Technical Note

Effect of Three-Dimensional Detector Orientation on Small-Field Output Factors

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Abstract

The IAEA TRS 483 has recommended that the orientation for cylindrical ionization chambers be perpendicular to the beam for small-field output factor (OF) measurements. The recommendation was based on the unavailability of field output correction factor data for measurements using parallel orientation at the time of publication. Two three-dimensional (3D) air ionization chambers were used to perform measurements in parallel and perpendicular orientations and compared to data determined using a PTW 31018. The aim of the study was to establish whether the 3D detectors behaved as spherical or cylindrical devices. From the results, it was confirmed that the PTW 31016 and PTW 31021 detectors are suitable for OF measurements in both orientations for field sizes down to an equivalent square field of 1.8 cm and 0.96 cm, respectively, using the field output correction factor data published in the IAEA TRS 483. The preferred orientation is parallel to the beam to facilitate beam profile measurements and minimize the irradiation of the chamber stem and detector cable and decrease the volume averaging factor.

Keywords: Equivalent square field, field output factor, orientation

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INTRODUCTION

Output factor (OF) is the variation in dose at a reference depth with field size, normalized to a reference field size. For broad beams, it is determined as the ratio of the detector response measured under nonreference conditions and corrected for all influence quantities to the dosimeter readings measured under reference conditions and corrected for influence quantities.[1] The use of the ratio of the detector response for OF measurements is only advised when dosimetry quantities are not influenced by field size.[2-4] For small fields, there is a dependency of the dosimetric quantities, such as the perturbation factors, with the field size.[2-4] To correct for the dependency, a field output correction factor (FOCF) needs to be applied to the detector response. The field OF (FOF) $\Omega^{f_{clin},f_{msr}}_{Q_{clin}Q_{msr}}$ of a given clinical (clin) beam relative to a machine-specific reference (msr) beam is given by:

$$\Omega^{f_{clin}f_{msr}}_{Q_{clin}Q_{msr}} = \frac{M^{f_{clin}}_{Q_{clin}}}{M^{f_{msr}}_{Q_{msr}}} k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}} \qquad (1)$$

$M^{f_{msr}}_{Q_{msr}}$ is the electrometer reading in the clinical small field corrected for all relevant influence quantities (temperature, pressure, humidity, polarity, ion collection efficiency, etc); $M^{f_{msr}}_{Q_{msr}}$ is the electrometer reading in the static msr field corrected for all relevant influence quantities (temperature, pressure, humidity, polarity, ion collection efficiency, etc.); $k^{f_{clin},f_{msr}}_{Q_{clin}Q_{msr}}$ and is a FOCF, which corrects for the difference in the response of a detector in the msr field, $f_{msr,}$ with beam quality Q_{msr} to that in the clinical small field with beam quality Q_{clin}.[2-4]

The concept of the msr field was first introduced by Alfonso *et al*.[3] and a new formalism for reference dosimetry of small and nonstandard fields was suggested. This formalism was adopted, with some adjustments, in a dosimetry Code of Practice for a small static field which was published by the International Atomic Energy Agency (IAEA) in collaboration with the American Association of Physicists in Medicine,[2,4] referred to as the IAEA TRS 483 in this article.

The orientation of a detector in the beam relative to the beam axis has an influence on the measured data. The IAEA TRS

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483 has recommended that the orientation of cylindrical air ionization chambers be perpendicular to the beam for FOF measurements. Measurements with the liquid-filled ionization chamber, PTW 31018, should be performed with parallel orientation.[2] Palmans *et al*. in 2018 indicated that the recommendations given in the TRS 483 were based on the availability of data at the time when the guidance document was being drafted.[5] The advantage of using parallel orientation of the ionization chambers is the decrease in the volume averaging factor, minimizing the irradiation of the chamber stem and detector cable.[6] This article investigates whether there is a statistically significant difference in FOF data measured with three-dimensional (3D) cylindrical air ionization chambers oriented either parallel or perpendicular to the beam axis. For centers relying on using the FOCFs published in the IAEA TRS 483, which were obtained using detectors in perpendicular orientation, this study determines the suitability of the IAEA TRS 483 FOCF for both the orientations when using 3D ionization chambers. The results of this study are relevant for applications where the detectors cannot be used in the recommended geometry such as in patient-specific quality assurance and other measurements in phantoms where beams are delivered from multiple directions. This study, unlike that of Godson *et al*.[7] who found larger differences in detector response, used a single collimation system and incorporated the IAEA TRS 483 FOCF values, which are not collimator dependent for perpendicular orientations of the detectors.

Materials and Methods

Measurements were performed on a Siemens Primus 6 MV flattened beam with field sizes defined by an 82-leaf multileaf collimator. The leaves were of 1 cm projection width at the isocentric plane in the X-axis (cross-plane) direction and a conventional asymmetric collimator in the Y-axis (in plane) direction. The central leaf pair was centered on the cross-plane major axis. Vented 3D cylindrical ionization chamber types PTW 31016 ("pinpoint") and 31021 ("semiflex") together with a liquid-filled ionization chamber type PTW 31018 were used for the determination of the FOFs in small fields [Table 1 for their specifications]. The PTW 31018 was used only in the parallel orientation, whereas the PTW 31016 and 31021 were used in parallel and perpendicular orientations relative to the beam axis, respectively. A PTW 60012 diode E was used to determine the equivalent square field (S_{clin}).

A motorized PTW MP3 water phantom together with a PTW tandem, an external high-voltage supply, and a PTW Unidos E electrometer was used for data acquisition. The stepper motor of the MP3 allowed for movement of the detectors with a speed of 50 mm/s and a positioning accuracy of 0.1 mm. The water tank was visually aligned with the gantry and the alignment of the scanning arm was confirmed using a spirit level when the tank was filled with water. The settings of the gantry angle and the collimator were verified using a spirit level and cross-plane profile measurements. Each detector was initially positioned on the beam central axis (CAX) using the co-ordinates of the water tank for the cross-plane (X) and in-plane (Y) settings and aligning it with the field using the light projection of the machine crosshair. This was verified along the major axes as well, using the light projection of the cross-hair. The engineering diagrams provided by the manufacturer were used to position the detectors' effective point of measurement at the point of measurement.

The FOF measurements for small fields are dependent on the precise location of the CAX. For each chamber orientation, lateral scans were performed to confirm the CAX. The FOFs were then measured at the CAX. PTW Mephysto mc^2 version 7.42 software (Physikalisch-Technische Werkstaetten, PTW-Freiburg, im Breisgau, Germany.) was used to automate the beam profile measurements and calculate the CAX position. All measurements in this study were performed using an isocentric technique for set field sizes of 10 cm × 10 cm, 6 cm × 6 cm, 4 cm × 4 cm, 3 cm × 3 cm, 2cm × 2 cm, 1 cm × 1 cm, and 0.6 cm × 0.6 cm and 10 cm × 10 cm data were used for normalization. The profiles and FOF were measured at a depth of 10 cm in water and a source to axis distance of 100 cm.

For FOF measurements, 100 monitor units were delivered and at least three sets of readings were collected for each data point. The FOCF published in the IAEA TRS 483 was used for the PTW 31016. Equation 2 was used to determine the FOCF for the PTW 31021 using the PTW 60012 (unshielded diode) and 60019 (synthetic microdiamond) as reference detectors.[2]

$$k_{Q_{\mathrm{clin}},Q_{\mathrm{msr}}}^{f_{\mathrm{clin}},f_{\mathrm{msr}}}(\mathrm{sfd}) = \frac{M_{\mathrm{Q_{clin}}}(\mathrm{ref})\,\mathrm{x}\,k_{Q_{\mathrm{clin}},Q_{\mathrm{msr}}}^{f_{\mathrm{clin}},f_{\mathrm{msr}}}(\mathrm{ref}) \Big/ M_{\mathrm{Q_{msr}}}(\mathrm{ref})}{M_{\mathrm{Q_{clin}}}(\mathrm{sfd}) \Big/ M_{\mathrm{Q_{msr}}}(\mathrm{sfd})} \qquad (2)$$

Where the M_{Q} (ref) is the reading of a reference detector in a reference field of quality Q corrected for influence quantities and M_{Q} (sfd) is the reading of a detector in the small field corrected for influence quantities. The FOFs determined in this work were compared with data published by Followill *et al*.[8] for a Siemens machine. The ratio of the FOF determined with a detector oriented in perpendicular and in parallel to the beam was compared to the data published by Casar *et al*.,[6] referred to as Casar data in this article.

Cranmer-Sargison[9] described a method for calculating the effective field size, which was adopted by the IAEA TRS 483 working group[2] as a way of calculating S_{clin} for small fields. This method was used in this study. Measurement uncertainties in this study were evaluated following the GUM framework.[10,11]

Results

Table 2 shows the FOF data obtained when ionization chambers were oriented parallel and perpendicular to the beam for various S_{clin}. The averaged data for each orientation were from at least three measurement sessions and the percentage differences in the data obtained for the different orientations were determined from these averaged data. The field size measurements were

Table 1: Summary of the specifications of the ionization chambers used during the study

Ionization chamber type	Central electrode	Nominal sensitive volume	Dimensions of sensitive volume	Wall material and thickness	Reference point
PTW 31016	Aluminum	0.016 cm^3	Radius 1.45 mm length 2.9 mm	PMMA + graphite, 85 mg/cm^2	2.4 mm from chamber tip, on chamber axis
PTW 31018	Graphite	0.0017 cm^3	Radius 1.25 mm depth 0.35 mm	Polystyrene + graphite + varnish, 107 mg/cm^2	0.975 mm from the entrance window, on chamber axis
PTW 31021	Aluminum	0.07 cm^3	Radius 2.4 mm length 4.8 mm	PMMA + graphite, 84 mg/cm^2	3.45 mm from the chamber tip, on chamber axis

PMMA: Polymethyl methacrylate

Table 2: Averaged field output factor data obtained when the PTW 31016 and PTW 31021 were oriented parallel (II) and perpendicular (T) to the beam and the associated percentage differences for a range of S_{clin}

Nominal field size (cm^2)	S_{clin} (cm)	Detector used	FOF	SD in FOF	Detector used	FOF	SD in FOF	Percentage difference in FOF from II and T
10×10	9.90	31016-II	1.000	-	31016-T	1.000	-	-
6×6	5.69		0.916	0.002		0.917	0.002	0.1
4×4	3.72		0.860	0.003		0.861	0.003	0.1
3×3	2.73		0.828	0.004		0.830	0.003	0.3
2×2	1.81		0.777	0.009		0.777	0.011	0.1
1×1	0.81		0.577	0.067		0.566	0.077	1.9
10×10	10.03	31021-II	1.000	-	31021-T	1.000	-	-
6×6	5.98		0.922	0.004		0.922	0.003	0.08
4×4	3.95		0.863	0.003		0.864	0.005	0.1
3×3	2.95		0.833	0.004		0.834	0.007	0.07
2×2	1.93		0.788	0.007		0.788	0.009	0.01
1×1	0.96		0.637	0.007		0.631	0.018	0.9
0.6×0.6	0.59		0.451	0.058		0.443	0.066	1.8

performed using a PTW 60012 detector oriented parallel to the beam. There was no repositioning of the water tank between each measurement series and the variations were therefore only caused by the changes in the detector orientation and positioning. T represents data when the ionization chamber was oriented perpendicular to the beam axis and II represents data when the ionization chamber was oriented parallel to the beam axis.

Figure 1 shows the average FOF compared with data measured using a PTW 31018 detector and the data published by Followill *et al*.[8] An analytical function method proposed by Sauer *et al*. was used to compare the data for the same S_{clin}.[12] The measurement uncertainties determined when using these ionization chambers in this study are given in Table 3.

Figure 2 shows the ratio of the FOFs when the detector is oriented perpendicular to the FOF when the detector is oriented parallel to the beam axis (FOF-T/FOF-II), as a function of S_{clin} compared with the ratio of FOCF for perpendicular and parallel orientations axis (FOCF-T/FOCF-II), provided by Casar *et al*.[6] Casar *et al*. used PTW 31016 and 31021 detectors in Varian and Elekta linacs.

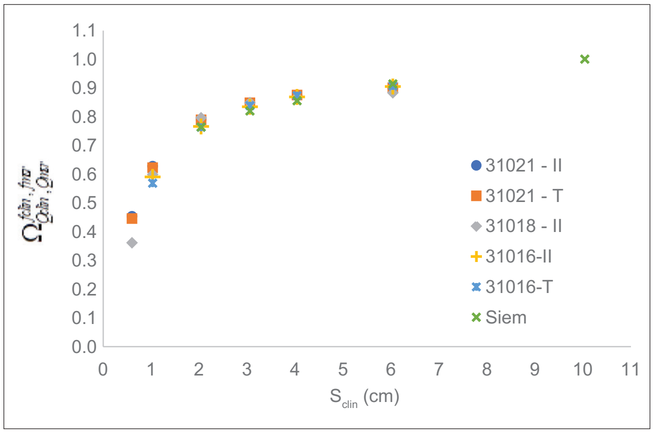

Figure 1: Averaged field output factor data obtained when ionization chambers were oriented parallel (II) and perpendicular (T) to the beam. Siemens represents the data published by Followill *et al*.[7] for a Siemens 6 MV photon beam. Plots were made for the same S_{clin}

DISCUSSIONS

As shown in Figure 1, at S_{clin} of 2 cm × 2 cm, the percentage difference in the data from this study to the data published by Followill *et al*. was about 0.2% for the PTW 31016 detector, 4% for the PTW 31018 detector, and 3% for the PTW 31021 detector. The measurement uncertainties at this field size ranged from 1.7% to 3.9% for k = 2, equal to a confidence level of 95%, as shown in Table 3.

Volume averaging is dependent on the detector size. For a detector that has similar cavity dimensions radially and

Table 3: Combined relative uncertainty for the field output factors determined using the PTW detectors for *k*=2, equal to a confidence level of 95% when ionization chamber is oriented perpendicular to the beam

S_{clin} (cm)	PTW 31016	PTW 31018	PTW 31021
6×6	0.8	1.2	1.6
4×4	1.0	1.2	1.7
3×3	1.1	1.5	2.4
2×2	2.3	1.7	3.9
1×1	5.1	2.1	7.3
0.6×0.6	-	2.9	-

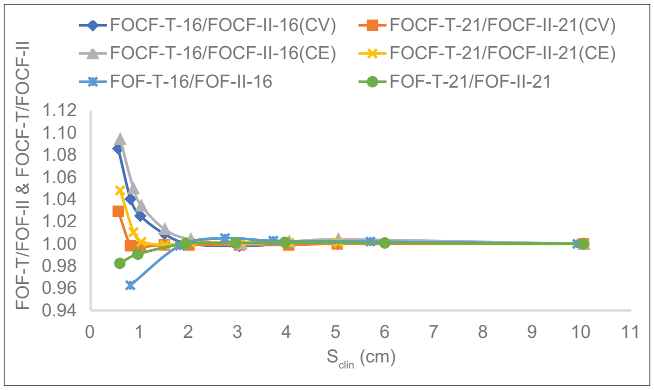

Figure 2: Ratio of field output factors when the chambers were mounted with the chamber stem parallel (II) and perpendicular (T) to the beam axis, as a function of S_{clin} compared with the ratio of the FOCF for perpendicular and parallel orientations, provided by Casar *et al.*[6] Data from this study represented by FOF-T-16/FOF-II-16 from the PTW 31016 detector and FOF-T-21/FOF-II-21 from the PTW 31021 detector. FOCF-T-16/FOCF-II-16(CV) and FOCF-T-16/FOCF-II-16(CE) are from Casar using PTW 31016 in Varian and Elekta linacs respectively. FOCF-T-21/FOCF-II-21(CV) and FOCF-T-21/FOCF-II-21(CE), are from Casar data using PTW 31021 in a Varian and Elekta, respectively

longitudinally, it is expected that the response of that detector will be the same regardless of the orientation of the detector.[2,6] For $S_{clin} \leq 1.8$ cm, the FOF data obtained with the PTW 31016 detector oriented parallel to the beam were slightly higher than that obtained with it oriented perpendicular to the beam. For PTW 31021, this was observed also for $S_{clin} \leq 1.02$ cm. This disagrees with the observations of Casar *et al*. who found that FOCF for $S_{clin} \leq 1.5$ cm was higher for the perpendicular orientation than the corresponding values determined for the parallel orientation[6] and this is shown in Figure 2. The variations in the data observed for the $S_{clin} < 1$ cm are due to the sensitivity of FOF to measurement setup at such small fields because the radial and longitudinal dimensions of the cavity volume are similar in both the detectors.

The data obtained using a PTW 31016 show agreement within the measurement uncertainty regardless of the orientation of the detector. The difference is ≤ 0.3% for all S_{clin} except for $S_{clin} = 0.8$ cm where it is 1.9%. This difference is still within the measurement uncertainty of 2.3% for FOF at S_{clin} of 0.8 cm. According to the IAEA TRS 483, this detector should not be used for $S_{clin} <1$ cm, as its FOCF is more than 5%. The manufacturer recommends that the minimum field size for use is 2 cm × 2 cm. From the data in this study, the PTW 31016 may be used in both the orientations with the FOCF published in the IAEA TRS 483 down to a S_{clin} of 1.8 cm. For $S_{clin} < 1.8$ cm, FOCF determined using this chamber in a parallel orientation needs to be determined.

For FOF data collected using the PTW 31021, the FOF is consistent for all S_{clin}, as shown in Figure 1 and Table 2, within the measurement uncertainties. The longitudinal and radial cavity dimensions for this detector are equal. Even though the manufacturer has recommended that this detector can be used down to a field size of 2.5 cm × 2.5 cm, the data show that the detector may be used in any orientation for smaller field sizes down to 0.6 cm × 0.6 cm. This was also observed by Casar *et al*. for this detector; however, the recommendation from Casar *et al*. was not to use this detector for $S_{clin} <1.5$ cm because of the FOCFs that are more than 5%.[6]

CONCLUSION

The PTW 31016 and PTW 31021 detectors are suitable to be used for OF measurements in both the orientations for field sizes down to the equivalent square field of 1.8 cm and 0.96 cm, respectively, using the FOCF data published in the IAEA TRS 483. The recommended orientation is however parallel to the beam to minimize stem and cable irradiation during measurements.[2]

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Conflicts of interest

There are no conflicts of interest.

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