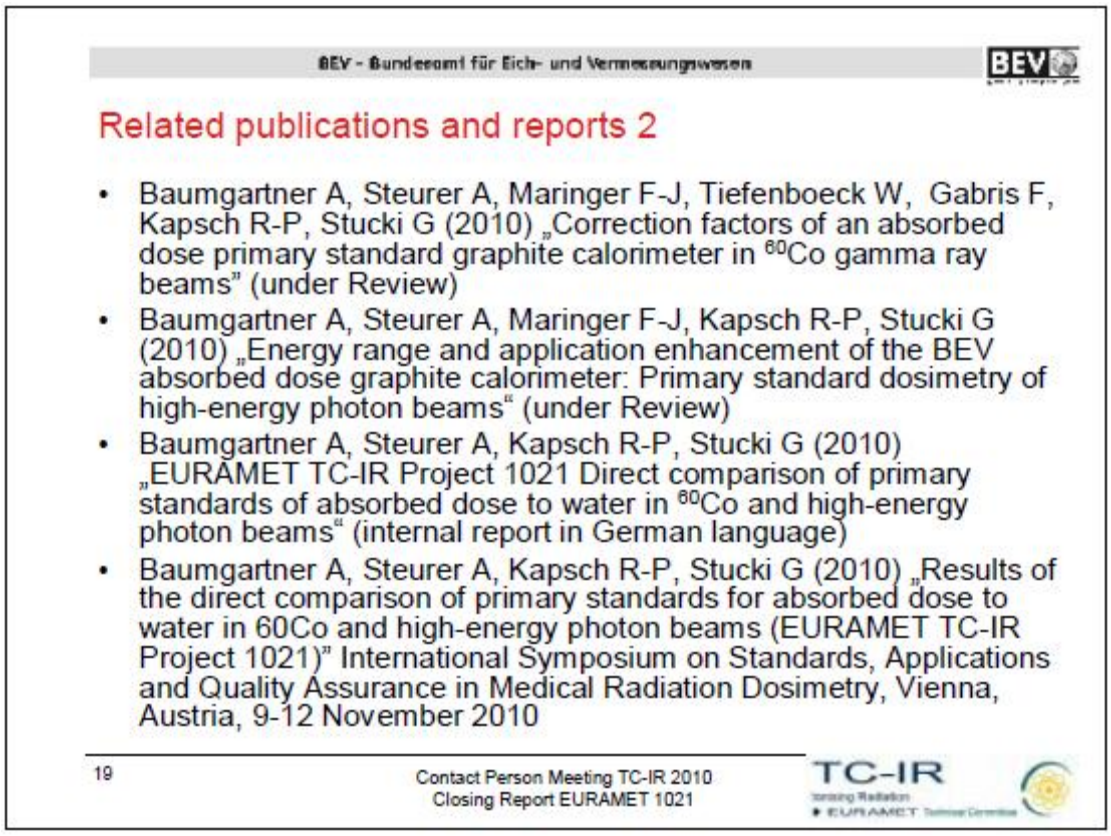

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Related publications and reports 2

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- Baumgartner A, Steurer A, Kapsch R-P, Stucki G (2010) „Results of the direct comparison of primary standards for absorbed dose to water in 60Co and high-energy photon beams (EURAMET TC-IR Project 1021)" International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry, Vienna, Austria, 9-12 November 2010

19

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