

Reference Dosimetry according to the New German Protocol DIN 6800-2 and Comparison with IAEA TRS 398 and AAPM TG 51*

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ABSTRACT

The preceding DIN 6800-2 (1997) protocol has been revised by a German task group and its latest version was published in March 2008 as the national standard dosimetry protocol DIN 6800-2 (2008 March). Since then, in Germany the determination of absorbed dose to water for high-energy photon and electron beams has to be performed according to this new German dosimetry protocol. The IAEA Code of Practice TRS 398 (2000) and the AAPM TG-51 are the two main protocols applied internationally. The new German version has widely adapted the methodology and dosimetric data of TRS-398. This paper investigates systematically the DIN 6800-2 protocol and compares it with the procedures and results obtained by using the international protocols. The investigation was performed with 6 MV and 18 MV photon beams as well as with electron beams from 5 MeV to 21 MeV. While only cylindrical chambers were used for photon beams, the measurements of electron beams were performed by using cylindrical and plane-parallel chambers. It was found that the discrepancies in the determination of absorbed dose to water among the three protocols were 0.23% for photon beams and 1.2% for electron beams. The determination of water absorbed dose was also checked by a national audit procedure using TLDs. The comparison between the measurements following the DIN 6800-2 protocol and the TLD audit-procedure confirmed a difference of less than 2%. The advantage of the new German protocol DIN 6800-2 lies in the renouncement on the cross calibration procedure as well as its clear presentation of formulas and parameters. In the past, the different protocols evolved differently from time to time. Fortunately today, a good convergence has been obtained in concepts and methods. © 2011 Biomedical Imaging and Intervention Journal. All rights reserved.

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INTRODUCTION

In Germany, the dosimetry for linear accelerators is currently performed according to the new DIN 6800-2

(2008 March) [1]. In this protocol, the absorbed dose in water is used as a measuring quantity for high-energy photon and electron beams. In order to better meet international consistency, the preceding DIN 6800-2(1997) [2] was modified and adapted to the Technical Report Series No. 398 (TRS 398) of the IAEA [3]. The description of the measurements and methods, the correction parameters for various chambers and the

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evaluation for uncertainties are the main parts of DIN 6800-2 (2008 March). The physical basics are illustrated in its appendix. The new data of the correction factors and the interaction coefficients of the IAEA TRS 398 are taken for the calculation of the absorbed dose in the new DIN, so that the international consistence of the dose calculation is assured. Although not all parameters were taken directly from TRS 398, the effects of the deviations from the TRS 398 remain low [4]. The main difference between the old protocol and the new one lies in the electron dosimetry as well as in the evaluation of the uncertainties. In this work, the authors have applied the new DIN 6800-2 (2008 March) to check the clinical dosimetry in reference to the TRS 398 (2000) as the base for the future application of the DIN 6800-2. Furthermore, the authors also included the protocol AAPM TG-51 (1999) [5] in the comparison. Although TRS 398 is aiming at being a “Code of Practice” rather than a dosimetry protocol in its real meaning, it will also be called a dosimetry protocol along with the two other documents in this manuscript.

MATERIALS AND METHODS

The measurements for the evaluation of the depth dose distributions were performed in a Wellhoefer water phantom (Blue Phantom) with the plane-parallel Roos chamber 34001 (PTW). The cylindrical chamber CC-13 (Wellhoefer) was used as a reference chamber. The relative measurements were done and evaluated with the Software Scanditronix-Wellhöfer OmniPro-Accept 6.3.

The determination of the absorbed dose in water was also done in the Blue Phantom with two cylindrical chambers (PTW-31013 type) as well as with two plane parallel chambers (PTW-34001 type, Roos-Chamber).

For the absolute dosimetry, the Scanditronix-Wellhoefer-Assembly system was used only for the positioning of the measuring chamber. The absolute charge was measured with the electrometer models PTW-UNIDOS and PTW-UNIDOS E. Positioning of the ionisation chamber was performed by adjusting the reference point of a specific chamber to the measuring depth as required in the respective protocol (Table 1). The reference point of the cylindrical chamber is located at the central axis and at the middle point of the chamber cavity (r_{cyl} = internal radius of the chamber cavity). For the Roos-chamber, the reference point is located on the inner surface of the entrance window which is at the centre of the window (PMMA thickness of the window: 1 mm). Each chamber type is calibrated in a Co-60 radiation beam with its reference point at measuring depth.

The operating voltage for the cylindrical chamber is 400 V, whereas the Roos-chamber is connected to a voltage of 200 V. Furthermore, additional measurements were performed in a special type of water phantom PTW 4322 with TLD-dosimeters according to an audit procedure called technical control measurement (MTK) of the German medical products law (LMKM). The results were taken to additionally check the accuracy of this work.

Two linear accelerators, a Siemens ONCOR Impression (with 6 MV-Photon and 5, 7, 8, 10, 12, 14 MeV-Electron beams) and a Siemens ONCOR Avantgarde (with 6 and 18 MV-Photon and 6, 9, 12, 15, 18, 21 MeV-Electron beams) were available as irradiation units in the department for this study.

Principle of the determination of the absorbed dose in water

All ionisation chambers were calibrated with a Co-60 source (and thus provided with calibration factor N). For the determination of the absorbed dose in water D_w for photon and electron beams, having the dosimeter reading M at the depth of measurement z_{ref} , the following equation is generally applied to all protocols as:

$$D = M \cdot N \cdot \prod_{i=1}^n k_i \quad (1)$$

where N – as mentioned – is the calibration factor for absorbed dose to water for Co-60 beam.

The product of the correction factors $\prod k_i$ contains the required corrections to take into account all the deviations between the calibration and the measuring conditions for the determination of the absorbed dose in water. In all protocols, the most important corrections are those for the polarity of the chamber voltage (k_p), for the ion recombination correction (k_s), for the air density effect (k_ρ) and for the radiation quality k_Q for photons and k_E for electrons, respectively. In the DIN-Protocol, an additional correction factor k_r is included for the cylindrical chamber, which takes explicitly into account the different position of cylindrical chambers during the calibration (reference point at measuring depth) and the user’s measurement (reference point $0.5 r_{cyl}$ lower than measuring depth). In the other protocols, this correction factor is embedded in the quality correction factor k_Q as one of the constituent perturbation factors.

The reference conditions for the determination of the absorbed dose to water are listed in Table 2.

Determination of correction factors

Determination of the correction factor k_ρ for the air density

k_ρ is calculated from the temperature in the phantom and the absolute pressure at the measuring place as follows:

$$k_\rho = \frac{p_0 T}{p T_0} \quad (2)$$

With T = temperature in the phantom, p = air pressure in place as well as the corresponding reference values of temperature ($T_0 = 293.2$ K) and pressure ($p_0 = 1013.25$ hPa).

All chambers are calibrated at 20°C in Germany. Therefore, the authors have also used 20°C for the calculation of absorbed dose for the AAPM- protocol instead of the temperature 22°C given there.

Table 1 Positioning of ionization chamber type according to the protocols.

Chamber Type	IAEA TRS 398 (2000)		DIN 6800-2 (2008 March)		AAPM TG-51 (1999)	
	Photon	Electron	Photon	Electron	Photon	Electron
cylindrical-chamber	Reference point at the measuring depth	Reference point 0.5 r_{cyl} below the measuring depth	Reference point 0.5 r_{cyl} below the measuring depth	Reference point 0.5 r_{cyl} below the measuring depth	Reference point at the measuring depth	Reference point at the measuring depth
Plane-parallel chamber	-	Reference point at the measuring depth	-	Reference point at the measuring depth	-	Reference point at the measuring depth

Table 2 Reference conditions for the determination of depth dose curve and the absorbed dose to water for all 3 protocols (IAEA suggests a field size FS = 10 × 10 cm² for Electron beams, we have chosen the values for IAEA FS = 20 × 20 cm² for all protocols for comparison).

	Dose depth distribution		Absorbed dose to water	
	Photons	Electrons	Photons	Electrons
Reference-Field size	10 × 10 cm ²	20 × 20 cm ²	10 × 10 cm ²	20 × 20 cm ²
SSD	100 cm	100 cm	100 cm	100 cm
Reference depth	-	-	$z_{ref} = 10$ cm	$z_{ref} = 0.6 * R_{50} - 0.1$ [cm]

Table 3 Determination of the correction factor k_s (where D_i = Dose per radiation pulse in mGy, U_1 = normal chamber operating voltage, U_2 = lower chamber voltage, d = Electrode distance, M_1 = measured value at U_1 , M_2 = measured value at U_2 , the constants γ and δ are to be taken from the DIN 6800-2 [Edition version: 2007], Table 4. The constants a_0 , a_1 and a_2 are listed in the corresponding protocol).

Dosimetry protocol	Determination of k_s	
	Theoretical (Formula)	Experimental (U_1, U_2, M_1, M_2)
AAPM TG-51 (1999)	(no formula is given)	$k_s = \frac{U_1/U_2 - 1}{U_1/U_2 - M_1/M_2}$ $k_s = \frac{M_1/M_2 - 1}{U_1/U_2 - 1}$
IAEA TRS 398 (2000)	(no formula is given)	or $k_s = a_0 + a_1 \frac{M_1}{M_2} + a_2 \left(\frac{M_1}{M_2} \right)^2$
DIN 6800-2 (2008 March)	$k_s = 1 + \frac{\gamma + \delta \cdot D}{U_1}$	$k_s = \frac{U_1/U_2 - 1}{U_1/U_2 - [(M - M_0)k_p k_p]_1 / [(M - M_0)k_p k_p]_2}$

Determination of the correction factor k_s for the ion recombination

k_s can be determined either experimentally by the “two-voltage-procedure” or theoretically by a formula. The different methods are presented in Table 3. The

authors have applied the experimental method. The difference between the experimental method and the theoretical calculation is smaller than 0.2% for all chambers and energies.

Table 4 Determination of the correction factors k_p (where M_+ respectively M_- = Monitor reading by the usual polarity, M_2 or M_- = Monitor reading with opposite polarity of the chamber voltage).

Dosimetry protocol	Determination of k_p
AAPM TG 51 (1999)	$k_p = \left(\frac{ M_+ + M_- }{2M} \right) / \left(\frac{ M_+ + M_- }{2M} \right)_{c_0}$
IAEA TRS 398 (2000)	$k_p = \left(\frac{ M_+ + M_- }{2M} \right) / \left(\frac{ M_+ + M_- }{2M} \right)_{c_0}$
DIN 6800-2 (2008 March)	$k_p = (M_1 + M_2) / M_1 / [(M_1 + M_2) / M_1]_{c_0}$

Table 5 Effective point of measurement and gradient correction for the cylindrical chamber PTW-31013.

Radiation type	Process	DIN 6800-2 (2008 March)	TRS 398 (2000)	AAPM TG 51 (1999)
Photons	Gradient correction	$k_r = 1.008$	none	none
	Effective point of measurement from the chamber axis	About 1.4 mm	none	none
Electrons	Gradient correction	$k_r = 1.008$	k_r in k_Q	$P_{gr}^Q(z_{ref})$
	Effective point of measurement from the chamber axis	About 1.4 mm	About 1.4 mm	none

Determination of correction factor k_p for the polarity of the chamber voltage

k_p can be experimentally determined by switching the polarity of the chamber voltage. The different methods for the determination of k_p according to the different protocols are shown in Table 4.

However, care must be taken in case the calibration laboratory has not corrected for the polarity effect (as documented in the certification). In this case, the subsequent treatment of the polarity effect depends on the facilities available to the user, and on what beam qualities must be measured:

- If the user beam quality is the same as the calibration quality (normally Co-60) and the chamber is used at the same polarizing potential and polarity, then k_{pol} will be the same in both cases and the user must *not* apply a polarity correction for that particular beam.
- If the user beam quality is *not* the same as the calibration quality, but it is possible to reproduce the calibration quality, then the polarity correction $[k_p]_{Q_0}$ that was not applied at the time of calibration must be estimated using one of the equations of Table 4 and using the *same polarizing potential and polarity* as was used at the calibration laboratory.

The polarity effect at the user beam quality, k_{pol} , must be determined the same way using the polarizing

potential and polarity adopted for routine use. A modified polarity correction is then evaluated as follows:

$$k_p = \frac{k_p}{[k_p]_{Q_0}} \quad (3)$$

This is then used to correct the dosimeter readings for polarity for each beam quality Q. For the determination of $[k_p]_{Q_0}$ measurements are generally performed with Co-60 beams. Since there is no Co-60 unit available in the authors' department, the authors have used the smallest photon energy they have (6MV-photons) for that purpose.

Determination of the additional correction factor k_r for cylindrical chambers specific to the German DIN protocol

This correction must always be included according to the DIN Protocol for cylindrical chambers (for photon- and electron beams). It takes into account the different position during the calibration (reference point at measuring depth) and the user's measurement (reference point $0.5 r_{cyl}$ lower than measuring depth) explicitly as a correction factor, in contrast to the other protocols, where this effect is taken into account as a perturbation factor to be applied in the calculation of the beam quality correction factor.

Table 6 Formalism for the determination of the quality correction factors for photon beams $k_Q(z_{ref})$ and Electron beams $k_E(z_{ref})$.

Dosimetry-protocol	DIN 6800-2 (2008 March)		IAEA 398 (2000)		AAPM TG 51 (1999)	
	Photons	Electrons	Photons	Electrons	Photons	Electrons
Reference depth z_{ref}	10 cm	$0.6 \cdot R_{50} - 0.1$ cm	10 cm	$0.6 \cdot R_{50} - 0.1$ cm	10 cm	$0.6 \cdot R_{50} - 0.1$ cm
	$k_Q^\circ = k_Q \cdot k_r$	$k_Q^\circ = k_E' \cdot k_E'' \cdot k_r$	$k_Q^\circ = k_Q$	$k_Q^\circ = k_Q$	$k_Q^\circ = k_Q$	$k_Q^\circ = P_{gr}^Q \cdot k_{R50}' \cdot k_{ecal}$
Cylindrical-Chamber	$k_r = 1 + r_{cyl} / 2 \cdot \delta$	$k_r = 1 + r_{cyl} / 2 \cdot \delta$				$P_{gr}^Q = \frac{M(z_{ref} + 0.5 r_{cyl})}{M(z_{ref})}$
	k_Q from Tab. 6	$k_E' = f(R_{50})$ k_E'' from Tab. 8	k_Q from Tab. 14	k_Q aus Tab. 18	k_Q aus Tab. I	$k_{R50}' = f(R_{50})$ k_{ecal} aus Tab. III
	Effective point of measurement	Effective point of measurement	Chamber axis	Effective point of measurement	Chamber axis	Chamber axis
	-	$k_Q^\circ = k_E' \cdot k_E''$	-	$k_Q^\circ = k_Q$	-	$k_Q^\circ = k_{R50}' \cdot k_{ecal}$
Plane parallel Chamber	-	$k_E' = f(R_{50})$ k_E'' from Tab. 9	-	k_Q from Tab. 18 or k_Q from Tab. 19 $N_w \rightarrow$ from the cross calibration	-	k_{R50}' from Gl. 20 k_{ecal} from Tab. II or $k_{ecal} \cdot N_w^{Co60}$ from the cross calibration
	-	Chamber axis	-	Chamber axis	-	Chamber axis

k_Q° : Equivalent quality correction factor

Description for the chamber positioning (Reference point):

- Reference point of the cylindrical chamber : Chamber axis with the displacement (Effective point of measurement): $z_{ref} + 0.5 \cdot r_{cyl}$ and without displacement : chamber axis in the depth z_{ref}
- Reference point of a plane-parallel chamber: on the inner window on the symmetrical axis without displacement: chamber axis in the depth z_{ref}

For the calculation of k_r , the following relation is given in DIN 6800-2 (2008 March):

$$k_r = 1 + \left| \delta \right| \frac{r}{2} \quad (4)$$

With r_{cyl} = inner radius of the chamber cavity and δ = relative gradient of the dose depth curve at the reference depth during the calibration with Co-60 radiation (for Co-60-beam: $\delta = 0.006 \text{ mm}^{-1}$). For the cylindrical chamber PTW-31013 ($r_{cyl} = 2.8 \text{ mm}$), $k_r = 1.008$ is obtained.

Determination of correction factor k_Q for the radiation quality of photons

The radiation quality must be determined before since calculated values of k_Q are provided in tables as a function of the radiation quality. The radiation quality for high-energy photon beams is characterized according to DIN 6800-2 (2008 March) and IAEA TRS 398 by the quality index Q which is specified by the tissue phantom ratio $TPR_{20,10}$. This is the ratio of the absorbed doses at depths of 20 cm and 10 cm in a water phantom, measured with a constant Source-Chamber-Distance of 100 cm and a field size of $10 \text{ cm} \times 10 \text{ cm}$ at the plane of the chamber. $TPR_{20,10}$ can be measured directly

according to its definition or by a depth dose measurement:

$$Q = 1.2661 \cdot \frac{M(20)}{M(10)} - 0.0595 \quad (5)$$

where $M(20)$ and $M(10)$ are the readings at 20 cm and 10 cm depths for a field size of $10 \text{ cm} \times 10 \text{ cm}$ defined at the phantom surface with an SSD of 100 cm. In the German protocol, this second method must be used.

In the American protocol TG-51, the beam quality in accelerator photon beams is specified by %dd(10)x, the percentage depth dose at 10 cm depth in a water phantom due to photons only ~i.e., excluding electron contamination. The value of %dd(10)x is defined for a field size of $10 \times 10 \text{ cm}^2$ at the phantom surface at an SSD of 100 cm. Consequently, for the determination of the dose depth curve above 10 MV, a lead plate, about 1 mm thick, must be positioned between the focus and the measuring chamber. When using the same positioning as for the reference dosimetry, the dose depth curve is shifted $0.6 r_{cyl}$ to take into account the displacement effect.

In DIN 6800-2 (2008 March), Table 6, IAEA TRS 398, Table 14 and AAPM TG 51, Table I, the correction factors k_Q are listed in dependence of radiation quality index Q for different chambers under the reference

Table 7 Influence quantities and their contributions to total uncertainties.

Influence quantities	Source	Cylindrical chamber Photon beams	Cylindrical chamber Electron beams	Roos- chamber Electron beams
N_w	DIN 6800-2 (2008)	0.45	0.45	0.45
Depth of measurement	Estimation	0.1	0.1	0.1
SSD	Estimation	0.1	0.1	0.1
Leakage current	Manufacturer's figure	0.2	0.2	0.2
k_p	DIN 6800-2 (2008)	0.1	0.1	0.1
k_s	DIN 6800-2 (2008)	0.1	0.1	0.1
k_p	DIN 6800-2 (2008)	0.17	0.17	0.17
k_Q or k_E	IAEA TRS 398	1.0	0.9	0.6
k_Q or k_E	DIN 6800-2 (2008)	1.0	1.2	1.3
Dosimeter reading	Manual PTW-UNIDOS	0.5	0.5	0.5
Long-term stability Dosimeter/Year	Manual PTW-UNIDOS	0.1	0.1	0.1
Total uncertainty (TRS 398)		1.25	1.17	0.96
Total uncertainty (DIN 6800-2)		1.25	1.42	1.50

conditions. The corresponding k_Q -value can be interpolated for the cylindrical chamber PTW-31013. The values of Table 6 in DIN 6800-2 (2008 March) are approximated by a polynomial of 4th degree, in order to calculate the correction factor k_Q by putting any value of the quality index into the equation:

$$k_{Q,PTW-31013} = 0.584322 + 3.295307Q - 9.246571Q^2 + 11.275614Q^3 - 5.175615Q^4 \quad (6)$$

For all protocols, a summary is given in table 6 for the determination of the radiation quality correction factor.

Determination of correction factor k_E for the radiation quality of the electrons

In all protocols the R_{50} of the energy depth curve represents the quality index for the radiation quality. The measurement of the dose depth curves is done with a cylindrical chamber by a displacement correction of $0.5 r_{cyl}$ in the direction of the focus for all protocols. This correction is not to be applied with plane parallel chambers.

The correction factor for radiation quality k_E consists of a quality-specific factor (k_E') and a chamber-specific factor (k_E''), which are determined separately in the DIN-Norms, whereas in the TRS 398 there is no split up.

The determination of the absorbed dose to water can be done in a quality index R_{50} dependent reference depth z_{ref} . The R_{50} can be calculated from the ion depth dose curves as follows:

$$R_{50} = 1.029 \cdot R_{50,ion} - 0.06 \text{ in cm} \quad (7)$$

This equation is valid for a $R_{50,ion} < 10$ cm which corresponds to an energy of < 25 MeV. From the half value depth R_{50} , the energy dependent reference depth can be calculated as:

$$z_{ref} = 0.6 \cdot R_{50} - 0.1 \text{ in cm} \quad (8)$$

DIN 6800-2 defines the following equation for the determination of energy quality specific factor k_E' in reference depth z_{ref} :

$$k_E'(z_{ref}) = 1.106 - 0.1312 \cdot R_{50}^{0.214} \quad (9)$$

Chamber quality specific factor k_E'' is given in the DIN 6800-2, Table 8, for different cylindrical chambers with different reference conditions in dependence of half value depth R_{50} . These values are approximated for the cylindrical chamber PTW-31013 by a polynomial of 3rd degree which deviate only of 0.3% at maximum compared to the values of the Table 8.

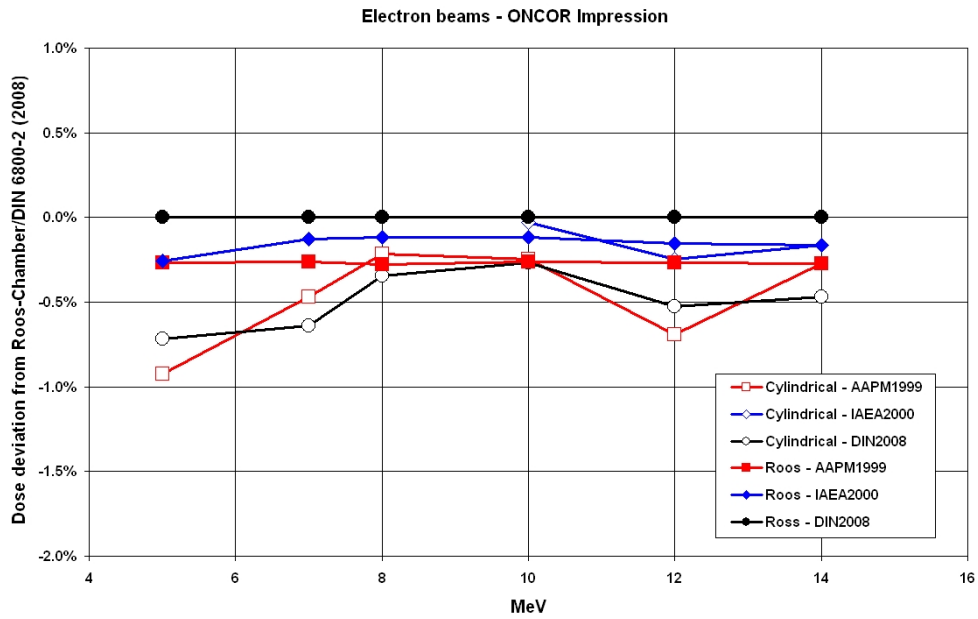


Figure 1 Comparison of the absorbed dose ratios in photon beams from the linear accelerators ONCOR Impression and ONCOR Avantgarde.

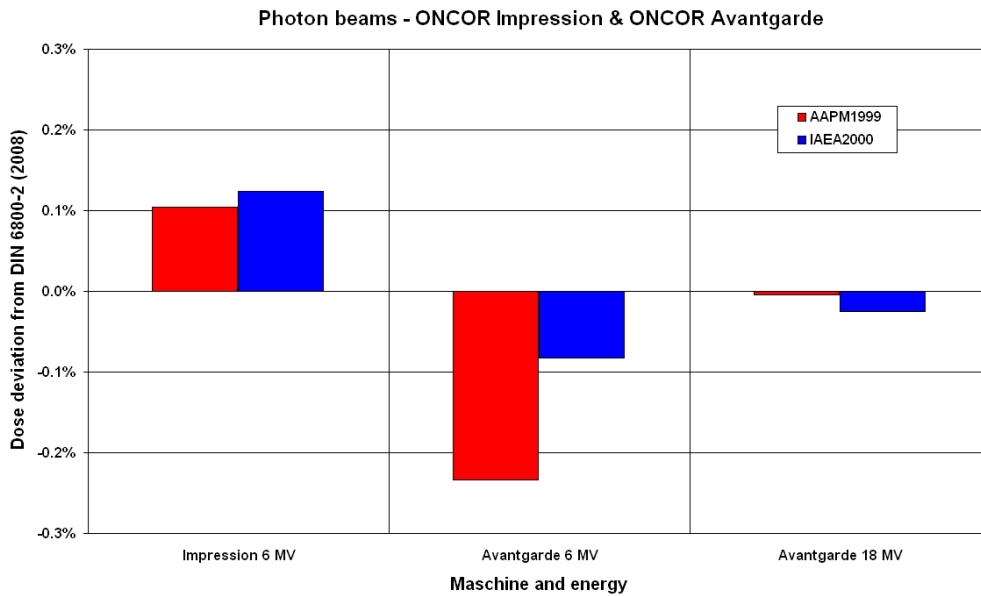


Figure 2 Comparison of the absorbed dose ratios as a function of electron energy from the linear accelerator ONCOR Impression.

$$k_E''(z_{ref})_{PTW-31013} = 0.947120 + 0.007313 R_{50} - 0.000352 R_{50}^2 + 0.000006 R_{50}^3 \quad (10)$$

Chamber specific factor k_E'' for plane parallel chambers equals the inverse value of the chamber specific perturbation factor p_{Co} for Co-60-beams, which is, according to DIN 6800-2 (2008 March), Table 9:

$$k_E''(z_{ref})_{PTW-Roos} = 0.981 \quad (11)$$

Therefore, the time-consuming cross calibration measurement for the determination of k_E'' for all known chambers is not necessary in DIN 6800-2 (2008 March). It is only necessary for the introduction of new types of chambers.

According to TRS 398, the product $k_E' * k_E'' (= k_E, in TRS as k_Q described)$ for diverse cylindrical and plane parallel chambers in TRS 398, Table 18, is listed as a function of the radiation quality R_{50} for the reference depth and can be found by interpolation for the cylindrical chamber PTW-31013. The IAEA proposes,

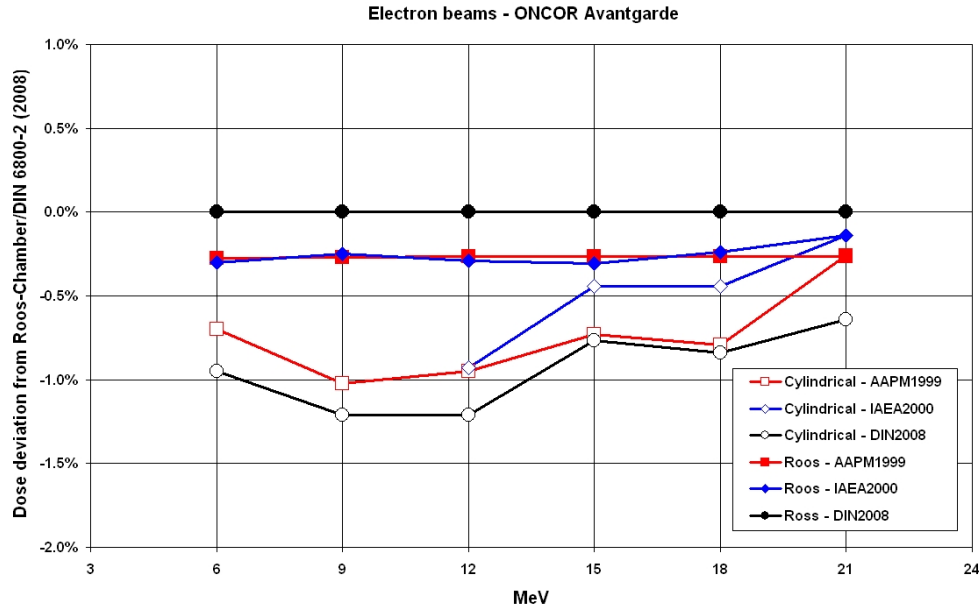


Figure 3 Comparison of the absorbed dose ratios as a function of electron energy from the linear accelerator ONCOR Avantgarde.

on the other hand, to perform a cross calibration for plane parallel chambers by using a cylindrical chamber instead of using the inaccurate values of Table 18. The authors have performed the cross calibration with the highest recommended energy of each accelerator (14 and 21 MeV-Electrons). Thereby, the calibration factor of the Roos-chamber will be newly determined. After that, the radiation quality factor of the Roos-chamber can be evaluated with the help of IAEA TRS 398, Table 19. The exact procedures are presented in literature [3, 6].

According to AAPM TG-51, the quality correction factor k_E for electrons as one of the constituent correction factors in equation 1 is substituted by:

$$k_E = P_{gr}^Q \cdot k'_{R_{50}} \cdot k_{ecal} \quad (12)$$

k_{ecal} is the chamber type dependent calibration factor N_w for Co-60- beam transformed to the reference radiation quality $R_{50} = 7.5$ cm. $k'_{R_{50}}$ is the calibration factor of this energy converted to the actual radiation quality R_{50} . P_{gr}^Q is an additional component of k_E and is the gradient correction factor in an electron beam that is dependent on the ionization gradient at the point of measurement. For cylindrical chambers, P_{gr}^Q is a function of the radius of the cavity; it is equal to 1 for plane-parallel chambers. k_{ecal} is given in the AAPM-Protocol for different chambers. $k'_{R_{50}}$ can be calculated for Farmer-type cylindrical chambers through an approximate formula given in the dosimetry protocol for reference depth z_{ref} [5, 7]. A cross calibration for plane parallel chambers is also recommended by the AAPM.

A summary of the formalism for the determination of the radiation quality correction concerning electrons is given for all three protocols in Table 6.

RESULTS AND DISCUSSION

For the photons and electrons, the deviation of the measuring values for both cylindrical chambers amounts about $\pm 0.3\%$, whereas for Roos chambers it is about $\pm 0.2\%$. These values are deduced from multiple measurements followed by a calculated average value with every chamber type for each protocol.

In Figure 1, the deviations of the dose values for photon beams measured with a cylindrical chamber are presented with respect to DIN 6800-2 (2008 March).

Figures 2 and 3 show the deviations of the dose values for electron beams, which are normalized to the values of the Roos-chamber according to DIN 6800-2 (2008 March), for both chamber types as a function of the energy for all three protocols. The measurements are done for both photon and electron beams with cylindrical chambers whereas the plane parallel chambers are only used for the electron beams.

Figure 1 shows the deviations for photon beams for both linear accelerators. According to AAPM and IAEA protocols from the values from DIN 6800-2 (2008 March), the deviations rise to a maximum of 0.23%. The DIN was adapted to the IAEA. As expected, the deviation of the IAEA from the DIN (2008) reaches an average of a max. of about 0.1%.

Figures 2 and 3 show the deviations by the electron beams, each for one accelerator. The deviations for all

chambers are given in relation to the values of the Roos-chamber according to protocol DIN 6800-2 (2008 March). The measuring values of all chambers according to all protocols are generally smaller than the values of the Roos-chamber according to DIN 6800-2 (2008 March). The largest deviation is about -1.3%. As observed, the deviation of the dose values between the cylindrical and the plane parallel chambers varies between 0.5 to 1.3% according to DIN 6800-2 (2008 March).

For the electron beams, it shows the tendency that the measuring values of the Roos chamber deviate from each other for only a maximum of about 0.3% according to TRS 398 and AAPM in reference to DIN 6800-2 (2008 March), whereas the corresponding values of the cylindrical chamber are of a max. of about 1.0 %.

The results following DIN 6800-2 are checked with TLD inter-comparison by the MTK. For photon beams, a deviation of max. 1.8% and for electron beams of max. 2.0% are found between the TLD measurements and the measurements with chambers according to DIN 6800-2 (2008 March).

In an earlier work, the authors compared protocols DIN 6800-2 (1997), IAEA TRS 398 and AAPM TG 51 for the linear accelerators Siemens Mevatron M6300 and M7445. In that work, the deviations of the two other protocols in relation to DIN 6800-2 (1997) showed 1% for photons and 1.6% for electrons [7]. In contrast to that work the current deviations are decreased by more than a half for photon beams whereas the values for the electrons progressed a little.

The uncertainties in the measured values consist of a series of independent, single uncertainties. The total uncertainty is calculated from the geometrical sum of the individual uncertainties. In the protocol AAPM TG 51 (1999) no uncertainties are given for the determination of the correction factors for the radiation quality. In contrast to that, a discussion on the uncertainty measurements of the radiation quality corrections is found in DIN 6800-2 (2008 March) and IAEA TRS-398. By the other influencing variables, the uncertainties were estimated by us or the manufacturer's information was considered.

For the determination of dose for photon and electron beams with cylindrical chambers, the total standard uncertainties is estimated according to TRS 398 a maximum of 1.25% and a maximum of 1.42% according to DIN 6800-2 (2008 March), whereas for electron beams with Roos chamber 0.96% and 1.50% according to TRS 398 and DIN 6800-2 (2008) is found, respectively. The influence quantities which contribute to an important part to the total uncertainty are presented in Table 7 [8].

CONCLUSION

DIN 6800-2 was widely revised and almost adapted to the IAEA TRS-398. While in the IAEA and the AAPM, a cross calibration measurement for plane parallel chambers with a cylindrical chamber is

recommended, an experimental calibration factor for the different plane parallel chambers is given in DIN 6800-2 (2008 March) so that the relative inaccurate individual cross calibration measurement is spared for the user. In DIN 6800-2 (2008 March), an analysis of the measurement uncertainties is discussed for the first time.

In connection with the TRS 398, measurements of electron beams are now also done in z_{ref} according to DIN 6800-2 (2008). Furthermore, only the R_{50} is used in contrast to the old DIN 6800-2 (1997) where both R_{50} and R_p were used for the characterisation of the electron radiation quality.

While in the DIN protocol no limits are mentioned by the use of a cylindrical chamber for electron energy lower than 10 MeV, the IAEA TRS 398 and AAPM do not recommend the use of the cylindrical chamber for electron beams with energy below 10 MeV. The IAEA gives no correction factors for that radiation quality whereas there exists a possibility of calculation through a formula according to AAPM.

The deviation between the three protocols is less than 0.23% for the photons, and stays within a maximum of 1.2% for the electrons. A measuring point displacement (effective point of measurement) is done in the DIN by the cylindrical chambers for photon beams which is considered by the correction factor k_r , whereas according to IAEA and AAPM no displacement of the measuring point is necessary. However, according to AAPM, radiation quality factors can be explicitly considered through the gradient factor. In the IAEA protocol, the gradient correction is contained in the radiation quality factor for the electrons. Results showed that the deviation for the electron beams between the protocols DIN 6800-2 (2008), IAEA and AAPM in reference to the Roos-chamber is relatively low.

The authors' experience shows that the time required for the clinical dosimetry is almost the same as for all three protocols. The advantage of DIN 6800-2 (2008 March) lies in the following points: there is no need for cross calibration measurement for plane parallel chambers as given in the protocol as well as a clear overview of all important formulas and parameters needed for the dosimetry. The IAEA and AAPM and the DIN give parameters for a number of the existing chambers on the market.

For the introduction of new chambers, the corresponding parameters must be determined by other ways, for example by a time expensive cross calibration formalism or through the manufacturer company.

In the past the different protocols were developed differently from time to time; fortunately today, we have achieved a good convergence in the concepts and methods.

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