



**University  
of Victoria**

Graduate Studies

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

of

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**“Design and Evaluation of a Monte Carlo Model of a Low-Cost  
Kilovoltage X-ray Arc Therapy System”**

Department of Physics and Astronomy

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9:00 A.M.

Clearihue Building

Room B017

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(Supervisor)

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Dr. Adam Krawitz, Department of Psychology, UVic

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## **Abstract**

There is a growing global need for proper access to radiation therapy. This need exists predominantly in low- and middle-income countries but exists in some high-income countries as well. The solution to this problem is complex and requires changes in government policy, education and technology. The objective of the work contained in this dissertation is the development of novel external beam radiation therapy system capable of treating a variety of cancers. The intent of this system is to provide a cost-effective radiation therapy system, which can primarily be utilized in low- and middle-income countries. This new system uses kilovoltage rather than megavoltage x-rays and is therefore much more cost-effective. The ultimate purpose of this kilovoltage radiation therapy system is to improve access to radiation therapy worldwide by supplementing current radiation therapy technology.

As a first step, the kilovoltage x-ray arc therapy or KVAT system was modeled using the EGSnrc BEAMnrc and DOSXYZnrc Monte Carlo software tools. For this initial study 200 kV arc-therapy was simulated on cylindrical water phantoms of two sizes each of which contained a variety of planning target volume (PTV) sizes and locations. Additionally, prone and supine partial breast irradiation treatment plans were generated using KVAT. The objective of this work was to determine whether or not skin sparing could be achieved using the KVAT system while also delivering a clinically relevant dose rate to the PTV. The results of the study indicated that skin sparing is indeed achievable and that the quality of KVAT treatment plans improves for full 360-degree arcs and smaller PTV sizes.

The second step of this project involved the Monte Carlo simulation of KVAT treatment plans for breast, lung and prostate cancer. Spherical PTVs of 3-cm diameter were used for the breast and lung treatment plans while a 4-cm diameter PTV was used for prostate. Additionally, inverse optimization was utilized to make full use of the non-conformal irradiation geometry of KVAT. As a means of comparison, megavoltage treatment plans that could be delivered by a clinical linear accelerator were generated for each patient as well. In order to evaluate the safety of KVAT treatment plans, dose constraints were taken from published Radiation Therapy Oncology Group (RTOG) reports. The results of this study indicated that the 200 kV breast and 225 kV lung KVAT treatment plans were within dose constraints and could be delivered in a reasonable length of time. The 225 kV prostate treatment plan, while technically within dose constraints, delivered a large dose to non-critical healthy tissues due to the limited number of beam angles that did not pass through bony anatomy. It was concluded that plans such as prostate with large volumes of bone present might not be feasible for KVAT treatment.

The third step aimed to expand upon previous work and simulated more realistic KVAT treatment plans by using PTV volumes contoured by radiation oncologists. Additionally, this study used a completely redesigned KVAT geometry, which employed a stationary reflection anode and a new collimator design. The design modeled in this study was based upon the specifications of the prototype system under construction by PrecisionRT, a commercial partner. Three stereotactic ablative radiotherapy (SABR) lung patients were selected that had received treatment at the Vancouver Island Cancer Centre. In order to fully cover the PTVs of each patient, spherical sub-volumes were placed within the clinically contoured PTV of each patient. Dose constraints for at-risk organs were taken from an RTOG report on stereotactic body radiation therapy and were used to inversely optimize the 200 kV KVAT treatment plans. The calculated KVAT plans were compared with the clinical 6 MV SABR plans delivered to each patient. The results of this study indicated that KVAT lungs plans were within dose constraints for all three patients with the exception of the ribs in the second patient who had a tumor directly adjacent to the rib cage.

The fourth and last step of this project was the experimental validation of a simple, proof-of-principle KVAT system. Simple geometric methods were used to design a collimator consisting of two slabs of brass separated by 6 cm, each with 5 apertures, which would create an array of 5 converging beamlets. The collimator was used with a tabletop x-ray tube system. A rectangular solid water phantom and cylindrical TIVAR 1000 phantom were placed on a rotation stage and irradiated using 360-degree arcs. EBT3 gafchromic film was placed in each phantom to measure two-dimensional dose distributions. The dose distributions were analyzed and compared to Monte Carlo generated dose distributions. Both the rectangular solid water phantom and cylindrical TIVAR phantom showed skin sparing effects in their dose distributions. The highest degree of skin sparing was achieved in the larger 20 cm diameter cylindrical phantom. Furthermore, the measured film data and calculated metrics of the rectangular phantom were within 10% of the MC calculated values for two out of three films. The discrepancy in the third film can be explained by errors in the experimental setup.

In conclusion, the work contained in this dissertation has established the feasibility of a cost-effective kilovoltage arc-therapy system designed to treat deep-seated lesions by means of Monte Carlo simulations and experimental dosimetry. The studies performed so far suggest that KVAT is most suitable for smaller lesions in patient anatomy that does not involve large amounts of bony anatomy. Perhaps most importantly, an experimental study has demonstrated the skin-sparing ability of a simple KVAT prototype.