This study aimed to better understand and improve upon the Micro-X X-ray tube cathode design; specifically, their carbon nanotube field emitter. Improvement was defined not just by better emitter performance and lifetime, but also by better time and cost efficiency of the emitter production process. An emitter's performance is determined by its current density, gate voltage and gate voltage degradation over time. A good performing emitter will measure low gate voltages for emitter currents ranging between 10-160 mA. IV curves were used to track the gate voltage against emitter current and plotted for comparison. The lifetime performance of the emitters in this study was determined by tracking gate voltage increase over time. The effects of CNT ball milling, substrate material and glass particle size on the performance of carbon nanotube field emitters was investigated. This work was performed in collaboration with Adelaide-based company Micro-X who produced the world's first commercially available CNT cold cathode X-ray tube. A general overview is shown in **Figure 1**.

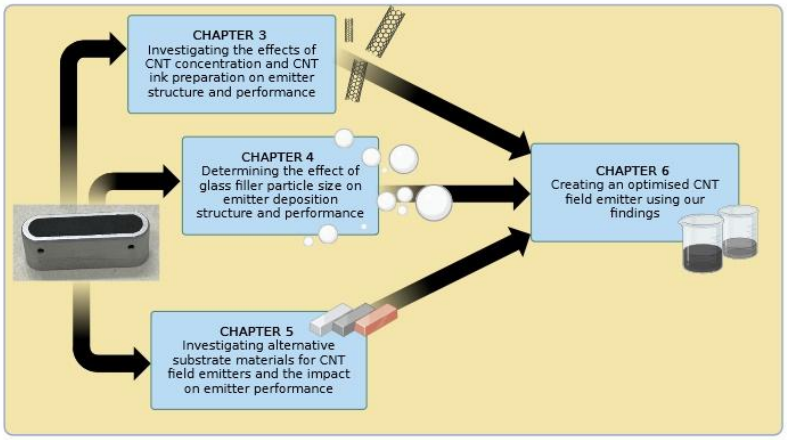

***Figure 1**: Diagram outlining the areas of focus for each section of the thesis. (Created with BioRender.com).*

Chapter 3 describes the investigation of the effect of CNT properties, CNT concentration and overall CNT ink preparation methods on field emitter performance and lifetime. The standard method used by Micro-X requires two different CNT inks to produce their proprietary emitters. The role of each ink in producing a functional field emitter was able to be demonstrated. Micro-X's standard process also involves the ball milling of the CNTs for the CNT inks. We were able to

demonstrate that this process was not only unnecessary but produced worse-performing field emitters. Chapter 4 investigated another aspect of the CNT inks which was the glass filler material used to form the bonds between the CNT ink deposition and the emitter substrate. Using planetary ball milling, the effect of the average glass particle size and particle uniformity was shown to have a small but significant effect on an emitter's structure and performance. It was observed that as the ball milling time was increased, the average glass particle size decreased. Subsequently, emitters made using smaller glass particle sizes were found to perform better with lower gate voltages required for field emission. Chapter 5 involved investigating different substrate materials as alternatives to Micro-X's standard material, molybdenum. Kovar, a type of low thermal expansion steel, had been previously selected by Micro-X due to it being a vacuum-safe weldable material. However, issues arose where emitters would degrade much faster. It was found that this was likely due to the formation of a brittle oxide layer at the interface with the CNT deposition. Due to weldability being the priority, we explored the potential of thin films of molybdenum being deposited on Kovar as potential alternative substrates. It was also found that while the emitters functioned, there were issues in adhesion between the Kovar and the molybdenum, even after vacuum baking at 700 $^{\circ}$C. Additionally, a cheaper material was also of interest and so copper was explored as an alternative material. Bulk copper substrates were investigated along with the electroplating of copper to Kovar substrates using a thin intermediate nickel layer to promote better bonding of the copper. It was found that copper was a viable alternative material to molybdenum, where good adhesion was observed between the CNT ink and the substrate and resulted in comparable performance with standard emitters. The copper electroplated substrates demonstrated the same adhesion quality; however, voids were observed in the plating layers which were a result of the electroplating method. Overall, it was shown that the original pure molybdenum substrate was still better overall, where it provided the best bonding to the CNT ink

deposition. Finally, chapter 6 took the learnings from the previous chapters to create an optimised "super emitter". These emitters were made using pure molybdenum substrates, 10-hour ball milled glass and a single CNT ink. Overall, this emitter displayed lower gate voltages at 100 mA, lower resistances and comparable emitter lifetimes to standard Micro-X emitters. They were also faster and easier to produce due to only requiring a single emitter ink compared to the standard method which uses two.