General Impact Factor (GIF): 0.875
Scientific Journal Impact Factor: 1.205
e- ISSN: 2394-5532
p- ISSN: 2394-823X
International Journal of Applied And Pure Science and Agriculture
www.ijapsa.com

A simple approach to study the performance of electron Monte Carlo algorithm in cancer treatment using medical Linear Accelerator

P. Niyas [1,2] , **KK. Abdullah**[2], **MP. Noufal** [1,2]
[1]*Department of Medical Physics, Baby Memorial Hospital,*
[2]*Department of Physics, Farook College, Calicut-673632, Kerala, India*

Abstract

Radiation therapy is a cancer treatment technique using ionizing radiations. This is possible by a medical Linear Accelerator (LINAC) along with a Treatment Planning System (TPS). Most commercial TPS incorporates complex treatment planning algorithms. The electron Monte Carlo (eMC) dose calculation algorithm of the Eclipse^{TM} TPS is based upon Monte Carlo simulation of the LINAC head and modelling of the beam characteristics. In this study, a simple and direct dosimetric method is introduced to check the performance of this algorithm for clinical use. The eMC calculated values of different dosimetric quantities such as treatment monitor units (MU), output factors (O.F) and cutout factors are compared with the measured data for available applicators, energy and selected Source to Surface Distances (SSD). Measurements were performed in Varian clinac - iX LINAC using plastic water phantom and 0.13 cm^3 ionization chamber. The cutouts, made up of an alloy cerrobend, were prepared in various sizes and shapes. Our results show that the eMC calculated relative O.F for all applicators at different SSDs agree with the measurement within 3%. A clinically acceptable variation of 3% is observed in the cutout factors for square cutouts with sizes of 4 x 4 cm^2 or larger. The comparison of irregular clinical cutouts in low and high energy beams with nominal and extended SSDs, yields that Monte Carlo calculated MU matches with corrected MU within 4%. Our results indicate that eMC algorithm shows acceptable agreement with the measured data. The implemented new method of direct measurement successfully validates the eMC for clinical use.

Keywords: Linear accelerator; electron Monte carlo (eMC); monitor units; electron cutout; out put factor.

I. Introduction

The X-ray was discovered in 1895 by a German Physicist W. C. Roentgen and radiotherapy began the year afterwards. Radiotherapy is the medical use of ionizing radiation, generally as part of cancer treatment to control or kill cancerous cells. This modality can be used either alone or in combination with surgery and/or chemotherapy. A mass of cells experiencing uncontrolled cell division is referred to as a tumour, and is cancerous when invasive to surrounding healthy normal tissues. The treatment of cancer requires destroying masses of cancer cells. Ionizing radiation produces irreparable damages and causes for killing of tumour cells. The objective of radiation therapy is to deliver a prescribed amount of ionizing radiation (or dose) to the tumour while limiting the complications of dose to surrounding normal tissues. The mostly used form of radiation in the treatment of cancer is photons and electrons of energies in the order of Million electron Volts (MeV). Usually photons are used to treat the deep seated tumors and electrons are used for peripheral lesions [1]. The planning of curative external beam radiation therapy typically begins with a Computed Tomography (CT) scan of a patient for a fixed setup. The 3-dimensional anatomical information of CT scan is then imported into a computerized Treatment Planning System (TPS) that is used to produce and calculate a deliverable treatment plan to the patient. Once a suitable plan has been determined and approved, patients are positioned appropriately at the treatment unit and the planned radiation fields are delivered.

Radiation dosimetry is the measurement and calculation of the absorbed dose in matter and tissue resulting from the exposure to ionizing radiation. This scientific subspecialty in the fields of health and medical physics is focused on the calculation of internal and external doses from ionizing radiation. Accuracy in radiotherapy is very essential. There can be many sources of errors including both random and systematic deviations in dose delivery such as in patient setup, target delineation, intra and inter fractional target movements, dose calculation and dosimetric measurements. According to International Commission on Radiation Units & Measurements (ICRU) guidelines, dosimetry systems must have the potential to deliver prescribed dose with in an accuracy of 5% [2]. The dose-response curve is quite steep and therefore even a small change in dose to the tumor volume may results in a significant change in tumour control probability [3]. Similarly, such a dose change may also results in the unacceptable normal tissue damages.

Different treatment planning algorithms are available specifically for both photons and electrons. These dose calculation algorithms are considered as the most unique, critical and complex pieces of software in the TPS. It consists of a sequence of instructions, which operate on a set of input data and transform them in to the required output results. Initially the electron beam dose calculations were done based on empirical functions that utilized ray line geometries and assumed broad beam dose distributions in homogeneous media [4]. After that, Pencil Beam algorithm is introduced with the capability of predicting the effects of contour irregularity and beam obliquity. This was based on Gaussian pencil beam distributions obtained from multiple scattering theories [5]. However both the above algorithms failed for field sizes smaller than the extent of lateral scatter equilibrium [6] because of their inefficiency to calculate the Monitor Units (MU) accurately. A more advanced Monte Carlo based algorithm, electron Monte Carlo (eMC) is available in Eclipse^{TM} treatment planning system (Varian Medical Systems, Palo Alto, CA). This eMC can produce treatment plans quickly when compared to other commercially available Monte Carlo algorithms, but with similar dose calculation accuracy. The perfection and acceptability of this algorithm have been evaluated by several groups [7-11]. In the current study we have investigated the performance of this algorithm in MU calculations of various irregular shaped electron beams used for clinical treatments. We have done this in a new approach which is simple, direct and easy to execute.

II. Materials and Methods

Varian Eclipse^{TM} eMC algorithm is a fast implementation of the Monte Carlo method for dose calculation of electron beam treatment planning [7]. The algorithm consists of 1) electron transport/dose deposition model (transport model, Macro Monte Carlo method) performs the transport and dose deposition caused by the electrons in the patient and 2) electron beam phase-space model (Initial Phase Space model, IPS) describes the electrons that emerge from the treatment head of the linear accelerator. Commissioning of an accelerator for previous electron beam calculation algorithm includes the measurement of relative output factors (O.F) for different field sizes and various Source to Surface Distances (SSD). Whereas eMC uses energy dependent dose kernel libraries of macroscopic spheres of various radii and materials, that are pre calculated with the EGS4 Monte Carlo code and therefore minimal amount of measured beam data is required for the commissioning [7].

Measurements were conducted in Varian clinac-iX Linear Accelerator (LINAC) with 120 leaf millennium MLCs (Varian Medical Systems, Palo Alto, CA). The LINAC is capable of delivering both photon and electron beams of multiple energies. Available electron energies are 6, 9, 12 and 15 MeV. Our LINAC is equipped with different electron beam applicators with sizes of 6 cm X 6cm, 10 cm X 10 cm, 15 X 15 cm, 20 cm X 20cm and 25 cm X 25 cm. An applicator is used to collimate the beam, and is attached to the treatment unit head such that the electron field is defined at a closest distance from the patient [12].The machine is calibrated for both beams using the primary calibration protocol TRS-398 [13]. The electron beam calibration was performed prior to this study so that an electron beam of 200 MU with an applicator 10 X 10 cm^2 will give an absorbed dose of 200 cGy at a depth of maximum dose (d_{max}) in water at SSD of 100 cm. This is interpreted as the reference dose rate of the machine which is equal to 1 cGy/MU. The above calibration was performed in water phantom, whereas the rest of the measurements were done in plastic water phantom [14]. An ionization chamber CC13 of volume 0.13 cm^3, a thimble chamber from IBA ((IBA Dosimetry, Schwarzenbruck, Germany), was used for the measurement. Figure 1 depicts the experimental set up of LINAC along with plastic phantom and ionization chamber.

The present work involves two different steps. The first step was to measure relative O.F for all electron energies with available applicators and three distinct SSDs of 100 cm, 105 cm and 110 cm. All the measurements were carried out in the respective d_{max} of every beam. The d_{max} of all beams were measured at the time of commissioning of the machine and the data are tabulated [Table 1].

Energy (MeV)	d_{max} (mm)
6	14.0
9	20.0
12	27.0
15	30.0

Table 1: Values of d_{max} in mm for various energies.

Relative O.F is defined as the ratio of beam output for a particular applicator to the beam output at reference applicator (10X10) measured at respective d_{max} of different energies. It depends on various beam parameters such as electron energy (E), applicator size, beam shaping inserts (cutouts) and SSD. For all electron beams the O.F are measured in plastic phantom by delivering a fixed number of MUs for different SSD. This measured relative O.F is compared with that generated in TPS by eMC algorithm. Quality Assurance (QA) plans were created in Eclipse™ TPS using plastic water phantom for all above combinations of energy, applicators and selected SSDs. Dose of 200 CGy is prescribed at d_{max} of all beams and MU values are calculated. The MU is a measure of radiation output from LINAC. A small field requires more number of MUs to get the same dose as compared to the large fields. In the electron beam dosimetry, the number of MU required to deliver a prescribed dose (D) in cGy to the calibration depth can be calculated as

$$MU = \frac{D}{(k \times O.F)} \qquad (1)$$

Where k is the reference dose rate of the linear accelerator (=1 cGy/MU) at Source Calibration Distance. From the known values of D and eMC calculated MU, relative O.F can be derived. These values are compared with the measured values.

In the second part of this study, cutout correction factors for both regular [square] and irregular shaped cutouts are measured and compared with the corresponding eMC calculated data. For this, a simple and direct relative dosimetric method is developed. A cutout is an insert made up of an alloy cerrobend which is placed on the applicator to produce customized shape for radiation beam in different clinical use (figure 2). The cerrobend is a low-temperature melting alloy containing bismuth, lead, tin, and cadmium in 50.0%, 26.7%, 13.3% and 10.0% by weight, respectively. The shielding thickness of the cutouts should he approximately equal to the maximum range of the highest electron energy beam passing through it [15]. Different square cutouts of sizes from 10X10 cm^2 to 3X3 cm^2 are prepared in the mould room of our therapy center. The irregular cutouts were obtained from 10 patients with different sites of cancer who had already completed their treatment recently. QA plans for all these cutouts are prepared in Eclipse^{TM} using eMC algorithm and the corresponding MUs are noted. The required MU can also be calculated manually by using initially measured O.F. The effect of applicator correction, not the cutout correction factor has been considered during this calculation. Now measurements are carried out by delivering above MU on the phantom using corresponding cutouts (both regular and irregular). From the measured data, the cutout correction factors can be calculated. This correction will be applied to the manually calculated MU to get the corrected MU (MU_{corr}), which is shown below in equations (4 & 5).

We have the basic equation for MU, $MU = \frac{D}{(k \times O.F)}$

Deliver this MU using treatment cutout. Suppose nC_1 is the charges collected by ionization chamber, then

$$D_{corr} \propto nC_1 \qquad (2)$$

Where D_{corr} = corrected dose.

Deliver 200 MU (= 200 cGy) at dmax of the above energy with 10X10 applicator (without cutout). Let nC_2 is the collected charges for this MU. Then

$$200 \propto nC_2 \qquad (3)$$

From equations (2) and (3)

$$D_{corr} = \frac{nC_1}{nC_2} \times 200 \qquad (4)$$

Ratio of prescribed dose, D to D_{corr} represents the fraction of MU_{corr} (due to cutout) to the initial MU.

Therefore

$$MU_{corr} = \frac{D}{D_{corr}} \times MU \qquad (5)$$

These MU_{corr} are compared with the eMC generated MUs.

Figure 2: Examples of irregular electron cutouts used for patient treatment.

Figure 1.a: Measurement set up with LINAC along with plastic water phantom

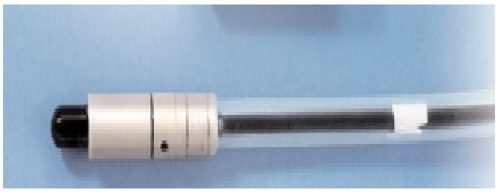

Figure 1.b: CC-13 thimble chamber used for measurement.

III. Results and Discussions

The relative O.F is measured in plastic phantom for all stated combinations of electron beam. These values along with the eMC calculated relative O.F are given in Table 2. It is observed that, the eMC generated values agree with the measurement for all energies at different SSDs. Mean and standard deviation of the ratio of O.F are 0.984±0.0175, 0.989±0.0089, 0.985±0.0077 and 0.986±0.0070 for 6, 9, 12 and 15 MeV electron beams respectively. There is a significant correlation between these two data sets, which is clearly shown in figure 3.

The detailed results of cutout factor measurements are explained in Tables 3 & 4. In the square cutouts the agreement between measurement and eMC values are better for cutout sizes of 4 x 4 cm^2 or larger. The maximum percentage of variation is 2.9%, where as for cutout of 3 x 3 cm^2 the disagreement is 4.4%. In irregular clinical electron cutouts with different energies and SSDs Monte Carlo calculated MU matches with corrected MU (actual measurement) within 4.0%. There is a discrepancy of maximum 8.0% observed for 3 cutouts. The variation of eMC generated MU from the uncorrected MU (without cutout correction) is also calculated. These observations are plotted in figure 4.

The eMC calculated O.F follows the measured O.F very well within the accuracy of 3% (mostly within 2%). The comparison of these factors with respect to SSD for all applicators does not show any trend or reproducibility (figure 5). Hence the statistical column analysis is performed using GraphPad prism (Graphpad software, *San Diego, CA, USA*, version 6.07). One way ANOVA, in which the mean of each column (Ratio of O.F for each SSD) has been compared with the mean of every other column and found that the observed variations in O.F with SSD are not statistically significant.

Our results of cutout factor measurements are well agreed with the previously published studies [9-11]. Ratio of the MUs between eMC calculated and measured represents relation of eMC generated cutout factors with measured values. Another important aspect of this study is the investigation in irregular cutouts. These clinically used cutouts for various sites (head and neck, chest wall and inguinal region) hold different sizes and shapes. The treatment MUs calculated by eMC algorithm for selected combinations of energy, applicator and SSD are found to be in reasonably good agreement with the measurement except for few. The observed variation is for three cutouts which are highly irregular, relatively smaller in size, with lower energy and of SSD =110 cm. Large discrepancies between relative cutout factors for 3×3 cm^2 or other small irregular cutouts can be influenced by measurement uncertainty or statistical variations of eMC calculations. However, because of this stochastic nature of Monte Carlo calculation it is very important to do an independent performance check of this algorithm in the respective clinical set up. The simple and direct method that we performed in our center validates eMC algorithm for clinical use.

	Energy	**ROF for 6 MeV**		**ROF for 9 MeV**		**ROF for 12 MeV**		**ROF 15 MeV**	
SSD	Applicator	eMC	Meas.	eMC	Meas.	eMC	Meas.	eMC	Meas.
100 cm	6X6	0.957	0.963	0.994	0.976	0.977	0.998	0.966	0.971
	10X10	0.973	1.000	0.973	0.985	1.000	0.985	0.985	1.000
	15X15	0.976	1.000	0.976	0.980	0.996	0.984	0.980	0.994
	20X20	0.990	1.014	0.976	0.980	0.985	0.995	0.962	0.981
	25X25	0.990	1.014	0.977	0.957	0.964	0.993	0.939	0.953
105 cm	6X6	0.858	0.842	1.019	0.870	0.867	1.003	0.866	0.866
	10X10	0.870	0.893	0.973	0.881	0.895	0.985	0.877	0.896
	15X15	0.881	0.895	0.984	0.877	0.896	0.979	0.877	0.896
	20X20	0.889	0.912	0.974	0.881	0.889	0.991	0.866	0.886
	25X25	0.886	0.913	0.970	0.855	0.870	0.982	0.851	0.861
110 cm	6X6	0.756	0.736	1.027	0.781	0.776	1.007	0.778	0.779

10X10	0.791	0.800	0.988	0.794	0.808	0.982	0.787	0.808
15X15	0.794	0.808	0.982	0.797	0.811	0.983	0.794	0.808
20X20	0.803	0.827	0.971	0.791	0.805	0.982	0.787	0.803
25X25	0.803	0.828	0.970	0.772	0.789	0.979	0.772	0.781

Table 2: Detailed comparison of eMC generated relative O.F with measured values for different energies and SSDs.

Abbreviations: ROF = relative output factor, Meas. = measured

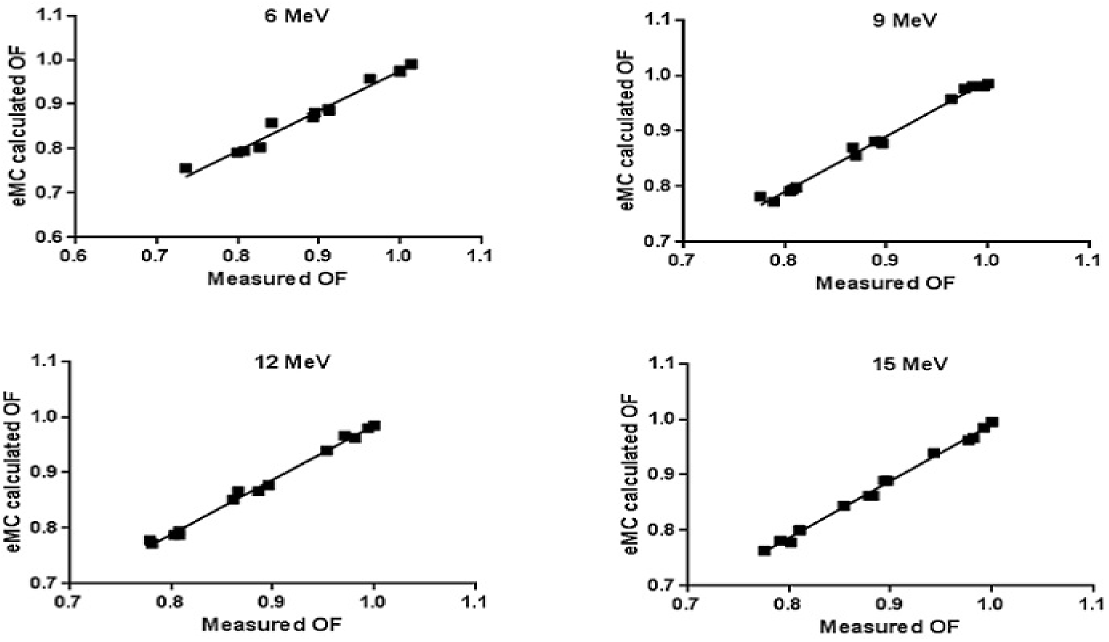

Figure 3: Better correlation is observed between eMC calculated O.F and measured data. Observations for different energies are plotted.

Applicators	**Energy (MeV)**	**SSD (cm)**	**O.F$_{meas}$**	**MU$_{calculated}$**	**Cutout size**	**MU$_{corr}$**	**MU$_{TPS}$**	**Ratio=MU$_{TPS}$ / MU$_{corr}$**
10X10	6	100	1.000	200.0	cutout 3X3	202.1	211.0	1.044
6X6	6	100	0.963	207.7	cutout 4X4	208.0	214.0	1.029
10X10	6	100	1.000	200.0	cutout 5X5	201.3	207.0	1.028
10X10	9	100	1.000	200.0	cutout 6X6	202.9	201.0	0.991
10X10	9	100	1.000	200.0	cutout 7X7	200.6	203.0	1.012
10X10	12	100	1.000	200.0	cutout 8X8	201.0	200.0	0.995
10X10	15	100	1.000	200.0	cutout 9X9	200.0	200.0	1.000
10X10	6	100	1.000	200.0	cutout 10X10	200.0	201.0	1.005

Table 3: Agreement of eMC generated correction factor with measured data for square cutouts. Ratio of MU$_{TPS}$ to MU$_{corr}$ represents the relative variation of cutout factors.

Abbreviations: O.F$_{meas}$ = initially measured O.F, MU$_{calculated}$ = manually calculated MU, MU$_{corr}$ = Corrected MU by measurement, MU$_{TPS}$ = eMC calculated MU.

Applicators	**Energy (MeV)**	**SSD (cm)**	**O.F$_{meas}$**	**MU$_{calculated}$**	**cutout shape**	**MU$_{corr}$**	**MU$_{TPS}$**	**Ratio=MU$_{TPS}$ / MU$_{corr}$**
15X15	6	100	0.999	200.2	cutout shape1	204.0	203.0	0.995
15X15	6	100	0.999	200.2	cutout shape2	200.0	204.0	1.020
15X15	12	110	0.808	618.7	cutout shape3	672.5	694.0	1.032
15X15	6	110	0.808	618.8	cutout shape4	696.5	723.0	1.038
15X15	6	100	1.000	200.0	cutout shape5	214.2	220.0	1.027
15X15	12	100	0.994	201.3	cutout shape6	217.0	212.0	0.977
10X10	9	105	0.895	223.5	cutout shape7	242.1	251	1.037
10X10	9	110	0.808	247.5	cutout shape8	269.6	285	1.057
20X20	6	110	0.827	241.8	cutout shape9	252.8	273	1.080
15X15	6	110	0.808	247.5	cutout shape10	259.3	276	1.064

Table 4: Comparison between eMC calculated treatment MU and measured data for irregular clinical electron cutouts. A sample of 10 patients cutouts of different shapes and sizes are selected for this study.

Abbreviations: O.F$_{meas}$ = initially measured O.F, MU$_{calculated}$ = manually calculated MU, MU$_{corr.}$ = Corrected MU by measurement, MU$_{TPS.}$ = eMC calculated MU.

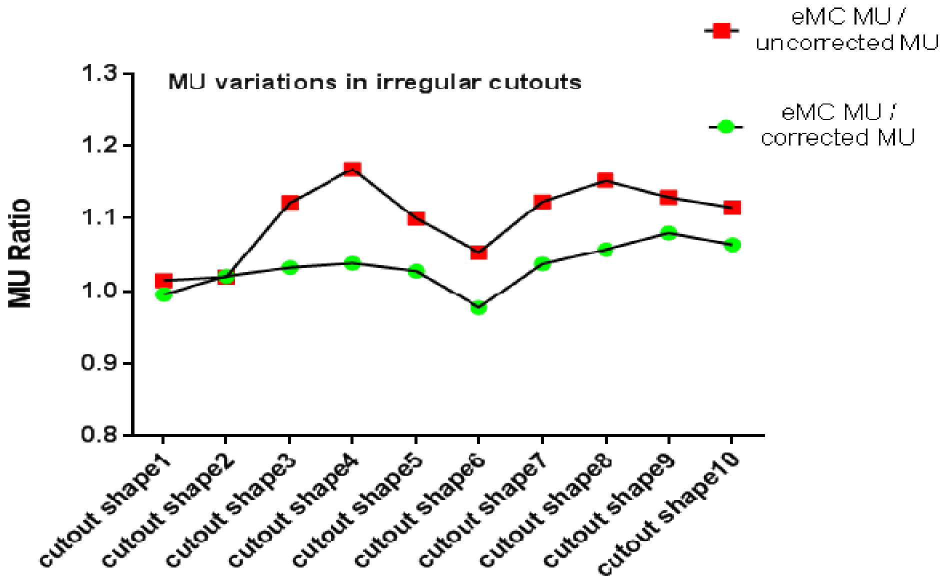

Figure 4: Ratio of MUs of eMC towards both corrected and uncorrected MU. Large variation is observed when MU is not corrected.

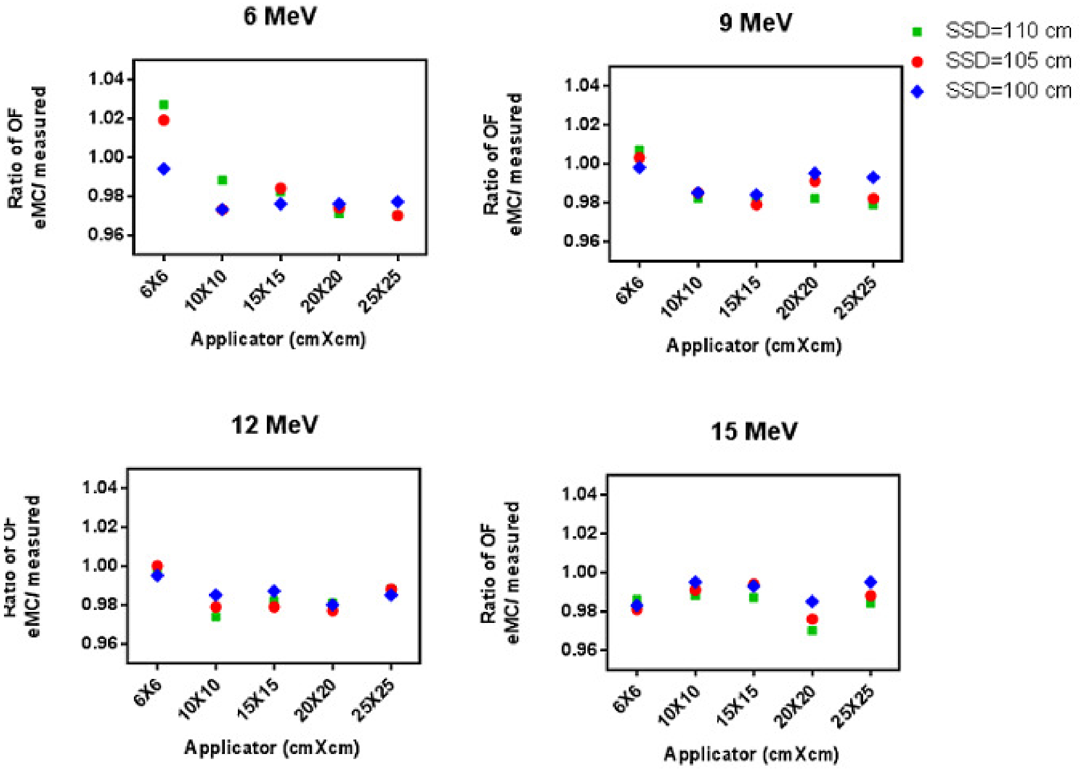

Figure 5: Comparison of relative O.F with respect to SSD. No statistical significant variations have been observed.

IV. Conclusion

Our new approach with simple and direct measurement results good performance of electron Monte Carlo algorithm in Eclipse^{TM} TPS. The results of comparison of relative output factor and cutout factor are appreciable with the given measuring system. For smaller and irregular cut outs, the noticed discrepancy is consistent with the published data. In conclusion, the observed agreement of eMC with the measurement in different scenario validates it's clinical use.

Bibliography

[1] Olsson, Marie-Louise. 2003. Monte Carlo simulations of the Elekta SLi Plus electron applicator system A base for a new applicator design to reduce radiation leakage.
[2] International Commission on Radiation Units and Measurements. Report 24. Determination of Absorbed Dose in a Patient Irradiated by Beams of X and Gamma-ray Beams in Radiotherapy Procedures, ICRU publication, Bethesda, USA 1976.
[3] Mijnheer, B. J., J. J. Battermann, and A. Wambersie.1987. What degree of accuracy is required and can be achieved in photon and neutron therapy? Radiotherapy and Oncology, 8.3: 237-252.
[4] Sternick E. 1977. Algorithms for computerized treatment planning. In: Orton CG, Baagne F, editors. Practical aspects of electron beam treatment planning: Proceedings of the Practical Aspects of Electron Beam Treatment Planning Symposium. Cincinnati, Ohio. New York: American Institute of Physics; p. 52.
[5] Hogstrom KR, Starkschall G, Shiu AS. 1992. Dose calculation algorithms for electron beams. In: Purdy JA, editor. Advances in radiation oncology physics: Dosimetry, Treatment Planning and Brachytherapy. American Institute of Physics Monograph 19. New York: American Institute of Physics:p. 900.
[6] Lax I, Brahme A. 1980. Collimation of high energy electron beams. Acta Radiol Oncol., 19(3):199–207.
[7] Neuenschwander H, Mackie TR, Reckwerdt PJ. 1995. MMC-a high-performance Monte Carlo code for electron beam treatment planning. Phys Med Biol.,40(4):543–74.
[8] Ding GX, Duggan DM, Coffey CW, Shokrani P, Cygler JE. 2006. First macro Monte Carlo based commercial dose calculation module for electron beam treatment planning – new issues for clinical consideration. Phys Med Biol.,51(11):2781–99.
[9] Popple RA, Weinber R, Antolak JA, et al. 2006. Comprehensive evaluation of a commercial macro Monte Carlo electron dose calculation implementation using a standard verification data set. Med Phys., 33(6):1540–51.
[10] Hu, Angie, et al. 2008. Evaluation of an electron Monte Carlo dose calculation algorithm for electron beam. Journal of Applied Clinical Medical Physics 9.3.
[11] Xu, Zhigang, et al. 2009. Evaluation of the eclipse electron Monte Carlo dose calculation for small fields. Journal of Applied Clinical Medical Physics 10.3.
[12] Strydom, W. Y. N. A. N. D., W. I. L. L. I. A. M. Parker, and M. A. R. I. N. A. Olivares. 2005. Electron beams: physical and clinical aspects. Podgorsak EB (edn) Radiation oncology physics: a handbook for teachers and students. International Atomic Energy Agency (IAEA), Vienna : 273-299.
[13] AC03205248, Anonymus, ed.2000. Absorbed dose determination in external beam radiotherapy: an international code of practice for dosimetry based on standards of absorbed dose to water. Internat. Atomic Energy Agency.
[14] McEwen, M. R., and D. Niven. 2006. Characterization of the phantom material Virtual Water™ in high-energy photon and electron beams. Medical physics, 33.4 : 876-887.
[15] Griffin, Jonathan Alexander. 2006. Radiation Dosimetry of Irregularly Shaped Objects.