Research Article

# Commissioning and validation of the electron Monte Carlo dose calculation at extended source to surface distance from a medical linear accelerator

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## Abstract

**Introduction:** Radiotherapy is one of the major modality for cancer management playing curative, adjuvant, and palliative and sometimes has an alternative role to chemotherapy. Radiotherapy is practiced in two ways viz. External beam therapy and Brachytherapy. Electron beam therapy is widely used in the management of cancers. An electron beam is characterized by a finite range of penetration with a rapid dose fall off towards a slowly decaying x-ray background as the electrons traverse through tissues. The electron monte carlo (eMC) dose calculation algorithm for eclipse treatment system has been introduced by Varian Medical systems. The algorithm is commissioned and validated by comparing percentage depth dose (PDD) and gamma index. **Methods:** Percentage depth dose curves were generated for all the energies for 4x4 $cm^2$ and 10x10 $cm^2$ field sizes. The depth of maximum dose ($R_{100}$), therapeutic depth ($R_{85}$), depth of 50% isodose ($R_{50}$) and the relative surface ($D_s$) were compared with the measured and calculated PDD curves. **Results:** The eMC calculated fluence and measured fluence were compared for all the energies and cones at nominal source to surface distance and extended distances. For 4x4 $cm^2$ field size the maximum shift in $R_{100}$ was 5 mm, $R_{85}$ was 1.9 mm, $R_{50}$ was 0.9 mm and the variation in the relative surface ($D_S$) was about 25Gamma analysis shows excellent agreements with greater than 98% of the pixels passing the gamma requirements. **Conclusion:** We have successfully commissioned and validated the electron monte carlo dose calculation at extended source to surface distance.

**Key words:** Eclipse, Electron Monte Carlo, Fluence, Gamma value.

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## Introduction

Radiotherapy, is one of the principal modalities used in the treatment of cancer, the other two being surgery and chemotherapy. For over 50 years, electron beam therapy has been an important radiation therapy modality in the management of cancers. This broad acceptance is attributed in part to the unique characteristics and the easy accessibility of electron beams to practitioners. Electron beams are produced from the linear accelerators that can be found in most radiation oncology centers. In certain clinical situations, electron beam treatments are performed at extended source to surface distance (SSD 100 – 120 cm) due to the limitation of the electron collimator/cone and the site of treatment. Additionally sometimes a larger field size or increased penumbra may be needed for a particular radiation treatment. Sites such as head and neck, vulva and groin and breast may require extended distances for electron beam treatments as body anatomy may obstruct the positioning of the electron applicator. Dosimetry and beam characteristics at extended SSDs and small field sizes are dependent on the collimator/cone design, mode of electron production and beam energy.

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Electron beam treatments are carried out not only at nominal source to surface distance (SSD=100 Cm) but also at the extended SSDs. Most of the planning systems use empirical methods and pencil beam algorithms which has limitations in predicting the percentage depth dose and optimum fluence at extended SSDs. The electron monte carlo (eMC) dose calculation algorithm is available in the Varian eclipse treatment planning system. The algorithm consists of

1) Electron transport/dose deposition model (transport model, macro monte carlo method [1]) performing the transport and dose deposition caused by the electron in the patient.

2) Electron beam phase-space model (Initial Phase model, IPS) describing the electrons that emerge from the treatment head of the linear accelerator.

The eMC has six user selectable parameters for individual calculations: calculation grid size, accuracy, maximum number of particle histories, random number generator seed, smoothing method and smoothing level [2]. To attain accurate calculations and consistency within a reasonable amount of time, the calculation used in the study are done with 2.5 mm calculation grid size, 3D Gaussian smoothing method and medium level smoothing.

The accuracy of implementation of this algorithm was investigated by several groups [1-4]. The beam data required for commissioning of this algorithm has been measured and the dosimetric quantities were validated by comparing the PDDs, absolute dose and gamma index for nominal and extended SSDs.

## Materials and Methods

### a) Configuration of the eMC Algorithm:

The following beam data measurements for the full open field and energy/applicator combination were carried out to configure the eMC algorithm [5]

1)Percentage depth dose curve in air at source to phantom distance (SPD=100 cm) for each energy, without an applicator, collimator jaws wide open (40x40 $cm^2$).

2)Beam profile in air at 95 cm source to detector distance (SDD) for all the energies (normalized to 1).

3)Percentage depth dose curve in water at source to phantom distance (SPD=100 cm) for each energy, with an applicator.

4)Absolute dose in water expressed in (cGy/MU) at the calibration point in the depth dose curve (measured at reference depth).

These measured data's were converted in to w2cad file and then imported into the eclipse beam configuration task. The eMC algorithm generates a calculated depth dose curve taking this input data.

### b) Validation

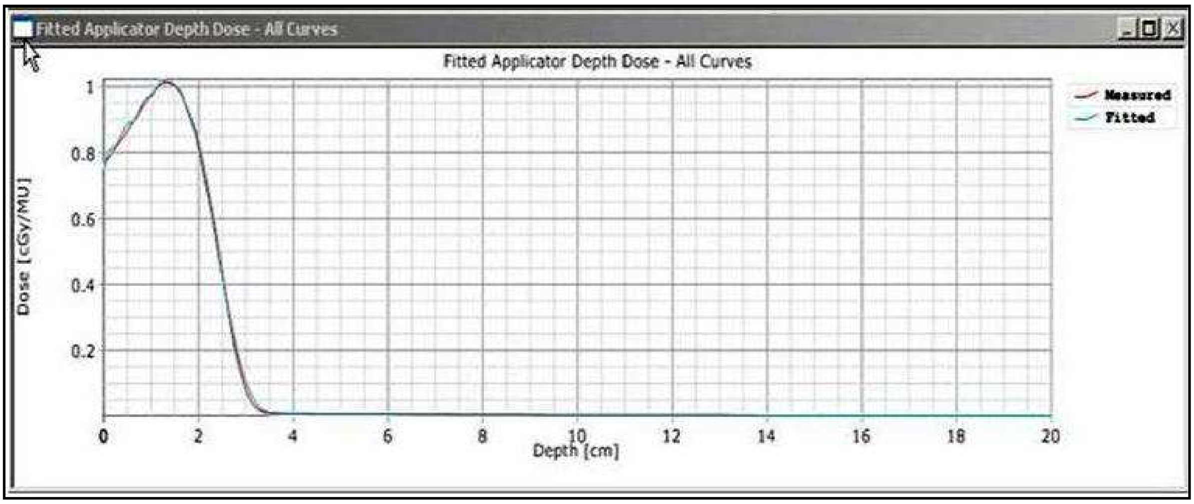
A water equivalent phantom was created in eclipse treatment planning system. The following measurements were made to evaluate the Varian eclipse electron monte Carlo (eMC) algorithm performance. Depth dose curves were generated for all the energies (6, 9, 12, 16 and 20 MeV) at 100, 102, 106 and 110 cm SSD's for 4x4 $cm^2$ and 10x10 $cm^2$ field sizes. Similarly isodose distributions were generated for all the energies at 100, 102, 106 and 110 cm SSD's for 4x4 $cm^2$, 6x6 $cm^2$, 10x10 $cm^2$, 15x15 $cm^2$ and 20x20 $cm^2$ field sizes and for a irregular cut-out (6.5x9 $cm^2$ used for patient treatment). The measurements were done with the Clinac 2100 - DHX linear accelerator (Varian Medical Systems Palo Alto, CA). The PDD curves were measured using a scanning water tank system (RFA 300, Scanditronix Medical AB with Omni Pro 6 software). Initial eMC plans were created in eclipse for each cone size and energy combination without normalization point. Dose maximum values were determined in these plans by using Eclipse vertical dose profile tool along the central axis. The plans were normalized to 100% at their respective $d_{max}$ for analysis. The depth of maximum dose ($R_{100}$), therapeutic depth ($R_{85}$), depth of 50% isodose ($R_{50}$) and the relative surface ($D_s$) were taken from the measured and calculated PDD curves. The accuracy of the dose calculation is evaluated by prescribing a known dose of 100 cGy at various SSDs. The plan was exported to the machine and dose was measured using Parallel plate chamber (NACP) using water phantom at the $d_{max}$. Using TRS 398 protocol [6] the dose was calculated and compared. The isodose distribution calculated by the treatment planning system (TPS) using eMC algorithm perpendicular to the beam central axis were normalized to the half the therapeutic depth ($R_{85}$) taken from the PDD curve. The isodose perpendicular to the beam central axis was measured using I'matriXX device (Scanditronix Wellhofer, Germany) and normalized similar to that of calculated. The planned isodose were transferred to the Omnipro I'matriXX software and compared with the measured isodose. Dose comparison tools such as gamma dose distribution and distance to agreement (DTA) have been used in the analysis [7, 8]. The acceptable gamma pixel parameters were set to 3% dose and 3 mm distance-to agreement. The eMC calculated fluence and measured fluence were compared for all the energies and all the cones at nominal distance (SSD=100 cm) and extended distances (102, 106, and 110 cm). Based on the fluence comparison the gamma values were estimated by the Omnipro I'matriXX software.

## Results

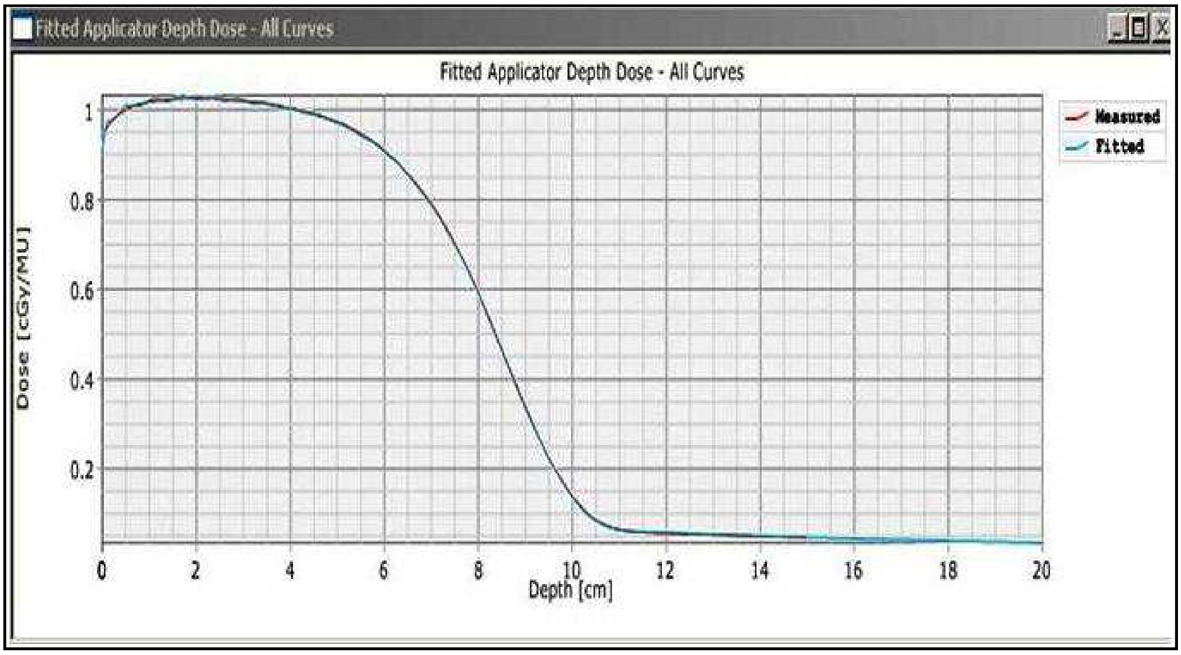
Figure 1 show the fitted PDD curves for a 10x10 $cm^2$ field size for 6 and 20 MeV electron beam at 100 cm SSD. The fitted PDD curve is the PDD measured using water phantom and the eMC generated PDD curve. Table 1 shows the comparison between the calculated and measured percentage depth dose data for electron beams of energy 6, 9, 12, 16 and 20 MeV for 4x4 $cm^2$ cone at nominal and extended SSDs. Table 2 shows the comparison for 10x10 $cm^2$ cone at nominal and extended SSDs.

**Table 1: Measured and eMC calculated PDD data comparison for 4x4 $cm^2$ cone.**

| Energy MeV | SSD cm | Measured | | | | eMC calculated | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | R100 cm | R85 cm | R50 cm | Ds % | R100 cm | R85 cm | R50 cm | Ds % |
| 6 | 100 | 1.4 | 1.98 | 2.49 | 75.8 | 1.3 | 1.93 | 2.45 | 59.7 |
| | 102 | 1.4 | 1.96 | 2.44 | 76.3 | 1.3 | 1.94 | 2.48 | 57.1 |
| | 106 | 1.4 | 1.91 | 2.40 | 77.6 | 1.3 | 1.88 | 2.42 | 65.1 |
| | 110 | 1.4 | 1.95 | 2.45 | 78.1 | 1.2 | 1.80 | 2.35 | 76.1 |
| 9 | 100 | 2.0 | 2.92 | 3.62 | 82.9 | 2.0 | 2.88 | 3.61 | 74.9 |
| | 102 | 2.0 | 2.87 | 3.58 | 83.4 | 2.0 | 2.86 | 3.61 | 70.4 |
| | 106 | 2.0 | 2.93 | 3.66 | 83.3 | 1.9 | 2.87 | 3.59 | 73.8 |
| | 110 | 2.1 | 2.94 | 3.66 | 83.6 | 2.0 | 2.87 | 3.58 | 70.0 |
| 12 | 100 | 2.3 | 3.76 | 4.89 | 88.9 | 2.0 | 3.76 | 4.89 | 77.1 |
| | 102 | 2.3 | 3.77 | 4.90 | 88.6 | 2.0 | 3.80 | 4.93 | 74.4 |
| | 106 | 2.3 | 3.86 | 4.95 | 87.8 | 2.0 | 3.85 | 4.98 | 69.4 |
| | 110 | 2.3 | 3.90 | 4.97 | 87.2 | 2.2 | 3.76 | 4.88 | 81.6 |
| 16 | 100 | 2.1 | 4.47 | 6.10 | 91.9 | 2.2 | 4.49 | 6.18 | 82.5 |
| | 102 | 2.1 | 4.52 | 6.15 | 91.4 | 2.3 | 4.53 | 6.20 | 81.9 |
| | 106 | 2.4 | 4.59 | 6.26 | 90.1 | 2.5 | 4.57 | 6.29 | 80.5 |
| | 110 | 2.3 | 4.62 | 6.32 | 89.4 | 2.8 | 4.62 | 6.25 | 84.9 |
| 20 | 100 | 1.6 | 5.04 | 7.29 | 93.2 | 1.5 | 5.08 | 7.31 | 91.2 |
| | 102 | 1.9 | 5.13 | 7.35 | 92.2 | 1.8 | 5.32 | 7.45 | 85.4 |
| | 106 | 2.2 | 5.26 | 7.53 | 90.6 | 1.8 | 5.24 | 7.53 | 93.5 |
| | 110 | 2.1 | 5.39 | 7.49 | 90.2 | 1.7 | 5.33 | 7.58 | 89.4 |




**(a)**




**(b)**

**Figure-1: Measured and eMC calculated PDD curves for 10x10 cm$^2$ at 100 SSD for a) 6 MeV and b) 20 MeV electron beams**

**Table 2: Measured and eMC calculated PDD data comparison for 10x10 cm$^2$ cone**

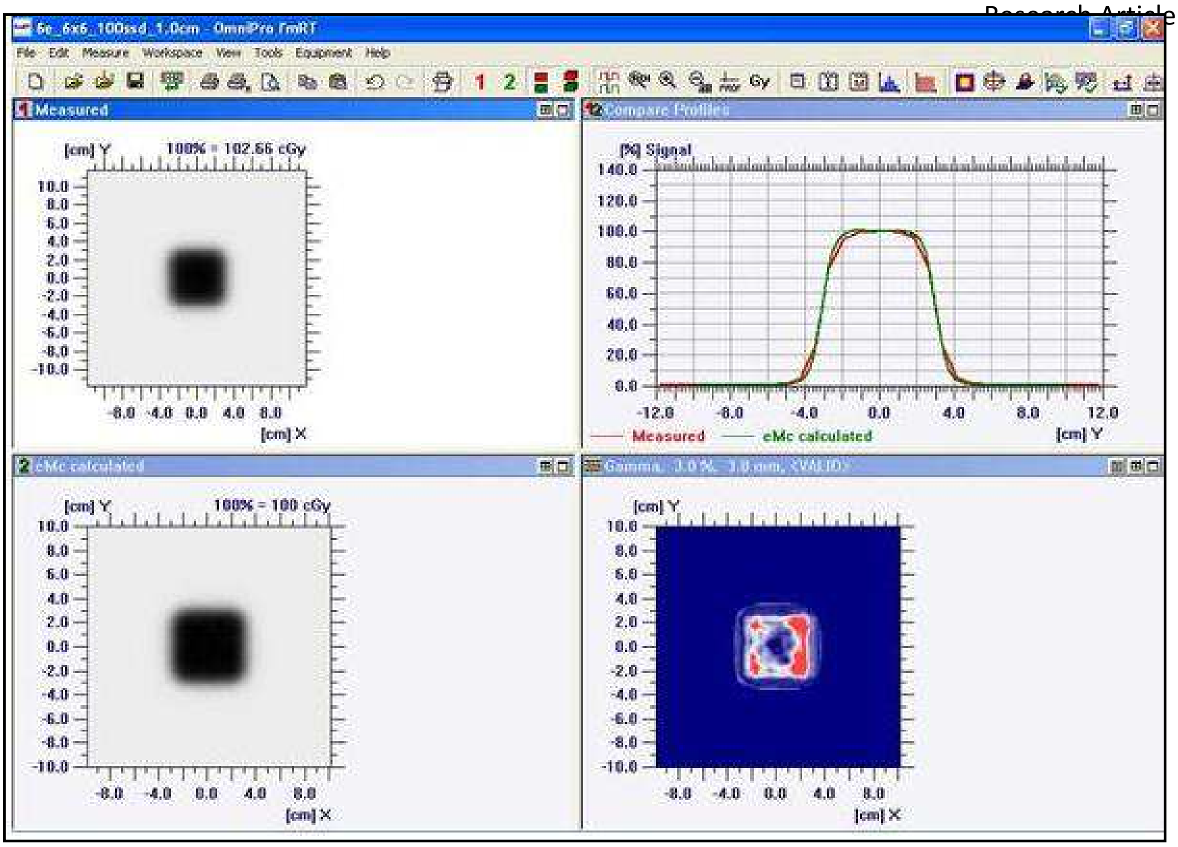
| Energy MeV | SSD cm | Measured | | | | eMC calculated | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | R100 cm | R85 cm | R50 cm | Ds % | R100 cm | R85 cm | R50 cm | Ds % |
| 6 | 100 | 1.3 | 1.94 | 2.42 | 76.2 | 1.2 | 1.92 | 2.45 | 63.9 |
| | 102 | 1.4 | 2.00 | 2.46 | 75.2 | 1.3 | 1.88 | 2.42 | 68.4 |
| | 106 | 1.4 | 1.95 | 2.41 | 75.0 | 1.2 | 1.92 | 2.45 | 63.8 |
| | 110 | 1.4 | 2.00 | 2.46 | 74.2 | 1.3 | 1.95 | 2.46 | 59.3 |
| 9 | 100 | 2.2 | 3.01 | 3.70 | 80.5 | 2.2 | 2.95 | 3.68 | 64.3 |
| | 102 | 2.2 | 2.99 | 3.65 | 79.9 | 2.2 | 2.99 | 3.66 | 72.3 |
| | 106 | 2.2 | 3.00 | 3.68 | 79.5 | 2.2 | 3.01 | 3.69 | 71.3 |
| | 110 | 2.2 | 3.05 | 3.72 | 78.4 | 2.2 | 2.99 | 3.68 | 68.3 |
| 12 | 100 | 2.9 | 4.13 | 5.04 | 86.2 | 3.0 | 4.11 | 5.05 | 71.6 |
| | 102 | 3.0 | 4.19 | 5.08 | 85.2 | 3.0 | 4.18 | 5.08 | 71.7 |
| | 106 | 2.9 | 4.18 | 5.08 | 84.3 | 2.7 | 4.14 | 5.05 | 73.1 |
| | 110 | 3.1 | 4.23 | 5.09 | 83.0 | 2.8 | 4.10 | 5.06 | 76.8 |
| 16 | 100 | 3.0 | 5.38 | 6.61 | 91.2 | 2.0 | 5.25 | 6.60 | 81.3 |
| | 102 | 3.3 | 5.42 | 6.69 | 90.0 | 2.6 | 5.28 | 6.58 | 88.1 |
| | 106 | 2.7 | 5.46 | 6.67 | 90.7 | 2.6 | 5.32 | 6.58 | 85.9 |
| | 110 | 2.9 | 5.52 | 6.72 | 89.2 | 2.5 | 5.30 | 6.61 | 86.4 |
| 20 | 100 | 2.0 | 6.35 | 8.29 | 92.8 | 3.2 | 6.31 | 8.26 | 88.6 |
| | 102 | 2.4 | 6.49 | 8.36 | 91.8 | 1.8 | 6.41 | 8.31 | 89.3 |
| | 106 | 2.7 | 6.55 | 8.40 | 89.9 | 2.8 | 6.38 | 8.29 | 80.0 |
| | 110 | 2.9 | 6.60 | 8.42 | 89.9 | 2.0 | 6.49 | 8.35 | 86.7 |

**Table 3: Absolute dose differences between measured and eMC calculated for various field sizes and energies at nominal and extended SSDs**

| Energy MeV | SSD Cm | 4x4 $cm^2$, % | 6x6 $cm^2$, % | 10x10 $cm^2$, % | 15x15 $cm^2$, % | 20x20 $cm^2$, % | 6.5x9.0 $cm^2$, % |
|---|---|---|---|---|---|---|---|
| 6 | 100 | 1.5 | 4.5 | 3.4 | 3.4 | 3.5 | 4.0 |
| | 102 | 0.3 | 2.8 | 2.7 | 3.0 | 3.2 | 2.0 |
| | 106 | 2.3 | 0 | 2.8 | 2.6 | 3.0 | 1.0 |
| | 110 | 4.2 | 1.7 | 2.6 | 2.4 | 3.0 | 1.0 |
| 9 | 100 | 1.9 | 0.8 | 1.4 | 0.4 | 0.4 | 1.0 |
| | 102 | 2.4 | 0.2 | 1.0 | 0.4 | 2.4 | 1.0 |
| | 106 | 2.9 | 1.7 | 0.8 | 1.1 | 3.0 | 1.0 |
| | 110 | 4.3 | 3.3 | 1.5 | 3.8 | 4.0 | 1.0 |
| 12 | 100 | 2.9 | 0.4 | 0 | 0 | 1.0 | 3.0 |
| | 102 | 2.1 | 1.6 | 2.8 | 0.8 | 2.0 | 3.0 |
| | 106 | 1.2 | 2.5 | 2.0 | 1.3 | 2.0 | 4.0 |
| | 110 | 1.3 | 3.3 | 2.3 | 1.4 | 3.0 | 4.0 |
| 16 | 100 | 4.2 | 0.4 | 3.9 | 3.1 | 3.0 | 4.0 |
| | 102 | 4.4 | 1.6 | 2.6 | 3.7 | 4.0 | 3.0 |
| | 106 | 2.2 | 2.5 | 2.4 | 3.6 | 4.0 | 4.0 |
| | 110 | 2.9 | 3.3 | 2.6 | 4.4 | 4.0 | 4.0 |
| 20 | 100 | 7.6 | 4.2 | 7.0 | 2.5 | 7.0 | 8.0 |
| | 102 | 8.4 | 3.4 | 7.6 | 5.4 | 7.0 | 10. |
| | 106 | 6.2 | 5.0 | 5.9 | 7.2 | 8.0 | 6.0 |
| | 110 | 1.2 | 3.9 | 6.7 | 6.5 | 2.0 | 5.0 |

**Table 4: Gamma value for various field sizes and energies at nominal and extended SSDs**

| Energy | SSD | 4x4 $cm^2$ | 6x6 $cm^2$ | 10x10 $cm^2$ | 15x15 $cm^2$ | 20x20 $cm^2$ | 6.5x9.0 $cm^2$ |
|---|---|---|---|---|---|---|---|
| **6** | 100 | 99.75 | 98.11 | 99.11 | 98.80 | 92.98 | 99.84 |
| | 102 | 99.65 | 100.0 | 98.86 | 98.97 | 99.67 | 99.98 |
| | 106 | 100.0 | 99.85 | 92.64 | 95.16 | 99.21 | 99.94 |
| | 110 | 99.88 | 99.75 | 97.88 | 98.56 | 99.88 | 99.96 |
| **9** | 100 | 99.67 | 99.23 | 95.12 | 99.98 | 99.93 | 99.86 |
| | 102 | 99.14 | 98.76 | 99.78 | 100 | 99.88 | 99.94 |
| | 106 | 99.49 | 99.70 | 96.76 | 99.97 | 99.96 | 99.94 |
| | 110 | 99.40 | 99.30 | 98.60 | 99.95 | 99.99 | 99.90 |
| **12** | 100 | 99.93 | 99.80 | 99.17 | 99.61 | 99.95 | 99.95 |
| | 102 | 99.50 | 99.85 | 99.90 | 99.84 | 99.95 | 99.98 |
| | 106 | 99.68 | 98.71 | 97.43 | 99.79 | 99.89 | 99.98 |
| | 110 | 99.68 | 99.89 | 99.57 | 99.97 | 99.95 | 99.98 |
| **16** | 100 | 99.93 | 99.85 | 95.04 | 99.89 | 99.95 | 99.95 |
| | 102 | 99.31 | 99.97 | 99.98 | 99.88 | 99.89 | 99.99 |
| | 106 | 99.68 | 98.81 | 99.45 | 99.98 | 99.86 | 99.97 |
| | 110 | 99.51 | 99.35 | 99.06 | 99.88 | 99.96 | 99.97 |
| **20** | 100 | 99.19 | 99.70 | 99.82 | 99.70 | 99.92 | 99.92 |
| | 102 | 98.90 | 99.30 | 99.97 | 99.92 | 99.82 | 99.77 |
| | 106 | 99.49 | 99.97 | 99.42 | 99.99 | 99.99 | 99.95 |
| | 110 | 99.30 | 99.87 | 99.88 | 99.78 | 99.83 | 99.99 |

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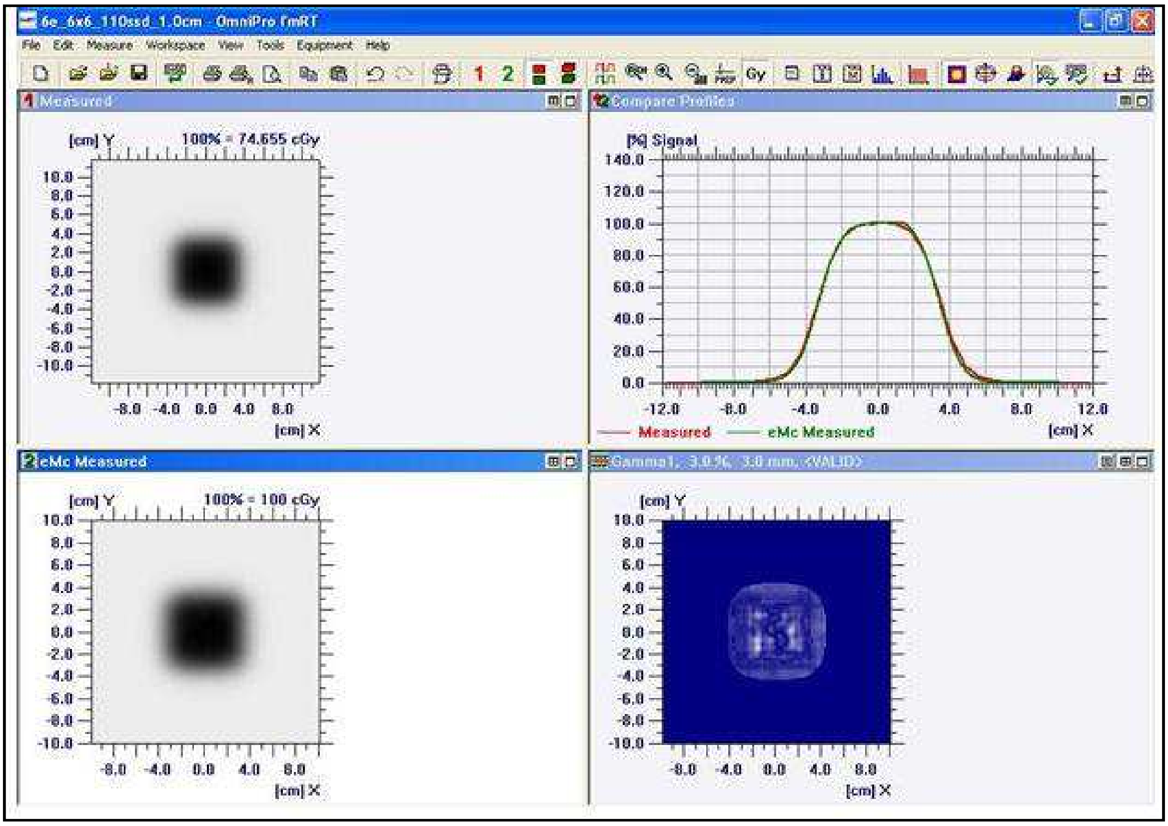
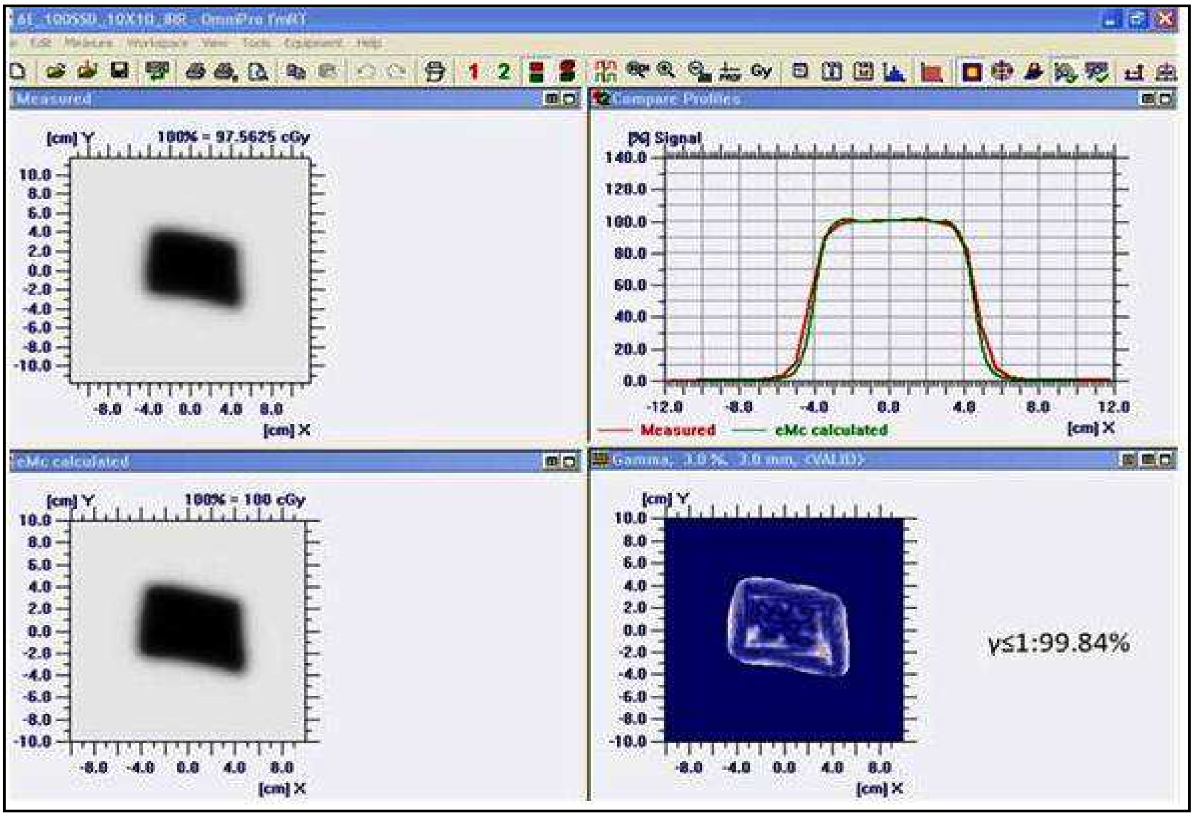
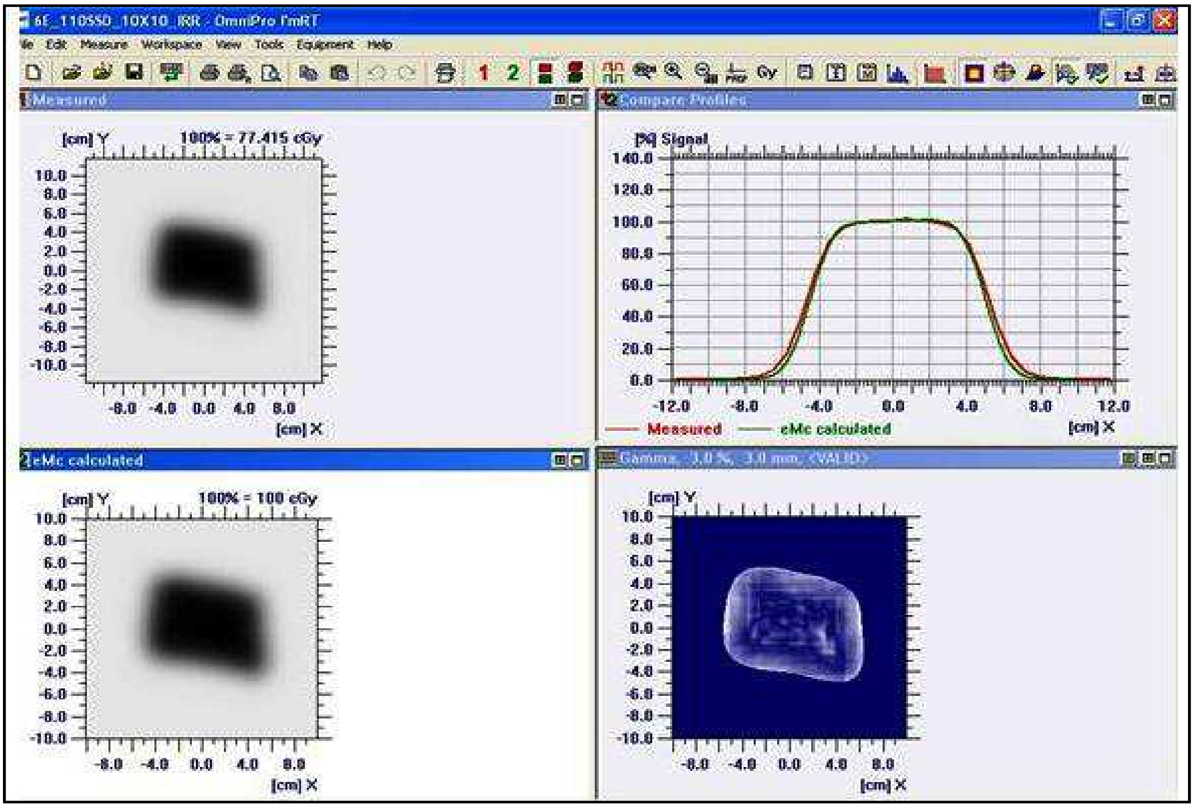



**(b)**

**Figure-2: Comparison of measured and calculated fluence for 10x10 $cm^2$ regular field size at a) 100 SSD b) 110 SSD**




(a)




(b)

**Figure-3: Comparison of measured and calculated fluence for 6.5x 9 $cm^2$ irregular field size at a) 100 SSD b) 110 SSD**

The eMC plans display surface dose by interpolating the dose at the first grid point inside the phantom and the first grid point outside the phantom, resulting in the surface under dose. Since for higher energies the maximum dose peak was broad there was a maximum of 10 and 12 mm shift observed with 16 and 20 MeV for 10x10 $cm^2$ field size. Table 3 shows the comparison of prescribed dose and the measured dose for all the electron energies and for all the cone sizes at nominal and extended SSDs. The agreement of dose was within 5% for 6, 9, 12 and 16 MeV for all field sizes. But for 20 MeV it has gone up to 8%. This was in agreement with the findings reported by Ding et al [4]. Figure 2 shows the gamma analysis for measured and eMC calculated fluence for a regular field (10x10 $cm^2$) at 100 and 110 cm SSD. Figure 3 shows the gamma analysis for the measured and eMC calculated isodose for an irregular field (6.5x9 $cm^2$) at 100 and 110 cm SSD. Table 4 shows the gamma values for 4x4 $cm^2$, 6x6 $cm^2$, 10x10 $cm^2$, 15x15 $cm^2$, 20x20 $cm^2$ and for irregular field size 6.5x9 $cm^2$ (used for patient treatment).

## Discussion

Based on our results in Table 1 and 2 , For 4x4 $cm^2$ field size the maximum shift in $R_{100}$ was 5 mm, $R_{85}$ was 1.9 mm, $R_{50}$ was 0.9 mm and the variation in the relative surface ($D_S$) was about 25%. For 10x10 $cm^2$ field size the maximum shift in $R_{100}$ was 12 mm, $R_{85}$ was 2.2 mm, $R_{50}$ was 1.1 mm and the variation in the relative surface ($D_S$) was about 20%. The plot of PDD from eMC plans overlaid with those of the measurements show good agreements except for the first 1 to 2 mm of the surface.

In a similar study by Xu et al [3] they have compared eMC calculations and measurements of depth doses, isodose distributions, and monitor units for several different energy and small field cutout size combinations at different SSDs. Their results indicate that the eMC algorithm can accurately predict depth doses, isodose distributions, and monitor units (within 2.5%) for field sizes as small as 3.0 cm diameter for energies in the 6 to 20 MeV range at 100 cm SSD. Their results were in consistent with the recommendation of Popple et al [9].

Yang et al. [10] have commissioned electron Monte Carlo (eMC) algorithm in Eclipse Treatment Planning System (TPS) for TrueBeam Linacs, including the evaluation of dose calculation accuracy for small fields and oblique beams and comparison with the existing eMC model for Clinacs. Pemler et al. [11] have evaluated the commercial electron beam treatment planning system on the basis of a Monte Carlo algorithm (Varian Eclipse, eMC V7.2.35). They have Measured dose distributions were used for comparison with dose distributions predicted by eMC calculations and the tests were carried out for various applicators and field sizes, irregular shaped cut outs and an inhomogeneity phantom for energies between 6 Me V and 22 MeV Monitor units were calculated for all applicator/energy combinations and field sizes down to 3 cm diameter and source-to-surface distances of 100 cm and 110 cm.

Ya et al [12] Commissioned the eMC algorithm on multiple identical linacs provided a unique opportunity to systematically evaluate the algorithm with actual measurements of clinically relevant beam and dose parameters. They have measured and eMC calculated dose distributions were compared both along and perpendicular to electron beam direction for electron energy/applicator/depth combination using measurement data from four Varian 21EX CLINAC linear accelerator and their results indicate that eMC algorithm in Eclipse provides acceptable agreement with measurement data for most clinical situations. The gamma analysis results show excellent agreements with greater than 98% of the pixels passing the gamma requirements.

Chamberland et al. [13] studied the accuracy of the electron Monte Carlo (eMC) dose calculation algorithm included in a commercial treatment planning system and compare its performance against an electron pencil beam algorithm. From their results eMC algorithm showed good agreements with the measurements in simple homogeneous and heterogeneous phantoms. Compared to the electron pencil beam algorithms, the eMC calculations predicted more accurately large dose perturbations due to inhomogeneities. The eMC algorithm can be considered for routine treatment planning. In our present study results in the Table 4 and Figures 2 and 3 show excellent agreements with greater than 98% of the pixels passing the gamma requirements.

## Conclusion

In conclusion the comparison of eMC calculations and measurements for various field sizes and energies shows that the Monte Carlo algorithm for electron planning is more accurate. The eMC algorithm performs well in a homogeneous water phantom with regular and irregular fields at nominal and extended SSD.

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**Permission from IRB:** Yes

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