The equivalence of the absorbed dose to water in high energy photon beams

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A comparison of the dosimetry for high-energy photon beams was carried out between the Physikalisch-Technische Bundesanstalt (PTB), Germany, and the STARDOOR Laboratory of the National Institute for Laser, Plasma and Radiation Physics (INFLPR), Romania. The comparison was based on the determination of absorbed dose to water for three beam qualities at PTB. The measurement results, reported as a ratio of the STARDOOR and PTB evaluations of absorbed dose to water, show good agreement (less than 0.5 % deviation). In this work, the degrees of equivalence between PTB and STARDOOR have been calculated and the results are expressed in terms of En-numbers according to ISO 13528:2005.

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1. Introduction

Interlaboratory comparisons are used to determine the performance of individual laboratories for specific tests and measurements, and to monitor the continuing performance of laboratories [1 - 6].

The bilateral comparison had been carried out for the absorbed dose to water determinations of the Physikalisch-Technische Bundesanstalt (PTB), Germany, and STARDOOR of the National Institute for Laser, Plasma and Radiation Physics (INFLPR), Romania. STARDOOR laboratory is the only accredited facility by National Accreditation Body (RENAR) in Romania to perform dosimetrical calibration and testing in the field of high energy ionizing radiation [7].

The measurements were carried out in the accelerator laboratory of the PTB in Braunschweig, Germany. The comparison is based on the reciprocal determination of absorbed dose to water in high energy photon beams of nominal accelerating voltages 6 MV, 10 MV, and 15 MV, which were generated by one of PTB's Elekta Precise medical linacs. Both, PTB and STARDOOR, used two of their own ionization chambers (secondary standards) for the measurements.

The results of the comparison are given in terms of the mean ratio of the absorbed doses to water determined by each laboratory using their respective dosimeter and ionization chamber. All dose measurements were done on the basis of the dosimetric Code of Practice IAEA TRS-398 [8], using air filled ionization chambers calibrated in the reference beam radiation quality ^{60}Co, traceable to the German primary standard of absorbed dose to water (water calorimeter) [9].

According to this Code of Practice, the absorbed dose to water $D_{w,Q}$ in a photon beam of beam quality, Q, is give by the relation:

$$D_{w,Q} = M_Q \cdot N_{D,w_0} \cdot k_Q \quad (1)$$

where M_Q is the reading of the dosimeter with the reference point of the chamber positioned at the reference depth in a water phantom and corrected for the influence quantities such as temperature, pressure, polarity effect, and ion recombination; $N_{D,w}$ is the calibration factor in terms of absorbed dose to water for the dosimeter at the reference beam quality ^{60}Co, and k_Q is a chamber specific factor which corrects for the difference between the reference beam quality ^{60}Co, used for calibration, and the actual beam quality, Q, used for the measurement.

The STARDOOR laboratory used correction factors k_Q which have been calculated according to Appendix B from IAEA TRS-398 [8] and presented by PTW-Freiburg manufactory recommendations [10].

The beam quality correction factors k_Q applied by PTB were determined experimentally using its primary standard for absorbed dose to water (water calorimeter) [11, 12].

The measurement uncertainty of the absorbed dose to water has been calculated by both participants according to the Guide to the Expression of Uncertainty in Measurement (GUM) [13] taking into account all the influence quantities.

2. Experimental set-up

The measurements of the absorbed dose to water had been performed at the PTB Elekta Precise clinical linear accelerator. A total of three photon energies (nominal accelerating voltages 6 MV, 10 MV, and 15 MV) were used to obtain the absorbed dose to water data. All the measurements were done in horizontal beam geometry. A cubic water phantom of side length 30 cm was used for absorbed dose to water measurements. The field size at the surface of the phantom was 10 cm × 10 cm at a source to surface distance (SSD) of 100 cm.

The two ionization chambers used by the PTB for absorbed dose to water measurements were a water proof Farmer type chamber, IBA FC-65G and a non-waterproof Farmer type chamber, NE 2571, which was put in a waterproof PMMA sleeve. The ionization charges were measured by means of a Keithley 616 electrometer.

The STARDOOR standard ionization chambers are Farmer type chambers PTW TN 30010 and TN 31010. The ionization charges were measured using an UNIDOS electrometer.

All ionization chambers used in this comparison were calibrated in terms of absorbed dose to water in the ^{60}Co reference field at the PTB and are traceable to PTB's primary standard of absorbed dose to water for ^{60}Co beams (water calorimeter).

Each ionization chamber was positioned in the water phantom with the reference point at a depth of 10 g/cm^2.

Air pressure, humidity, and temperature of the water in the phantom have been measured; the ionization chamber readings were normalized to the reference temperature of 20 ^{o}C and the reference air pressure of 101.325 kPa (no correction was applied for humidity).

Readings have been obtained with both polarities of the polarizing voltage in order to correct for the polarity effect; the correction factor for recombination has been obtained by the two voltage methods [8].

With each chamber, four dose values of about 0.2 Gy, 0.5 Gy, 0.75 Gy, and 1.0 Gy have been measured in each high-energy photon beam. All dose measurements have been normalized to the reading of an external monitor chamber which has been mounted at the shadow tray of the accelerator's radiation head [14].

The beam quality of the photon beams used for the measurements was characterized by the tissue-phantom-ratio, $TPR_{20,10}$, which has been measured by PTB in advance. The beam qualities are presented in Table 1.

Table 1. Summary of the beam qualities used in this study

Nominal accelerating voltage in MV	*Beam quality specified $TPR_{20,10}$*
6	0.683
10	0.733
15	0.760

3. Results

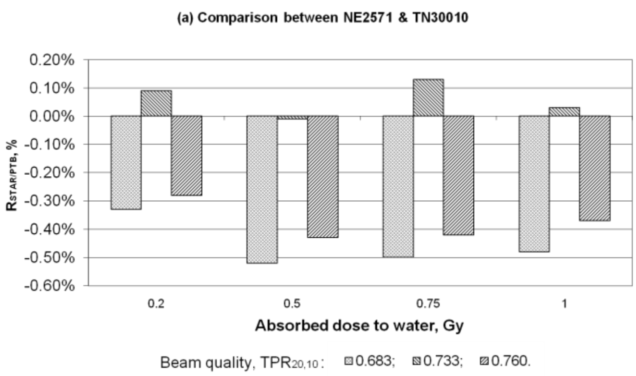
For all dose measurements the relative deviation of the STARDOOR results from the PTB measurements have been calculated, where D_{STAR} and D_{PTB} are the (normalized) dose values measured by STARDOOR Laboratory and PTB Laboratory, respectively:.

$$R_{STAR/PTB} = \left(\frac{D_{STAR}}{D_{PTB}} - 1 \right) \cdot 100\% \qquad (2)$$

The results are presented in Figures 1 a) and b). The absorbed doses measured independently by both laboratories show good agreement; the highest difference is 0.52 %.

The obtained values confirm the accuracy on measuring the compared value. Each laboratory have been considered proper expanded uncertainty (k = 2) taking into account the all influence quantities.

When uncertainty are estimated in a way consistent with the Guide to the expression of the uncertainty in measurements [13], E_n numbers express the validity of the expanded uncertainty estimate associated with each result [1, 15].



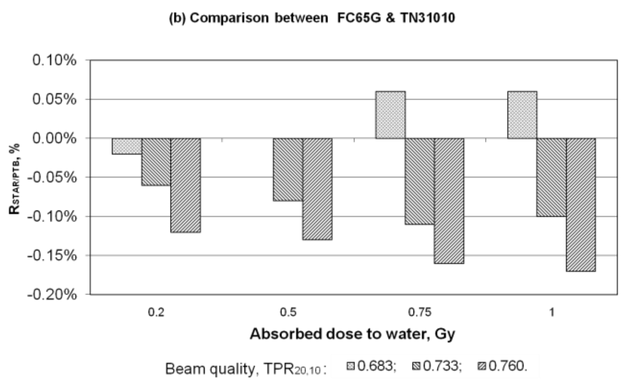


Fig. 1. Relative deviation of absorbed dose values measured by PTB and STARDOOR for different beam qualities, using the ionization chambers of types: a) NE2571 & TN 30010 and b) FG65G & TN31010

The degrees of equivalence between the PTB and the STARDOOR in this comparison have been calculated according ISO 13528:2005 and expressed in terms of the E_n-numbers. The E_n numbers represents the performance statistic and is calculated as follow:

$$E_n = \frac{D_{STAR} - D_{PTB}}{\sqrt{U_{STAR}^2 + U_{PTB}^2}} \qquad (3)$$

The E_n numbers were calculated for nominal absorbed dose to water value of 1.0 Gy. D_{STAR} and D_{PTB} are the measured absorbed dose to water corrected to all influence quantities reported by each laboratory. Each reported D_{STAR} and D_{PTB} were obtained from the mean of the 5 measurements. U_{STAR} and U_{PTB} are expanded uncertainty reported by participating laboratories: 0.84 % PTB and 0.98 % STARDOOR. The reference value has been designed the PTB values.

The E_n numbers have been calculated for all beam qualities, which correspond to the $TPR_{20,10}$ values of 0.693, 0.733, and 0.760 respectively.

The degree of equivalence is represented in Fig. 2 for all three radiation beam qualities used in this comparison for nominal absorbed dose to water of 1 Gy. For each beam quality, the E_n numbers were calculated for the degree of equivalence between FC65G & TN31010 ionization chambers and for NE2571 & TN30010 ionization chamber.

The calculated E_n numbers is [-0.05: 0.37]. This value well comply with the critical value of $|E_n| \leq 1$. The obtained E_n numbers express the validity of the estimated expanded uncertainty associated with each absorbed dose to water value.

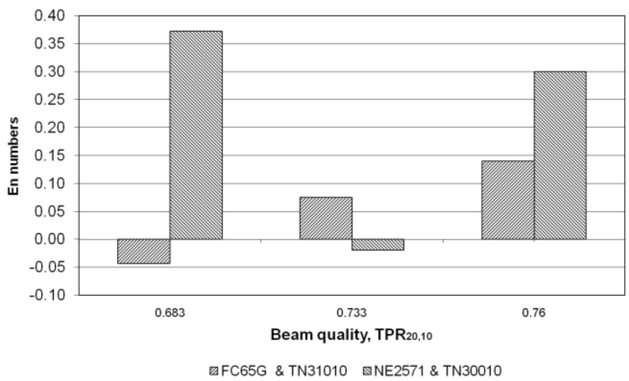


Fig. 2. The degrees of equivalence between the PTB and the STARDOOR of the absorbed dose to water values expressed in terms of the E_n-numbers according ISO 13528:2005

4. Conclusions

The relative difference between the absorbed dose to water values obtained by the two participating laboratories is at most 0.52 %. Considering the expanded uncertainty of each laboratory (0.84 % PTB and 0.98 % STARDOOR) there is a very good agreement between the absorbed doses measured by both laboratories.

The E_n numbers, calculated according to ISO 13528:2005, fulfill the acceptance condition for equivalence: $|E_n| \leq 1$, the calculated values being at most 0.4. The validity of the estimated expanded uncertainty associated with each absorbed dose to water value confirms the performance of laboratories participating to comparison.

Acknowledgements

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References

[1] ISO 13528:2005, Statistical methods for use in proficiency testing by interlaboratory comparisons.
[2] C. Kessler, P. J. Allisy, D. T. Burns, A. Krauss, R.-P. Kapsch, Metrologia **43**, Tech. Suppl. 06005 (2006).
[3] S. Picard, D. T. Burns, P. Roger, P. J. Allisy-Roberts, R. P. Kapsch, A. Krauss, Metrologia **48**, Tech. Suppl. 6020 (2011).
[4] F. Delaunay, R.-P. Kapsch, J. Gouriou, J. Illemann, A. Krauss, M. le Roy, A. Ostrowsky, L. Sommier, D. Vermesse, Metrologia **49,** S203 (2012).
[5] A. M. Stoica, A. A. Steţiu, M. Buruian, M. Steţiu, M. Monea, J. Optoelectron. Adv. M. **18**(5-6), 560 (2016).
[6] E. Stancu, C. Vancea, J. Valenta, J. Zeman, E. Badita, A. Scarisoreanu, Romanian Reports in Physics **67**, 693 (2015).
[7] F. Scarlat, A. Scarisoreanu, R. Minea, E. Badita, E. Sima, M. Dumitrascu, E. Stancu, C. Vancea, Optoelectron. Adv. Mat. **7**(7-8), 618 (2013).
[8] IAEA TRS 398, Absorbed Dose Determination in External Beam Radiotherapy, IAEA, 2000.
[9] A. Krauss, Metrologia **43,** 259 (2006).
[10] Absorbed Dose Determination in Photon and High Energy Electron Beams, PTW, 2006.
[11] A. Krauss, R.-P. Kapsch, Phys. Med. Biol. **52,** 6243 (2007).
[12] A. Krauss, R.-P Kapsch, M. Rouijaa, Standards, applications and quality assurance in medical radiation dosimetry (IDOS) – Proceedings of an International Symposium, International Atomic Energy Agency, Vienna, 209 (2011).
[13] ISO/IEC 98:1993, Guide to the Expression of Uncertainty in Measurement.
[14] R.-P. Kapsch, A. Krauss, O. Dössel, W.C. Schlegel, (ed.), World Congress on Medical Physics and Biomedical Engineering, September 7 - 12, 2009, Munich, Germany, Springer **25/I**, 85 (2009).
[15] IAEA TECDOC 1585, Measurement Uncertainty. A Practical Guide for Secondary Standard Dosimetry Laboratories, IAEA, 2008.

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