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Over-Response Correction of SNC 350p ROOS and PTW Markus Chambers in the Surface Dose and Build-Up Region Dosimetry of 6MV Photon Beam

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ABSTRACT

Introduction: The design characteristics of ionization chambers are critical for the accurate measurement of Percentage Surface Dose (PSD) and Percentage Depth Dose (PDD) in the build-up region. This study assesses the over-response correction in PSD and PDD for different field sizes, using Markus and ROOS fixed separation parallel-plate ionization chambers.

Material and Methods: The Sun Nuclear Corporation SNC 350P ROOS and PTW Markus parallel plate ionization chambers were used to measure 6 MV photon beam PDD along the central axis in the build-up region.The experiment was performed on a Solid Water® HE phantom with a density of 1.032 g/cm^3.The Measurements were taken at a Source Surface distance (SSD) of 100 cm with Field sizes of 10x10cm^2,20x20 cm^2, and 30x30cm^2 and at variable depths.

Results: For field sizes of 10x10 cm^2, 20x20 cm^2, and 30x30 cm^2 at a source-to-axis distance (SAD) of 100 cm, the PSD values obtained with the Markus chamber, before and after applying Rawlinson's equation for over-response correction, were as follows: 35.11%, 42.92%, 50.72% (before correction) and 28.37%, 36.19%, 44.05% (after correction). Similarly, the PSD values measured using the ROOS chamber, before and after applying over-response correction, were as follows: 41.61%, 50.50%, 58.04% (before correction), and 33.96%, 42.87%, 50.38% (after correction).

Conclusion: The application of over-response correction using Rawlinson's equation improved the accuracy of measurements for both chambers, emphasizing the significance of employing appropriate correction techniques to ensure precise dose measurements in the build-up region using ionization chambers.

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Introduction

Surface dose in radiation therapy refers to the dose of radiation received at the boundary between the patient's body (phantom) and the surrounding air. It is an important parameter to consider, particularly when the patient's skin is part of the target volume being treated or is a dose-limiting tissue being treated. Overexposure of the skin to radiation may result in acute skin reactions or long-term effects. The surface dose consists of two component doses. The first component is caused by contaminant electrons present in the air, collimator, and scattering material along the path of the radiation beam. These electrons result from photon interactions in the air or interactions with various components of the treatment system [1-3]. The second component is caused by secondary electrons generated within the patient's body [4]. The measurement of surface dose always varies depending on factors such as Field Size, Source-To-Skin Distance (SSD), Beam Energy, Beam Angle, Beam Modifiers, and the characteristics of the dosimetry tool used. Electron contamination dominates the dose delivered to the first few millimetersof the skin by therapeutic photon beams, due to interactions with air or patient-specific parameters and beam-limiting devices. To quantify this, it is recommended to estimate the build-up dose effect using an appropriate measuring device [5-9]. Precise selection of detectors is essential due to the steep dose gradient in the vicinity of the surface and within the build-up region. Ideally, detectors should have a small size along the beam path. For surface dose measurements, extrapolation chambers are recommended due to their high accuracy and reliability in radiation dosimetry.It is a specialized

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ionization chamber that can accurately determine the dose deposited in a thin layer at or near the surface of a material [10-11].However, extrapolation chambers are relatively complex and require careful calibration and operation. This makes them less accessible to all institutions, The Attix parallel-plate chamber [12-14] stands out as the most advanced detector for surface dose measurement. Its notable advantage lies in its solid water phantom construction, resulting in a side wall in-scatter over-response of less than 1% [4]. Alternatively, fixed-separation plane-parallel chambers are frequently employed to measure surface dose and dose in the build-up region. However, these chambers tend to over-respond in the build-up area, particularly at the surface, due to their larger separation compared to extrapolation chambers and their small guard ring.

Each dosimetry tool used in Radiotherapy has its own specific physical property and effective measuring depth varies for each dosimeter, the result of such measurement may differ from chamber to chamber. Traditionally, the surface dose from therapeutic photon beams was analyzed using a thermoluminescence dosimeter [14-16], Radiochromic film [17, 18], and various parallel plateionizationchambers [19-21].

Fixed-electrode separation (parallel-plate) chambers have become widely available and valuable for evaluating surface dose in clinical scenarios due to their appropriate physical design [22]. However, their precision in the Build-up region is questioned as the chamber volume creates additional ionizations, causing a disturbance in the cavity. To ensure accurate surface dose measurement it is crucial to account for the existing perturbation conditions when adjusting the ionization reading. Velkley et al. [21] have suggested the utilization of correction factors derived from extrapolation-chamber data with aluminium walls. These correction factors are obtained by modifying the depth dose curves in the Build-up region of various types of fixed parallel-plate ionization chambers. Gerbi et al. [11] have introduced an updated technique for precise surface dose estimation. The Rawlinson Equation [23] was used to apply corrections for over-response in the build-up region, which involves using correction factors derived from data collected from extrapolation chambers with aluminium walls.Overall, the study aims to understand the surface and build-up doses in a 6 MV flat photon beam and to evaluate the response of the SNC 350P ROOS [24] and PTW Markus parallel-plate [25] ionization chambers under different field dimensions and depths. By considering the various influencing factors such as beam energy, field sizes, depth of measurement, and the material properties of the medium through which the radiation passes and applying the appropriate correction to the measurements, they aimed to achieve precise surface dose estimation.

Materials and Methods

Design and Specification Parallel-Plate Ionization Chamber

SNC350p ROOS chamber

Figure1a shows the SNC350p ROOS parallel-plate ionization chamber (Model 1045). ROOS chamber has a 2 mm electrode gap, 15.6 mm collector diameter, 4.1 mm guard ring width, and entrance window mass density of 136 mg/cm^2. The wall diameter is 23.8mm. SupplementaryTable 1 shows the characteristics of the ROOS chamber.

PTW Markus chamber

Figure 1b shows the Markus parallel-plate ionization chamber (Model TW 23343, PTW, Freiburg, Germany). Markus chamber is composed of a compactguard ring with a width of 0.2 mm, an electrode separation of 2 mm, and a collecting volume of 0.055 cm^3. The entrance window mass density is 2.76 mg/cm^2. The wall diameter is 5.8 mm. Supplementary Table 1 Shows the characteristics of the Markus chamber.

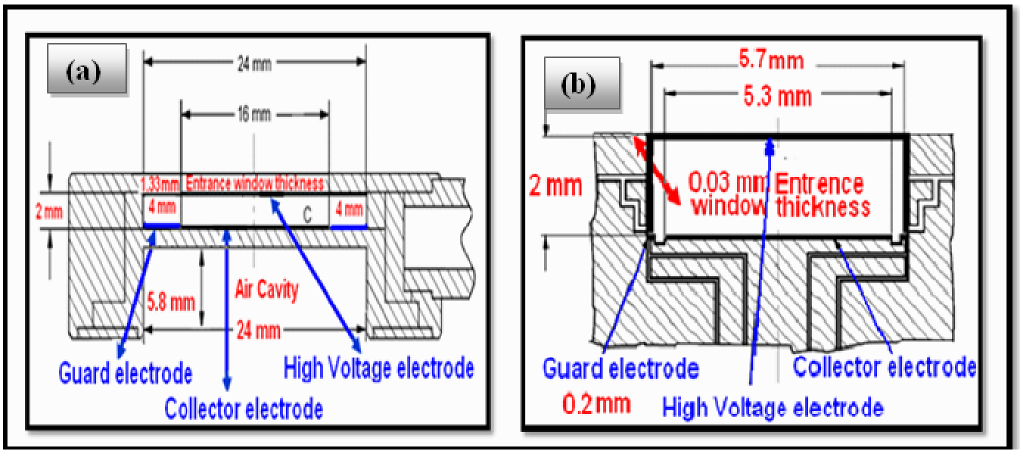

Figure 1. a) and b) shows the Schematic diagram of SNC350P ROOS and PTW Markus Chamber.

Table 1. The characteristics of Markus Chamber and ROOS Chamber

Ionization Type	TW 23343 (Markus Chamber)	SNC350p (1045) (ROOS Chamber)
Window Material	Polyethylene window, with graphite electrode, PMMA body.	Polymethyl Methacrylate (PMMA)
Entrance window (density)	0.03 mm PE (Polyethylene CH_2), 2.76 mg/cm^2 (density is 0.92g/cm3)	Total thickness 1.07 mm (136mg/cm$^{2)}$ 1.00 PMMA(1.19 g/cm^3) 0.05 Paint (2.55 g/cm^3) 0.02 Carbon (2.62 g/cm^3),(density is 1.28g/cm^3)
Water Equivalent Window Thickness	0.03 mm Without protection cap	1.07 mm
Collector Size (c)	5.4 mm diameter (circular)	15.6 mm diameter (circular)
Collector Area*	22.071 ≈ 22.1* mm^2	176.786 ≈ 176.8* mm^2
Nominal Volume	0.055 cm^3	0.388* cm^3
Electrode Separation	2mm	2 mm
Width of Guard Ring(g)	0.2mm	4.1 mm
Phantom Material	Water, and PMMA	Water, and PMMA

**Calculated, ** standard from catalogue*

Phantom and Irradiation Conditions for measurements of percentage depth dose (PDD) in the build-up region

The Sun Nuclear Corporation (SNC) 350P ROOS and PTW Markus parallel plate ionization chambers were used to measure the PDD along the central axis in the build-up region of the 6 MV photon beam. The measurements were done using a Solid Water® HE phantom, which has a density of 1.032 g/cm^{3}and the phantom consists of 30×30 cm^2 slabs thickness ranging from 1 to 10mm. Measurement was performed with field sizes of 10 x10 cm^2, 20x20 cm^{2,} and 30x30 cm^2 at 100 cm Source detector distance (SDD) and different depths at 0° incidence beam angle for 6MV photon beam from Truebeam SVC linear acceleratorThe chambers were connected to anSNC electrometer via a triaxial cable (Model: Sun Nuclear Corporation) and a bias voltage of +300 V was applied for both ROOS and Markus chambers. In order to achieve complete phantom scatter equilibrium for all measurements, a minimum backscatter thickness of 15 cm was used. Ion chamber readings in nanocoulombs (nC) were recorded for each exposure and at least three readings were taken for each measurement.

The electrometer readings so acquired were also corrected for environmental variation (temperature and pressure) by applying standard methods.

The entrance window thicknesses (the effective point of measurement) for Markus and ROOS chambers are 0.03 mm and 1.07 mm, respectively. The entrance window of the SNC350p ROOS chamber is far away from the surface and the entrance window of the Markus chamber is near to the surface, and measurements should be taken at the surface, therefore the PDDs curves are shifted 1.07 mm for ROOS and 0.03 mm for Markus chamber.

Prediction of over-response for commercial chambers using "Rawlinson Equation":

A parallel-plate ionization chamber, with a constant distance between its plates, can be employed to assess the depth dose within the Build-up region. Nevertheless, correction is required to account for the unchanging plate separation.

Rawlinson *et al*. [23] modified Velkley *et al.* [21]correction factors are available for parallel plate chambers that are commercially accessible, where the effect of the chamber structure and the material density of its walls also included which were not included in Velkley's formula [21].Rawlinson *et al.* [23] and Velkley *et al.* [21] provided an improved formula as follows:

$$\mathbf{P(d')} = \boldsymbol{P(d)} - \left[\boldsymbol{c(E)} \boldsymbol{X} \left(\frac{l}{w}\right) \boldsymbol{X} \left(\left(\frac{\rho}{1.17}\right)^{0.8}\right) \boldsymbol{X} \left(\boldsymbol{e}^{\frac{-4d}{dmax}}\right)\right] \quad (1)$$

Where ρ is the density of wall material (g/cm^3), l is plate separation, d is depth to the front surface of the chamber, c (E) = 27% for 6MV w is the inner diameter of the wall (w= c+2g, where c is the collector diameter, and g is the collector edge wall distance), P is the percentage build-up obtained with chamber plate separation and P' is corrected percentage build- up.

Rawlinson *et al*. [23] developed a formula for predicting the side wall effect due to the negligible chamber signal of electrons from the side of fixed separation parallel plate chambers. The formulation of the equation aimed to determine the chamber over-response in standard build-up conditions.

Results

Figure 2 (a) shows the PDDs as a function of depths for different field sizes (10x10 cm², 20x20 cm², and 30x30 cm²) at 100 SSD (source-to-surface distance) without over-response correction of the Markus chamber. For large fields, the PDD values were significantly increased from 23.94% to 41.90%. Figure 2(b) displays the PSD curves for the same field sizes after applying the correction of Rawlinson's equation for the Markus chamber. The corrected PSD values ranged from 16.32% for the 10x10 cm² field to 34.27% for the 30x30 cm² field. Table 2 presents the PSD and PDD values obtained with and without the Rawlinson correction for the Markus chamber in a solid water equivalent phantom. The table shows the PDD values at different depths for each field size, both with and without the correction.

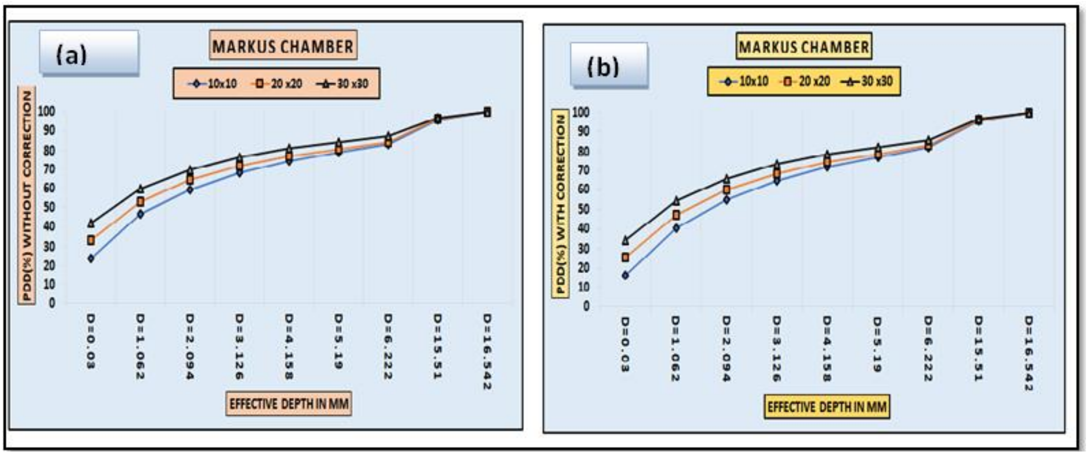

Figure 2. a) and b) Shows the PDDs without and with correction as a function of depths and different field sizes for the Markus (PTW) chamber.

Table 2. PSD and PDD values were obtained with and without over-responsecorrection using the Markus chamber

Phantom depth (mm)	Effective Point of Measurement (mm)	Equivalent depth in water (mm)	PDD (%)						Over response by PTW Markus Chamber (%)
			without over-response correction			with over-response correction			
			10x10	20x20	30x30	10x10	20x20	30x30	
0	0.03	0.03	23.94	33.10	41.90	16.32	25.50	34.27	7.62
1	1.062	1.062	46.59	53.00	59.95	40.81	47.22	54.16	5.79
2	2.094	2.094	59.48	64.30	69.96	55.08	59.90	65.57	4.39
3	3.126	3.126	68.02	71.6	76.50	64.69	68.27	73.16	3.34
4	4.158	4.158	74.50	77.00	81.17	71.96	74.51	78.64	2.53
5	5.19	5.19	78.87	80.70	84.28	76.95	78.77	82.36	1.92
6	6.222	6.222	83.37	84.40	87.38	81.90	82.95	85.92	1.46
15	15.51	15.51	95.50	96.30	96.79	95.38	96.13	96.67	0.12
16	16.542	16.542	99.80	99.80	99.80	99.71	99.71	99.71	0.09
% of Surface Dose at 0.5mm			35.11	42.92	50.72	28.37	36.19	44.05	6.67

Additionally, the table displays the percentage surface dose (PSD) at 0.5 mm for each field size, with and without the correction. The correction reduced the PSD values from 35.11%, 42.92%, and 50.72% to 28.37%, 36.19%, and 44.05% for the 10x10 cm², 20x20 cm², and 30x30 cm² fields, respectively.

Results of PSD and PDDs by ROOS chamber

PDD measurements were performed using the SNC 350p ROOS chamber, both without and with over-response correction. Figure 3 (a) and 3 (b) show the PDDs as a function of depths for the different field sizes (10x10 cm², 20x20 cm², and 30x30 cm²) at 100 cm SSD for the ROOS chamber, both without and with the correction of Rawlinson's equation. Table 3 presents the PSD and PDD values obtained with and without the Rawlinson correction for the ROOS chamber in a water-equivalent phantom. Similar to the Markus chamber results, the table includes the PDD values at different depths for each field size, both with and without the correction. The table also provides the percentage surface dose (PSD) at 0.5 mm for each field size, with and without the correction. The correction reduced the PSD values from 41.61%, 50.50%, and 58.03% to 33.96%, 42.87%, and 50.38% for the 10x10 cm², 20x20 cm², and 30x30 cm² fields, respectively.

PSD and PDD at effective point by ROOS and Markus chambers for different depth

Figures 4 and 5 illustrate the PDDs measured at the effective point of measurement for both chambers for small and large field areaswith and without over-response correction. The solid lines show the PDD measurements after shift 0.03 mm using Markus chamber and the dashed lines indicate PDDs measured after shift 1.07 mm using ROOS chamber. Table 4 shows the percentage depth dose differences between ROOS and Markus chambers with and without over-response correction for all depths and field areas. Data indicates that the highest values of PDD were at the surface, which decreased with increasing the field area, and the lowest values of PDDs were at 16 mm depth. It may be concluded that the structure of ionization chamber is essential for measurement of accurate PSD and PDD in build-up region.

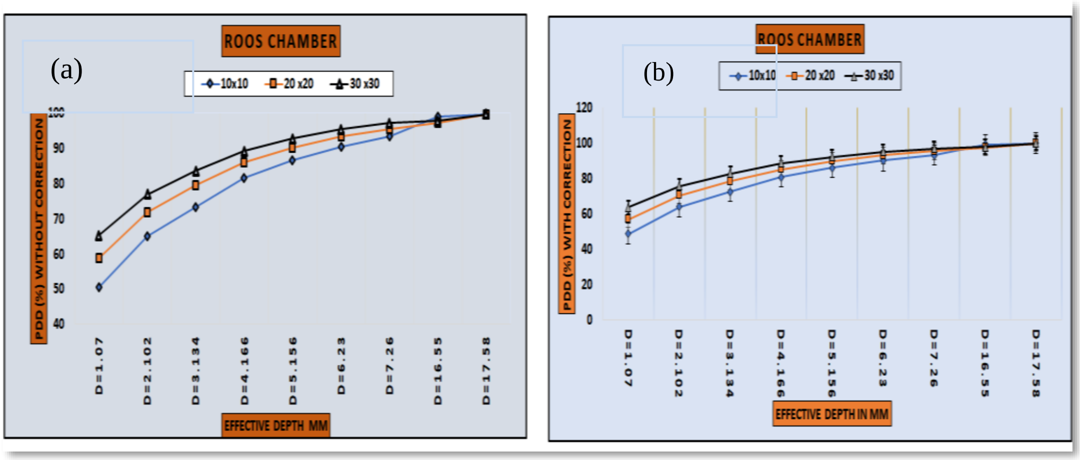

Figure 3. (a) and (b) Showthe PDDs without &with correction as a function of depths and different field sizes for the ROOS (SNC350p) chamber

Table 3. PSD and PDD values obtained with and without over response correction using ROOS chamber

Phantom depth (mm)	Effective Point of Measurement (mm)	Equivalent depth in water (mm)	PDD (%) without over-response correction			with over-response correction			SNC350p Over response by ROOS Chamber (%)
			10 x 10 cm^2	20 x 20 cm^2	30x 30 cm^2	10 x10 cm^2	20 x20 cm^2	30x 30 cm^2	
0	1.07	1.07	50.56	58.70	65.37	43.95	52.12	58.76	6.61
1	2.102	2.102	65.20	71.70	77.04	60.18	66.73	72.02	5.02
2	3.134	3.134	73.50	79.50	83.63	69.69	75.64	79.82	3.81
3	4.166	4.166	81.52	86.00	89.25	78.63	83.10	86.36	2.89
4	5.156	5.156	86.56	90.30	92.83	84.34	88.04	90.60	2.22
5	6.23	6.23	90.37	93.40	95.39	88.70	91.72	93.72	1.67
6	7.26	7.26	93.35	95.70	97.21	92.08	94.39	95.94	1.27
15	16.55	16.55	99.15	97.40	97.84	99.04	97.27	97.73	0.11
16	17.58	17.58	99.80	99.80	99.80	99.72	99.72	99.72	0.08
% of Surface Dose at 0.5mm			41.61	50.50	58.03	33.96	42.87	50.38	7.65

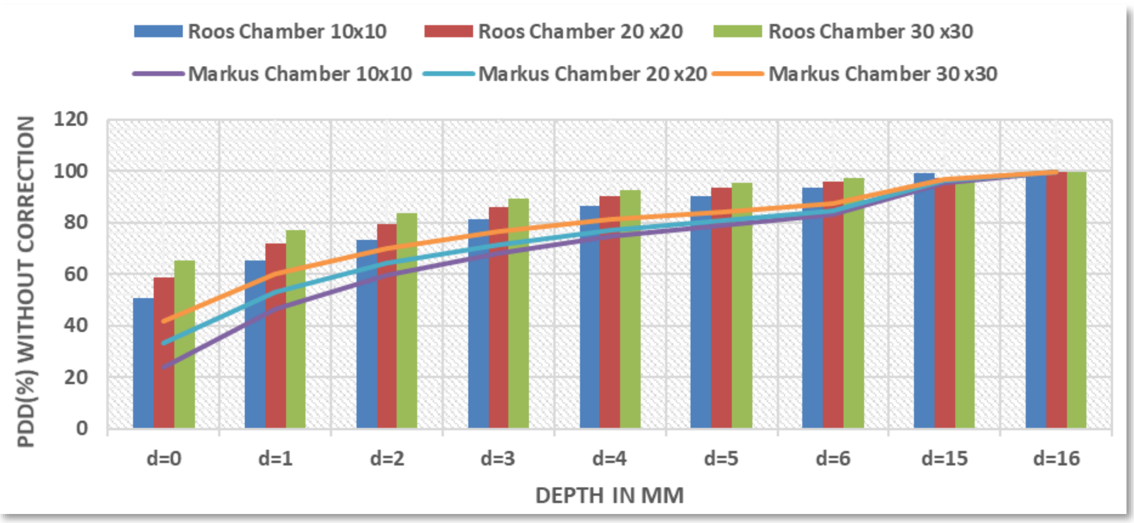

Figure 4. PDDs at the effective point of measurement without correction for ROOS (Bar column) and Markus chamber (Solid line) for 10x10,20x20 and 30x30cm^2

Both Markus and ROOS chambers have various preferable characteristics, *e.g.* The over-response correction of ROOS chamber is less than that of Markus. The thickness of the entrance window for Markus is too small compared to ROOS (1.07 mm for ROOS and 0.03 mm for Markus).

PSD (Dose at 0.5mm) for ROOS and Markus chamber for field size 30 x30 cm²

Tables 2 and 3showROOS chamber PSD value for 30x30 cm2 field size is 50.38% with over-response correction which is higher than Markus chamber PSD 44.05%with with response correction.

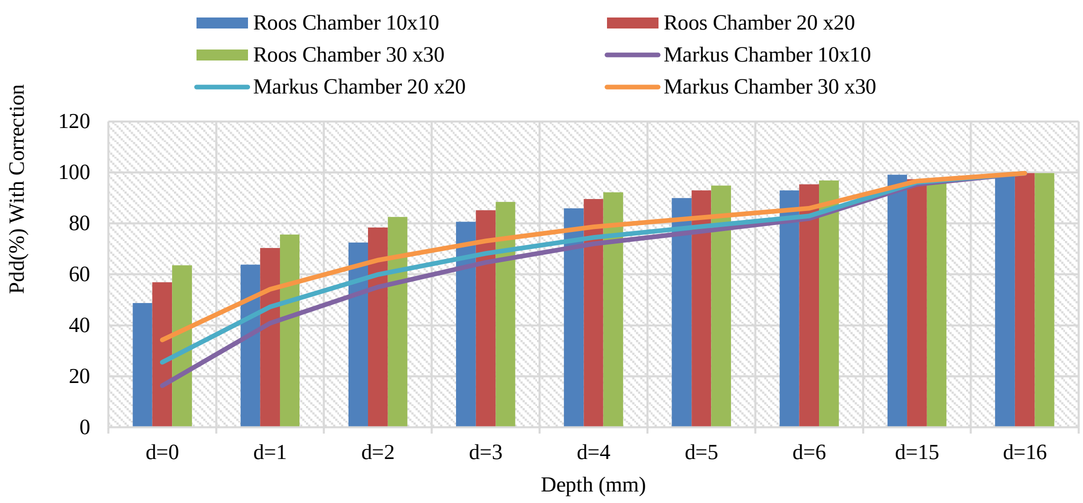

Figure 5. PDDs at the effective point of measurement with over-response correction for ROOS (Bar column) and Markus chamber (Solid line) for 10x10,20x20 and 30x30cm²

Table 4. Difference between PDDs of ROOS (SNC350p) and Markus (PTW) chambers for different depths

Depth (mm)	PDDs (%)					
	Without correction			With correction		
	10x10 cm²	20 x 20 cm²	30x30 cm²	10x10 cm²	20 x20 cm²	30x30 cm²
0	26.61	25.60	23.47	27.62	26.61	24.49
1	18.61	18.70	17.09	19.38	19.51	17.86
2	14.02	15.20	13.67	14.61	15.74	14.25
3	13.50	14.40	12.76	13.94	14.83	13.20
4	12.06	13.20	11.65	12.38	13.53	11.96
5	11.50	12.70	11.11	11.75	12.96	11.36
6	9.98	11.30	9.82	10.18	11.45	10.02
15	3.64	1.12	1.04	3.67	1.14	1.06
16	0	0	0	0.012	0.012	0.01

Table 5. Comparison of surface dose at 0.5mm depth with different field size and different chambers (ROOS and Markus)

Field Size (cm²)	Present work		Parsai*et al.*	David e. Mellenberg Jr	Gerbi and khan	Qi et al.
	Markus(P)	ROOS(P)	Extrapolation	Markus		Attix
10x10	28.37%	33.96%	33.4%	26.4%	28.52%	18.9%
20x20	36.19%	42.87%	-	37.50%	38.25%	29.10%
30x30	44.05%	50.38%	-	46.7%	45.98%	37.90%

Discussion

This study compares the percentage surface dose (PSD) values obtained using different ionization chambers, specifically ROOS and Markus chambers, for different field dimensions in the build-up region of a 6 MV flattened beam. The study also includes a comparison with results from other chambers, such as Attix and Extrapolation. The supplementary table shows a comparison of the surface dose at 0.5mm depth with different field sizes and different chambers, including ROOS and Markus chambers, as well as other studies conducted by different authors.Tables2 and3demonstratethe chamber over-response as a function of field dimensions in PSDs after applying correction of Rawlinson's equation and observed an increase in PSDs with large field size. The PSDs generally increase as the field dimensions increase. However, the ROOS chamber exhibited higher PSD values compared to the other chambers. This can be attributed to the entrance window thickness, which was positioned at 1.07 mm from the surface.On the other hand, the Markus chamber showed PSD values that were closer to the other chambers. This is because the structure of ionization chambers used in the Markus chamber has either zero or smaller entrance window thickness, along with various length (l) to width (w) ratios. By applying the correction factor, for 10 x 10 cm^2 field size corrected dose values for a 6 MV flattened photon beam using the ROOS chamber were found to be 33.96%. Ishmael Parsai et al. [26] performed surface dose measurements at a depth of 0.5 mm utilizing an extrapolation chamber and a 6 MV flattened beam with the same field size, showing a similarity with the corrected dose values of 33.4%. Supplementary Table 5illustratesthe PSD for each field size and detector type used in the respective studies.When comparing the PSDs obtained using the $M^{(P)}$ of the present method and the Markus M chamber, the results showed that the PSDs obtained using the Markus M chamber were slightly higher than those obtained using the $M(^{P})$ of the present method. The percentage differences were 1.97%, 1.308%, and 2.65% for field sizes 10x10 cm^2, 20x20 cm^2, and 30x30 cm^2, respectively. Next, when comparing the PSDs obtained using the $M^{(P)}$ of the present method and the Attix chamber, the results showed that the PSDs obtained using the Attix chamber [27] were lower than those obtained using the $M^{(P)}$ of the present method. The percentage differences were 9.47% and 7.092% for field sizes 10x10 cm^2 and 20x20 cm^2, respectively, and 6.15% for the 30x30 cm^2 field size. The comparison also involved comparing the PSDs obtained using the $R^{(P)}$ of the present method with the PSDs obtained using the Attix chamber. Similar to the previous comparison, the results showed that the PSDs obtained using the Attix chamber were higher than those obtained using the $R^{(P)}$ of the present method. The percentage differences were 15.061% and 13.77% for field sizes 10x10 cm^2 and 20x20 cm^2, respectively, and 12.48% for the 30x30 cm^2 field size. The polarity effect was not considered in this study, which could contribute to the differences observed in the results.

Conclusion

The knowledge about the specified physical properties of the chamber is crucial for accurately measuring the Percentage Depth Dose (PDD) and Percentage Surface Dose (PSD) in the build-up region. The choice between the Markus and ROOS chambers depends on the specific requirements of measurements. The Markus chamber may be preferred for its smaller PSD values, especially when accurate surface dose measurements are crucial. However, the ROOS chamber may be suitable for certain applications due to one of the preferable characteristics is that it provides a smaller value of over-response correction compared to the Markus chamber. This indicates that the ROOS chamber is more accurate in measuring the actual dose delivered by the radiation beam. For 6MV flattened beams, the PSD for the Markus chamber was smaller when compared with the ROOS Chamber with its smaller thickness (0.03mm) of the entrance window. The PSD for the ROOS chamber was increasing for all field dimensions with its higher thickness of the entrance window (1.07 mm).Ultimately, selecting the appropriate chamber involved considering the specific characteristics and requirements of the measurement setup.

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