Oncology
and Radiotherapy©
18(6) 2024: 001-009 • RESEARCH ARTICLE

Assessing feasibility of a flat ion chamber for surface dose measurement of 6 FF and 6 FFF X ray photon beams

Kanakavel Kandasamy, E. James Jebaseelan Samuel

Department of Physics, School of Advanced Sciences, VIT University, Vellore, Tamil Nadu, India

ABSTRACT

To prevent reddening on the patient's surface during radiotherapy treatment with MV X-ray beams, the surface dose must be low. In this study, we aimed to assess the feasibility of a flat ionization chamber for surface dose measurement. We used a medical linear accelerator capable of producing 6 FF and 6 FFF beams for three collimator sizes. We used Tref and Markus chambers, slab phantoms made of both acrylic and polystyrene from PTW. The thickness of the slabs was 1 mm, 2 mm, 5 mm, and 10 mm. First, the study evaluated basic dosimetric characteristics such as the linearity, reproducibility, and dose rate dependency of the Tref chamber. Next, we measured the surface dose using the Tref chamber and compared it with the Markus chamber. We found that the linearity, reproducibility, and dose rate dependency results were all within 0.5%. In both detectors, for the FF and FFF, SDs revealed a maximum difference of 8%. We observed an average surface dose difference of 10% between both chambers. Compared to Markus Chamber's results, Tref overestimated the surface dose. The Tref chamber, if associated correction factors are available to account for its overestimation in the buildup region, is to be an alternative solution for surface dose measurement.

Keywords: surface dose, tref chamber, Flattening Filter (FF), Flattening Filter Free (FFF) beam

Address for correspondence:

E. James Jebaseelan Samuel,

Department of Physics, School of Advanced Sciences, VIT University, Vellore, Tamil Nadu, India

E-mail: ejames@vit.ac.in

Word count: 3771 **Tables:** 07 **Figures:** 14 **References:** 20

Received: 13 May, 2024, Manuscript No. OAR-24-134739

Editor Assigned: 29 May, 2024, Pre-QC No. OAR-24-134739(PQ)

Reviewed: 01 June, 2024, QC No. OAR-24-134739(Q)

Revised: 05 June, 2024, Manuscript No. OAR-24-134739(R)

Published: 10 June, 2024, Invoice No. J-134739

INTRODUCTION

Modern treatment techniques in radiation oncology are Intensity Modulated Radiation Therapy (IMRT), Volumetric Modulated Arc Therapy (VMAT), Stereotactic Radiosurgery (SRS) and Stereotactic Body Radiation Therapy (SBRT) using a medical linear accelerator capable of producing different Mega Volt (MV) X-ray energy beams with a Flattening Filter (FF) and Flattening Filter-Free (FFF) such as X6 FF, X6 FFF, X10 FF, X10 FFF, and X15 FF [1-3]. To protect the skin, it is crucial to deposit the lowest possible dose on the patient's surface during treatment. Surface dose is defined as the ratio of dose measured at 0.5 mm depth of water or tissue at the junction between the air and the surface. Accurate knowledge of surface dose is important, but keeping a radiation detector accurate in the buildup region and measuring dose is very challenging. Therefore, the choice of a suitable measurement device is important. Hence a measuring detector should be flat in shape, like a parallel plate, with as much as possible minimal separation between its electrodes [4]. It depends on Source-to-Surface Distance (SSD), field size, beam angle, beam energy, and beam modifiers such as blocks and Multi Leaf Collimator (MLC) systems [5]. Velkley DE et al. have primarily focused on buildup region doses, which extrapolation chambers most accurately measure [6]. However, not every institution possesses this equipment. Parallel-plate ionization chambers are only a good alternative to extrapolation chambers because of their small entrance window. However, due to their internal construction, these chambers overreacted during measurements in the buildup region. Secondary electrons scatter from the chamber's sidewall, causing an overresponse, and as stated by Bruce J. Gerbi et al., overresponse correction factors can be used for all types of fixed parallel-plate chambers [7]. These factors are specific to chamber properties, volume, plate separation, and guard size. Because of their size and physical geometry, parallel-plate chambers are only suitable for phantom measurements. Reynolds TA and Higgins P investigated the challenges of surface dose measurement using different detectors [8]. Ugur Akbas et al. conducted another study that demonstrated the use of PTW Markus type chambers, EBT3 films, and MOSFET for surface and build-up region dose measurements across various field sizes using plastic phantoms [9]. Recently, PTW introduced the Transmission Ion Chamber (Tref) for small field dosimetry, which serves as a reference detector for relative dose measurement [10]. The Tref chamber boasts a wide area, a lower electrode separation, and a remarkably low thickness. As a novel work, we tried to use this Tref chamber for SD measurement in high-energy X-ray beams.

As a result, the goal of this study is to assess the feasibility of the transmission ion chamber for surface dose measurement and compare its results with those of the classical Markus chamber.

MATERIAL

We used a state-of-the-art linear accelerator, specifically the TrueBeam model, which Varian Medical Systems manufactured in Palo Alto in 2010 [11]. This advanced machine produced high-energy X-ray beams in both X6 FF and X6 FFF modalities. In this investigation, the dimensions of the machine's fields were $10\ cm^2 \times 10\ cm^2$, $20\ cm^2 \times 20\ cm^2$, and $30\ cm^2 \times 30\ cm^2$. We established dose rates of 600 MU/min and 1400 MU/min for 6 FF and 6 FFF treatments, respectively. For measurement purposes, we used the Tref and Markus chambers in conjunction with the Unidose electrometer [12]. We utilized imported RW3 (1.045 g/cc) and acrylic (1.19 g/cc) slab phantoms of several thicknesses, including 1 mm, 2 mm, 5 mm, and 10 mm [13]. Table 1 presents the physical characteristics of the Tref and Markus chambers, while figures 1 and 2 provide a schematic diagram of both chambers [14].

Tab. 1. Physical and Radiological characteristics of Tref and Markus chamber

Technical Specification	Markus	Tref
Chamber type	Air vented plane parallel plate	Large area plane parallel and air vented
Dimension of sensitive volume	radius 2.65 mm depth 2.0 mm	radius 40.8 mm depth 2.0 mm
Reference point of measurement	In chamber centre on	Inner surface of entrance window
Nominal chamber volume	0.055 cc	10.5 cc
Total area density with protective cap	106 mg/cm^2	72 mg/cm^2
Direction of incidence	Perpendicular to chamber plane	Perpendicular to entrance window
Nominal response	2 nC/Gy	325 nC/Gy
Polarizing Voltage	300 V	400 V
Water equivalent window thickness	1.06 mm	0.7 mm

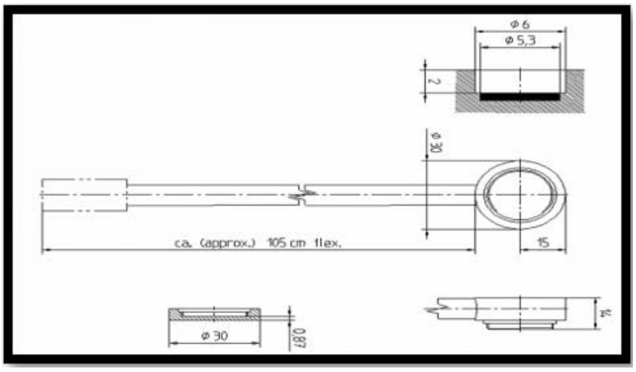

Fig. 1. Schematic diagram of Markus chamber

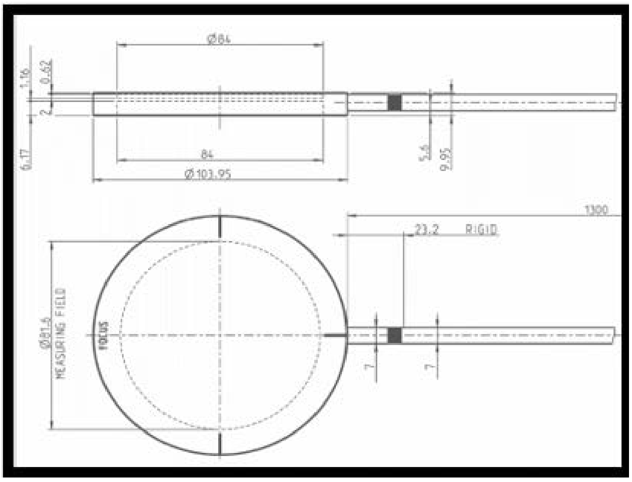

Fig. 2. Schematic diagram of Markus chamber

Figure 1 and 2, schematic diagram of Markus and Tref chambers respectively. This shows dimensions of those chambers in terms of diameter, length, and thickness of effective area.

METHODS

All measurements consistently maintain the Source-to-Chamber Distance (SCD) at a distance of 100 cm and ensured that their reference point of each chamber was utilized as mentioned in the table 1. We assessed the initial dosimetric properties of the Tref chamber, including linearity, repeatability, and dose rate dependency as recommended by IEC 60731 [15]. We positioned the chamber at the maximum depth for each photon beam to achieve this. We conducted measurements using different Monitor Units (MUs) ranging from 10 to 1000 for linearity, maintaining a constant 100 MU for reproducibility. Additionally, we conducted measurements at various dose rates: 100 MU/min, 200 MU/min, 300 MU/min, 400 MU/min, and 600 MU/min for the 6 FF photon beam, and 400 MU/min, 600 MU/min, 800 MU/min, 1000 MU/min, 1200 MU/min, and 1400 MU/min for the 6 FFF photon beam. The resulting data were analysed.

For surface dose measurements with all three field sizes mentioned above, depths of measurement (0, 1, 2, 3, 4, 5, and dmax) mm were chosen for both chambers. For 6 FF and 6 FFF photon beams, the dmax depths are 15 mm and 14 mm, respectively. We used acrylic and RW3 slabs for the Tref and Markus chamber respectively. All measurements involved the delivery of a dose of 100 MU. We corrected the collected meter readings for environmental factors like temperature and pressure, and then normalized them to the maximum depths of corresponding energies. This yielded the Tissue Maximum Ratio (TMR). We converted these TMRs to PDDs of 100 cm SSD by applying the Maynard factor at each depth [16]. We created a polynomial fit using Excel from the individual PDD graphs of each field and each detector and deduced the surfaced dose for 0.5 mm depth. We compared the measured SDs between both detectors and the energies.

RESULTS

Appropriate graphs are furnished for linearity, reproducibility, and dose rate dependency in figures 3-10, based on the measure-ment. We observed a maximum deviation of 0.2% for linearity, 0.09% for reproducibility, and 0.075% for dose rate dependency for the Tref chamber.

Figure 3 and 4, pictorial representation of Linearity for 6 FF beam. Figure 3 is representing charge measured (nC) *vs.* Monitor Unit (MU), whereas figure 4 shows dose versus normalized signal to meter reading of 100 MU.

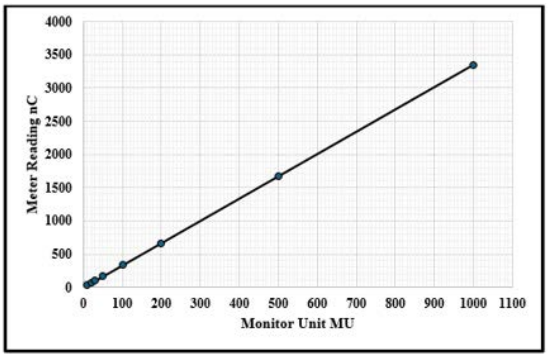

Fig. 3. Linearity 6FF tref

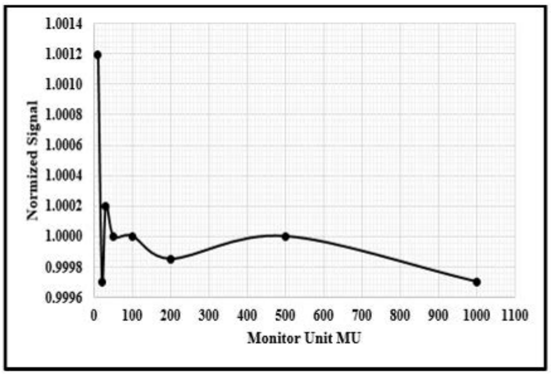

Fig. 4. Normalized linearity 6 FF tref

Figure 5 and 6, Pictorial representation of Linearity for 6 FFF beams. Figure 5 is representing Monitor Unit (MU) vs. charge measured (Gy vs nC) whereas 6 shows dose versus normalized signal to meter reading of 100 MU.

Figures 7 and 8, pictorial representation of Reproducibility for 6 FF and 6 FFF beams. Figure 7 is representing percentage deviation of measured charge vs. delivered Monitor Unit whereas figure 8 shows a representation on normalized meter readings of each MU to 100 MU versus delivered Monitor Unit.

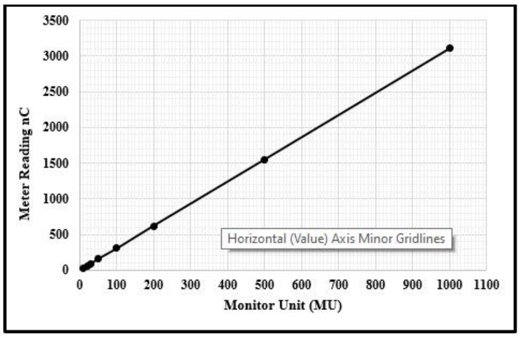

Fig. 5. Linearity 6FF tref

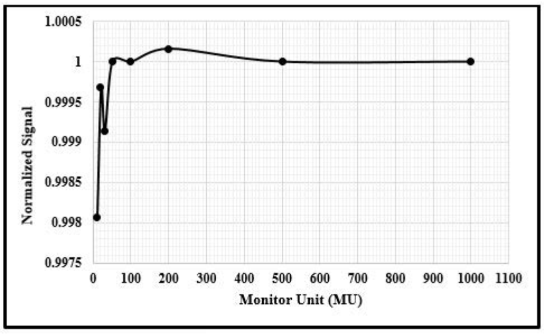

Fig. 6. Normalized linearity tref 6 FFF

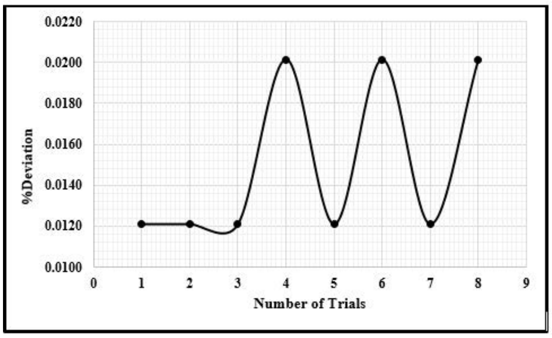

Fig. 7. Reproducibility tref 6FFF (%)

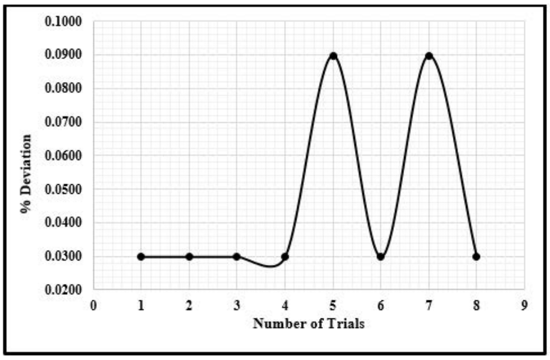

Fig. 8. Reproducibility 6 FF tref (%)

Figure 9 and 10, pictorial representation of Dose Rate dependency for 6 FF and 6 FFF beams for different dose rates.

Similarly, we placed derived PDD tables and corresponding curves in tables 2, 5 and figures 6, 9 for each field size, including both the Tref and Markus chambers. We used a depth of 0.5 mm and derived surface doses for the corresponding PDDs of field size and energies in table 6. The table presents the derived surface doses of the Tref and Markus chambers for the specified field sizes and 6 FF and 6 FFF energies. The table 7 displays the difference in SDs between the Tref and Markus chambers, as well as between the 6 FF and 6 FFF beams. The maximum difference observed in the SD between energies was about 8%, whereas the difference between both detectors was about 10% as an average.

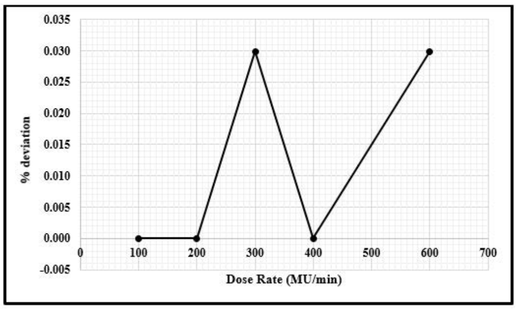

Fig. 9. Dose rate dependency 6FF tref (%)

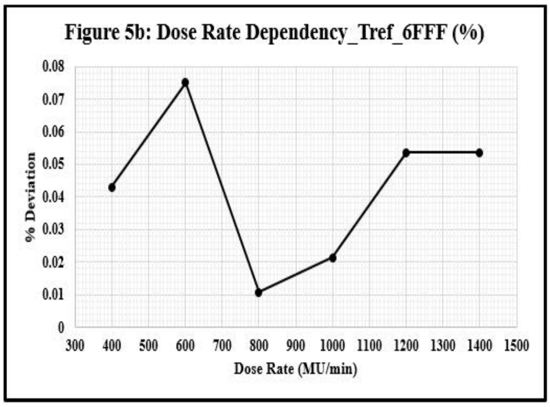

Fig. 10. Dose rate dependency tref 6 FFF (%)

Figure 11 shows necessary curves of PDDs measured for 10 cm^2 ×10 cm^2, 20 cm^2 ×20 cm^2, and 30 cm^2 × 30 cm^2 for 6 FF beam with Tref chamber.

Figure 12 shows necessary curves of PDDs measured for 10 cm^2 ×10 cm^2, 20 cm^2 × 20 cm^2, and 30 cm^2 ×30 cm^2 for 6 FFF beam with Tref chamber (Table 3).

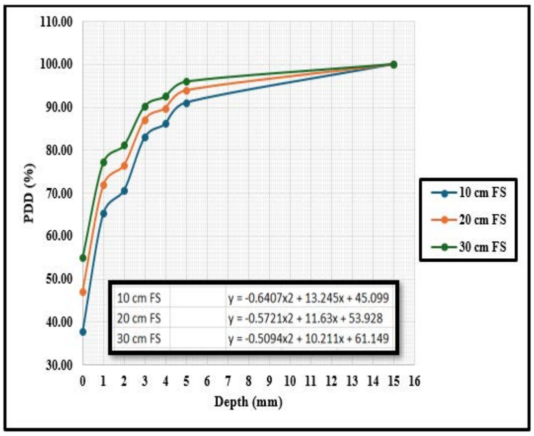

Fig. 11. PDDs (%) Tref 6FF

Tab. 2. PDDs for tref chamber for three field sizes 6 FF

Depth mm	10 cm FS	20 cm FS	30 cm FS
0	37.67	47.12	54.91
1	65.22	71.84	77.09
2	70.61	76.47	81.09
3	82.96	87.11	90.21
4	86.11	89.76	92.48
5	91.09	93.91	95.94
15	100	100	100

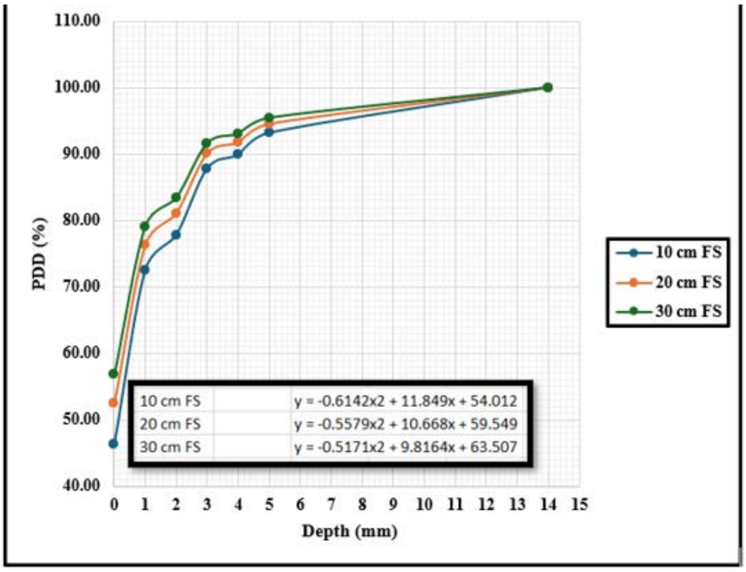

Fig. 12. PDD (%) Tref 6 FF

Tab. 3. PDDs for tref chamber for three field sizes 6FF

Depth mm	10 cm FS	20 cm FS	30 cm FS
0	46.34	52.47	56.78
1	72.53	76.3	79.11
2	77.81	81.09	83.43
3	87.82	90.07	91.61
4	89.88	91.74	93.05
5	93.18	94.51	95.44
14	100	100	100

Figure 13 shows necessary curves of PDDs measured for 10 cm^2 ×10 cm^2, 20 cm^2 ×20 cm^2, and 30 cm^2 × 30 cm^2 for 6 FF beam with Markus chamber (Table 4).

Figure 14 shows necessary curves of PDDs measured for 10 cm^2 ×10 cm^2, 20 cm^2 ×20 cm^2, and 30 cm^2 × 30 cm^2 for 6 FF beam with Markus chamber.

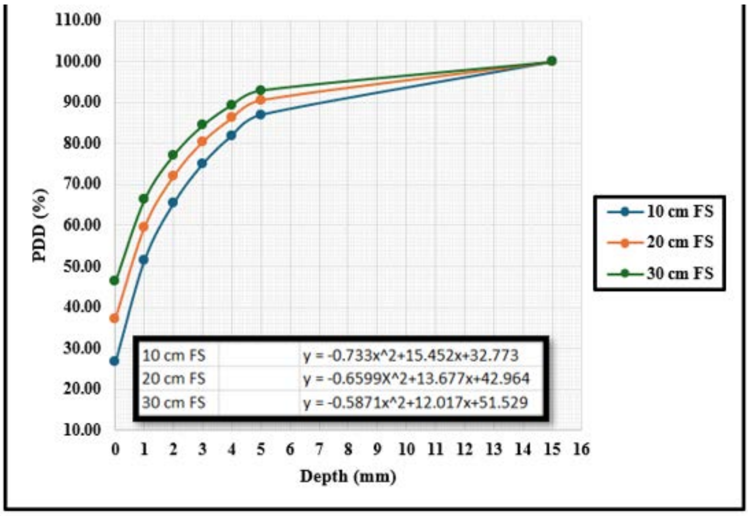

Fig. 13. PDDs (%) Markus 6FF

Tab. 4. PDDs for Markus chamber for three field sizes 6 FF

Depth mm	10 cm FS	20 cm FS	30 cm FS
0	26.62	37.33	46.37
1	51.55	59.64	66.33
2	65.44	72.04	77.18
3	75.04	80.44	84.45
4	82	86.22	89.46
5	87.07	90.63	93.03
15	100	100	100

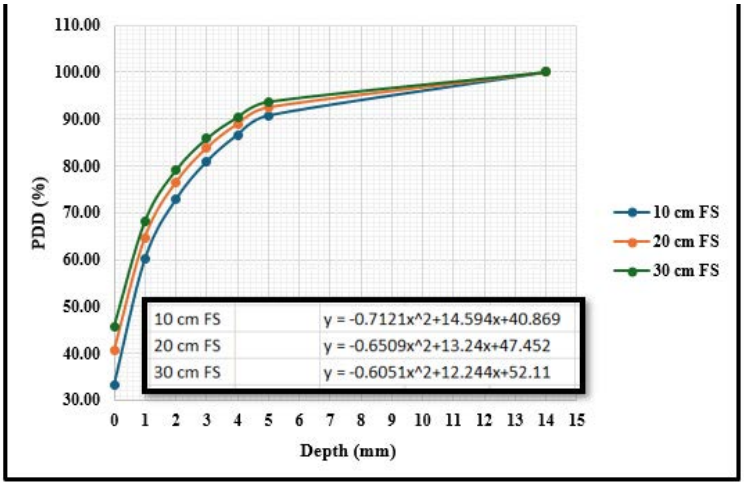

Fig. 14. PDDs (%) Markus 6 FFF

Tab. 5. PDDs for Tref chamber for three field sizes 6 FFF

Depth mm	10 cm FS	20 cm FS	30 cm FS
0	33.26	40.63	45.72
1	60.13	64.74	68.14
2	72.81	76.46	78.99
3	80.92	83.83	85.77
4	86.65	88.95	90.38
5	90.76	92.5	93.66
14	100	100	100

Tab. 6. Measured surfaced dose for both Tref and Markus chambers for both 6 FF and 6 FFF Beams

FS in cm²	Surface Dose %			
	6FF		6FFF	
	Markus	Tref	Markus	Tref
10 × 10	40.32	51.56	47.99	59.78
20 × 20	49.64	59.6	53.91	64.75
30 × 30	57.39	66.12	58.08	68.29

Tab. 7. Difference in surface dose (%) between energies and chambers

FS in cm²	Between Chambers		Between Energies	
	Markus	Tref	6 FF	6 FFF
10 × 10	7.67	8.22	11.24	11.79
20 × 20	4.27	5.15	9.96	10.84
30 × 30	0.69	2.17	8.73	10.21

DISCUSSION

The study clearly shows that increasing the radiation dose for both 6 FF and 6 FFF beams linearly increases the Tref chamber's response. On the other hand, reproducibility and dose rate dependencies were within 0.5% for the different dose rates applied. The dosimetric features of all the results are in line with what IEC 60731 says a radiation detector should have.

As discussed by Ravindra Shende et al., the removal of the flattening filter causes softening of the resulting beam, a decrease in scattering and electron contamination from the flattening filter. Due to the combined effect, there will be a significant rise in surface dose for the FFF beam compared to the FF [17]. Our study yielded the same results for both chambers. The Tref chamber's

SD results closely align with the recommendations of the AERB task group [18]. The Tref chamber, on the other hand, has a higher SD than the Markus chamber. This is because of its volume, relatively large separation compared with the extrapolation chamber and their small guard ring. These parallel-plate chambers show an over-response [19]. Both the FF and FFF beams exhibit this behaviour. According to Mellenberg DE, the classical Markus chamber already exhibits an overresponse when compared to the extrapolation chamber [20]. But we had not applied those correction factors for the classical Markus, as this study emphasized mainly assessing the feasibility of a Tref chamber for SD measurement. The future study will focus on determining the overresponse correction factor for a Tref chamber.

CONCLUSION

From this experiment, it is evident that the Traf chamber is an effective method for quantifying the surface dose of high-energy X-rays employed in medical applications. However, further research is required to determine the appropriate correction factors for addressing over-response when using this chamber.

ACKNOWLEDGEMENTS

Since, thanks to Dr. Muthuvel, Mr. Godwin Paul and Mrs. Kaviyarasi of Government Hospital Omanthurar, my colleagues: Mr. S. Vignesh and Mr. Venkatesan. Special thanks and respects to Mr. B. Viswanathan, Managing Director of PTW Dosimetry India who provides the Tref chamber for study purposes.

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