Notice of the Final Oral Examination
for the Degree of Doctor of Philosophy

of

SAMANTHA LLOYD

MSc (University of Victoria, 2011)
BSc (Thompson Rivers University, 2009)

“Measurement and Monte Carlo Simulation of Electron Fields for Modulated Electron Radiation Therapy”

Department of Physics and Astronomy

Monday, January 30, 2017
9:00 A.M.
David Turpin Building
Room A136

Supervisory Committee:
Dr. Andrew Jirasek, Department of Physics and Astronomy, University of Victoria (Co-Supervisor)
Dr. Isabelle Gagné, Department of Physics and Astronomy, University of Victoria (Co-Supervisor)
Dr. Sergei Zavgorodni, Department of Physics and Astronomy, UVic (Member)
Dr. Poman So, Department of Electrical and Computer Engineering, UVic (Outside Member)

External Examiner:
Dr. Andrew Alexander, Department of Medical Physics, Saskatchewan Cancer Agency

Chair of Oral Examination:
Dr. Christo Papadopoulos, Department of Electrical and Computer Engineering, UVic

Dr. David Capson, Dean, Faculty of Graduate Studies
Abstract

This work establishes a framework for Monte Carlo simulations of complex, modulated electron fields produced by Varian's TrueBeam medical linear accelerator for investigations into modulated electron radiation therapy (MERT) and combined modulated photon and electron radiation therapy (MPERT). Both MERT and MPERT have shown potential for reduced low dose to normal tissue without compromising target coverage in the external beam radiation therapy of some breast, chest wall, head and neck, and scalp cancers. This reduction in low dose could translate into the reduction of immediate radiation side effects as well as long term morbidities and incidence of secondary cancers.

Monte Carlo dose calculations are widely accepted as the gold standard for complex radiation therapy dose modelling, and are used almost exclusively for modelling the complex electron fields involved in MERT and MPERT. The introduction of Varian's newest linear accelerator, the TrueBeam, necessitated the development of new Monte Carlo models in order to continue research into the potential role of MERT and MPERT in radiation therapy. This was complicated by the fact that the field-independent internal schematics of TrueBeam were kept proprietary, unlike in previous generations of Varian accelerators.

Two approaches are presented for performing Monte Carlo simulations of complex electron fields produced by TrueBeam. In the first approach, the dosimetric characteristics of electron fields produced by the TrueBeam were compared with those produced by an older Varian accelerator, the Clinac 21EX. In these comparisons, differences in depth and profile characteristics of fields produced by the TrueBeam and those produced by the Clinac 21EX were found to be within 3%/3 mm. Given this information, complete accelerator models of the Clinac 21EX based on its known internal geometry were successfully modified in order to simulate 12 and 20 MeV electron fields produced by the TrueBeam to within 2%/2 mm of measured depth and profile curves and to within 3.7% of measured relative output. While the 6 MeV TrueBeam model agreed with measured depth and profile data to within 3%/3 mm, the modified Clinac 21EX model was unable to reproduce trends in relative output as a function of field size with acceptable accuracy.

The second approach to modelling TrueBeam electron fields used phase-space source files provided by Varian that were scored below the field-independent portions of the accelerator head geometry. These phase-spaces were first validated for use in MERT and MPERT applications, in which simulations using the phase-space source files were shown to model
depth dose curves that agreed with measurement within 2%/2 mm and profile curves that agreed with measurement within 3%/3 mm. Simulated changes in output as a function of field size fell within 2.7%, for the most part.

In order to inform the positioning of jaws in MLC-shaped electron field delivery, the change in output as a function of jaw position for fixed MLC-apertures was investigated using the phase-space source files. In order to achieve maximum output and minimize treatment time, a jaw setting between 5 and 10 cm beyond the MLC-field setting is recommended at 6 MeV, while 5 cm or closer is recommended for 12 and 20 MeV with the caveat that jaw-dependency on output is most sensitive to jaw position when the jaws are very close to the MLC field periphery. Additionally, output was found to be highly sensitive to jaw model. A change in divergence of the jaw faces from a point on the source plane to a 3 x 3 mm2 square in the source plane changed the shape of the output curve dramatically.

Finally, electron backscatter from the jaws into the monitor ionization chamber of the TrueBeam was measured and simulated to enable accurate absolute dose calculations. Two approaches were presented for measuring backscatter into the monitor ionization chamber without specialized electronics by turning off the dose and pulse forming network servos. Next, a technique was applied for simulating backscatter factors for the TrueBeam phase-space source models without the exact specifications of the monitor ionization chamber. By using measured backscatter factors, the forward dose component in a virtual chamber was determined and then used to calculate backscatter factors for arbitrary fields to within 0.21%. Backscatter from the jaws was found to contribute up to 2.6% of the overall monitor chamber signal. The measurement techniques employed were not sensitive enough to quantify backscatter from the MLC, however, Monte Carlo simulations predicted this contribution to be 0.3%, at most, verifying that this component can be neglected.