Improved simulation of small electron fields for external beam radiation therapy

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***Abstract*— This paper reports on improved simulation of small electron fields from a Siemens Primus linear accelerator. Accelerator simulation was performed using the Monte Carlo user code BEAMnrc. Source and geometry parameters used were obtained from previous measurements and simulation of the linear accelerator with maximum electron field size (40 × 40 cm²). Careful measurements of electron dose distributions were performed for fields ranging from an open 25 × 25 cm² electron applicator to a 10 × 10 cm² applicator containing a 1 cm diameter cerrobend insert. Monte Carlo calculated and measured data generally matched to within 2 % or 1 mm. This study has used improved source and treatment head simulation parameters and exacting measurements to closely match measured and simulated dose distributions for small electron fields.**

***Keywords*— Monte Carlo, electron beam, radiation therapy.**

I. Introduction

Accurate dose calculations for radiation therapy are dependent on an accurate definition of the source and beam modifiers. In some areas, the advantages of electrons – uniform dose and steep fall-off – can be counteracted by uncertainty in the dose delivered. More precise delivery techniques require more accurate fluence and dose calculations [1]. Monte Carlo simulation can accurately model particle transport and subsequent dose deposition but this requires accurate details on the electron beam and treatment head.

Faddegon *et al.* [2] developed methodology to extract detailed information on the source and geometry of a treatment head based on measurements done for the maximum field size (40 × 40 cm²) and no electron applicator. More recent work currently under review uses dose and geometry measurements with disassembly of the treatment head to derive these parameters with high accuracy [3]. It is prudent to verify whether these parameters on the source and geometry remain true for the treatment head for fields collimated with an electron applicator.

This study investigates the use of the improved source and geometry parameters, derived from simulation of a Siemens Primus accelerator at maximum field size [2], [3], for small electron fields. Small fields ranged from an open 25 × 25 cm² electron applicator to a 10 × 10 cm² applicator containing a 1 cm in diameter cerrobend insert.

II. Materials & methods

Measurements were performed on a Siemens Primus linear accelerator for electron energies 6 MeV, 9 MeV, 12 MeV, 15 MeV, 18 MeV and 21 MeV with 10 × 10 cm², 15 × 15 cm², 20 × 20 cm² and 25 × 25 cm² applicators and circular cerrobend inserts ranging from 1 cm to 5 cm in diameter. This data was obtained using a 60 cm × 60 cm × 58 cm scanning water tank (Wellhofer) at 100 cm SSD. For the open applicators, depth penetration and off-axis profiles were measured with a Roos chamber (PTW-Freiberg) and a CC13 chamber (Scandatronix-Wellhofer). For the cerrobend inserts an EFD diode (Scandatronix-Wellhofer) was used to maintain adequate spatial resolution in the small electron fields.

Off-axis profiles were measured at depths of 0.5 cm, d_{max}, in the fall-off and in the bremsstrahlung tail of each electron beam. Depth penetration measurements extended approximately 3 cm beyond the practical range. The detector was centered on the collimator rotation axis. The reference detector (CC13 or EFD) was positioned on the distal scraper bar of the applicator to minimize scatter into the field. The water tank was leveled to +/- 1.0 mm over the scan length. Data was obtained at slow scan speed, < 0.5 mm/sec for the smallest fields. This was to facilitate both minimum water displacement and to obtain adequate data points for averaging in noisy scans. The detector position at the water surface was verified frequently. The water level was checked ap-

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proximately every 2 hours and water added to account for evaporation and maintain the detector depth.

Relative output factors were measured with the Roos chamber. Current was measured with a MK614 electrometer (Keithley Instruments Inc). Three readings for 20 MU were taken for detector biases of +300 and -300 V.

Monte Carlo simulations were performed using the accelerator simulation code BEAMnrc (version 1.104) [4]. ECUT/AE and PCUT/AP values of 0.7 MeV and 1.0 keV were used, respectively. 800 million histories were tracked to achieve 1 % uncertainty in dose calculations. The Siemens Primus accelerator was modeled using both manufacturer provided specifications and direct measurement of components following disassembly of the treatment head.

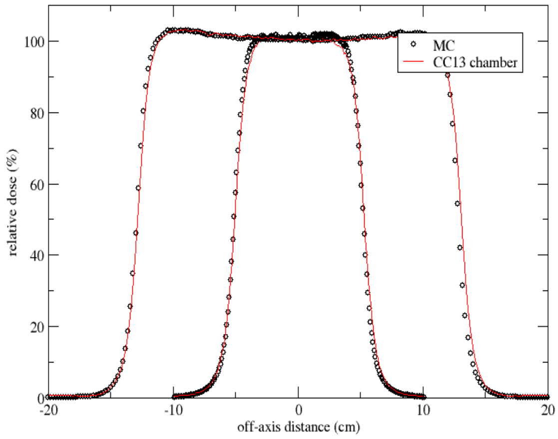

Fig. 1: Comparison of Monte Carlo and CC13 measured 12 MeV cross-plane profiles for 10 × 10 cm² and 25 × 25 cm² applicators.

The source and geometry parameters used were obtained from a previous investigation [3] which extracted accurate details on the source and treatment head components from measurement and simulation of the accelerator with maximum field (40 × 40 cm^2) and in 3 different states of disassembly of the treatment head: no scattering foils, primary scattering foil only, and full clinical configuration. The model fully accounted for measured asymmetry. The source used in simulation was an offset, angled pencil beam with Gaussian shaped energy and radial distributions. Components were the exit window, primary scattering foil, primary collimator, secondary scattering foil, dose chamber, jaws, MLC track and accessory rails. The dimensions and positions, calculated for the large field study, were the input for small field simulations. The electron applicator was modeled and jaws set to corresponding positions for each applicator. Phase-space information was scored at 90 cm SSD. Simulation of the final beam defining aperture and water phantom dose calculations were performed using the Monte Carlo EGSnrc code MCRTP [5]. The cerrobend inserts were simulated replacing the open applicator brass scraper bars. The inserts modified distance to the source (- 0.56 cm) and thickness (+ 0.03 cm), relative to the brass applicator scraper, was accounted for.

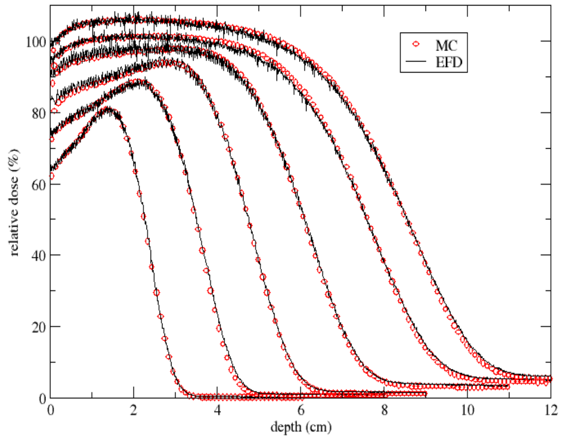

Fig. 2: Monte Carlo and EFD diode percentage depth dose curves for 6 – 21 MeV electron beams and 25 × 25 cm² applicator

III. Results and discussion

Percentage depth dose, off-axis profiles and relative output factors were calculated using MCRTP. Monte Carlo data was normalized and compared with ionization chamber and EFD diode measurements for the small electron fields. Since the source and geometry parameters used were obtained from the large electron field simulations [3], the only free parameters for small electron field simulations were the geometry of the applicators and the circular cerrobend inserts. Manufacturer specifications (confirmed by measurements) were used to model the electron applicators. The curved corners of the final scraper bars of the Siemens applicators were not modeled. This is only expected to lead to a reduction in field size for diagonal plots. Figure 1 shows excellent agreement between thimble chamber (CC13) measured and Monte Carlo cross-plane profiles for the 12 MeV electron beam and 10 × 10 cm^2 (1.4 % / 0.4 mm) and 25 ×

25 cm^2 (0.8 % / 0.8 mm) applicators. The 15 × 15 cm^2 and 20 × 20 cm^2 applicator profiles also showed this level of agreement. Monte Carlo calculated depth penetration (6 – 21 MeV) matched diode measurements to 0.6 mm, as seen for the 25 × 25 cm^2 applicator in figure 2.

The circular cerrobend inserts of nominal diameter 1 cm, 2 cm and 5 cm were measured as 1.00 cm, 2.12 cm and 5.22 cm respectively. The inserts were 0.56 +/- 0.05 cm closer to the source than the final applicator scraper bar. The cerrobend material was modeled with a thickness of 1.3 cm.

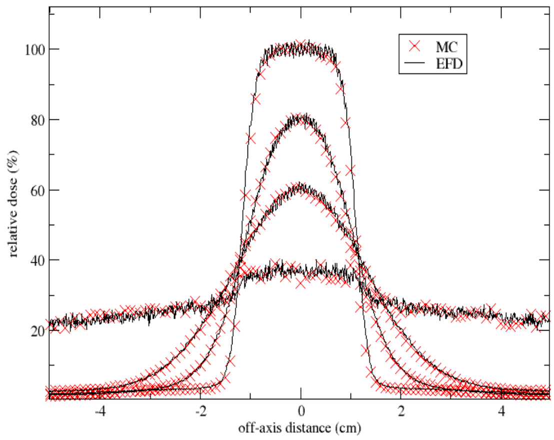

Fig. 3: Comparison of Monte Carlo and diode 12 MeV cross-plane profiles at depths of 0.5 cm, 2.7 cm, 4.7 cm and 8 cm for 2 cm diameter cerrobend insert.

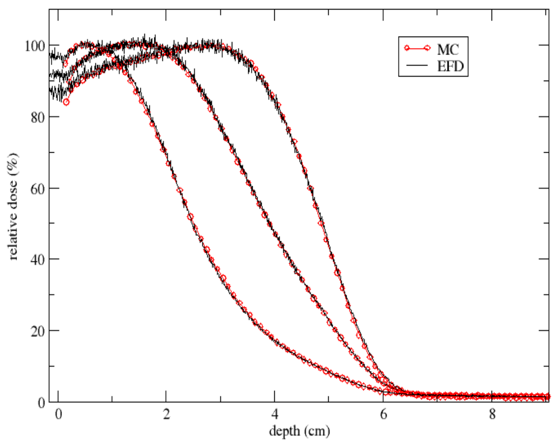

Fig. 4: Monte Carlo and measured percentage depth dose curves for 12 MeV beam and 1 cm, 2 cm and 5 cm diameter cerrobend inserts.

Figure 3 shows the 12 MeV cross-plane profiles for the 2 cm cerrobend insert. Monte Carlo and measured profiles are in good agreement at depths of 0.5 cm, d_{max}, in the fall-off region and in the bremsstrahlung region of the beam. The measured and simulated (bremsstrahlung) profiles at 8.0 cm depth match to 2.2 %. The field size of the profiles at 0.5 cm, d_{max} and in the fall-off are within 0.3 mm of measurements. The percentage depth dose curves for 1 cm, 2 cm and 5 cm cerrobend inserts are shown in figure 4. Monte Carlo and diode depth penetration matches to 0.5 mm or better.

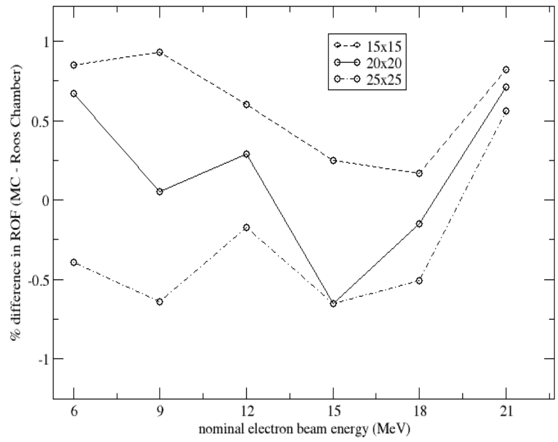

Fig. 5: Percentage difference between Monte Carlo and Roos chamber relative output factors for open applicators.

Relative output factor measurements were performed with a Roos parallel plate chamber. Figure 5 shows the percentage difference between Monte Carlo and Roos chamber ROF for 6 – 21 MeV electron beams and open applicators (relative to 10 × 10 cm^2 applicator). The differences between measurement and simulation are all within 1 %.
Careful measurements and simulations using improved source and geometry parameters have lead to closer matches between measured and calculated dose distributions for applicator collimated electron fields [6].

IV. Conclusion

This work has shown that recent methodology used to obtain accurate details on the source and geometry of the treatment head for large electron field configuration remains applicable for clinically relevant small electron fields. Measured and Monte Carlo calculated data generally showed good agreement to 2 % or 1 mm. For the largest applicator and higher energies dose profile differences of 2 – 3 % were seen. This paper takes advantage of careful measurements and accurate knowledge on the source and geometry of the treatment head in order to validate Monte Carlo simulations of applicator defined fields and subsequent dose calculations.

References

1. Klein EE, Mamalui-Hunter M, Low DA, "Delivery of modulated electron beams with conventional photon multi-leaf collimators," Phys Med Biol. 54, 327-339 (2009).
2. B. A. Faddegon, J. Perl and M. Asai. "Monte Carlo simulation of large electron fields," Phys. Med. Biol. 53, 1497-1510 (2008)
3. B. A. Faddegon, D. L. Sawkey, T. P. O'Shea, M. McEwen and C Ross. submitted to Med. Phys. (Feb. 2009)
4. D. W. O. Rogers, B.A. Faddegon, G. X. Ding, C.-M. Ma, J. We, and T. R. Mackie. "BEAM: A Monte Carlo code to simulate radiotherapy treatment units," Med. Phys. 22, 503-524 (1995)
5. B. A. Faddegon, J. Balogh, R. Mackenzie, and D. Scora. "Clinical considerations of Monte Carlo for electron radiotherapy treatment planning," Rad. Phys. and Chem. 53, 217-227 (1998)
6. J. A. Antolak, M. R. Bieda and K. R. Hogstrom. "Using Monte Carlo methods to commission electron beams: a feasibility study," Med. Phys. 29 (5), 771-786 (2002)