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

of

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BSc (University of British Columbia, 2015)

“Contrast Agent Imaging Using An Optimized Table-top X-ray Fluorescence and Photon-Counting Computed Tomography Imaging System”

Department of Physics and Astronomy

Tuesday, October 20, 2020
1:00 P.M.
Conducted Remotely

Supervisory Committee:
Dr. Magdalena Bazalova-Carter, Department of Physics and Astronomy, University of Victoria (Supervisor)
Dr. Cornelia Hoehr, Department of Physics and Astronomy, UVic (Member)
Dr. Frank van Veggel, Department of Chemistry, UVic (Outside Member)

External Examiner:
Dr. Yu Kuang, Department of Health Physics and Diagnostic Sciences, University of Nevada, Las Vegas

Chair of Oral Examination:
Dr. Ke Xu, Department of Economics, UVic

Dr. Stephen Evans, Acting Dean, Faculty of Graduate Studies
Abstract
Contrast agents are often crucial in medical imaging for disease diagnosis. Novel contrast agents, such as gold nanoparticles (AuNPs) and lanthanides, are being explored for a variety of clinical applications. Preclinical testing of these contrast agents is necessary before being approved for use in humans, which requires the use of small animal imaging techniques. Small animal imaging demands the detection of these contrast agents in trace amounts at acceptable imaging time and radiation dose. Two such imaging techniques include x-ray fluorescence computed tomography (XFCT) and photon-counting CT (PCCT). XFCT combines the principles of CT with x-ray fluorescence by detecting fluorescent x-rays from contrast agents at various projections to reconstruct contrast agent maps. XFCT can image trace amounts of AuNPs but is limited to small animal imaging due to fluorescent x-ray attenuation and scatter. PCCT uses photon-counting detectors that separate the CT data into energy bins. This enables contrast agent detection by recognizing the energy dependence of x-ray attenuation in different materials, independent of AuNP depth, and can provide anatomical information that XFCT cannot. To achieve the best of both worlds, we modeled and built a table-top x-ray imaging system capable of simultaneous XFCT and PCCT imaging.

We used Monte Carlo simulation software for the following work in XFCT imaging of AuNPs. We simulated XFCT induced by x-ray, electron, and proton beams scanning a small animal-sized object (phantom) containing AuNPs with Monte Carlo techniques. XFCT induced by x-rays resulted in the best image quality of AuNPs, however high-energy electron and medium-energy proton XFCT may be feasible for on-board x-ray fluorescence techniques during radiation therapy. We then simulated a scan of a phantom containing AuNPs on a table-top system to optimize the detector arrangement, size, and data acquisition strategy based on the resulting XFCT image quality and available detector equipment. To enable faster XFCT data acquisition, we separately simulated another AuNP phantom and determined the best collimator geometry for Au fluorescent x-ray detection.

We also performed experiments on our table-top x-ray imaging system in the lab. Phantoms containing multiples of three lanthanide contrast agents were scanned on our tabletop x-ray imaging system using a photon-counting detector capable of sustaining high x-ray fluxes that enabled PCCT. We used a novel subtraction algorithm for reconstructing separate contrast agent maps; all lanthanides were distinct at low concentrations including gadolinium and
holmium that are close in atomic number. Finally, we performed the first simultaneous XFCT and PCCT scan of a phantom and mice containing both gadolinium and gold based on the optimized parameters from our simulations.

This dissertation outlines the development of our tabletop x-ray imaging system and the optimization of the complex parameters necessary to obtain XFCT and PCCT images of multiple contrast agents at biologically-relevant concentrations.