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A STUDY ON THE EFFECTIVENESS OF TG-51 AT EXTENDED SSD IN IONISATION CHAMBER CALIBRATION BY CORRECTION FACTORS IN TOTAL BODY IRRADIATION DOSIMETRY

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Abstract

Purpose: The Aim of this study is to calculate and validate the ion collection efficiency of Farmerionization chamber and Markus ionization chamber by calculating ion correction factor P_{ion} and polarity correction factor and applying these values in total raw ion chamber reading to calibrate the machines accurately at extended SSD and to check the effectiveness of these chambers in reference dosimetry of TBI. Also the application of TG-51 is being studied at extended SSD by verifying the values of ion correction factor (P_{ion}), polarity correction factor (P_{pol}), percent depthdose (PDD) and dose rate. **Materials and Methods**: PDDs, Pion, P_{pol} were calculated for 6 MV and 18 MV photon beams under TBI standard conditions using solid water phantom and ion chambers (Markus 0.6 cc and Farmer 0.02cc).The standard deviations and correlation was also measured. **Results**: For 6 MV at SSD= 100 cm, the values of P_{ion} and P_{pol} are 0.992 and 0.996 forFarmer chamber and for Markus chamber respectively, and at extended SSD the values are 0.98 and 0.84 and their relative error lies less than 1%. For 18 MV the deviations in P_{ion} and P_{pol} values,at extended SSD were 15% and 13% respectively which are exceeding the permitted value of uncertainty, and at 100 cm SSD for Markus chamber the P_{ion} and P_{pol} values are 0.986 and 0.856 respectively which shows good agreement with the prescribed tolerance limit. **Conclusions**: Farmer ionization chamber and Markus ionization chamber are consistent andefficient at 100 cm but due to cable effect, the P_{ion} and P_{pol} values are not in good agreement at extended SSD hence these ionization chambers are not recommended at extended SSD for TBI dosimetry.

Keywords: Total Body Irradiation, Dosimetry, P_{ion}, P_{pol}, Mayneord's Factor, Source to Surface Distance

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1. INTRODUCTION

Total body irradiation refers to dosimetrically and therapeutically a complicated modality, which requires a precise and accurate dose distribution and treatment planning to deliver a dose uniformlyup to +10% [1].Calculations were being made in dosimetry have impact on planning the precise dose to the target volume. So commissioning Linacs is primary stage to acquire data as treatment planning depends upon this data. Measurements obtained in calibration are the basis of therapy. There is need of checking the effectiveness of ionization chambers used in dosimetry etc[1].As the simulation results are comparable with measurements, there is no denial of importance of absolutecalibration. From the clinical perspective, there is a requirement of validation of data for extendedand nominal SSDs [2].So there are some important parameters like Pion and Ppol, which are requiredto be calculated and and verified during TBI dosimetry.

Linacs are used for radiation therapy. Referring to many standard protocols, a protocol named TG-51 is the most commonly used [3].In these calculations, the relevant formulism given in TG-51 is being used to validate the parameters which ultimately helps in effectiveness of the ionizationchamber.

In TBI dosimetry, the treatment SSD is usually 500 cm and doing so there are a number of correction factors that are needed to be applied to lessen the uncertainty errors. There is a need of validation of chambers so consideration of all parameters is important [4].Observations were being taken using cylindrical and plane parallel chamber [5]. During TBI absolute dosimetry at extendedSSD, the polarity effect should not be ignored which is directly linked to many factors like SSD, cable effect, charge accumulation and dose per pulse etc. It is shown in results that Ppol is significantly very high at 500cm in Markus chamber and almost show a little variation from its recommended range using farmer chamber. So there should be a correction factor to minimize the errors in calibration, as TBI dosimetry is a special case so all the measurements have to be taken at extended SSD so there is a need of re commissioning the linac(5) (11).

Our main objective is to determine whether TG51 could be used at extended SSD and to assess the machine's output at extended SSD total body irradiation dosimetry requires the calibration of ionization chambers which includes measurement of different calibration and correction factors, beam quality and measurement like PDDS, TMRS, ion correction factor and polarity correction factor etc. We need calibration of the chambers by calculating all these parameters and by comparing the values of ion correction factor and polarity correction factor with standard protocol values at extended and nominal SSD. For estimating linearity and deviation from the average value and calibration output data, the standard deviation is often useful [6].

These observations have the goal of analysing the Pion and Ppol as a function of dose rate, absorbed dose in the fall off region, and checking the effects of beam interaction with matter, which is initially carried out on the water phantom. The major goals of this study are also to determine how Mayneord's factor affects PDDs and how to choose a beam specification by varying a PDD depending on the calibration procedure. The results

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obtained under isocentric settings in TBI dosimetry are insufficiently helpful without conversion. Furthermore, the extended SSD 500 cm measuring setup is utilised for exceptional cases like TBI. Re-commissioning of equipment in this regard was technically beneficial for the same readings at extended SSD for clinical TBI,which is 500cm. Ppol and Pion measured values had differences when utilising farmer and planar parallel chambers [7].

2. METHODS AND MATERIALS

2.1 Materials

All the measurements and data was acquired with the electrometer of operating voltage 300V.With Unidos electrometer, taking 100 monitor units, temperature of the setup was 23.5^{o}C and pressure was maintained at 1017.5 hPa.

2.2 Methods

The ion correction factor and polarity correction factor at nominal SSD were measured using the formulism given in TG-51 and compared with standard protocol and same readings were obtained at extended SSD for TBI dosimetry using same set up of calibration. TBI dosimetry under isocentric conditions are then helpful to choice a suitable ionization chamber. All calculations were being validate by obtaining the values under TBI dosimetric conditions. Some of the parameters of our interest are listed below.

2.3 TG-51 Protocol

In Task Group-51, the complete correction of ion chamber observations, *M* which is total ion chamber reading can be termed as product of ion correction factor, polarity correction factor, electrode potential, and invalidate chamber reading at observations side. Experts do agree with TG-51 values within experimental uncertainties range .so there should be the total uncertainty onphoton dose is 0.1% [8].

$$M = P_{ion} P_{pol} P_{TP} P_{elec} M_{raw} \text{ (C or Rdg)} \quad (1)$$

Table 1: Specifications of chambers

	Nominal sensitive volume (cm^3)	Nominalresponse (nc/Gy)	Ion collectiontime (μs)	Chamber voltage (V)
Farmer	0.6	20	140	100-400
Markus	0.02	0.67	22	50-300

2.4 Temperature correction factor (P_{TP})

The calibration was maintained in experimental laborites at standard conditions to validatechamber readings. This correction factor must be taken into account for charge accumulation.

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$$P_{\mathrm{TP}} = \frac{273.2+T}{273.2+22.0} \times \frac{101.33}{P} \qquad (2)$$

2.5 Polarity Correction Factor (Ppol)

Because of polarization, this impact directly related to fluctuation in the charge reading. Ppol also altered by the cable location.

$$P_{\mathrm{pol}} = \left| \frac{\left(M^{+}_{\mathrm{raw}} - M^{-}_{\mathrm{raw}}\right)}{2M_{\mathrm{raw}}} \right| \qquad (3)$$

2.6 Ion Correction Factor (Pion)

It deals with the collection of charges in chambers. It depends upon rate at which dose is delivered at two operating voltages technique.

$$P_{V_H} = \frac{I-(V_H/V_L)^2}{M^H_{raw}/M^L_{raw}-(V_H/V_L)^2} \qquad (4)$$

2.7 Absorbed dose

For TBI dosimetry water used as a medium for calibration. So beam needs to calibrate in water atsome reference point (d ref = 5cm or 10cm). In this regard, there is a need of calibration factors for conversion, so a factor is taken for Linac beam which is KQ. Its measured accuracy is ±0.5percentage.

$$D^Q_W = \mathrm{M}K_Q \ N^{60\,Co}_{D,W}\ (\mathrm{Gy}) \qquad (5)$$

3. RESULTS AND DISCUSSIONS

Initially the calibration of Farmer chamber and advanced Markus chamber using for 6MV and 18MV photon beam using the above formulas different correction factors were calculated. The following outputs are being observed.

3.1 Calibration results at nominal and extended SSD

Where 0.6 cc refers the Farmer chamber nominal sensitive volume and 0.02cc refers the Markus chamber sensitive volume. Correction factors for total body irradiation (TBI) dosimetry has been investigated from table 2,It is shown at 5 cm and 10 cm depths For Farmer chamber the ion correction factor for 6 MV photon beam nearly approached unity and Markus chamber showed this factor less than unity.The Polarity correction factor for 6 MV photon beam has been measured,output values were unity for farmer chamber and less than unity for Markus chamber, but for 18 MV the value of Ppol is on average for both Farmer and Markus chamber is found to be high but not exceeding the prescribed

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values in TG-51,so at smaller field sizes these chambers aresuitable and can be used for TBI dosimetry [9] and are being recommended for smaller fields alongCAX.

Table 2: Calibration at 500 cm source to surface distance at field size 10x10cm^2

Beam (MV)	Depth (cm)	Ion Correction Factor		Polarity Correction Factor	
		Farmer	Markus	Farmer	Markus
6	5	0.9987	0.9984	1.1065	0.6984
	10	0.9991	0.8997	1.0003	0.7989
18	5	0.9976	0.8654	1.1062	1.1000
	10	0.9995	0.8875	0.8999	0.1004

Table 3: Calibration in Solid Water at extended source to surface distance of 500 cm at 40x40 cm2

Energy (MV)	Depth (cm)	Polarity Correction Factor		Ion Correction Factor	
		FarmersChamber	Markus Chamber	Farmer	Markus
6	5	0.98667	0.8872	0.883	0.786
18	5	0.66867	0.6558	0.884	0.778

There was very little change in polarity effect at low to high rate of dose delivery [10].For 6 MVat larger field size Ppol value are less than unity so these values cannot effect the chamber efficiency and can be ignored but as far as Pion values are concerned a very small variation in ion combination can directly change the chamber activity. Variation can be handled by correct positioning of wirefor this it should be placed far away from the chamber .At voltage 300 to -300 and depth 5 cm thediodes readings were from 38 to -24,after calculation of Pion and Ppol, the relative errors were 0.5 and 0.2 respectively at nominal distance for 6MV both for Farmer and Markus respectively ,Whichis quite normal, as far as the plane parallel chamber using 18 MV is concerned the relative error is 0.8 and 0.4 at 5 cm and 10 cm respectively and for farmer chamber which is acceptable and recommended according to the standard protocols .For smaller field size the% error in polarity correction factor is 0.003 and 0.994 for 6 MV. For 18 MV beam energy 0.1322 and 0.1122 at 5 cmand 10 cm respectively. The error in Ion correction factor for 6 MV are 0.51 and 0.204 and for 18MV error is 0.206 and 0.79.

3.2 Ion Correction and Polarity Correction Factor

With the help of polarization effect, the estimation of ions produced can be done accurately. The enhancement of polarization effect was observed at extended SSD also it increases due to the cableeffects when the beam leaves the chamber [11]**.**

Table 4: Ion correction factor at 100cm and 500 cm SSD

Energy (MV)	SSD=100 cm		SSD=500cm	
	.6cc	.02cc	.6cc	.02cc
6	0.1188	0.1087	0.1000	0.9867
18	0.0221	0.1102	0.1321	0.9861

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Table 5: Polarity correction factor at 100cm and 500cm source to surface distance

Energy(MV)	100 cm		500cm	
	.6cc	0.02cc	0.6cc	.o2cc
6	0.1103	0.1043	.04321	0.8402
10	.1212	.0098	.1012	0.8595

From table 4, it was shown, all polarity correction factors at nominal SSD are in agreement with standard protocols (< 0.1%).A rising trend in P_{pol} was recorded when changes were being made to the spatial points of wire, then 0.2% to 0.3% tolerance limit was observed if the average values are not taken[12].With increased beam energy the relative error decreases for P_{ion} values and for P_{pol} values, error decreases almost two times with increased beam energy at smaller field size. The Pion values are high at extended SSD if large volume of chambers are used with high exposure rate and show less than 1% k_{pol} values if less than 120 cm^3 volume of ionization chamber is used. As far as P_{pol} is concerned its value show rising trend if thickness of electrodes is more and the depth of chamber is greater in the phantom. Because photons reacts with electrodes and releases secondary beta particles which ultimately are the responsible for ion collection increment and decrement, so for extended SSD these parameters should be considered.

3.3 Absorbed Dose from Golden Beam Data, And Calculated from Mayneord's Factor and Measured PDDs

If ionization chamber is calibrated properly then from the literature it is shown that only plane parallel chambers are suitable for measuring the PDDs, Percent depth dose using Mayneord's factor shown overlapping with the measured data at nominal SSD and shown difference when SSD increased. The deviations show an increasing trend with increasing depth, with reference to it, calculated PDDs with Mayneord's factor show less decrease at extended source to surface distance. And surface dose shows -126% deviation from standard prescribed tolerance limit after dmax it shows a gradual rising trend with increased depth. The PDD values are taken and calculated with Mayneord's factor and comparing them with Golden beam values resulted only for 6 MV at 3 cm, one value was significant that can be shown variations by if polarity or operating voltage of machine or ionization chamber is changed.

Table 6: Percent depth dose from golden beam data, and calculated from Mayneord'sfactor and measured PDDs for 18 MV in solid water phantom

Depth(cm)	Golden Beam Data	PDD by Mayneord's factor	PDD measured	%Deviation
	SSD=100cm PDD(30*30)	SSD=200cm PDD(30*30)	SSD=200cm PDD(30*30)	
3	95.40	96.79	94.13	2.78
6	84.99	88.68	85.1	4.33
9	74.67	80.05	76.37	4.80
12	65.16	71.68	68.59	5.38
15	56.86	64.11	61.439	6.61

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Table 6's findings indicate that the depth dose in the fall-off zone between 9 cm and 15 cm are almost linear. Results of data showed a minimum amount of overlap between computed and measured PDDs [13]. Every 3 cm, the deviation for 18 MV rises by an average value of 4.78, the PDD value at extended SSD grew by two times and When determined using the inverse square law changed the least, Nevertheless, these values have only a little impact on ion recombination, therefore there is no need to use the polarity correction factor.

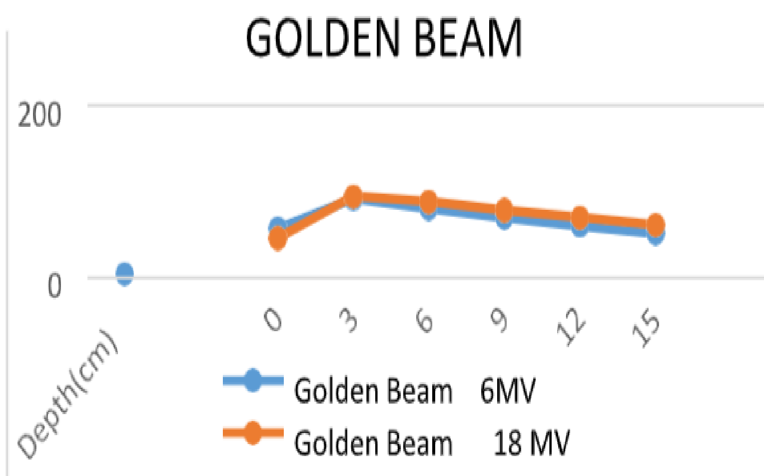

Fig 1: PDDs from golden beam data for 6MV and 18 MV at 30x30 cm^2 field size

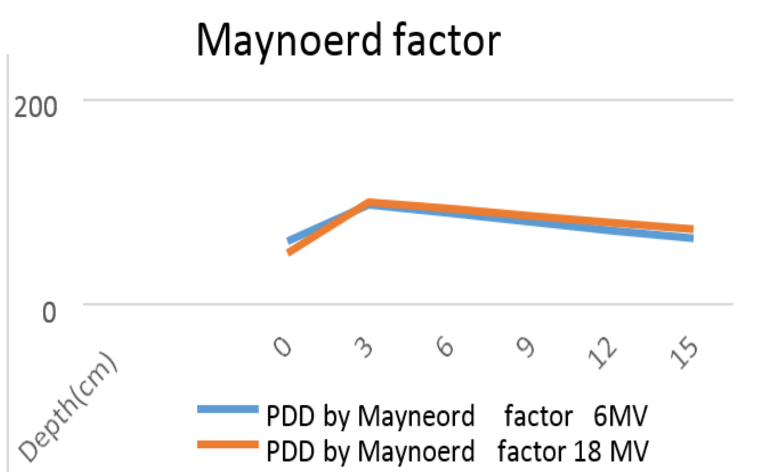

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Fig 2: PDDs from Mayneord's factor for 6MV and 18 MV at 30x30cm^2 field size

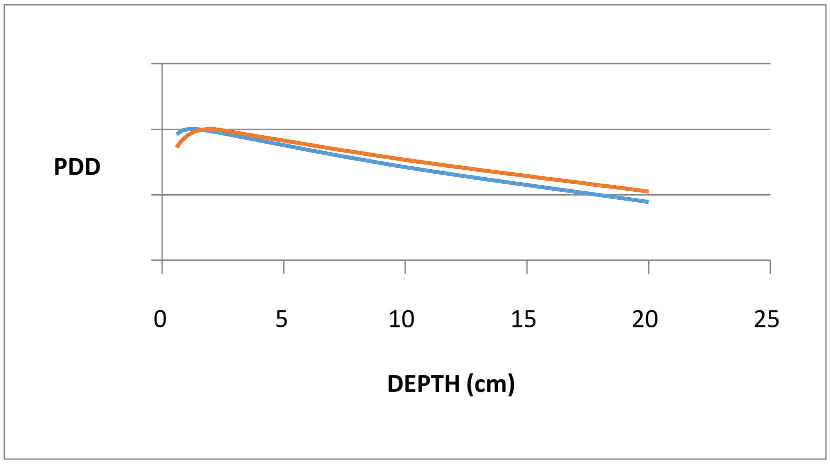

Fig 3: PDD curves for combination of 6 MV and 18 MV photon beam energy at 30x30 cm^2

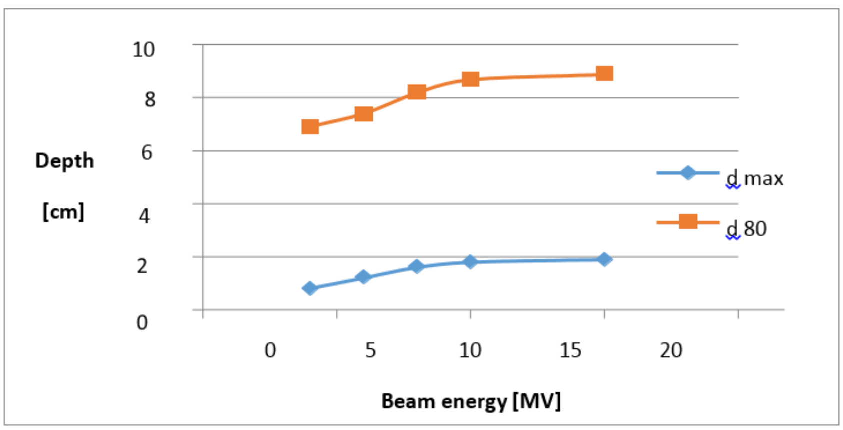

Fig 4: PDD curves shows dose from d_{80} to d_{max} at 30 x 30 cm^2

In fig 4 dose was observed for fall off region from dmax to d 80 with average decrease of 3.1%in the absorbed dose cm^{-1}[14].The separation between the curves increased as the photon beam energy became high, it indicates that due to increased PDD values the penetration is high as beamenergy increases. The pdd value is used to obtain beam specification so ion chamber should be properly checked. If quality conversion factor is equal to unity then the chamber without applyingpolarity conversion factor can be used.

3.4 Polarity correction factor, ion correction factor and dose rate

If ion chambers are used to measure the pdd then dose rate does not affect the pdd values. From 1x1 cm^2 up to 30 x30 cm^2 field sizes, as dose rates are linked with the surface doses and monitor units so their values are directly influenced by very small

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change in the surface doses, dose rate increases as the field size increases and ultimately the value of Pion increases every 9.9 cm. For 6 MV the surface dose at 30x30 $cm^2$is 62.161 and its corresponding dose rate is 0.61 For 18 MV at1x1 cm^2 by taking 100 MUs the surface dose is 38 and its corresponding dose rate is 0.38 and whentaken field size is 30x30 cm^2 the surface dose is 51.5 and its corresponding dose rate will be 0.51.The Ppol values increased with decreased dose per pulse and Pion values increase with increased dose per pulse. The Pion value shows less dependency on nominal dose rate but its value rises when beam energy increased.

4. DISCUSSIONS

As the validation of correction factors and selection of chambers are the main aim of reference dosimetry so the correction factors deviations from tolerance levels provide the basis of data usedin treatment planning [19].As TBI dosimetry and related parameters are of prime importance so the out comings were being compared with the standard task group 51.Calibration of ionization chambers is very much important to achieve the accurate values of dose and it is valid if calculated beam data is considered rather than measurements taken under TBI conditions. As Ppol values are overlapping the tolerance limit at nominal distances but show very high deviations at extended source to surface distance so measured values are recommended for TPS commissioning only at nominal distance. Due to time limit, work burden, high Ppol values and cable effect, it is recommended to use the Optically Stimulated Luminescence diodes and GAFCHROMIC TM films for TBI dosimetry [15]. Using plane parallel ionization chamber for both 6 MV and 18MV the deviation lies under prescribed tolerance limit that is <0.3% for Ppol and ≤1.05% for Pion. However, at extended source to surface distance the deviation for both ion correction factor and polarity correction factor found to be 14% and 15% respectively. Which violates the uncertainty level according to standard protocols[16].When PDD measured values were compared with calculated values after applying Mayneord's factor there was a deviation of -9.22933 at 1.5 cm, -0.1 at 2.5 cm,-0.5171 at 3.5 cm and at 5.5 cm it is 0.0987 , if on average there is a 6.8% deviationin PDD calculated and measured values every 7 cm then Mayneord's Factor is only useful if PDD has to be calculated and switched from one SSD to another SSD[17]. High photon beam energy has demonstrated greater penetration, which is one of the primary causes of rising PDD [4]. The calibration factor must be added to the total absorbed dose value in dosimetry for the calibration of equipment like an ionization chamber. When using 6MV it is observed that surface dose is increased by applying Mayneord's Factor andfor increasing SSD like at 100 cm the dose rate is 0.30 and the measured value of absorbed dose is 0.3065 at 200 cm at same SSD but after Mayneord's factor is applied the surface dose increasedand has the value of 0.61 for 30x30cm^2 field size. For small beam energy dose rate is less increased by increasing SSD.PDDs at 200 cm with Mayneord's factor shows Precision as the values lied within 3.5 % and dose uniformity was within 2%. One most important behavior of chambers and electrodes is at increasing potentials, because particles accumulation capacity of chamber followsthe difference dose per pulse, dose rate and type of chamber among potentiometers. So it also effectthe ionization chamber efficiency.

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For 18MV at 100 cm dose rate is 0.51, at 200 cm dose rate is 0.21, and by applying Mayneord's factor the dose rate is 0.49 for 30x 30 cm^2. Pion and Ppol values are effected by dose per pulse and dose rate, keeping the dose rate constant and operating voltage doe not effect the output of the ionization chamber reading. For high beam energy the dose rate almost becomes double for extended SSD. According to the results, for 6 MV the surface dose due to a high error level in doserate and PDD calculations, the relevant parameters must be directly measured under TBI conditions. Because of many other issues involved too, like to maintain the standard temperature and pressure conditions and correction factors are usually implemented in the calculations, to minimize the effects of polarity in total ion chamber reading [10].

5. CONCLUSIONS

Since the values of ion correction factor and polarity correction factor meet the standard values at100 cm and shows less than 1% difference so both Farmer chamber and Markus chamber are efficient enough for dosimetry at nominal SSD and their output can be used in treatment planningbut as their deviations are very high and have shown the 14% and 15 % for Pion and Ppol respectivelyfrom their average values at 500 cm source to surface distance, in TBI case ,so these ionization chambers cannot be used for extended SSDs[20].Also there is a direct link of polarity correction values to the accumulation capacity of charges of chamber, so ion recombination values are considered significant for the choice of chamber[21].And if machine shows less than 0.15% Pion value the chamber is fit for dosimetry. Because Plane parallel chamber is less polarity dependent so it is most suitable to measure, the pdd values if field sizes are extended enough. Mayneord's factor is useful for smaller fields [22]. Pion values almost remain unchanged with depth but its values shows variations as a function of dose per pulse.TG-51 can be used at nominal SSD but there are no standard set values at extendedSSD regarding TBI dosimetry.so only those machines should be used which shows closest matched data with the standard protocol.

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Conflicts of Interest: None declared

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