

Extrapolation chamber mounted on perspex for calibration of high energy photon and electron beams from a clinical linear accelerator

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ABSTRACT

The objective of the present study is to establish radiation standards for absorbed doses, for clinical high energy linear accelerator beams. In the nonavailability of a cobalt-60 beam for arriving at Nd, water values for thimble chambers, we investigated the efficacy of perspex mounted extrapolation chamber (EC) used earlier for low energy x-rays and beta dosimetry. Extrapolation chamber with facility for achieving variable electrode separations 10.5mm to 0.5mm using micrometer screw was used for calibrations. Photon beams 6 MV and 15 MV and electron beams 6 MeV and 15 MeV from Varian Clinac linacs were calibrated. Absorbed Dose estimates to Perspex were converted into dose to solid water for comparison with FC 65 ionisation chamber measurements in water. Measurements made during the period December 2006 to June 2008 are considered for evaluation. Uncorrected ionization readings of EC for all the radiation beams over the entire period were within 2% showing the consistency of measurements. Absorbed doses estimated by EC were in good agreement with in-water calibrations within 2% for photons and electron beams. The present results suggest that extrapolation chambers can be considered as an independent measuring system for absorbed dose in addition to Farmer type ion chambers. In the absence of standard beam quality (Co-60 radiations as reference Quality for Nd,water) the possibility of keeping EC as Primary Standards for absorbed dose calibrations in high energy radiation beams from linacs should be explored. As there are neither Standard Laboratories nor SSDL available in our country, we look forward to keep EC as Local Standard for hospital chamber calibrations. We are also participating in the IAEA mailed TLD intercomparison programme for quality audit of existing status of radiation dosimetry in high energy linac beams. The performance of EC has to be confirmed with cobalt-60 beams by a separate study, as linacs are susceptible for minor variations in dose output on different days.

Key words: Calibration, extrapolation chamber, high energy beams, radiation standards

Introduction

Calibration of photon and electron beams from a medical linear accelerator is carried out by using absorbed dose calibrated gas cavity chambers in water phantoms and applying different international protocols.^[1-4] Accuracy of the measured doses must be within 2%, so as to achieve an overall delivery of radiation doses to patients within 5% accuracy limits, for the expected clinical outcome. The International Atomic Energy Agency (IAEA) network of secondary standard laboratories maintains national standards for traceability of field level dosimeters.

Realization of absorbed doses in the primary standard laboratories is achieved from absolute measurements using, (a) standard graphite ion chambers (to determine absorbed dose to water) (b) graphite calorimeters in water, and (c) chemical dosimeters with Fricke solutions.^[1]

For low-energy x-rays and beta radiations, Bohm and Schneider^[5] developed an extrapolation chamber (EC), which is a specially designed parallel plate ionization chamber, capable of accurately measuring the differential specific charge (dq/dm), by varying air mass in the cavity by precise control of electrode separation. The principle and application of the EC for measurement of x-ray outputs have been reported in literature.^[6-8] Zankowski and Podgorsak^[9,10] reported the efficacy of specially built extrapolation chambers as an integral part of polystyrene and solid water phantom, to measure absorbed doses in cobalt-60 gamma beam, 4 to 18 MV x-rays, and 6 to 22 MeV electron beams. Mehenna Arib^[11] reported their experience

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in performing absolute dosimetry with high-energy photon beams using a commercially available Perspex embedded EC and compared it with water measurements. If realization of the absorbed dose using these chambers is achieved from first principles, this chamber could become a departmental standard, in the absence of any traceable calibration, for the users.

In our institution we do not have a standard cobalt-60 machine for determination of $N_{d,water}$ factors for thimble chambers. There is no secondary standards laboratory in this country for traceability of our beam level dosimeters. Therefore, keeping the objective of developing our own radiation standards for the absorbed dose, with high energy photons and electrons, we investigated the role of the EC for measurement of absorbed doses, with clinical radiotherapy beams. The doses measured with the EC were then compared with those estimated for water, using TRS 398 protocols with thimble ion chambers.

Theory of Extrapolation Chambers

A brief account of the construction and working of an EC for measurement of the absorbed dose is given by Kron.^[12] The dose estimated by air cavity in a medium D_{med} (Spencer-Attix cavity relation) is given by Eq. (1).

$$D_{med} = (Q/m). W_{air}. S_{med,air} \quad (1)$$

Where Q is the charge collected under saturation condition in the chamber sensitive air mass 'm', $W_{air} = 33.97$ eV is the mean energy required to produce an ion pair in air, and $S_{med,air}$ is the ratio of the restricted collision mass stopping powers of the medium and air for the electron spectrum, at the position of the cavity. The sensitive air mass satisfies the Bragg-Gray cavity condition, which stipulates that the cavity is so small that its presence does not perturb the charged particle field in the medium.

For small air cavities, the ratio Q/m is a constant, allowing Q/m to be replaced by the easier-to-measure derivative dQ/dm . The modified Spencer-Attix relationship of the dose with the medium is given by the relation

$$D_{med} = (dQ/dm). W_{air}. S_{med,air} \quad (2)$$

For parallel plate ionization chambers with variable air volume, Eq (2) can be rewritten as

$$D_{med} = (1/\rho A). (dQ/dz). W_{air}. S_{med,air} \quad (3)$$

Where ' ρ ' is the density of air volume, A is the effective area of the measuring electrode, ' z ' is the separation between the polarizing and measuring electrodes. The perturbation caused by the air cavity in the medium is overcome by making the size infinitesimally small. This is achieved by the EC, making

it possible to accurately measure the value of dQ/dz .

Materials and Methods

Radiation beams

There are two linear accelerators in the center, Clinac 2300 CD and Clinac 600 CD (Varian, USA). The available radiation beams are 6 MV, 15 MV X-Rays, and 6, 9, 12, 15, 18, 22 MeV electrons with 1 m focus-axis-distance (FAD).

Extrapolation chamber

A Perspex embedded EC Model 23392 (Sl. No. 117, M/s PTW Freiberg, Germany) with the following specifications is used in this study (PTW Technical Documentation^[13]). Chamber entrance window - 0.0035 mm polyethylene terephthalate (PETP, Hostaphan) mylar foil. The area of the entrance window is 0.66 mg/cm². The measuring volume can be varied between 0.353 to 7.422 cm³ by moving the electrode using a piston operated by a micrometer screw. The distance between the electrodes is variable from 0.5 mm to 10.5 mm with the accuracy of parallelism being +1 μ m.

Diameters of the entrance window and the rear electrode are 60.5 mm each. The rear electrode is made up of perspex and methyl methacrylate (PMMA), with a graphite coated surface. The diameter of the measuring electrode is 30 mm. There is a guard electrode with a width of 14.8 mm and an insulating ring with a thickness of 0.2 mm and a width of 0.2 mm. The design of the chamber is such that the leakage current is $<10^{-12}$ A. For effective plate separation of 0.5 mm, the saturation effect occurs at a voltage of >50 V (99.5% saturation) for dose rates as high as 335 Gy/s. Figure 1 and Figure 2 are the schematic views of the EC and the design of the micrometer screw arrangement.

Electrometer

The chamber is connected to a Unidos electrometer (PTW, Freiburg) with dual polarity and available voltages up to 400 V, in steps of 50 V. The leakage of the ionization measurement is as low as 1 pC. The recombination correction is calculated by measurement of charges repeated with +400 V and +200 V, using the TRS 398 (IAEA)¹ protocol. For electron absorbed dose measurements, the charges are averaged for +400 V and -400 V bias voltages.

Geometry of measurement

Figure 3 shows the geometry of measurement of the absorbed dose for photon and electron beams. Figure 4 shows the end on view in the direction of the beam entrance. The chamber wall is kept at an isocenter distance of 100 cm for photons. The required thickness of 15 mm and 28 mm perspex, necessary to give the maximum buildup for a dose of 6 MV and 15 MV beams, respectively, are added on the surface level of the EC for measuring the absorbed dose/Mu for photons. For electron energies of 6 MeV and 15 MeV,

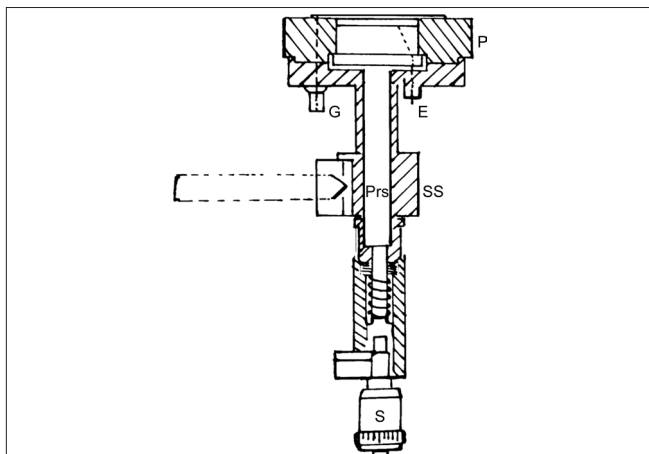


Figure 1: Schematic diagram of the extrapolation chamber (EC). G-Ground, E-Bias voltage to collecting electrode, SS-Stainless steel body, P-perspex body of EC, Pis-Piston, S-Micrometer screw



Figure 2: Micrometer design for selection of plate separation in the extrapolation chamber (EC)

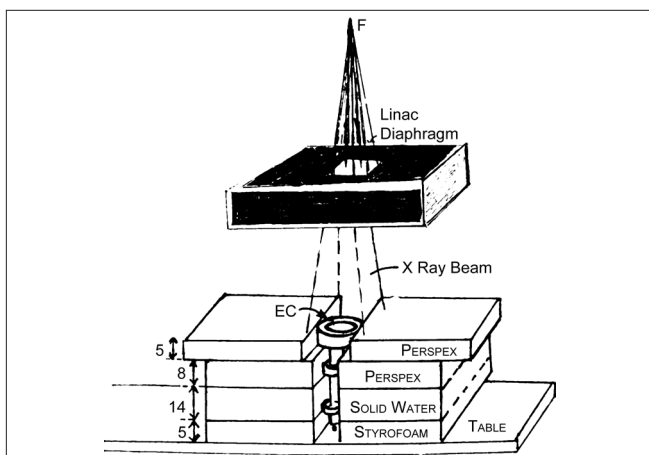


Figure 3: Geometry of calibration of the absorbed dose with extrapolation chamber

the measurements are performed at 15 mm and 35 mm buildup depths by keeping the perspex plates on the surface of the entrance window of the EC and adjusting 100 cm at the surface of the phantom. A field, 10 cm \times 10 cm, is used at the isocenter for both photon and electron beams. The plate separation is decreased progressively from 10 mm to 1.0 mm by adjusting the micrometer screw. The ionization charge is collected for 100 MU exposures. The leakage charges are measured for each setting.

The charge in nC, corresponding to 1.5 mm plate separation, is used for calculation of the absorbed dose (based on the recommendation of Zankowski and Podgorsak,^[10] suggesting 1 to 2 mm as the true Bragg-Gray region for the EC). Recombination correction is carried out by using the standard two voltage technique +400 V and +200 V. For electron beams, the charge collected for +400 V and -400 V are averaged. Measurements carried out during the period December 2006 to June 2008 have been analyzed. The calculated readings have been converted to absorbed dose in perspex by using Eq. (4). The values for $\rho = 1.293 \times 10^{-3} \text{ g/cm}^3$ at standard

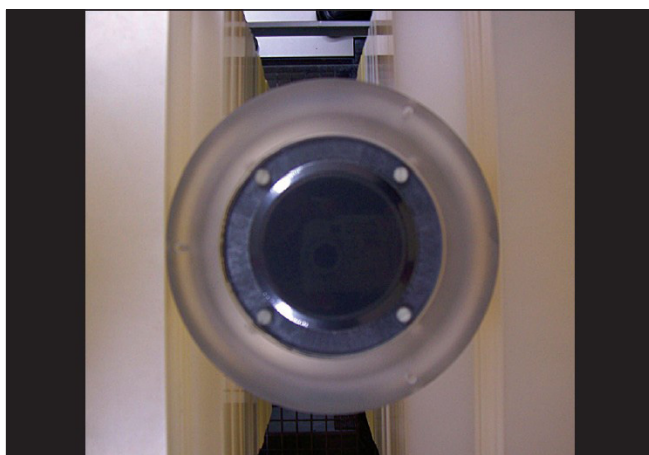


Figure 4: End on view of ion collection volume in EC. Outer perspex body (circular) and the perspex phantom underneath, during measurement, are seen in the figure

Table 1: Stopping power ratios used for absorbed dose calculations

Beam quality	Energy	$S_{\text{perspex..SW}}$	$S_{\text{SW,air}}$
X-Rays	6 MV	0.9919	1.106
electrons	15 MV	0.9914	1.071
	6 MeV	0.9900	1.075
	15 MeV	0.9900	1.013

pressure $P_0 = 1013 \text{ hPa}$, temperature $T_0 = 273.15 \text{ K}$, and $A = \pi \cdot 0.00149^2 \text{ sq.m}$, where the effective radius of the collecting volume is 14.9 mm.

$$D_{\text{perspex}} = (I/\rho A) \cdot (dQ/dz) \cdot (W)_{\text{air}} \cdot S_{\text{perspex..SW}} \cdot S_{\text{SW,air}} \quad (4)$$

Table 1 shows the values of stopping power ratios of perspex to solid water (SW) (Seuntjens *et al.*^[14]), and solid water to air (Zankowski and Podgorsak^[10]) used in Eq. (4) to derive the absorbed dose to water.

Calculation of absorbed dose from EC readings.

The absorbed dose cGy/MU is calculated using the relation

$$D_{\text{perspex}} = 33.87 \cdot (1/\rho A) \cdot (dQ/dz) \cdot S_{\text{perspex..SW}} \cdot S_{\text{SW.air}} \cdot K_s \cdot K_{\text{tp}} \quad (5)$$

For air with relative humidity of 45%, the value of W_{air} is 33.87eV and dQ/dz is obtained experimentally for each radiation beam, with appropriate buildup conditions. K_s and K_{tp} are corrections for recombinations and for air density variations with respect to standard ambient conditions (20°C and 1013 hPa). The multiplication values for obtaining absorbed dose Gy/C are constants for different radiation qualities used, and are obtained by referring to appropriate conversion factors as in Eq. (5).

Estimation of absorbed dose from thimble chambers

The reference absorbed dose data are made available by 0.6 cc (FC65) ion-chamber measurements in water, using the TRS 398 protocol in the Blue Phantom radiation field analyzer (Scanditronix Wellhofer). The ion chambers used in this study have Nd water calibration factors supplied from Scanditronix Wellhofer Laboratories (Germany). The 0.6 cc chamber is connected to Dose 1 reference standard electrometers. Absorbed doses in the water were obtained on the same day when EC measurements were carried out, to account for the corresponding radiation outputs in linear accelerators.

Results

Measured absorbed doses with EC

Figure 5 shows the representative variation of the

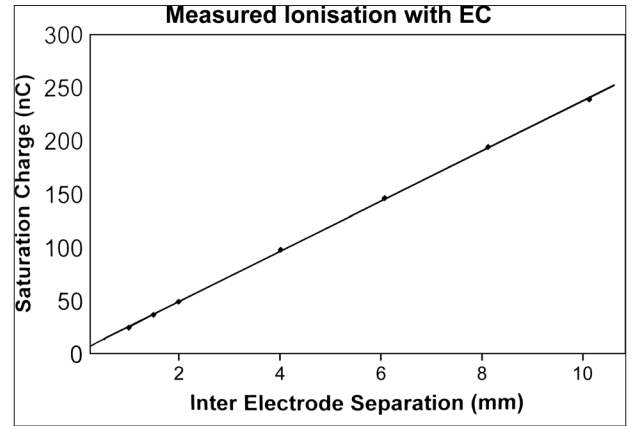


Figure 5: Variation in the uncorrected ionization charge (nC) from EC, for 6 MV x-rays, for different inter-electrode separations

collected ionization charges in nC, for various plate separations, obtained using micrometer screw adjustments. Tables 2 and 3 show the summary of results from many measurements of photon and electron beams, using the EC, obtained over a long period of time. The mean values of each plate separation, without applying other corrections, along with the standard deviations are shown. It can be seen that over a long period of time, all the measurements are within a maximum standard deviation of 2% despite variations in ambient conditions.

Table 4 shows the calculated absorbed doses in the perspex, using the EC, compared with 0.6 cc ion chamber measurements in water. All the results of the EC-estimated absorbed doses show good agreement (not exceeding 2%) with well-established thimble chamber measurements.

Discussion

The present study has outlined the efficacy of calibrating the absorbed dose in high-energy linear accelerator

Table 2: Measured uncorrected ionization charge for high-energy X-ray beams

Measured period	X-ray energy/Machine	Collected mean charge (nC/100MU) for various inter-electrode separations (mm) (micrometer settings)						
		10	8	6	4	2	1.5	1.0
Dec/06 to May/07 n = 3	6MV CLINAC 600CD	226.1±	184.0±	140.0±	94.7±	48.4±	36.7±	25.05±
		0.64%	0.57%	0.45%	0.33%	0.03%	0.64%	0.20%
Jul/07 to June/08 n = 6	6MV CLINAC 2300 CD	235.4±	191.4±	145.4±	98.5 ±	50.6±	38.4±	26.3±
		0.93%	1.05%	1.12%	1.23%	1.32%	1.42%	1.70%
Jul/07 to June/08 n = 6	15MV CLINAC 2300 CD	235.8±	193.9±	147.9±	100.5±	51.7±	39.3±	26.8±
		1.64%	1.89%	1.76%	1.86%	1.88%	1.93%	1.94%

Table 3: Measured uncorrected ionization charge for high-energy electron beams

Measured period	Electron energy/Machine	Collected mean charge (nC/100MU) for various inter-electrode separations (mm) (micrometer settings)						
		10	8	6	4	2	1.5	1.0
Jul/07 to June/08 n = 3	6MeV CLINAC 2300CD	226.2±	188.2±	145.7±	99.6±	51.0±	38.5±	26.2±
		1.15%	1.35%	1.48%	1.72%	1.82%	1.96%	1.11%
Jul/07 to June/08 n = 2	15MeV CLINAC 2300 CD	203.0±	170.2±	132.2±	90.4±	45.6±	34.3±	22.8±
		0.50%	0.61%	0.64%	0.74%	0.93%	0.76%	0.95%

Table 4: Absorbed doses measured with EC and comparison with thimble chamber data

No.	Machine and beam	FAD/FSD Buildup thickness	Calibration factor (EC) cGy/nC	Recombination corr. Ks	Temp.press. corr. Ktp	dQ/dz nC/mm	Measured absorbed dose by EC and 0.6cc chamber cGy/MU		
							EC	0.6cc	Devn. %
1	CLINAC	100 cm	4.11776	1.0045	1.015	0.2483	1.0421	1.0447	-0.25
2	600CD	FAD			1.013	0.2489	1.0428	1.0447	-0.20
3	6MV	1.5mm	4.11776	1.0045	1.016	0.2452	1.0297	1.0166	+1.3
1	CLINAC	Ppx BU			1.002	0.2608	1.0809	1.0622	+1.5
2	2300CD	100 cm			1.016	0.2570	1.0797	1.0572	+2.1
3	6MV	FAD	4.01521	1.010	1.011	0.2525	1.0554	1.0588	-0.3
4		1.5mm			1.014	0.2576	1.0765	1.0759	+0.1
5	CLINAC	Ppx BU			1.021	0.2576	1.0933	1.0730	+0.7
6	2300CD		3.99468	1.0043	1.021	0.2559	1.0805	1.0599	+1.2
1	15MV	100 cm			1.002	0.2640	1.0728	1.0652	-1.7
2		FAD	3.76468	1.0143	1.016	0.2653	1.0927	1.0768	+1.1
3	CLINAC	2.8mm			1.011	0.2555	1.0471	1.0744	+1.1
4	2300CD	Ppx BU			1.014	0.2657	1.0887	0.9909	+1.0
5	6MeV				1.021	0.2641	1.0983		
6	Electron	100 cm			1.021	0.2623	1.0858	1.0585	-0.85
1	CLINAC	FSD			1.010	0.2438	1.0345	1.0594	+0.2
2	2300CD	1.5mm			1.021	0.2408	1.0013	1.0594	-0.30
	15 MeV	Ppx BU							
	Electron	100 cm			1.011	0.2680	1.0496		
1		FSD			1.010	0.2709	1.0610		
2		3.5mm			1.021	0.2670	1.0566		
3		Ppx BU							

radiation beams using an EC. This is possible from the first principles, because of the precise definition of the circular cavity area and the separation between electrodes is known to a high resolution of (1/100)th of a millimeter. The precise estimation of the ionization gradient (dQ/dz) is possible with the design feature of a Bohm-type beta standard ionization chamber (Bohm and Schneider^[5]).

Earlier reports by Klevenhagen^[8] and Zankowski and Podgorsak^[9,10] have brought out the possibility of using such designed prototype versions of extrapolation chambers for the estimation of the absorbed dose from clinical linacs and tele-cobalt beams. These authors have used polystyrene and solid water phantoms for the construction of extrapolation chambers, and measured absorbed doses at selected depths in tissue-equivalent media. We have used the commercially available EC, in which the outer body is perspex and the inner piston is perspex, carrying an electrically conductive coating. In the above circumstances, we added the calculated stopping power ratio of perspex to solid water. Seuntjens *et al.*^[14] have extensively discussed methods to determine absorbed dose to water from solid phantom measurements. We compared various phantoms and provided correction factors for deriving absorbed doses. For beam qualities 6MV and 15 MV, the referred correction factors for stopping power ratio perspex to solid water are 0.9919 ($1.088/1.097 = 0.9919$) and 0.9914 ($1.063/1.0723 = 0.9914$), respectively. However, we have used these values to derive the absorbed dose calibration factor in Eq. (4). It can be seen that by multiplying the stopping power ratio of Perspex to solid water, then by ratio of solid water to air, we ultimately arrive at a dose to the Perspex material of the EC. Good agreement is seen with

the absorbed dose in water [Table 4]. Therefore, it appears that some discrepancies arising due to nonwater equivalence of the EC material get canceled on account of, (a) absence of scatter owing to nonexistence of phantom material under the EC body [Figure 3] or (b) due to the presence of stainless steel metallic parts of the measuring system replacing the gap between the solid measuring phantom plates.

The diameter of the measuring electrode is 30mm, the guard electrode has a 14.8mm width, an insulating ring thickness of 0.2mm, and width of 0.2mm. We have used 14.9 ($14.8 + 0.2/2$) mm for effective radius, for calculating the area (A). In a recent report^[11] have confirmed by measurements the effective diameter 30.04mm, which is in agreement with the quoted value from the technical document, from PTW-Freiburg. They have calibrated the EC to a standard cobalt-60 beam and used the EC for determination of the absorbed dose to high-energy photon beams. In our present study we have calculated the calibration factor for EC for different energies and used these factors [column 4, Table 4] to estimate the absorbed doses in high-energy beams.

The outer body surrounding the back side of the perspex piston and mounting of the micrometer screw arrangement are made of stainless steel. Its interference appears to be insignificant, though its influence on the back scatter has to be separately characterized. We feel that as the collecting volume is just below the mylar foil, the probability of backscattered photon will be insignificant. In Figure 5 the differential ionization charge has linear variation with inter-electrode distance 'z'. The earlier work by Zankowski and Podgorsak (1997), has shown that the Bragg Gray cavity

region holds good for 'z' values 1 to 2 mm. In our work also, the value of $(dQ/dz)_{1.5\text{cm}}$ has yielded a correct estimation of the absorbed doses. Moreover, it was observed from our data that substitution of dQ/dz values obtained from other plate separations underestimate the absorbed doses for all the radiation beams.

The use of the EC as radiation standards for absorbed doses, for clinical high-energy linear accelerator beams, is highly dependent upon precision machining of the chamber. In particular warping of perspex can occur over a period of time. This can significantly affect the volume and the extrapolated volume, particularly for the determination of zero volume data. The thimble chambers, generally used in the radiation physics departments, have fixed volumes, good stability, and reproducibility for a long time. In comparison, therefore, it may be necessary to have a standard graphite chamber as a parallel radiation standard to check the performance of the EC at fixed intervals.

Uncorrected ionization readings have not shown many variations on measurements carried out over many occasions, because the corrections for temperature and pressure were within 2% against a reference temperature of 20°C. In Table 4, the calibration factors for various beam qualities derived from Eq. (5) are listed for use with similar extrapolation chambers. Our initial experience with the EC shows that this will constitute one of the radiation standards in beam level dosimetry, to recognize the necessary accreditation in the area of radiological standards. The same measurements may have to be repeated in ^{60}Co beams, for confirming the application of EC for such beams. However, because of the nonavailability of ^{60}Co machines around our institution we could not perform such a study.

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References

1. International Atomic Energy Agency (2000) Absorbed dose determination in external beam radiotherapy: An international code of practice for dosimetry based on absorbed dose to water. Technical Report Series No. 398. Vienna 2000.
2. AAPM TG51. A protocol for the determination of absorbed dose from high energy photon and electron beams. *Med Phys* 1999;17:1.
3. Ding CX, Cygler JE, Kwok CB. Clinical reference dosimetry: Comparison between AAPM TG-21 and TG-51 protocols. *Med Phys* 2000;27:1217-25.
4. Saiful Huq M, Andreo P. Reference dosimetry in clinical high-energy photon beams: Comparison of the AAPM TG-51 and AAPM TG-21 dosimetry protocols. *Med Phys* 2001;28:46-54.
5. Bohm J, Schneider U. Review of extrapolation chamber measurements of beta rays and low energy x-rays. *Radiat Prot Dosim* 1986;13:193-8.
6. Failla G. Measurement of tissue dose in terms of the same unit for ionizing radiations. *Radiology* 1937;29:202-15.
7. Genna S, Laughlin JS. Absolute calibration of cobalt-60 gamma ray beam. *Radiology* 1955;65:394-405.
8. Klevenhagen SC. Determination of absorbed dose in high energy electron and photon radiation by means of an uncalibrated ionization chamber. *Phys Med Biol* 1991;36:239-53.
9. Zankowski CE, Podgorsak EB. Ionization gradient chamber in absolute photon and electron dosimetry. *Radiol Oncol (Slovenia)* 1996;30:138-41.
10. Zankowski CE, Podgorsak EB. Calibration of photon and electron beams with an extrapolation chamber. *Med Phys* 1997;24:497-503.
11. Mehenna Arib. Absolute dosimetry of high energy photon beams by means of a PMMA embedded extrapolation chamber. p. 47-48, Abstracts, International Conf. Med Phys ICMP 16th, Dubai, 2008.
12. Kron T. Dose measuring tools. In: The modern technology of radiation oncology. In: Dyk VK, Madison WI, editors. Medical Physics Publishing; 1999. p. 753-821.
13. Instruction Manual. Extrapolation Chamber according to Bohm Type 23392, D431.131.0/4, PTW Freiburg, cert. DIN EN ISO9001, DIN EN 46001.
14. Seuntjens J, Olivares M, Evans M, Podgorsak E. Absorbed dose to water reference dosimetry using solid phantoms in the context of absorbed dose protocols. *Med Phys* 2005;32:2945-53.

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