MICRO-X

NANO-ELECTRONIC X-RAY TECHNOLOGY

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M I C R O - X   N E X   T E C H N O L O G Y

MICRO-X

Nano-Electronic X-ray (NEX) Technology

- Demonstrated CNT X-ray tube reliability and performance with 5 years in hospitals.

- Expanding to new tubes and new imaging systems for applications in both medical and security.

- About Micro-X
  - Based in Adelaide Australia Listed ASX:MX1
  - Approximately 100 employees globally
  - www.micro-x.com

- **Presentation Overview**
  - Historic challenges of CNT X-rays
  - Micro-X NEX technology
  - Medical Applications of NEX technology.

120kV · 100mA · 80mAs

160kV · 10mA · Constant Potential

100kV · 60mA · 2.5mAs

Mobile Digital Radiology

FDA Certified Nov 2017

350+ sold · 16 Countries

X-ray Camera

First Customer Demos June 2023

CT Baggage Screening

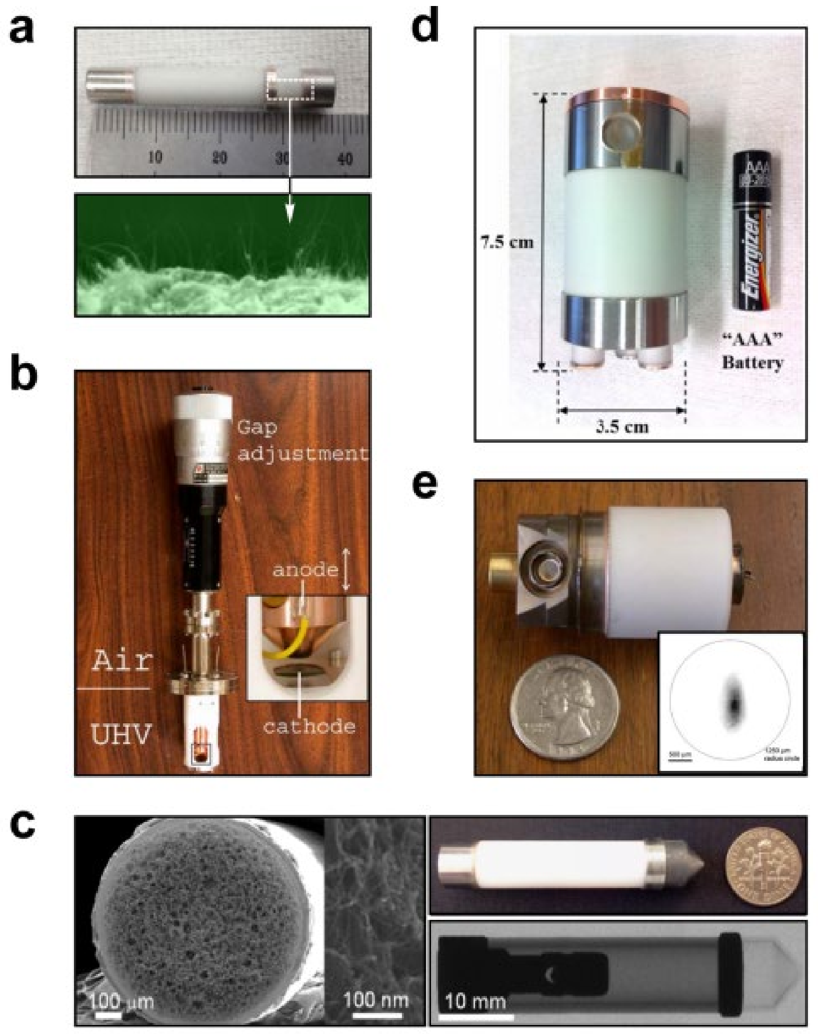
Prototype Delivered to TSA Aug 2023

Stroke Imaging

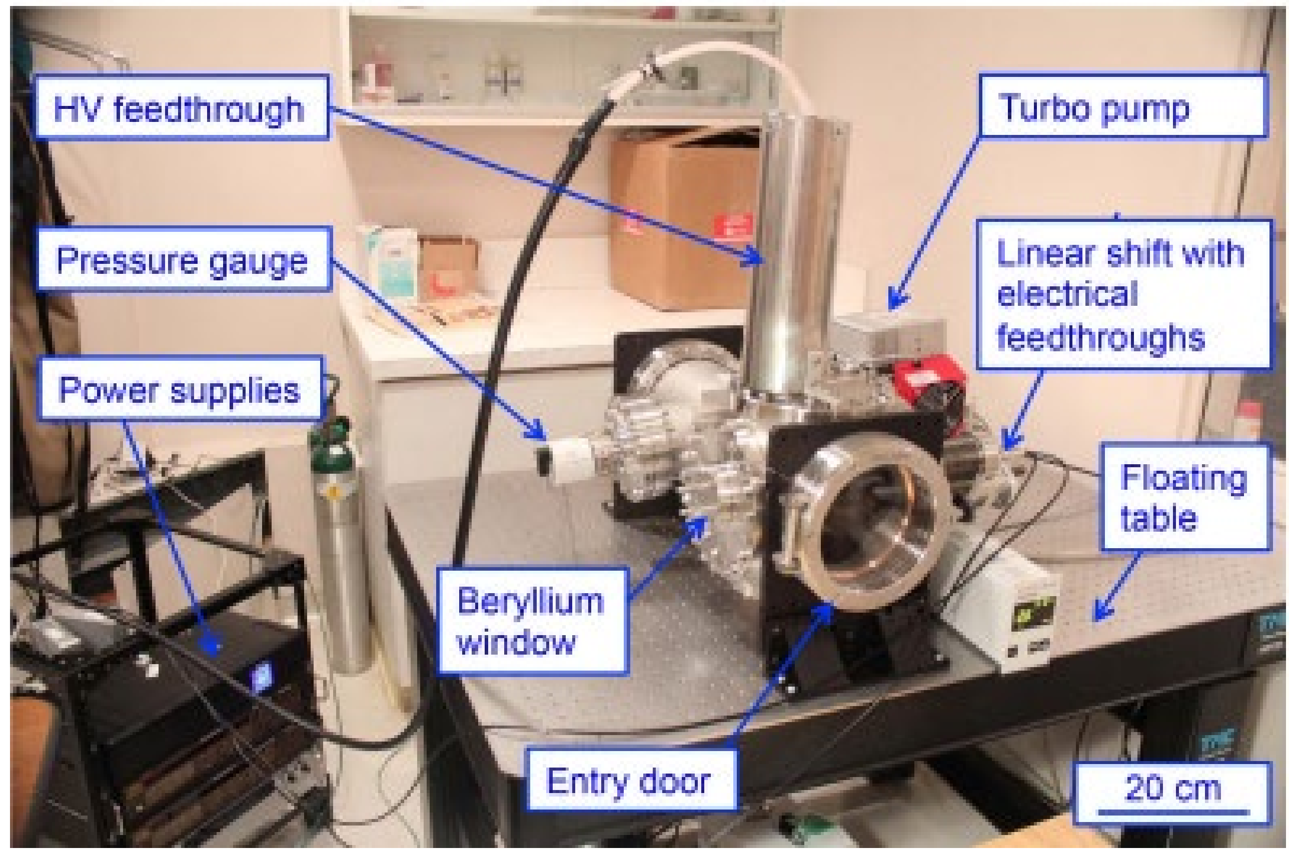
Building first Integrated Prototype

HISTORIC PERSPECTIVE

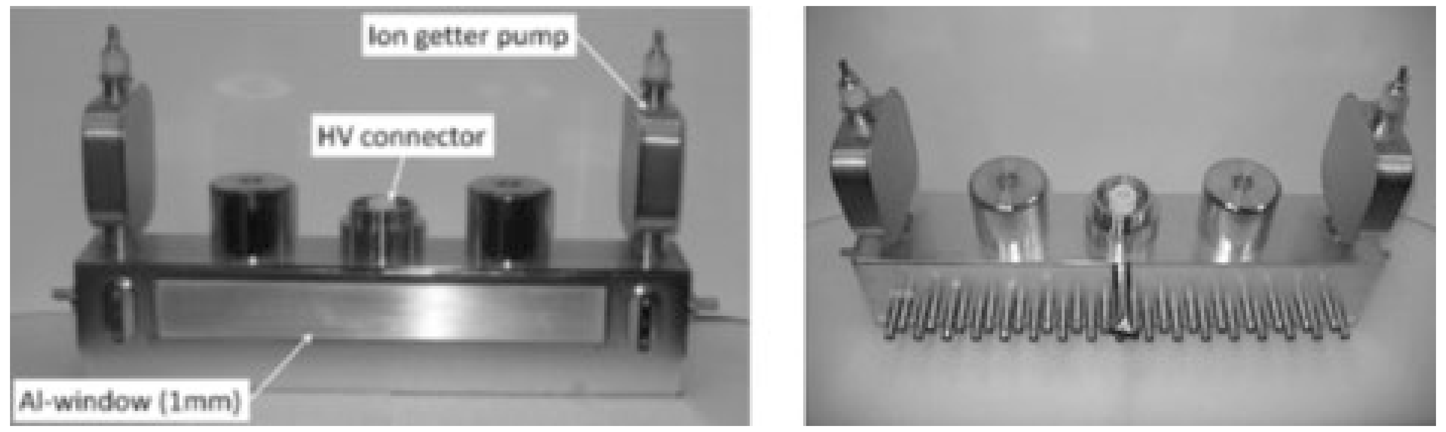
Historical Limitations of Field Emission based X-ray



Parmee, Richard J., et al. "X-ray generation using carbon nanotubes." Nano Convergence 2.1 (2015): 1-27.



Cheng, Shuo, et al. "Low-bremsstrahlung x-ray source using a low-voltage high-current-density nanostructured field emission cathode and a transmission anode for markerless soft tissue imaging." Journal of Microelectromechanical Systems 24.2 (2014): 373-383.

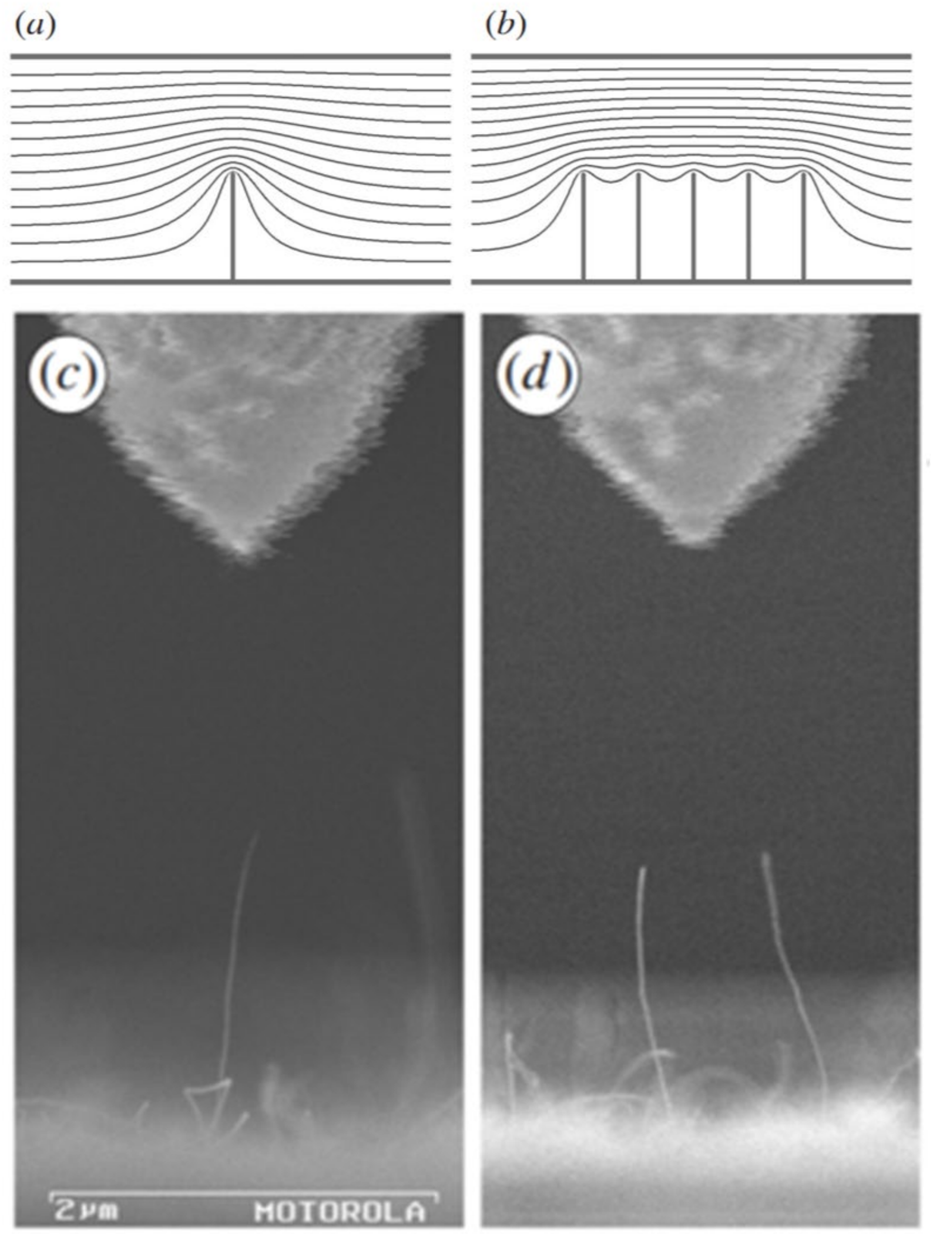


Qian, Xin, et al. "High resolution stationary digital breast tomosynthesis using distributed carbon nanotube x-ray source array." *Medical physics* 39.4 (2012): 2090-2099.

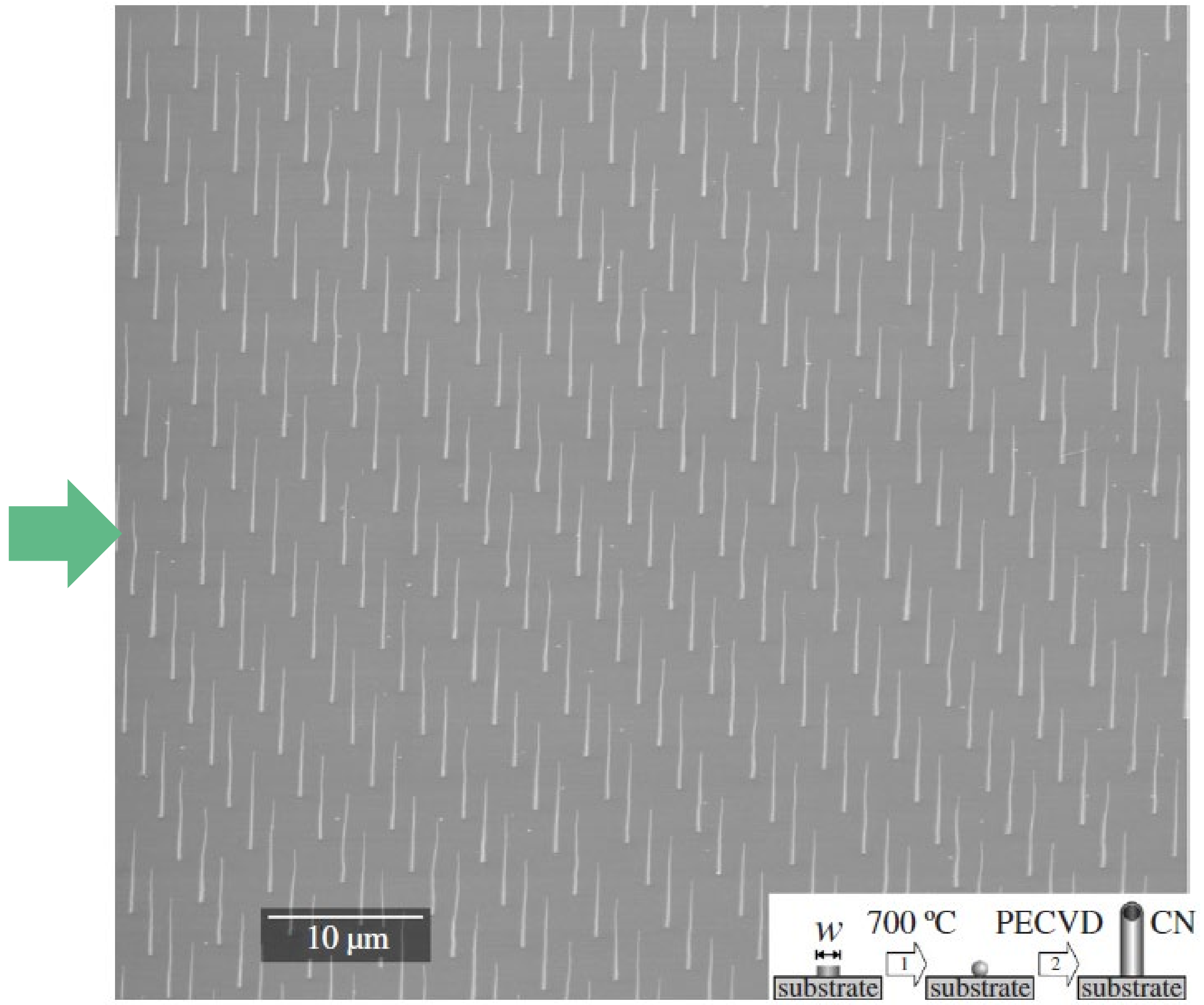
- Historically there has been significant investment but limited real applications of CNT or other field-emission X-ray sources.
- Historic limitations and challenges of field-emission X-ray sources:
  - **Low Current** –field-emission X-ray tubes have too low dose for most medical applications.
  - **Instability and short life** – field-emission X-ray tubes have been unstable at high-voltages and have short lives. The short life has often been attributed to emitter degrading due to high-voltage arcing.
  - **Scalability** – one-off and prototype tubes demonstrated, but very limited in scale. Poor emitter repeatability and cost are most often causes.

HISTORIC PERSPECTIVE

Historical Limitations of Large Area Field Emission Devices



De Jonge, Niels, and Jean–Marc Bonard. "Carbon nanotube electron sources and applications." Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences 362.1823 (2004): 2239-2266.



Teo, K. B. K., et al. "Plasma enhanced chemical vapour deposition carbon nanotubes/nanofibres—how uniform do they grow?." Nanotechnology 14.2 (2003): 204.

- Individual CNT devices must be scaled to large area emitter to deliver milliamps of current required for medical imaging applications.
- Conventional approach is to replicate near ideal field-emission devices with optimal spacing. Once achieved, it is challenging and expensive to modify size of emitter.
- In a uniform electric field and a uniform large area emitter, devices with lower work function will turn on sooner than others.
- In large area emitter, better CNTs work harder than others and burn out. With fewer CNTs, the remaining devices have to work harder.
- Conventional large area CNT devices are typically limited in the few milliamp current for stable long-life operation.

MICRO-X NEX TECHNOLOGY

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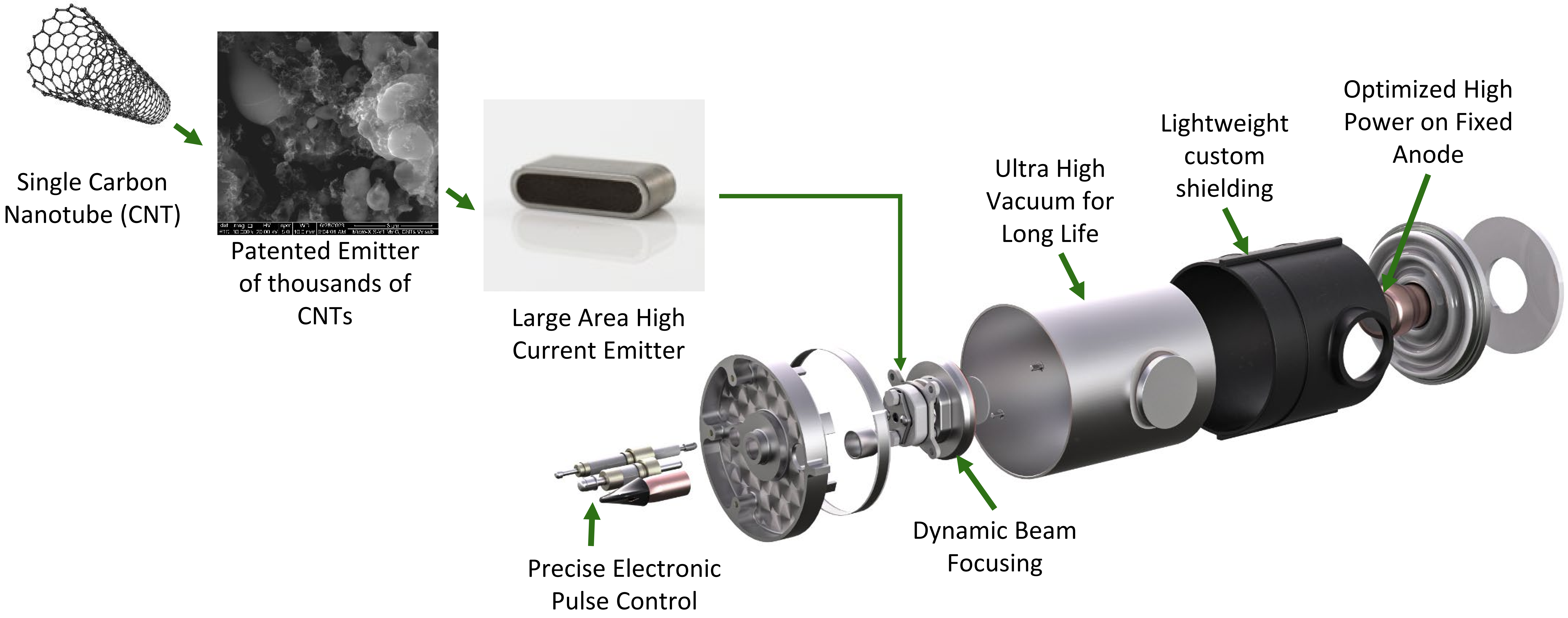
Overcoming the Limitations of Field-Emission X-ray



MICRO-X NEX EMITTERS

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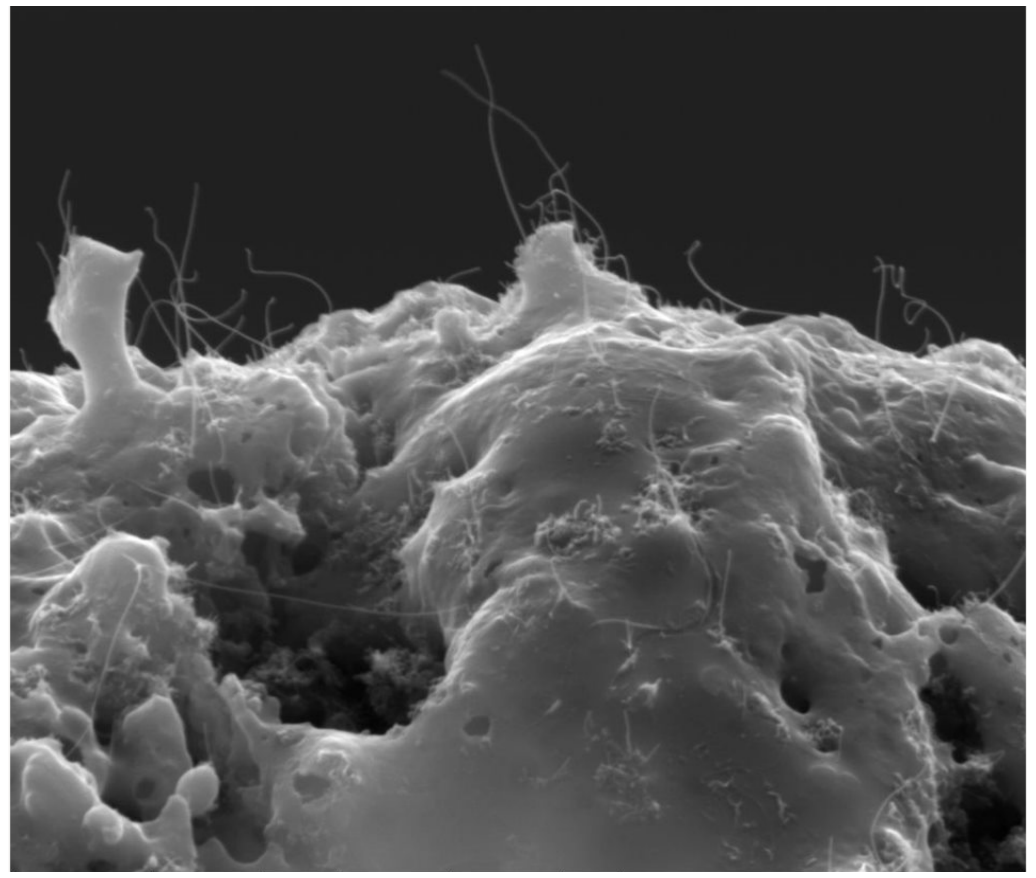
Micro-X Patented CNT Electron Emitter

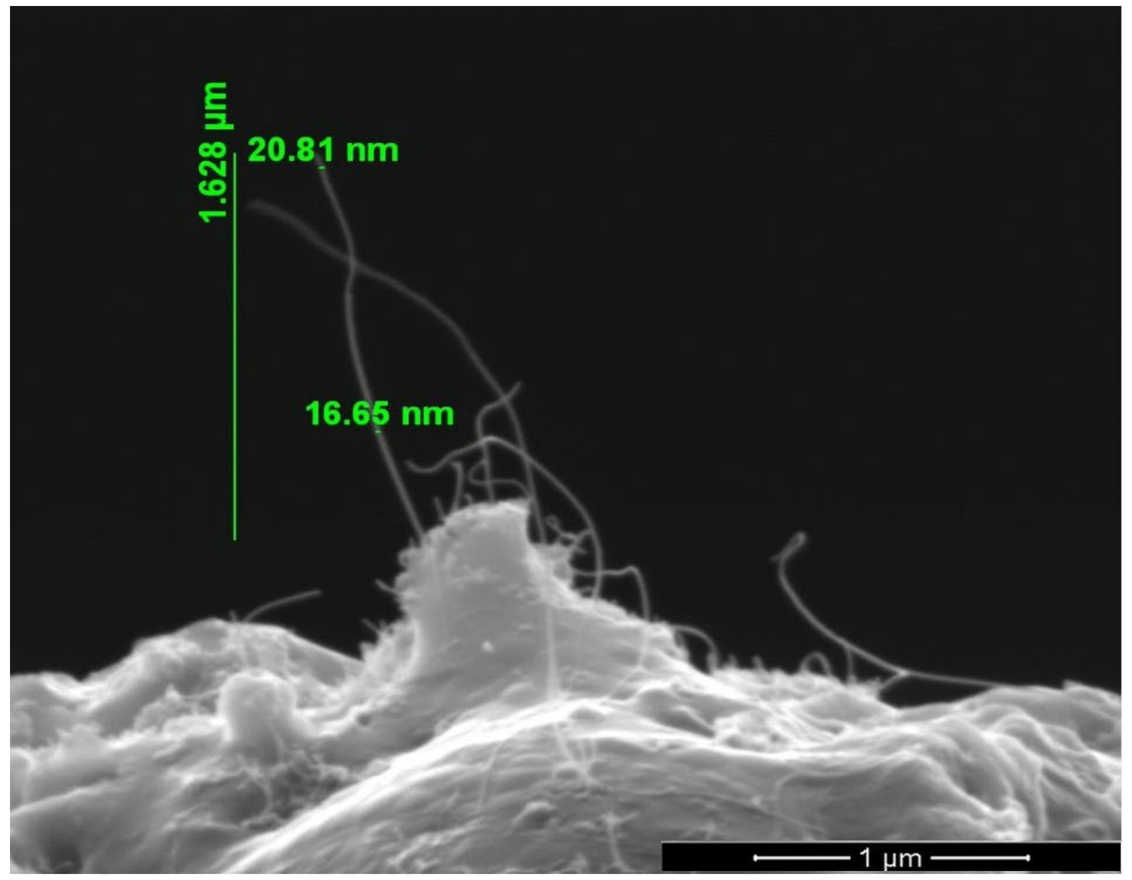
- Few-walled CNTs bonded to metal electrode with a patented matrix material.

- Matrix material has two key properties:
  1. High Resistivity – material has multiple highly resistive pathways linking electrode and CNTs. This property forces even current sharing among different CNT field emitters.
  2. Multiple levels of field enhancement – uneven surface provides multiple levels of field enhancement. Allows more CNTs to be placed closer together.

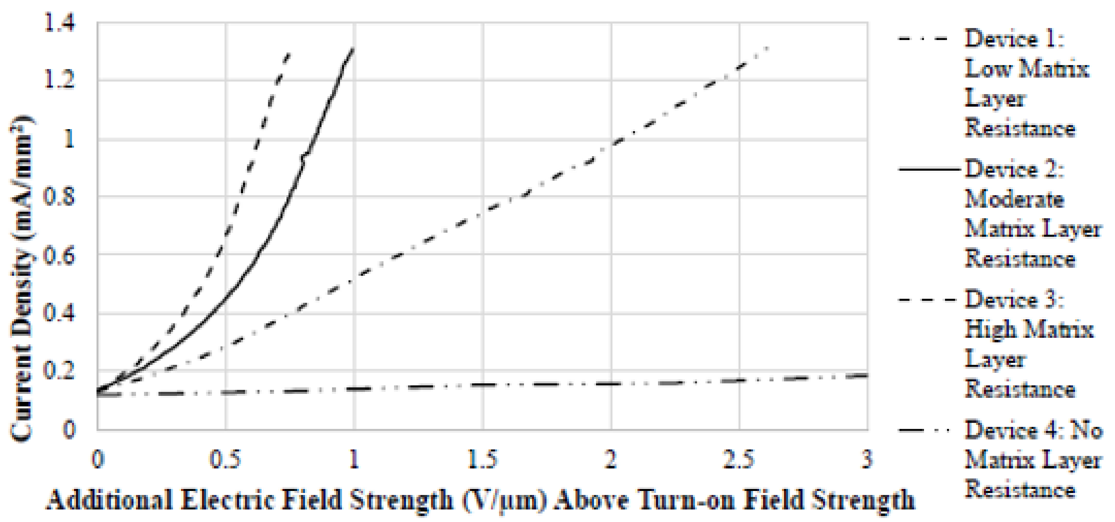
- Allows for an easily scalable field emission device; have demonstrated $1mm^2$-$100mm^2$ devices using same fabrication process.

- Provides stable long-life high current; have demonstrated up to 200mA and more than 10 years life.

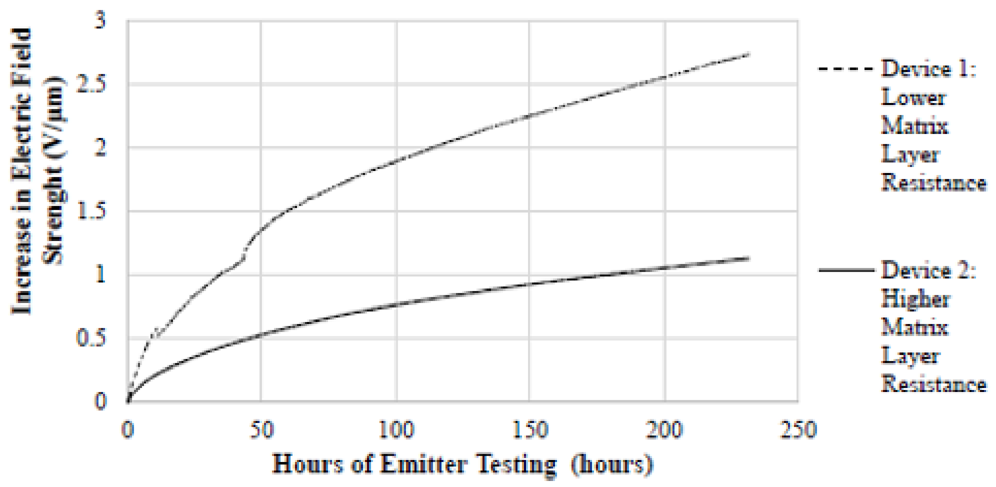




More Control of Emitter



More Stable Emitter



MICRO-X NEX TUBES

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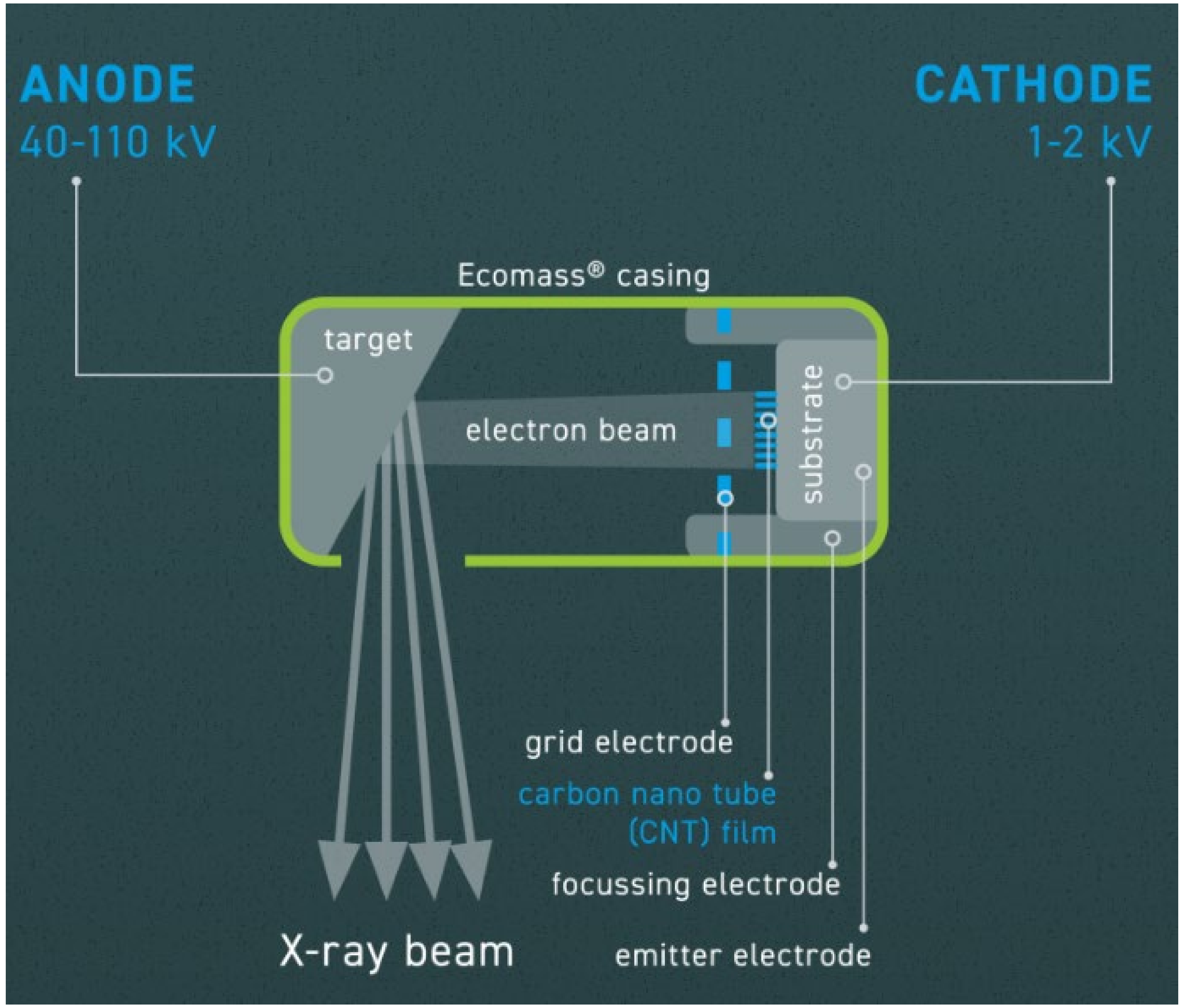
Micro-X NEX Tube



- Voltage between a grid electrode and the cathode electrode produces electric field to turn on CNT emitters.
- Voltage between anode and cathode generates the tube potential voltage, accelerating electrons from emitter into anode target to produce x-rays.
- Independent focusing voltage alters the electric fields to change the shape and size of the focal spot on the anode. Change in electric field alters path of electrons moving from cathode to anode.
- Emitter voltage completely independent of tube voltage. Emitter can be turned on to full current when anode is completely off. Anode voltage can be turn on to full voltage with no current if emitter is off.

MICRO-X NEX TUBES

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Micro-X NEX Tube

- Metal and ceramic X-ray tube specifically designed for CNT field-emission electron source.
- High component cleanliness and tube processing allows for ultra-high vacuum (10^-11 TORR). Vacuum levels key to long-life CNT performance.
- Simple robust design with no moving parts.
- Tungsten target set in a copper anode.
- No heat produced anywhere in the tube except at the focal spot.
  - Large coper anode rapidly pulls heat away from focal spot and has high bulk load.
  - Cool body enables use of custom formed tungsten filled polymer shielding to reduce weight.

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Manufacturing NEX Tubes

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Parts Cleaning

First step is to inspect the components of the tube and then clean each component.

Different materials have different cleaning processes.

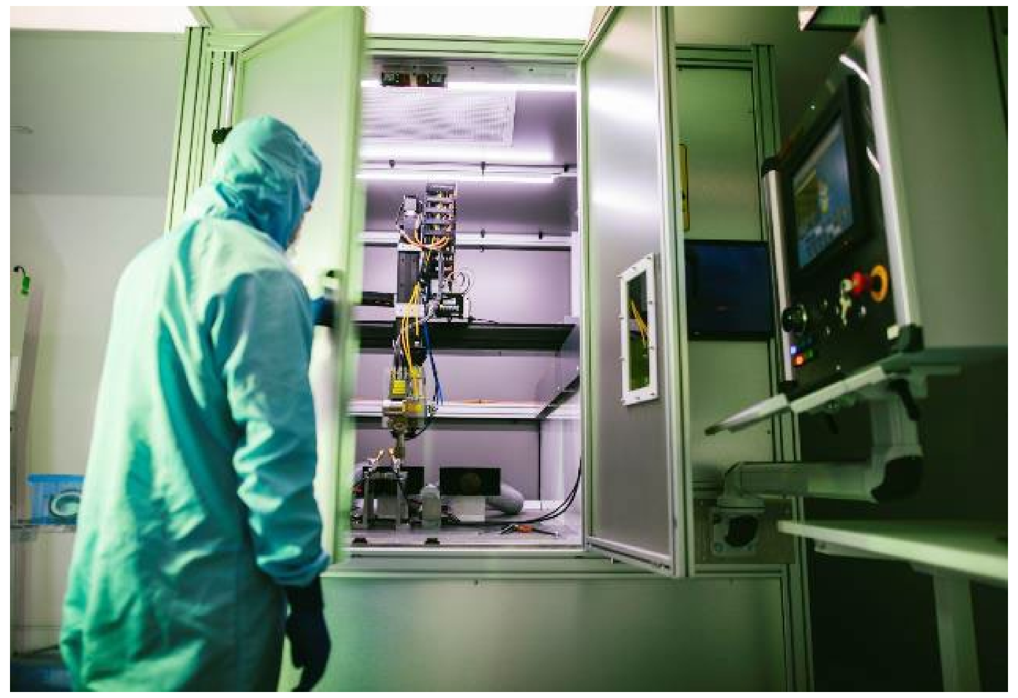
All done in a clean lab.

Tube Assembly

Cleaned components are passed into cleanroom.

Emitter is screened to ensure full performance.

Tube is assembled.



Tube Welding

Assembled tube is welded to form vacuum seal.

Automated laser welder is used to weld tube.

Laser welder is also in cleanroom controlled environment.

Tube Baking

Sealed tube is mounted movable vacuum cart and pumped down.

Tube is baked to 500C to drive out residual contamination.

Modular bakeout design is easily scalable.

Tube Conditioning

Tube is ramped up to deliver full x-ray performance.

Tube is pinched-off to seal vacuum.

Tube focal spots are measured to validate manufacturing performance.

M I C R O - X N E X T U B E S

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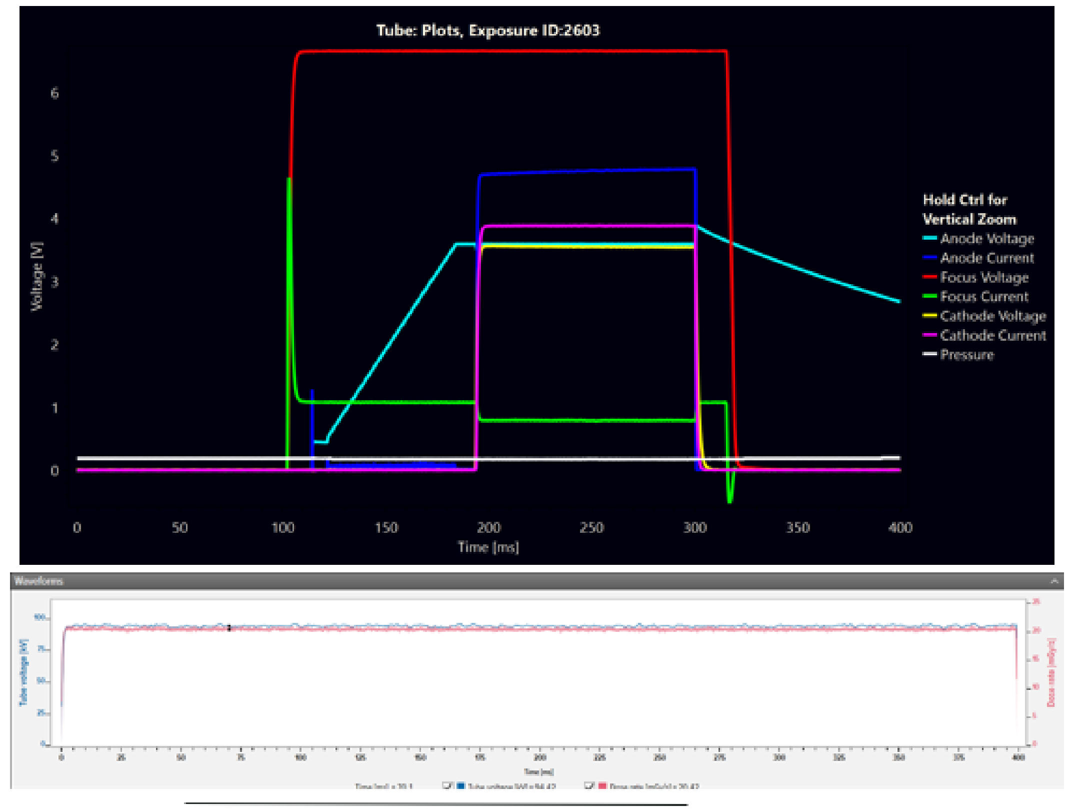
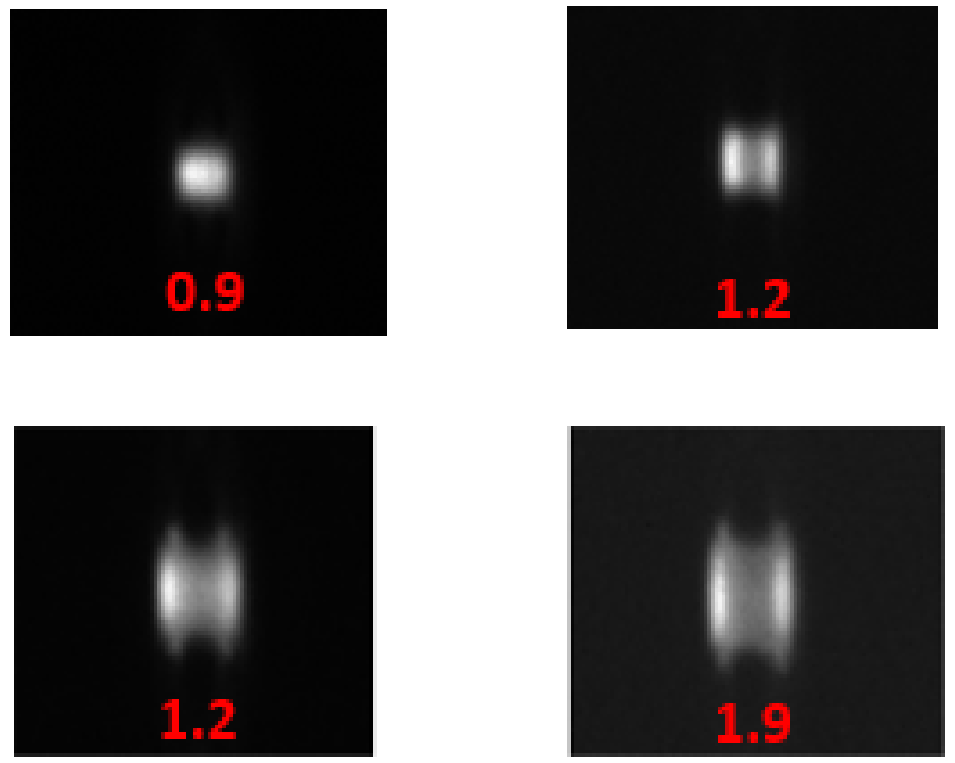
Advantages of the Technology



Electronic Control

Tube dose precisely follows the emitter voltage.

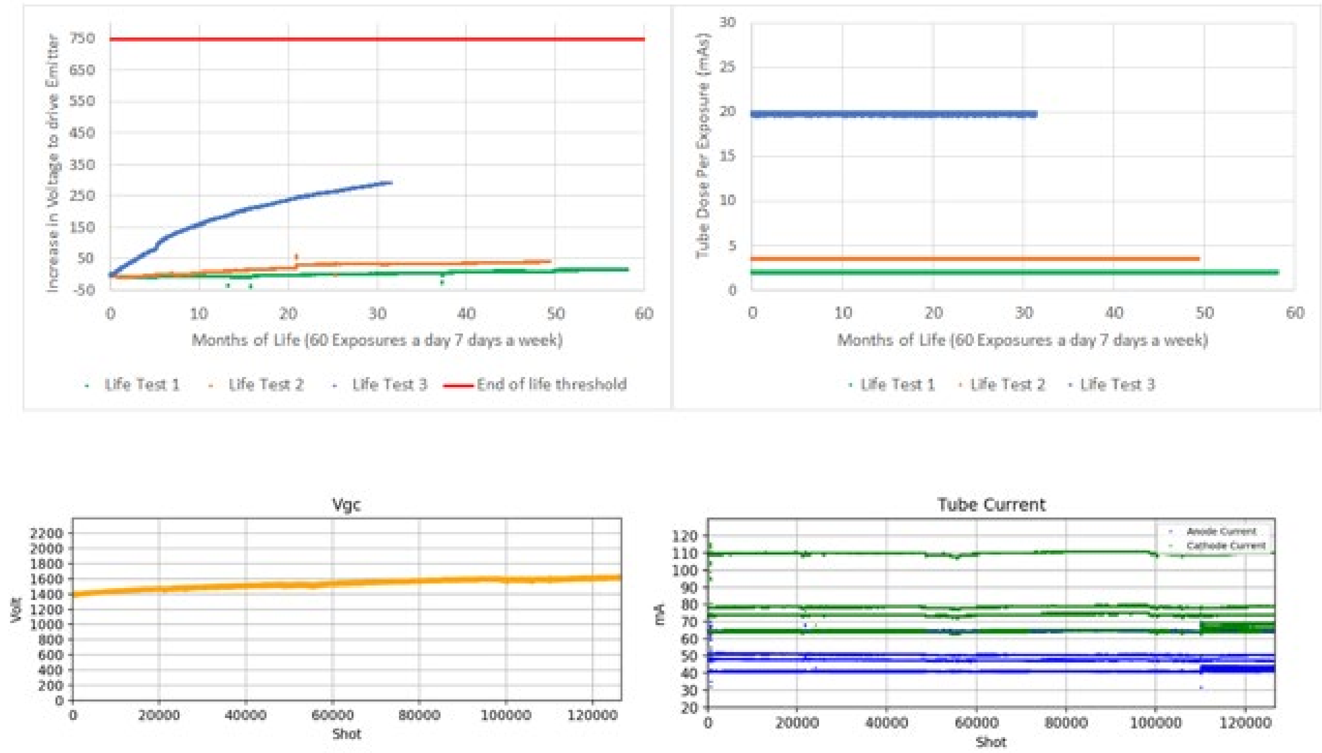
Capable of rapid and precise pulses of x-ray dose that appear as perfect RECT functions on dose meter.



Dynamic Focal Spot

Adjustable focal spot to manage the heat on the anode.

Focal spot mostly independent of the emitter size.



Stable Long-Life

Tube performance: current, dose, and focal spot stays completely constant through life of tube.

Tube has demonstrated 10+ years of life.

Emitter doesn't fail instantaneously, can track slow degradation of emitter.

Small and Simple

Technology allows for smaller and lighter x-ray tube designs.

No moving parts or oil allow for simple design.

Enables custom tubes to be design for each application.

M E D I C A L   A P P L I C A T I O N S

Designing Custom Tube for Mobile Radiology

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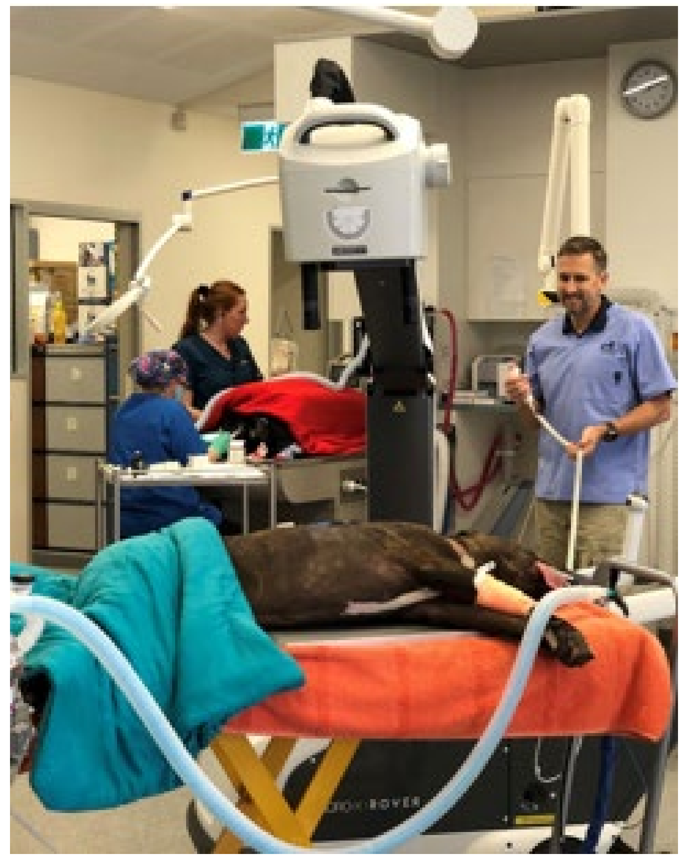
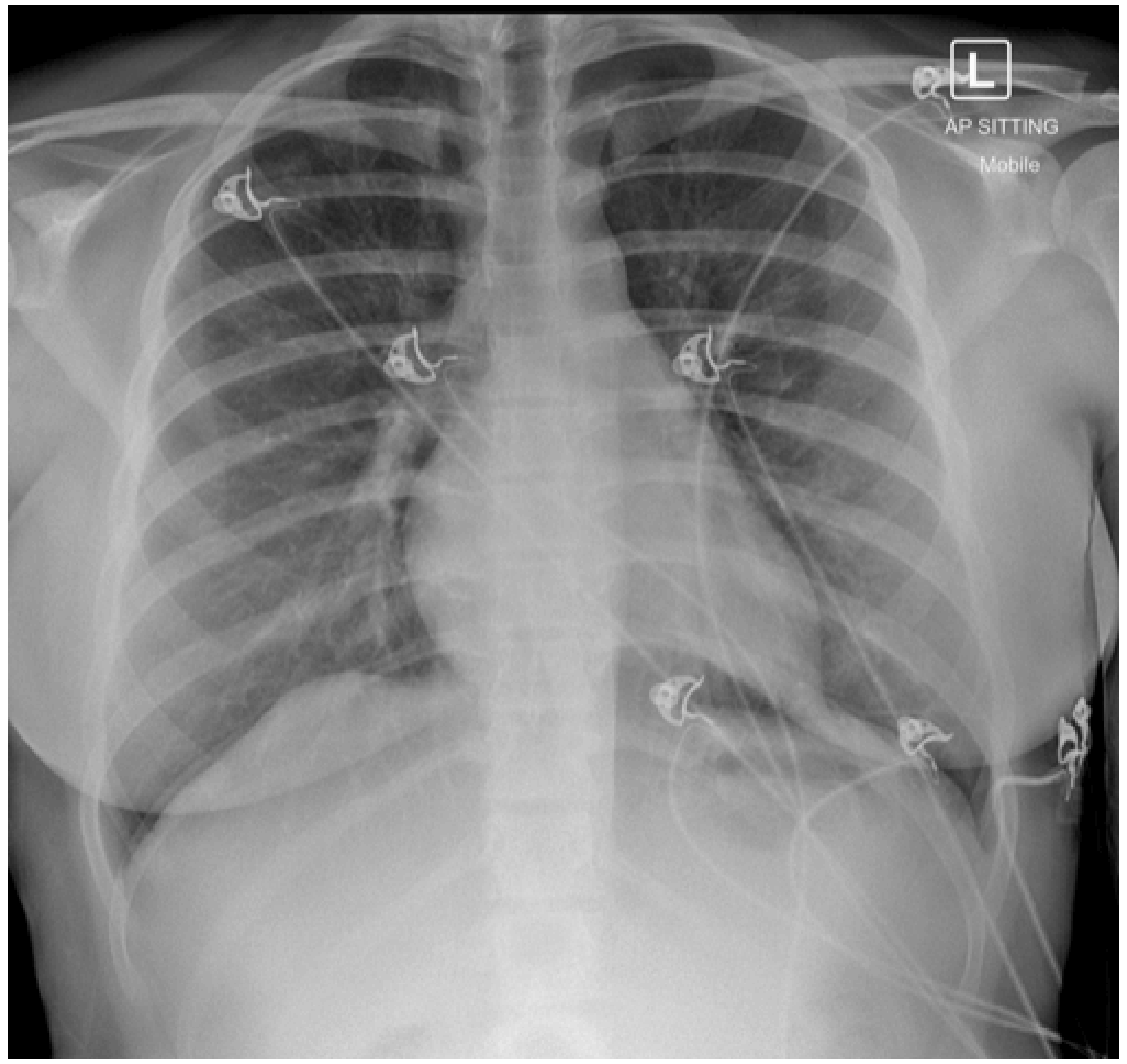
- Fundamental challenge of mobile radiology is safely suspending a portable x-ray tube over patient.
  - Weight and support must be added to system to counterbalance weight of tube.
  - Results in mechanically complex systems with poor reliability or a challenging to move systems with reduced imaging.

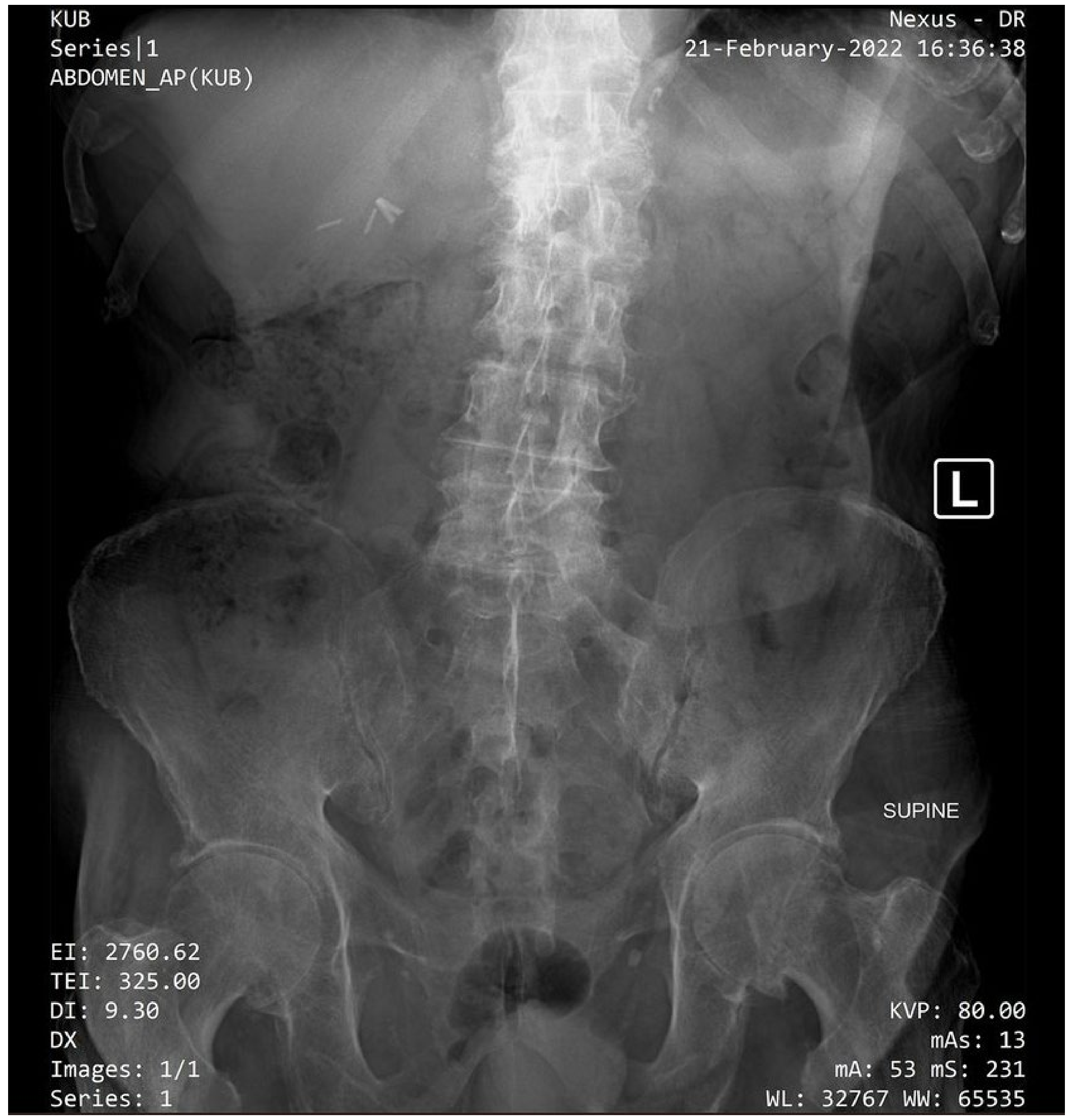
- Micro-X used unique advantages of NEX technology to design a tube optimized for mobile radiology:
  - **Lightweight** – tube is 2kg & entire head (with collimator) is 6kg. Enables lightweight & robust system.
  - **Adjustable tube power** – goes up to 9kW for short exposures, enables fast chest exposures.
  - **Dynamic focal spot** – leverages physics of digital radiology to use larger focal spot to accommodate higher power with fixed anode.
  - **Efficient dose** – uses precise electronic control to minimize power loss and operate off LiFePO4 batteries.

MEDICAL APPLICATIONS

Lightweight, Rugged, and Reliable with High Quality Imaging







- High-quality digital X-ray images covering full range of mobile exposures.
- Demonstrated clinical equivalence to conventional mobile x-ray unit in blind reader study.
- Currently utilized in a board range of applications: hospitals, veterinary care, deployed field hospitals in Ukraine, in-home care, and sports stadiums.

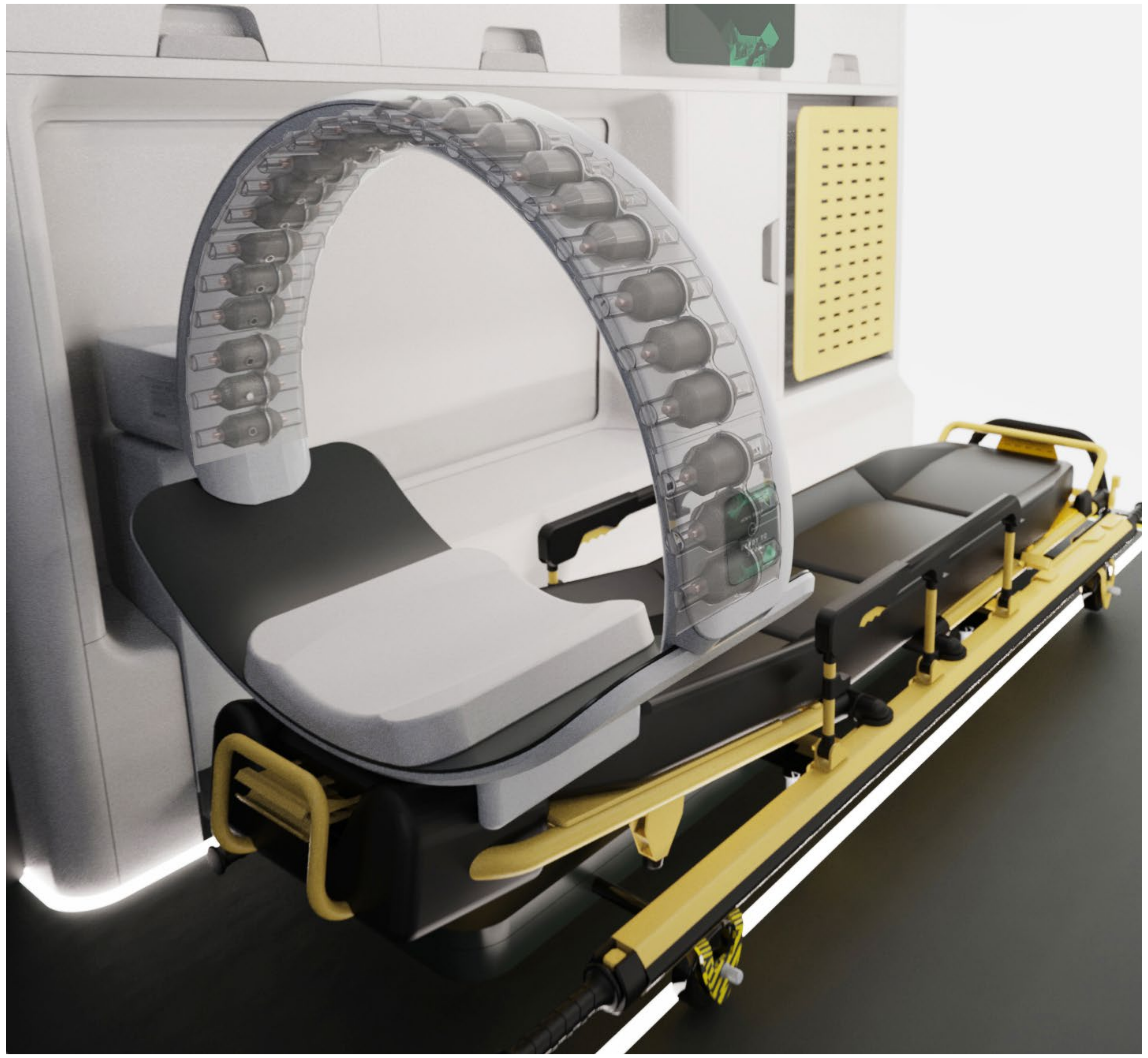
MEDICAL APPLICATIONS

Portable Stroke Imaging

- Funded by Australian Stroke Alliance and Medical Futures Fund to develop a stroking imaging system:
  - ➢ Capable of imaging small bleeds in the brain.
  - ➢ Rapidly image the whole brain – image in 10 seconds or less.
  - ➢ Small, light, and rugged to be deployed into any ambulance or medical aircraft.
  - ➢ Cost effective to be widely deployed to enable early diagnosis of ischemic and hemorrhagic strokes.

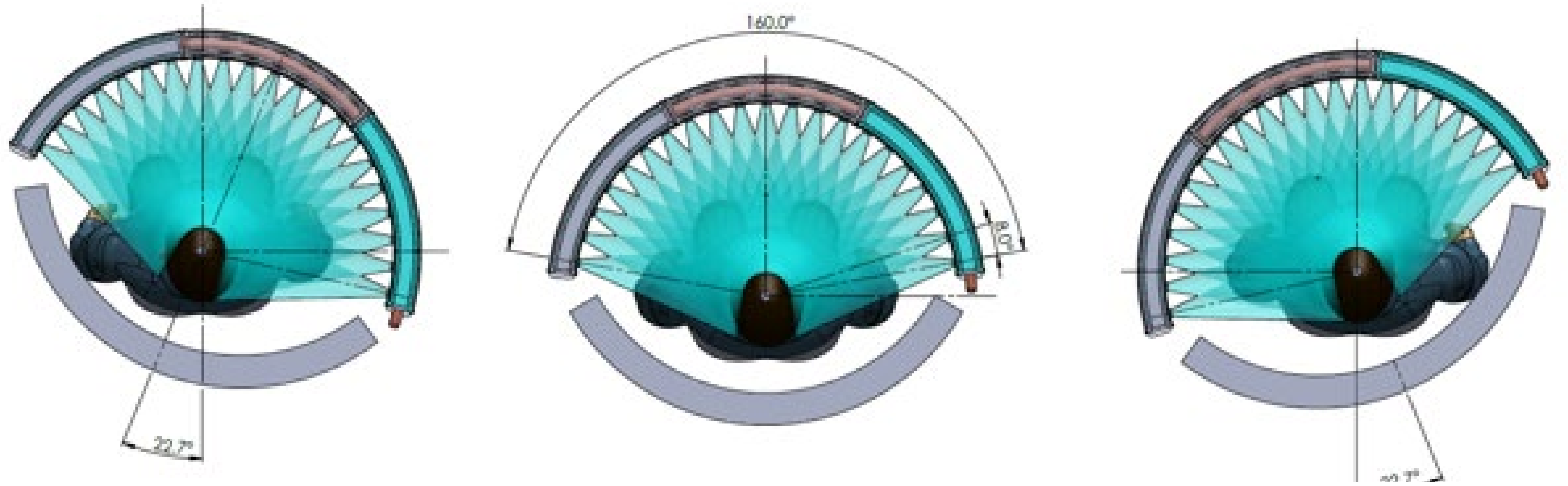
- Requires new dedicated CNT X-ray tube that:
  - ➢ Small, robust, and modular– achieved through small tube rather than a multi-beam tube.
  - ➢ Rapid switching between different x-ray tubes.
  - ➢ 100kV and 0.5-1mAs per view.

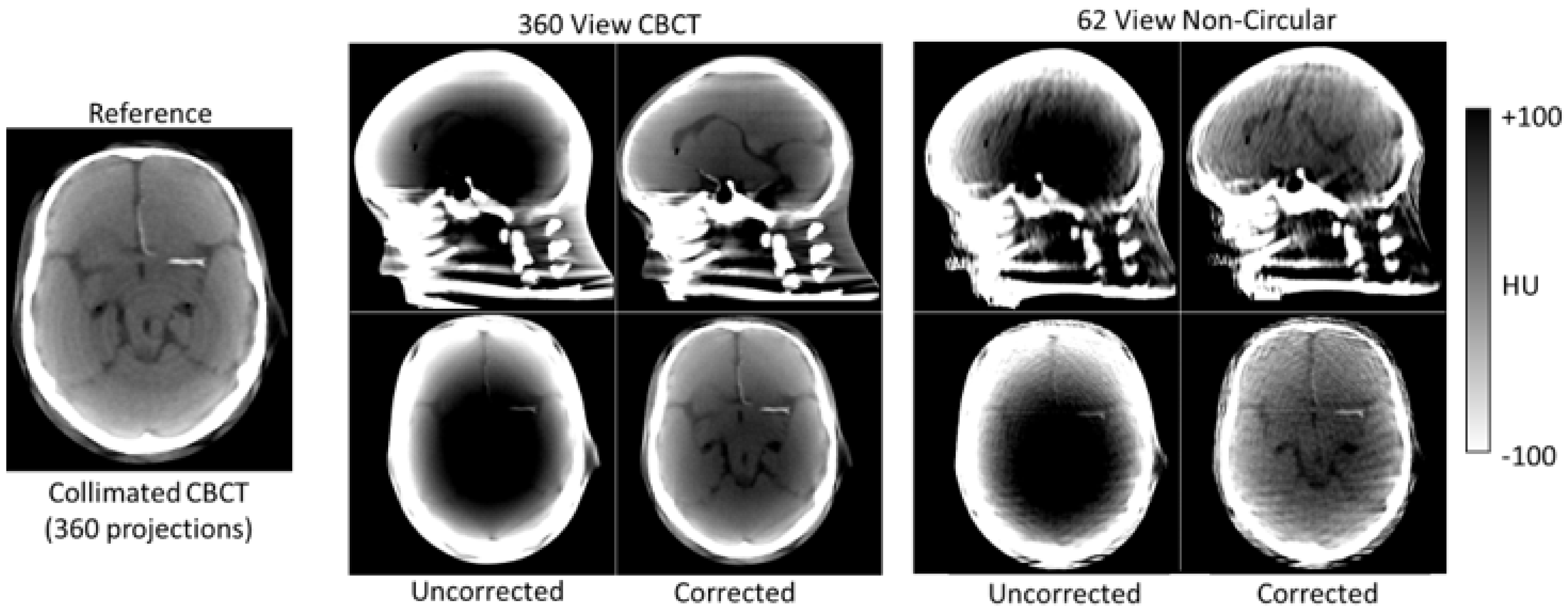
- Combined with curved large area detector to generate cone-beam CT, enables rapid imaging of entire brain.



M E D I C A L   A P P L I C A T I O N S

Portable Stroke Imaging





- Partnered with Johns Hopkins I-START Laboratory.

- Imaging Geometry – use simple system rotational index.
  - System starts at -22.5 degrees and all tubes expose once for a stationary scan of 21 different views on curved detector.
  - Entire system rotates 22.5 degrees and then each tube exposes again when system is stationary.
  - Repeated one more time for total of 45 degrees to ensure full CT coverage and 63 total views.

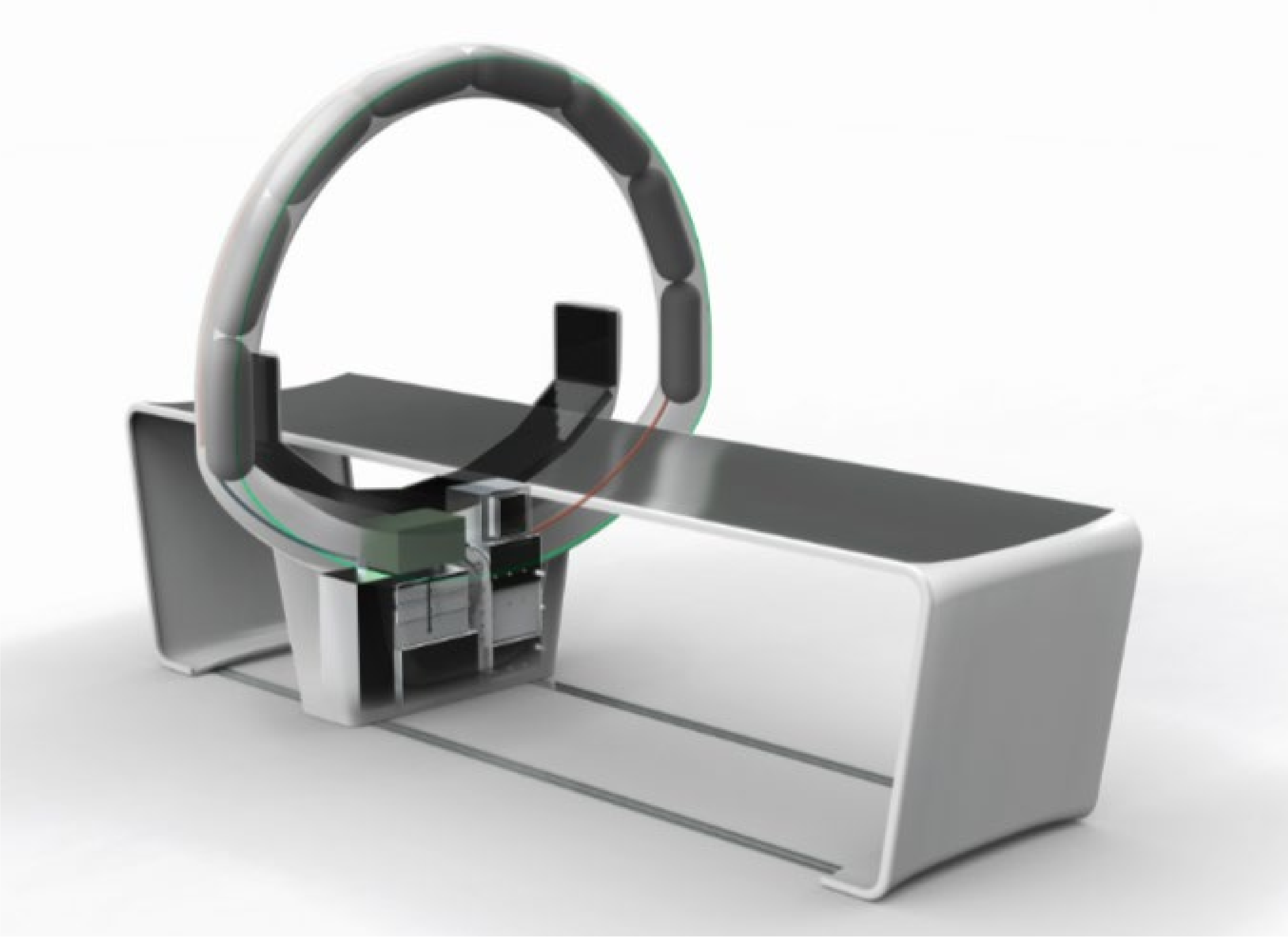
- Reconstruction Algorithms
  - Initial use a model-based iterative reconstruction algorithm with smoothing prior.
  - Investigating diffusion-based imaging with posterior sampling.

- Scatter correction
  - Model unique geometry to account for non-symmetric scatter.
  - Investigating convolutional neural network to model scatter estimate scatter in each projection view.

MEDICAL APPLICATIONS

Future Applications

- Exploring concepts for full CT based on CNT X-ray tubes and fixed gantry CT concepts.
- Concept relies on multi-beam X-ray tubes to increase the density of views with target of 128 different views distributed along the arc.
- Use of conventional CT detector and translate system for “fixed gantry” helical CT scans.
- Dynamic control of each emitter allows for very short and high current pulses from each x-ray view.
- Fixed gantry, lightweight tubes, linked high-voltage and cooling enables simpler more cost-effective design.

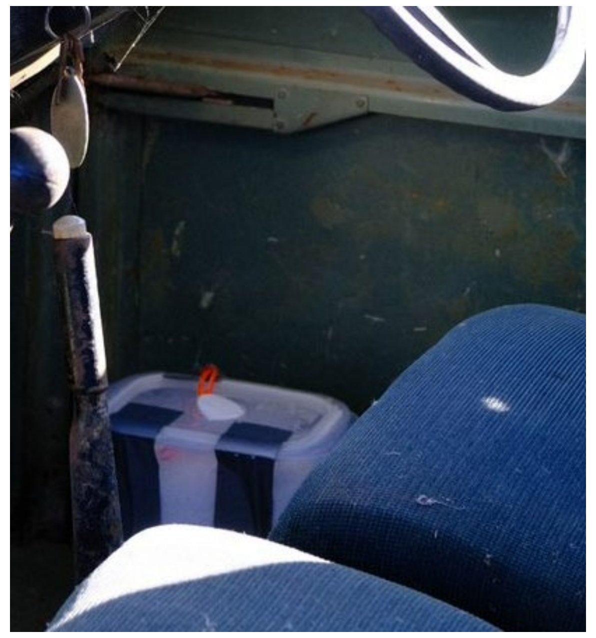


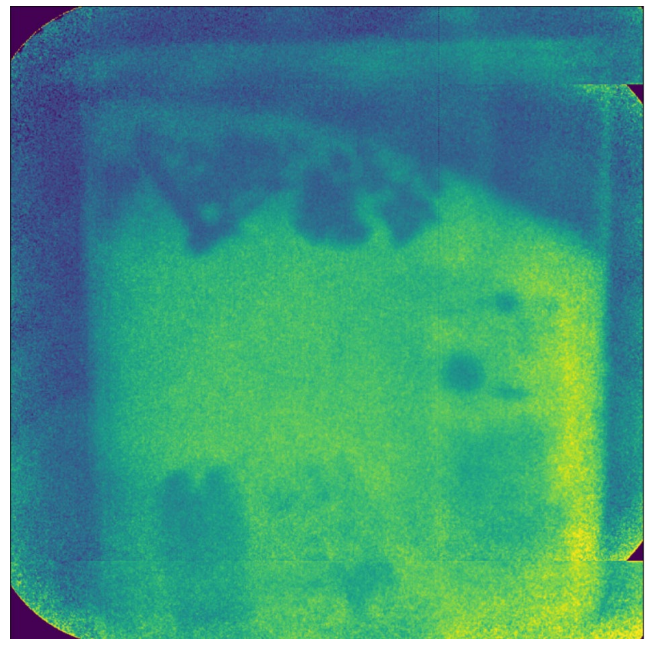
SECURITY APPLICATIONS

Other Micro-X NEX Technology based products

Argus – X-ray Camera

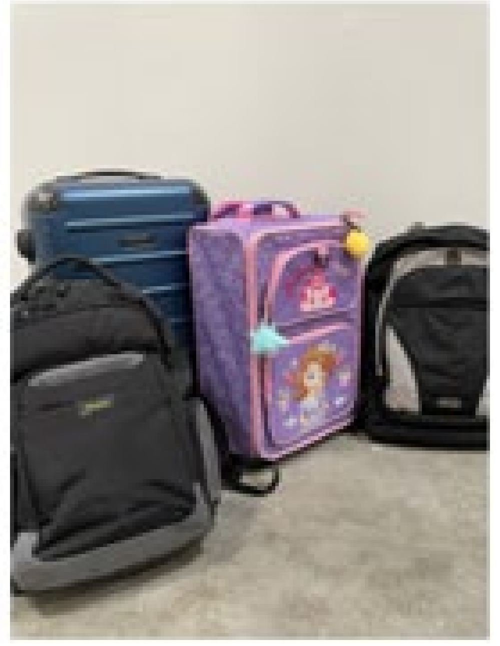
2D "Snap-Shot" image of X-ray Backscatter for EOD

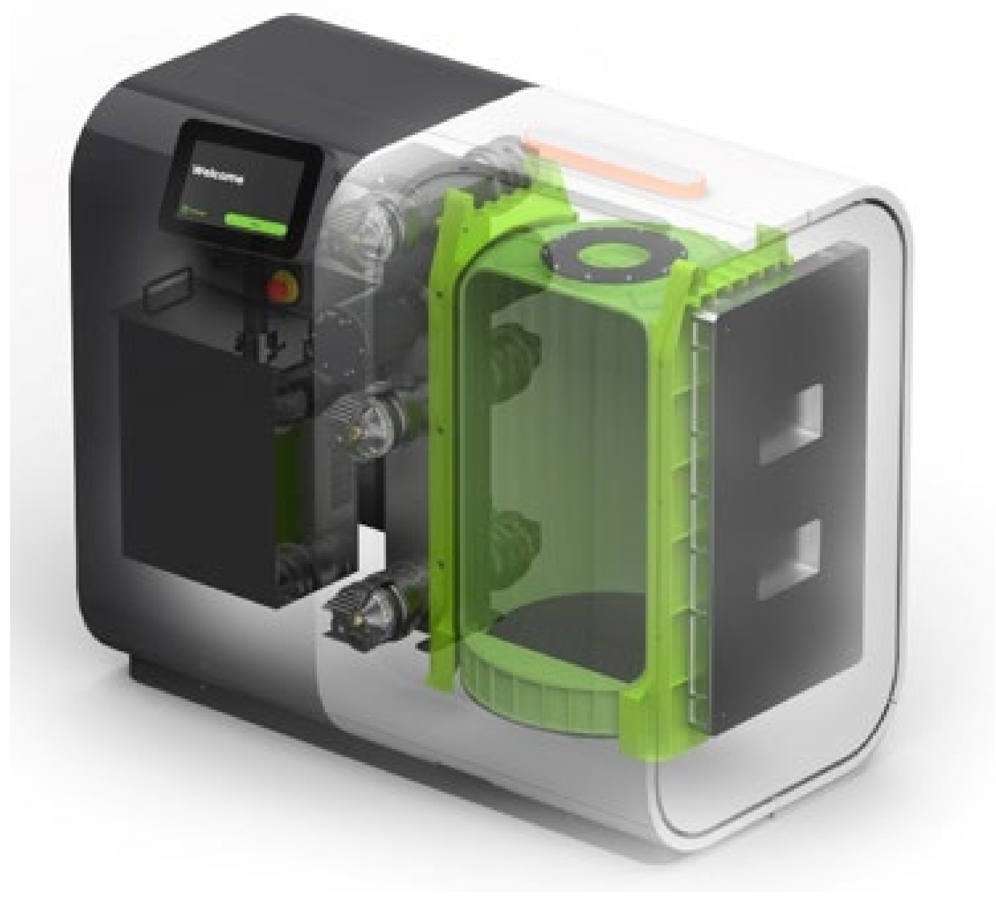


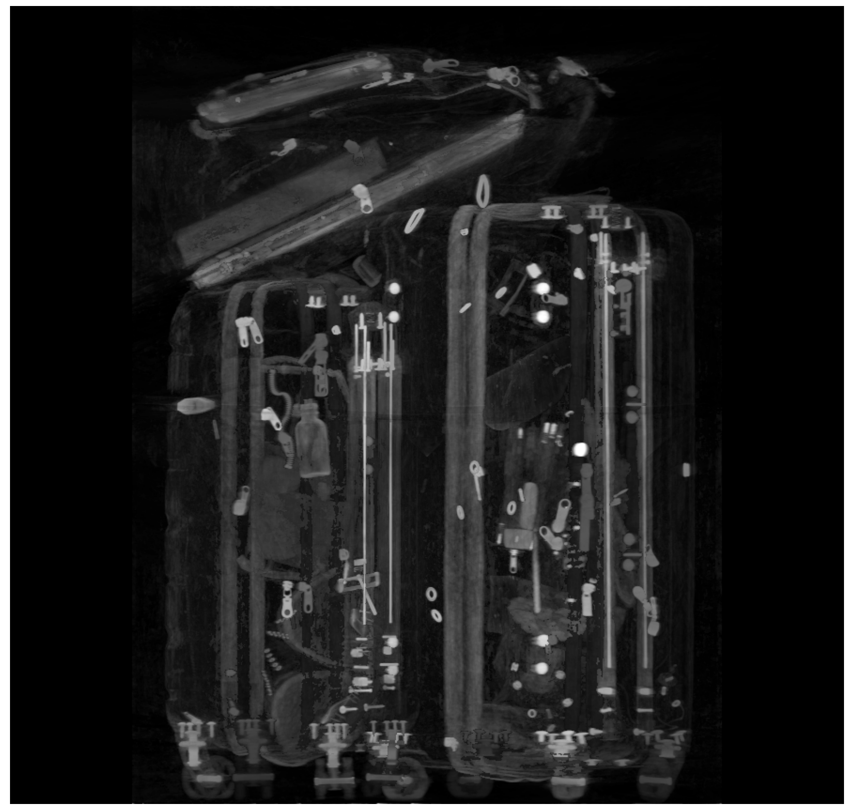


CT Baggage Screening

DHS S&T and TSA Funded Development Project







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Thank You

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