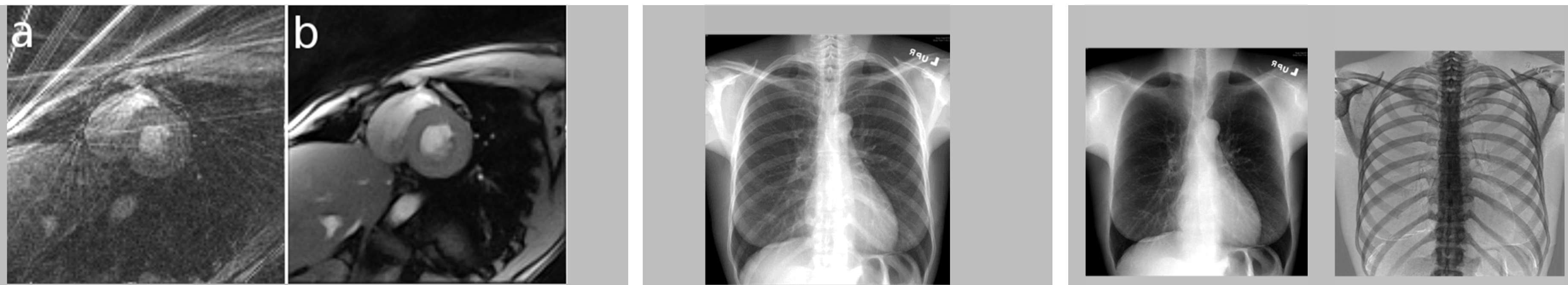
SAND2016-8270C

Exceptional service in the national interest

Sandia National Laboratories



Comparing Imaging Capabilities of Multi-Channel Detectors to Traditional X-Ray Detector Technology for Industrial and Security Applications

Edward S. Jimenez, Noelle M. Collins, Erica A. Holswade, Madison L. Devonshire, and Kyle R. Thompson,

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2011-XXXXP

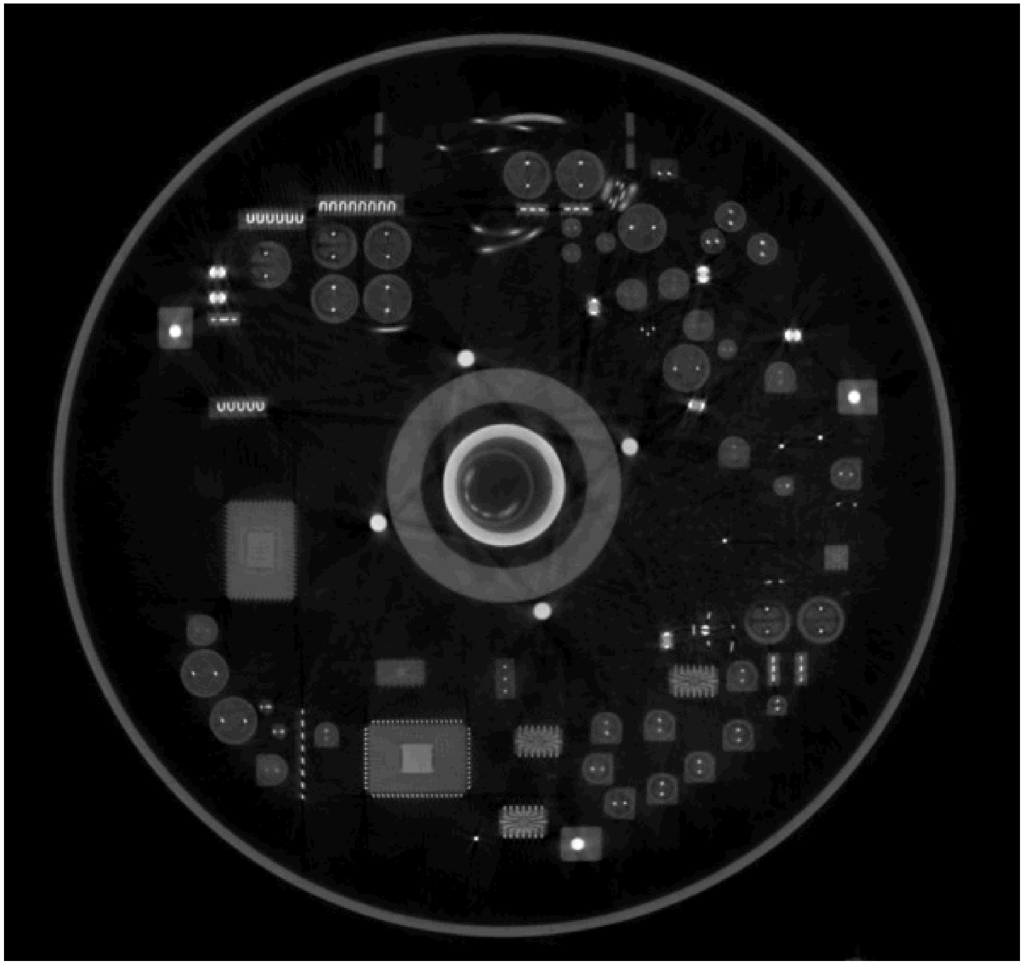
Objective

- Create an advanced capability at Sandia National Laboratories
  - High Energy Color X-ray Imaging for R&D in Industrial and Security Applications.

- Industrial Applications
  - Verification and Validation
  - High-Magnification Computed Tomography
  - High-Energy Computed Tomography
  - Quality Assurance
  - Anomaly Detection

- Security Applications
  - Checkpoint Screening
  - Materials Identification
  - Real-time Multi-Energy CT

Example: CT Artifacts

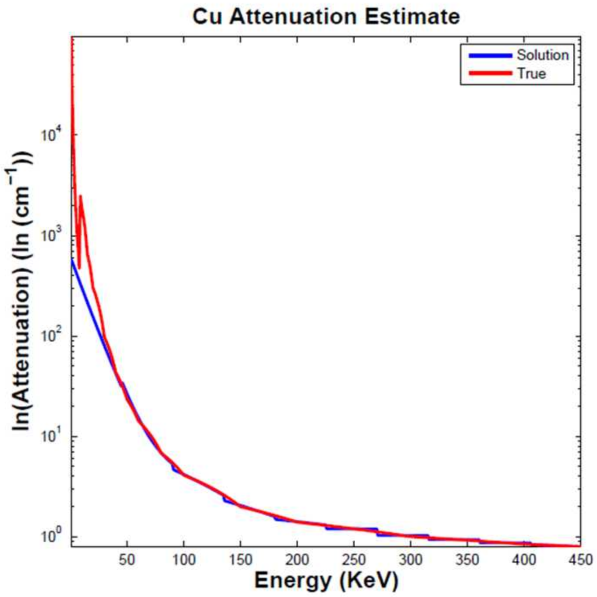


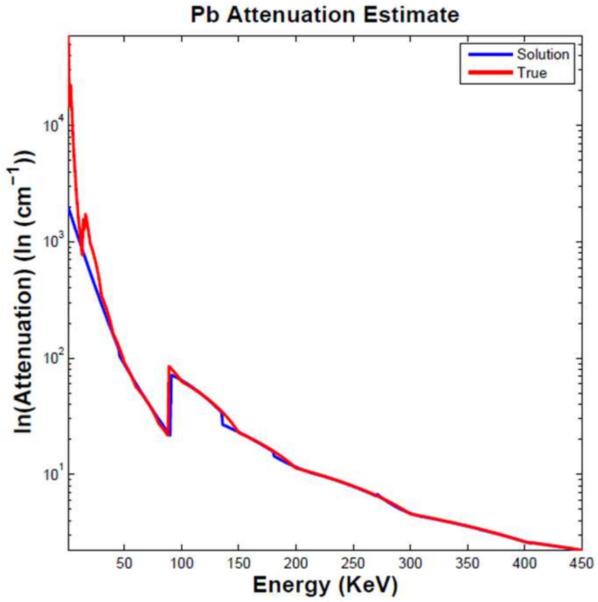
Example: Material Identification

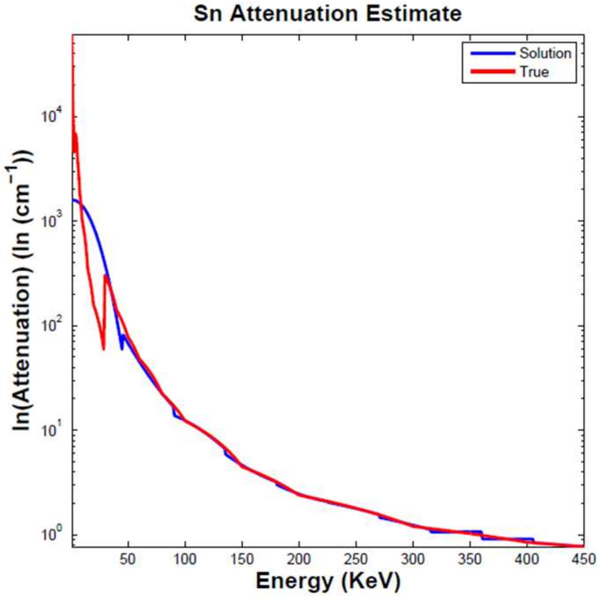
Noise

Constraints

Geometry







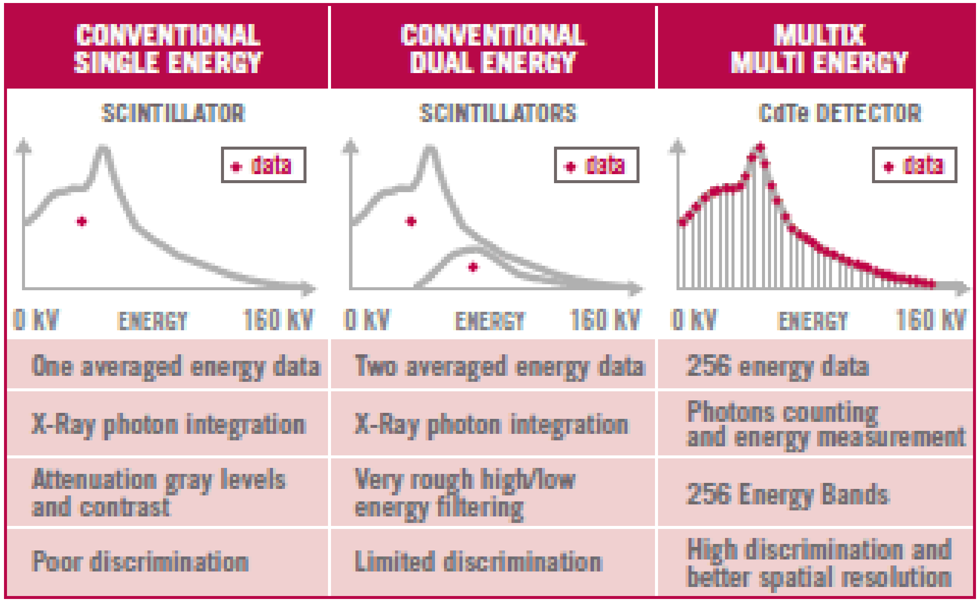
Example: LLNL

- Developed by Wurtz et. Al. in 2009
- Lawrence Livermore National Laboratories
- Evolution on Dual-energy Radiography Methods
- Does not require material thickness or geometry information

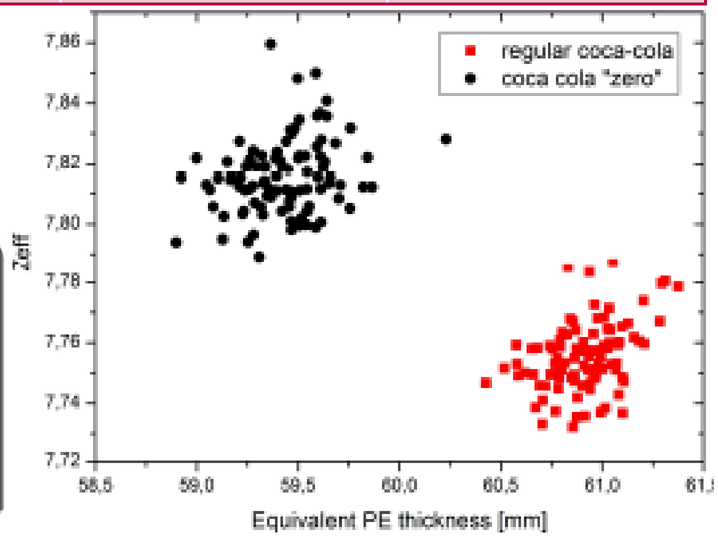
$$\left(\frac{\frac{I}{I_0}|_l}{\frac{I}{I_0}|_h}, ln\left(\frac{I}{I_0}|_l\right) \right)$$

Solution: Energy Resolved Imaging

- Virtually mono-energetic energies.
  - Results in cleaner data for analysis and segmentation.
- Single scan for multi-energy data!
  - Reduce dose and scan time
- High Risk: Very new technology;
  - Large payoff for many engineering, science, and security applications that could significantly evolve each area.



CONVENTIONAL SINGLE ENERGY	CONVENTIONAL DUAL ENERGY	MULTIX MULTI ENERGY
SCINTILLATOR	SCINTILLATORS	CdTe DETECTOR
One averaged energy data	Two averaged energy data	256 energy data
X-Ray photon integration	X-Ray photon integration	Photons counting and energy measurement
Attenuation gray levels and contrast	Very rough high/low energy filtering	256 Energy Bands
Poor discrimination	Limited discrimination	High discrimination and better spatial resolution



Figures from Multix Detector Documentation

Energy Resolved Imaging in Medicine

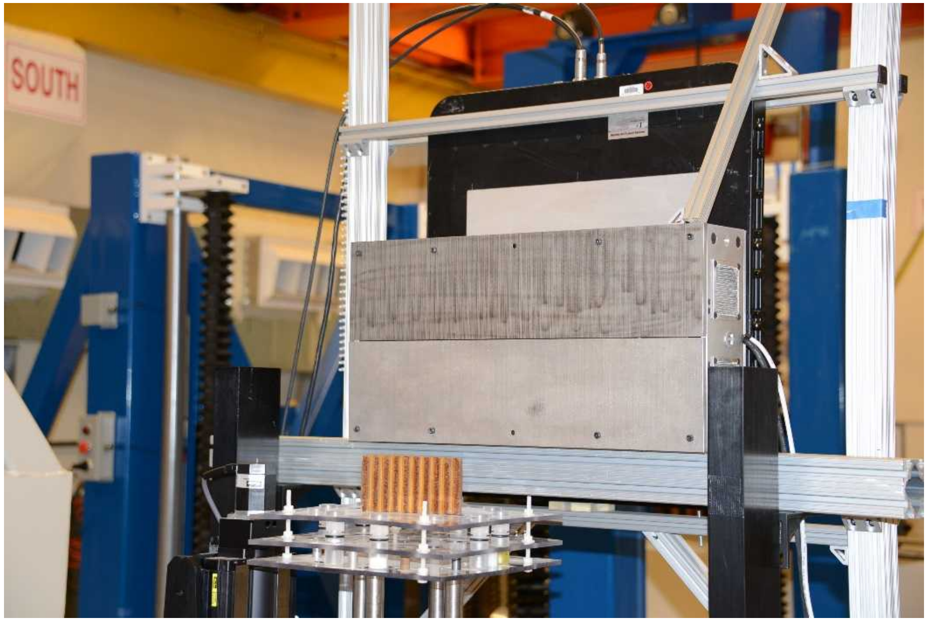
- Dual-Energy Radiography
  - Bone Mineral Density
  - Tissue Emphasis
  - Material Removal

- Color X-ray Imaging
  - Low-Energy Applications
  - Some non-medical applications
  - Computed Tomography

Multix Detector

- Sandia has acquired a 5 module Linear Array Detector
  - Calibrated for up to 300 keV X-rays
    - Only one we know of in existence
  - 128 Pixels per Module / 640 Total Pixels
  - 1M Counts per second per pixel
  - 128 channels
  - ~2.34 keV wide channels
  - 0.5 meters wide
  - 0.8mm pixel pitch

System Configuration

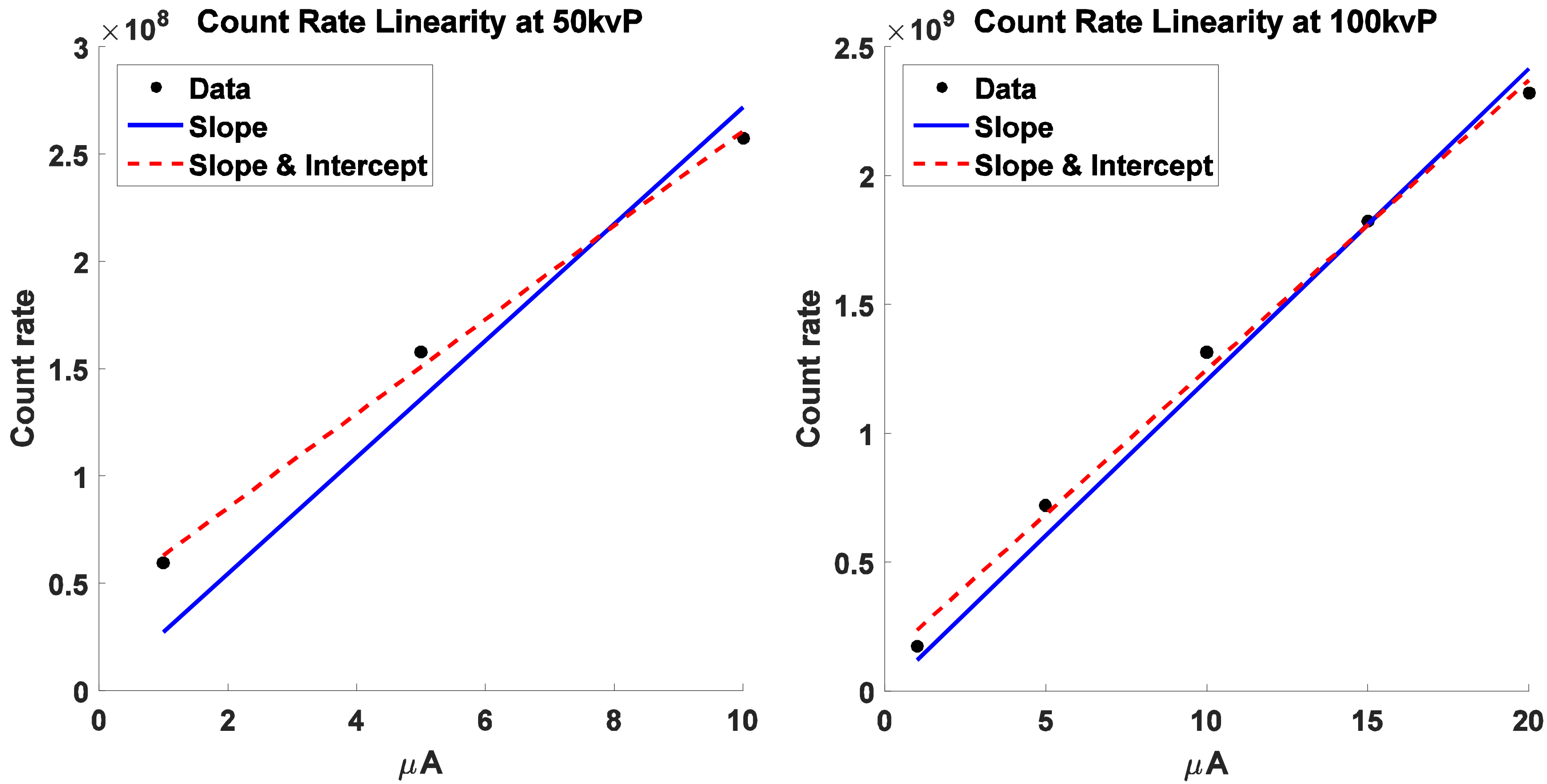


Technology Integration Experiments

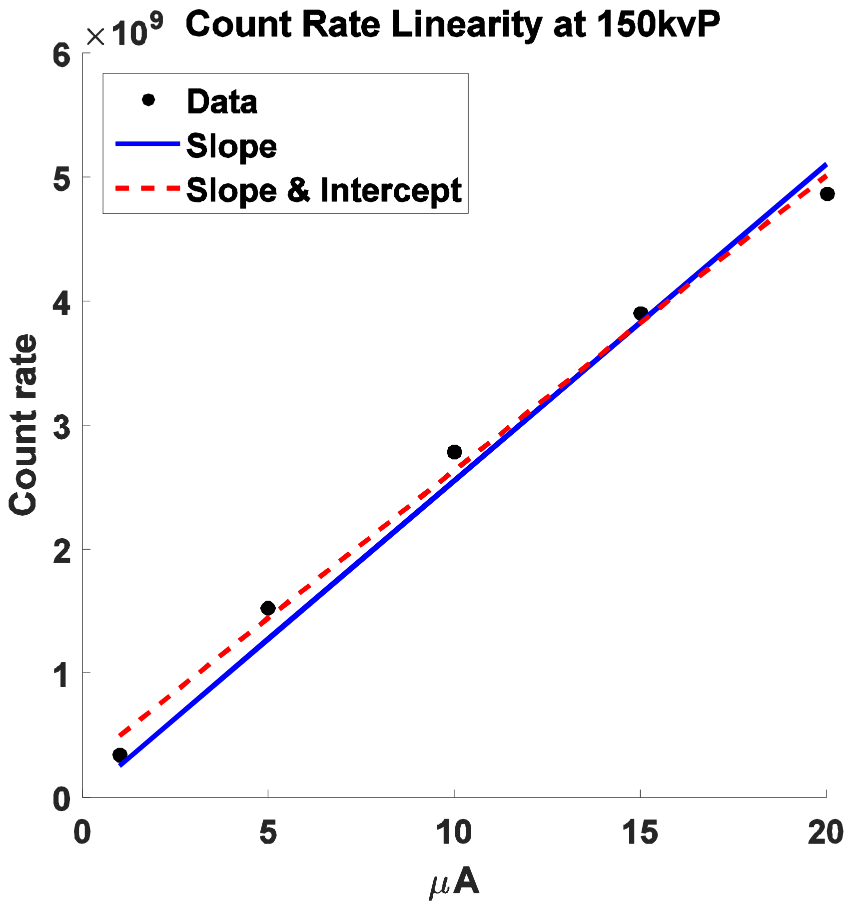
- Count rates
  - 1M/pixel advertised
  - Test at various currents
- Attempt Metrics/Measurements
  - Collins et. Al.
  - LLNL Metric
- Mean pixel output
  - Materials of interest
- Normalized Spectrums
- SNR
  - Across Pixels
  - Across Energy

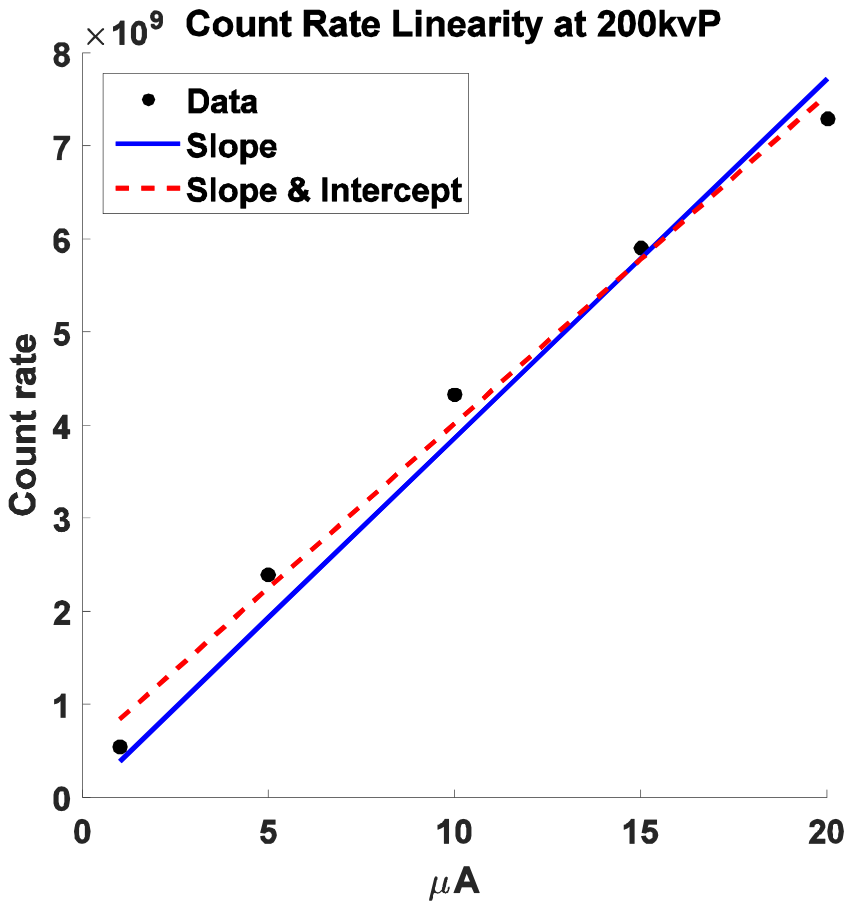
- System
  - Comet 450keV
    - Only run up to 300kVP
    - ~6 meter source to detector
  - Multix Detector
    - 128 Channels
    - 640 Pixels
- Materials (sheets)
  - Lead (0.76mm/0.03in)
  - Tin (0.813mm/0.032in)
  - Copper (0.2mm/0.008in)
  - Polyethylene (13.5mm/0.53in)
  - Water (59.2mm/2.33in)
    - Cubic plastic container

Count Rate 50 & 100keV

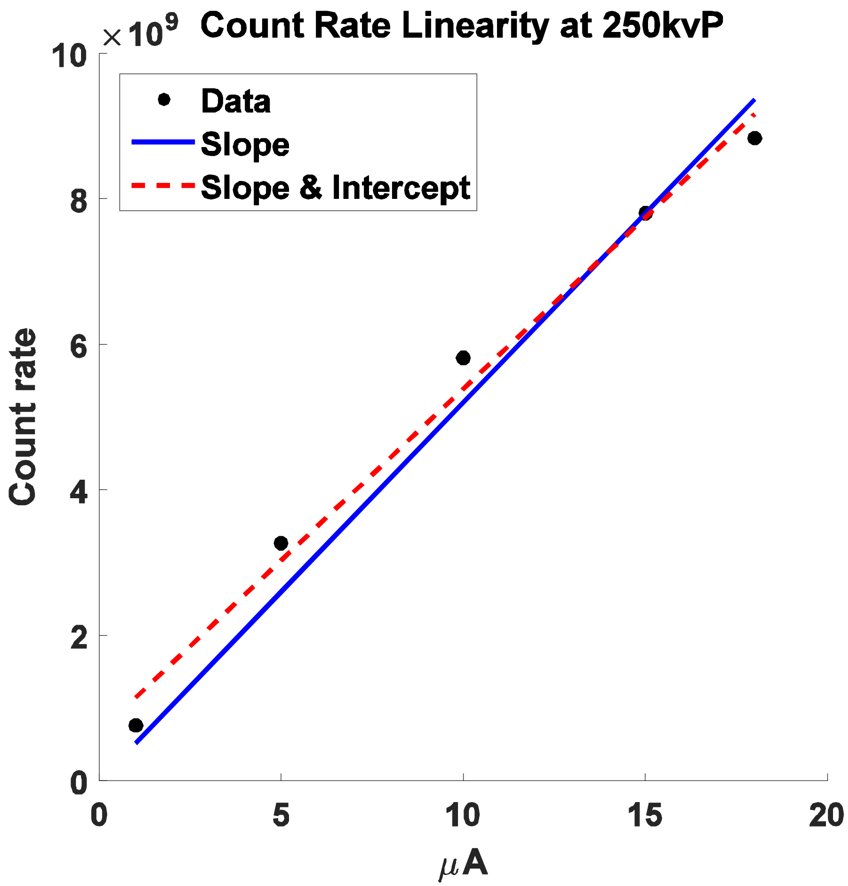


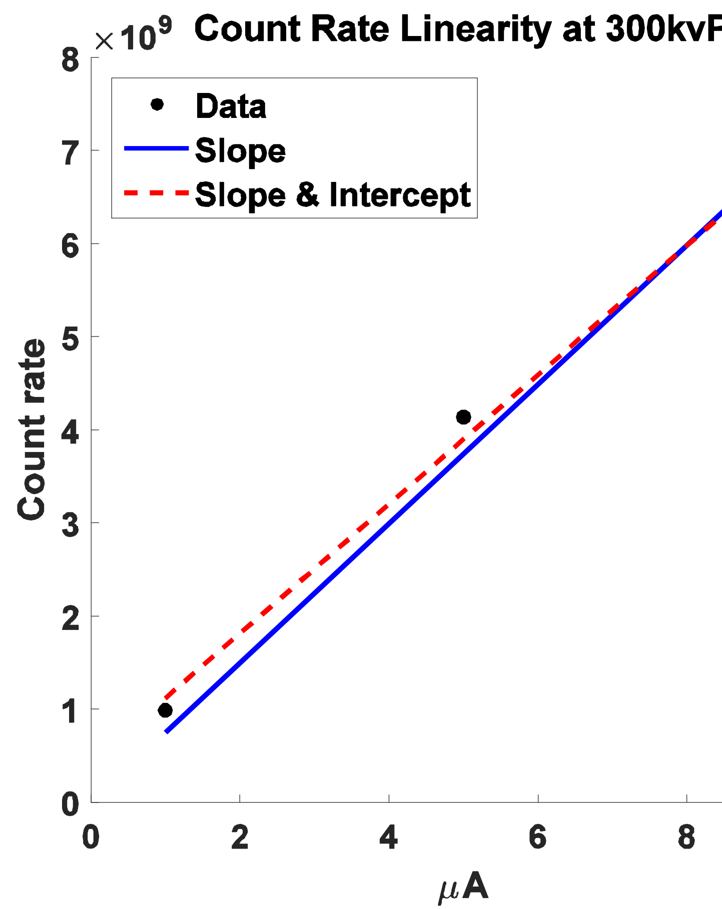
…150keV & 200keV





…250keV & 300keV





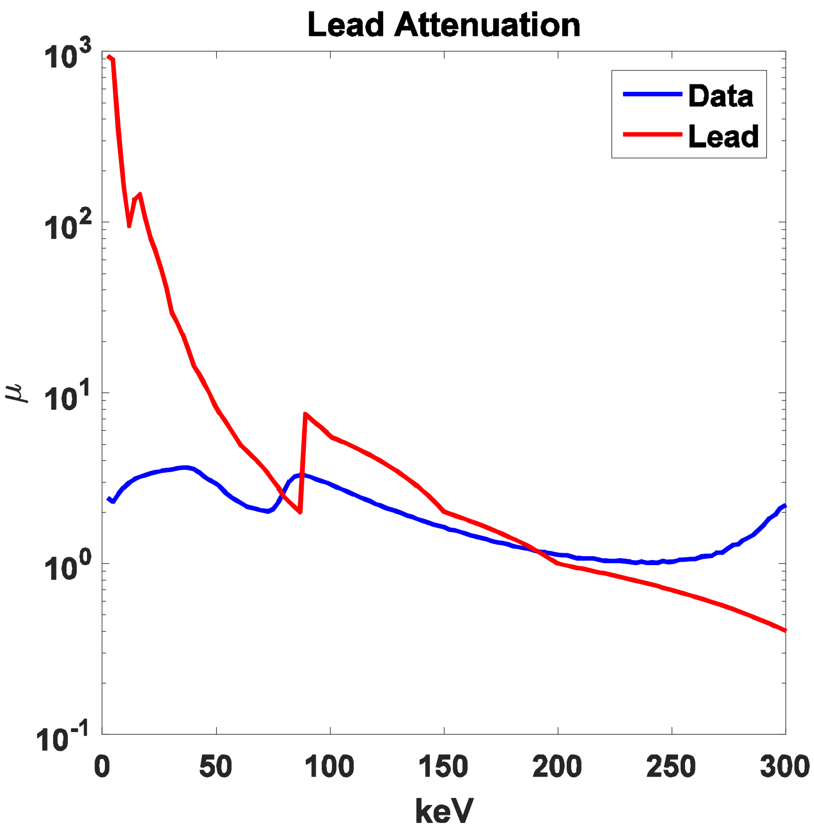
Direct Calculation

- Known information
  - Experimental Geometry
  - Material density and thickness
- Beer's Law
  - **μ** - linear attenuation coefficient
  - l – thickness
  - ρ - density
  - I_{in} - initial spectrum
  - I_{out} - attenuated spectrum

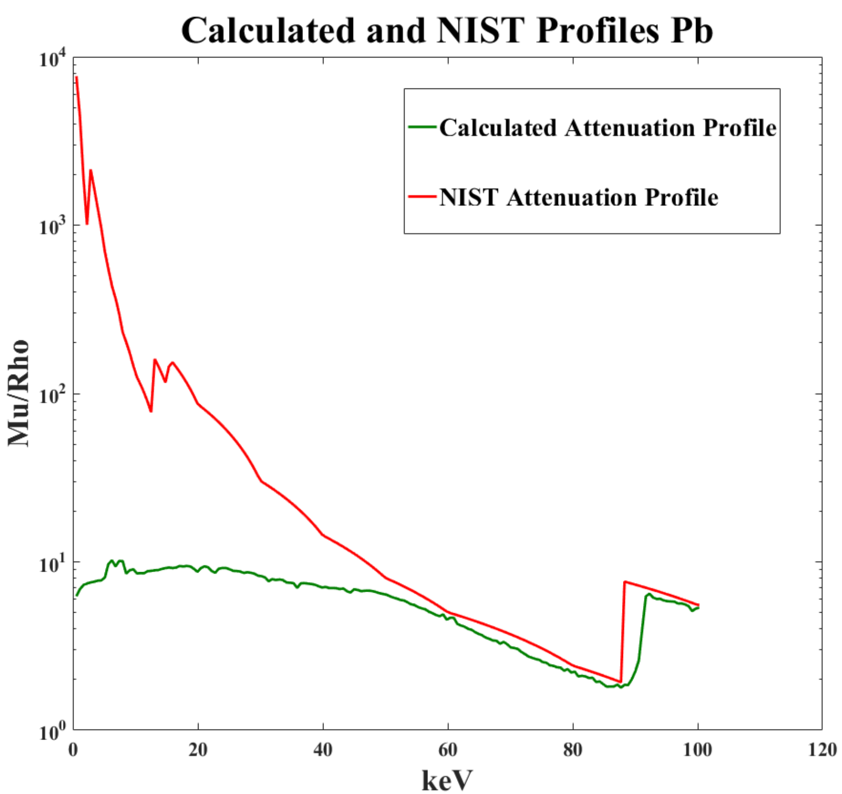
$$\frac{\mu}{\rho} = -\frac{1}{l} \cdot \frac{1}{\rho} \cdot ln\left(\frac{I_{in}}{I_{out}}\right)$$

Lead Estimate

Multix

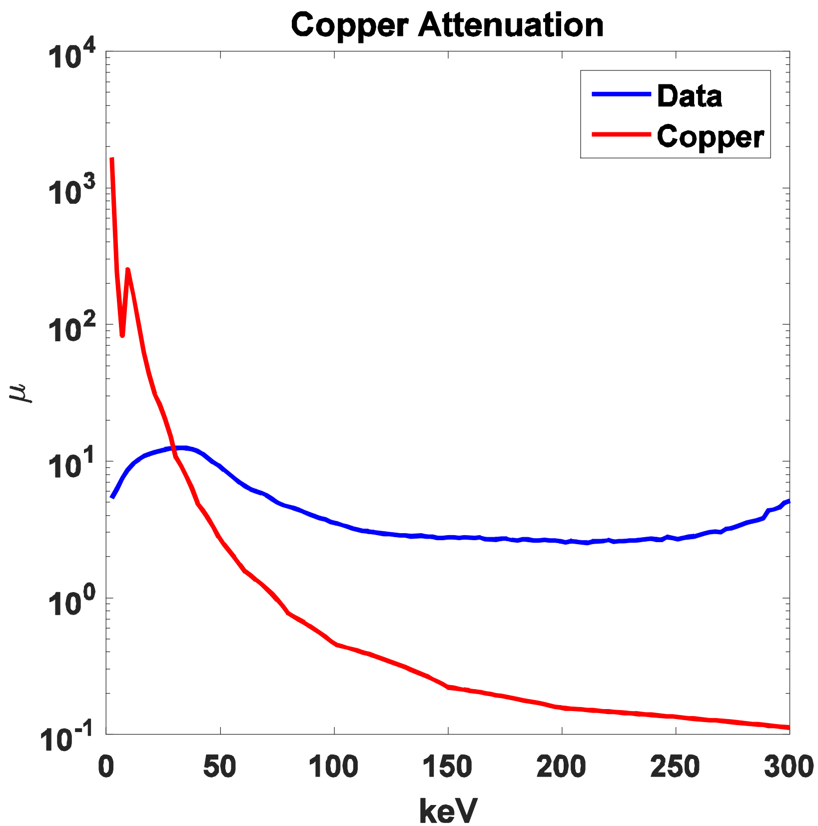


Amptek

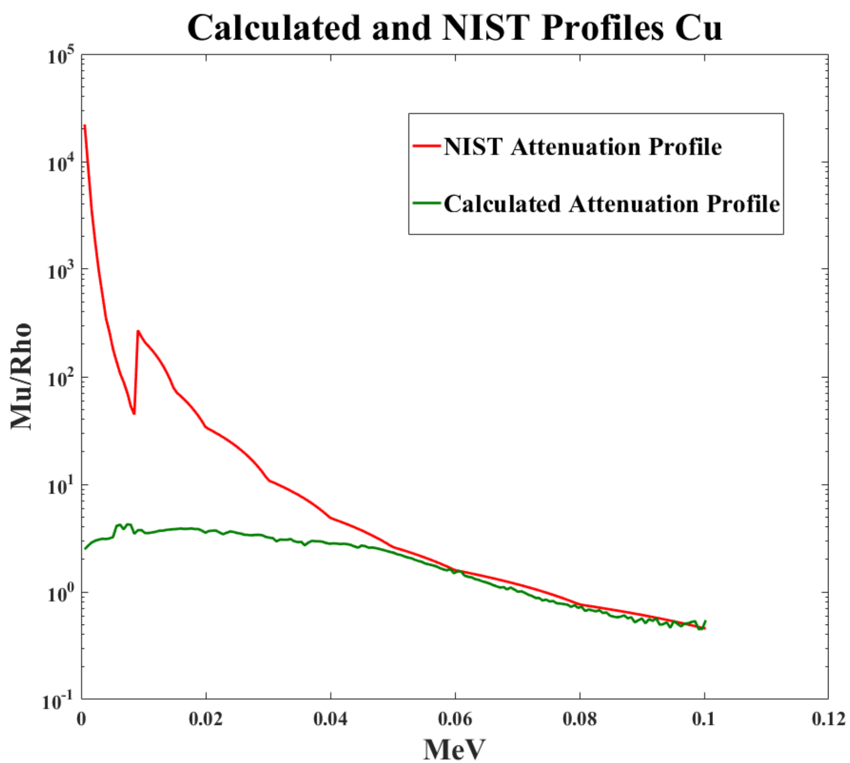


Copper Estimate

Multix

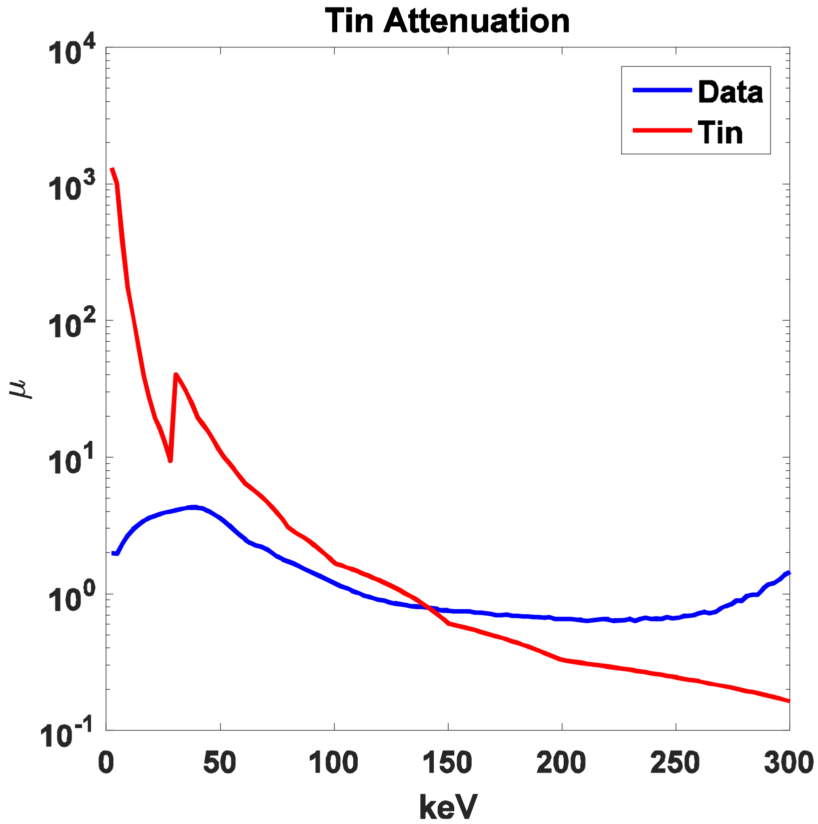


Amptek

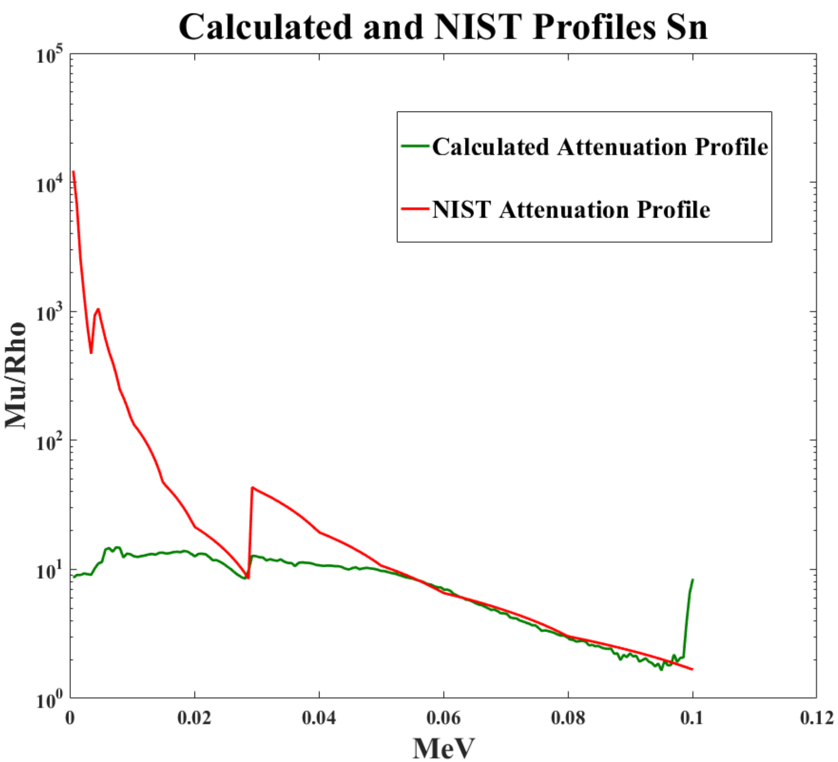


Tin Estimate

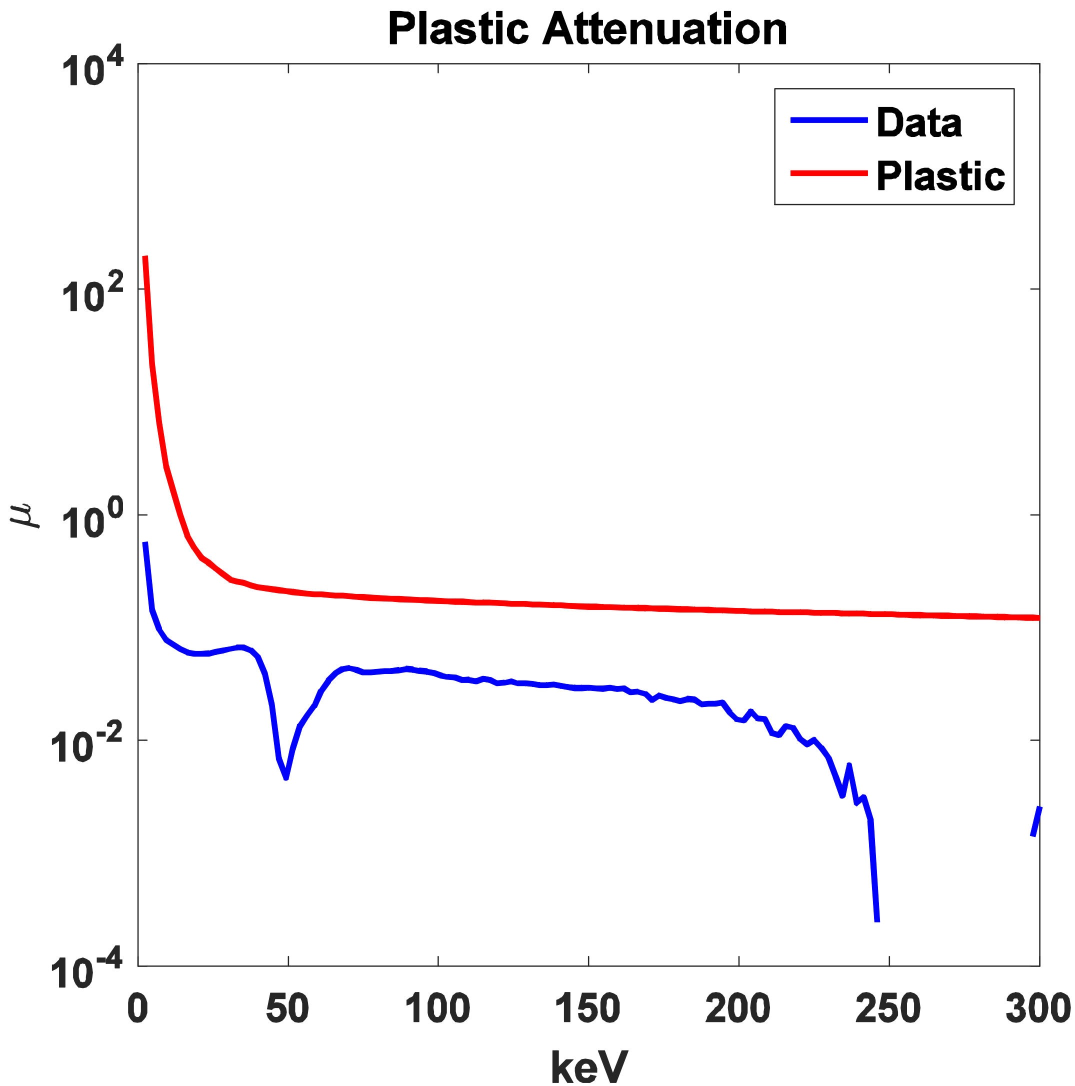
Multix



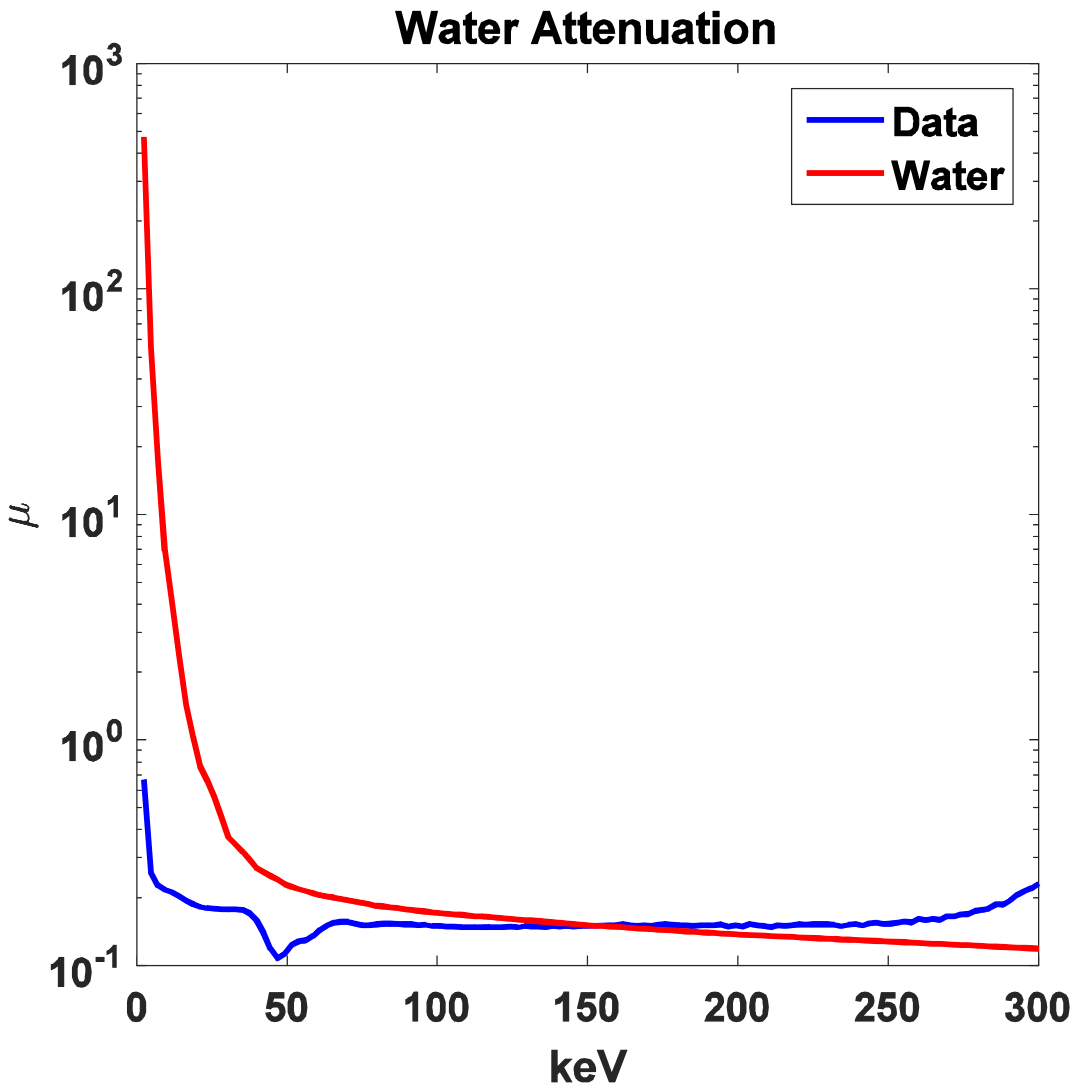
Amptek



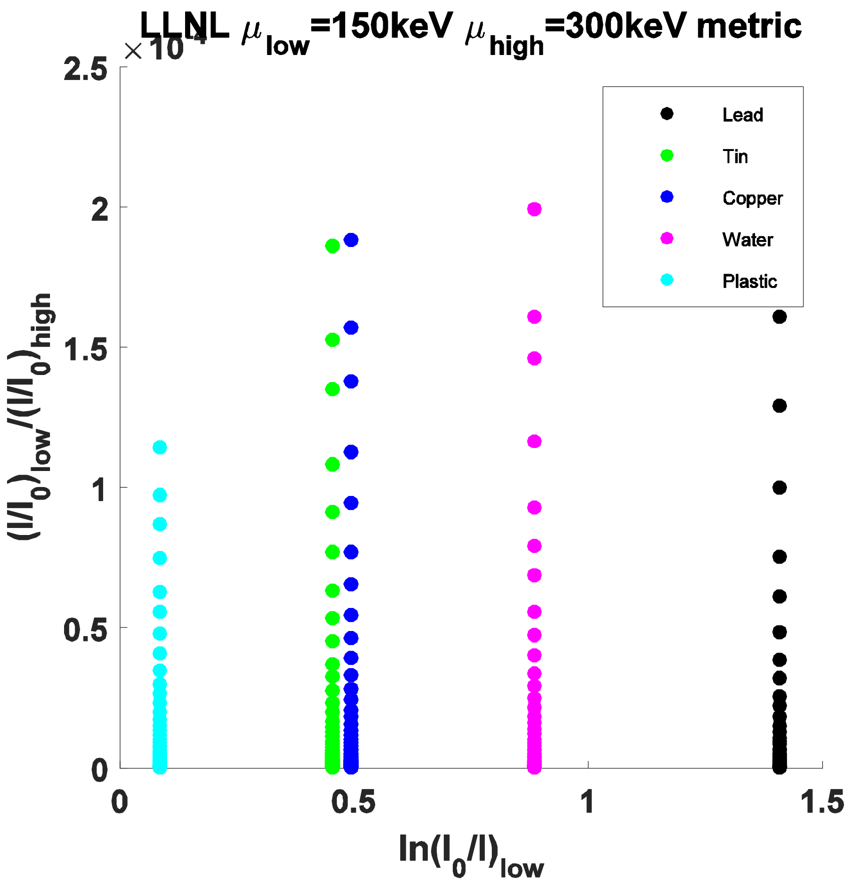
Polyethylene Estimate



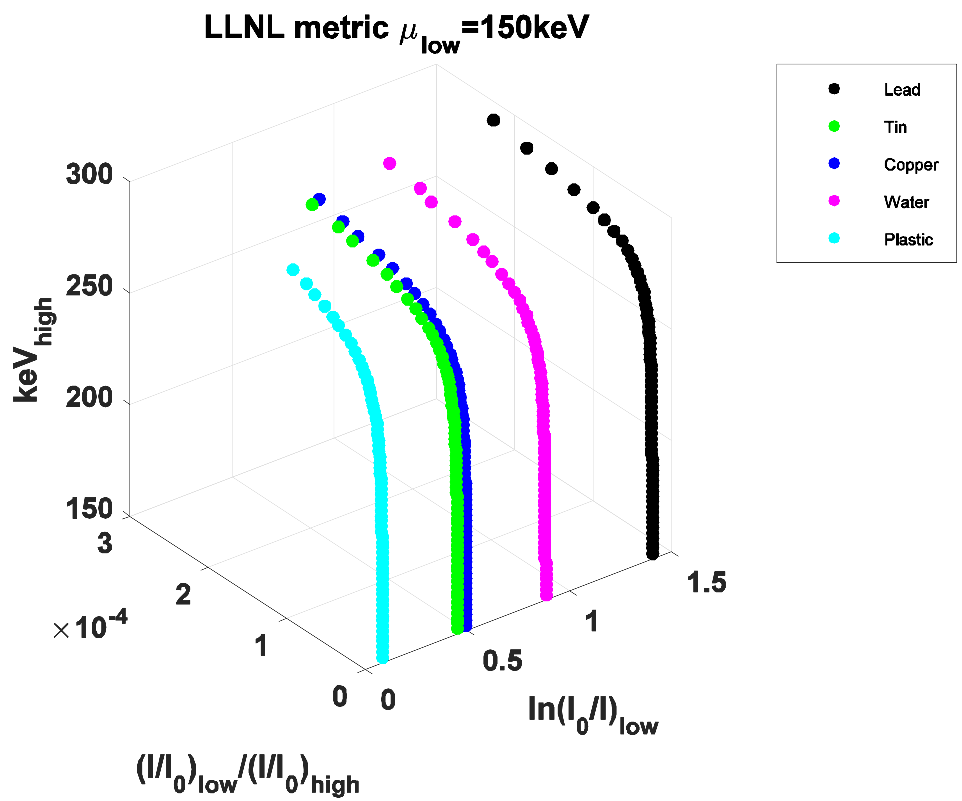
Water Estimate



LLNL Metric

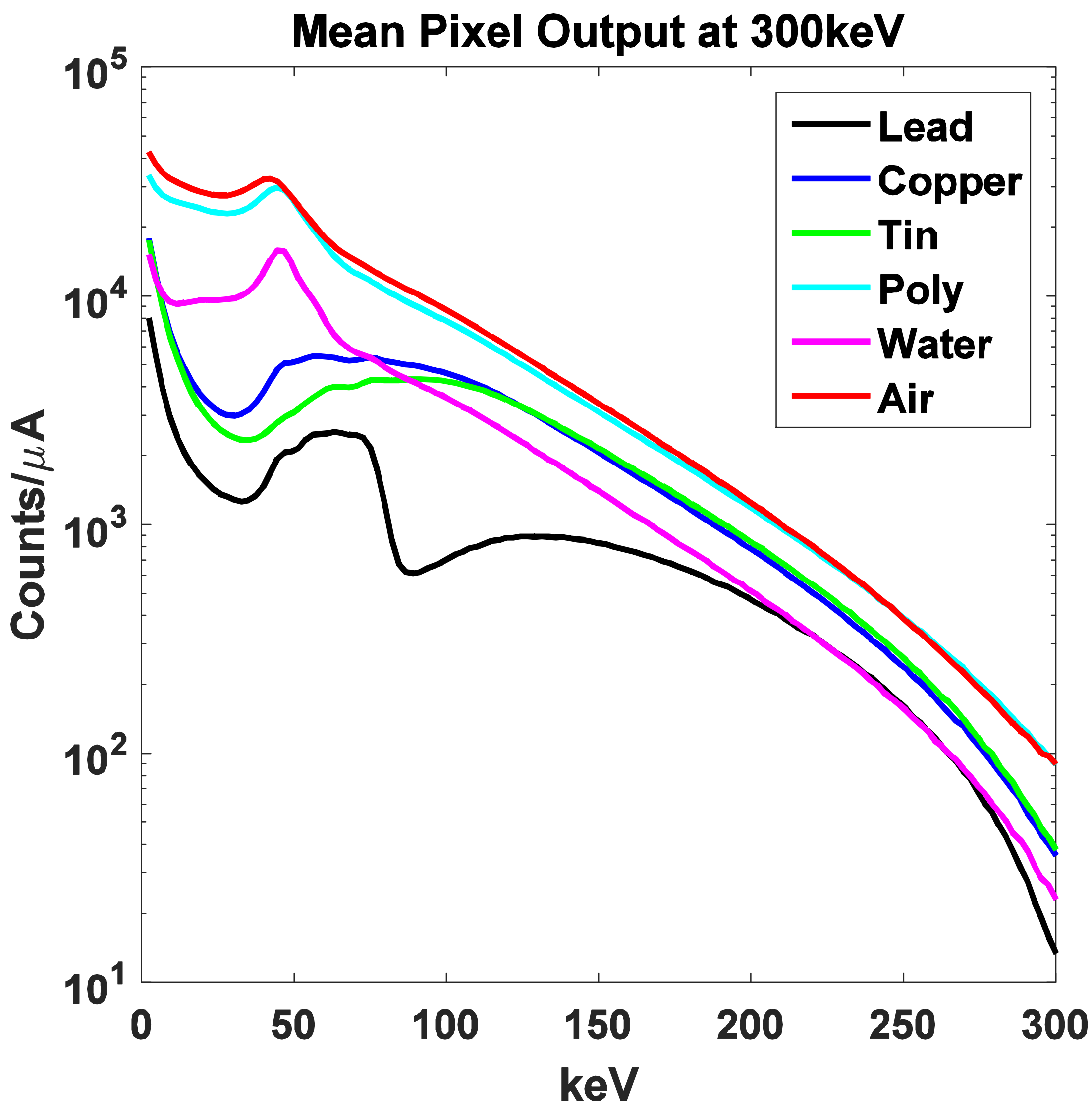


LLNL μ_{low}=150keV μ_{high}=300keV metric
$\times 10^{-4}$
$(I/I_0)_{low}/(I/I_0)_{high}$
$\ln(I_0/I)_{low}$
Lead
Tin
Copper
Water
Plastic

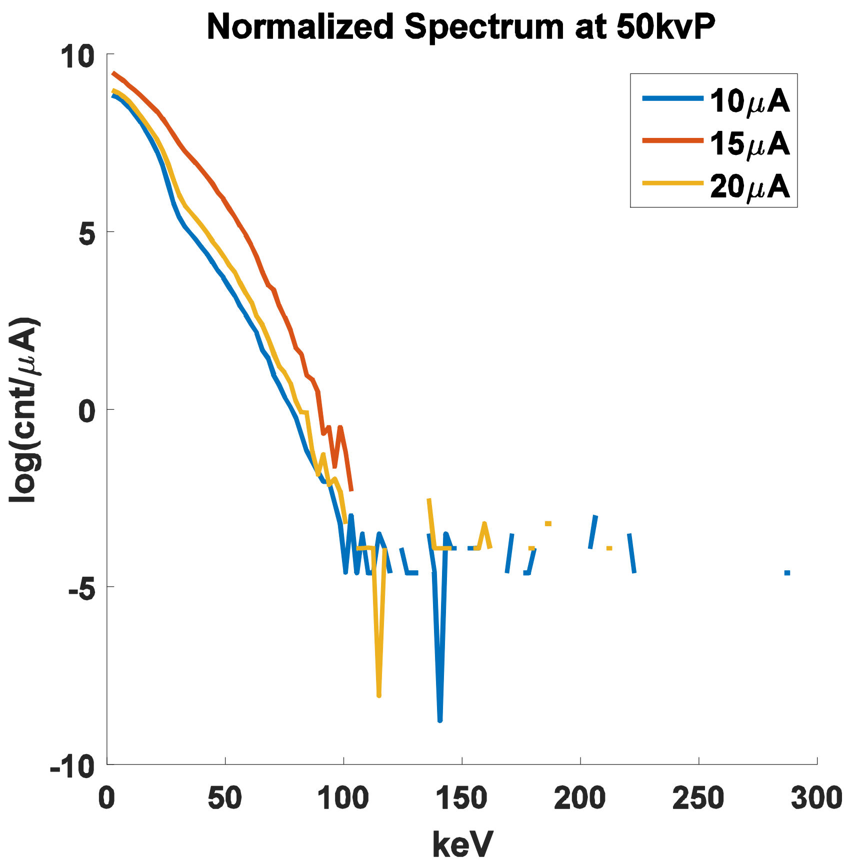


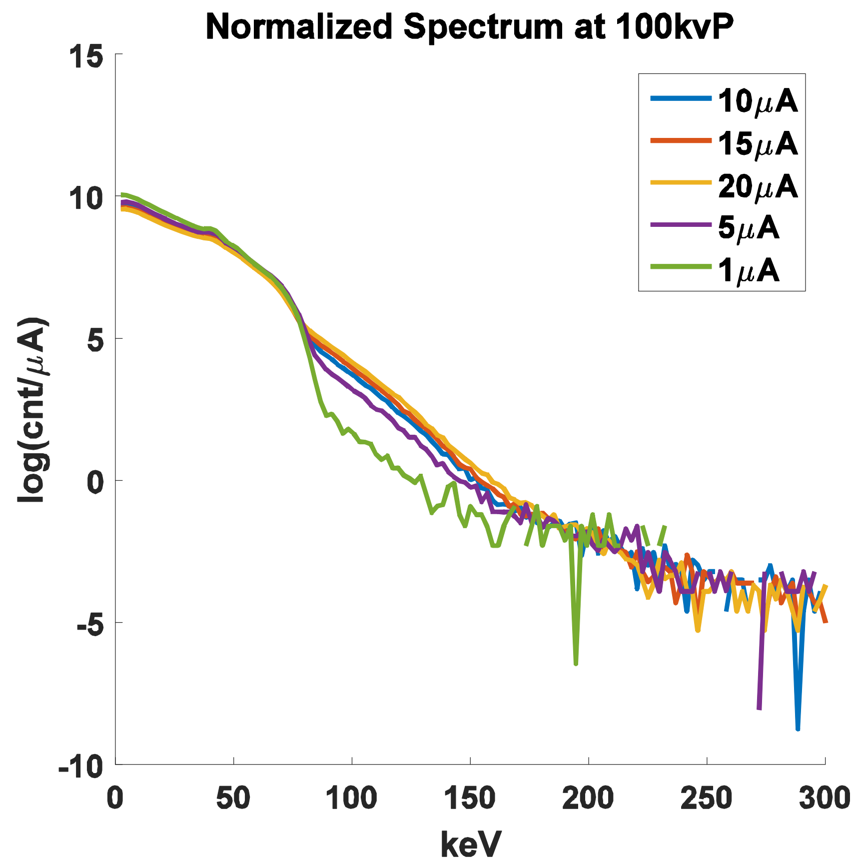
LLNL metric μ_{low}=150keV
keV_{high}
$\times 10^{-4}$
$(I/I_0)_{low}/(I/I_0)_{high}$
$\ln(I_0/I)_{low}$
Lead
Tin
Copper
Water
Plastic

Mean Pixel Output

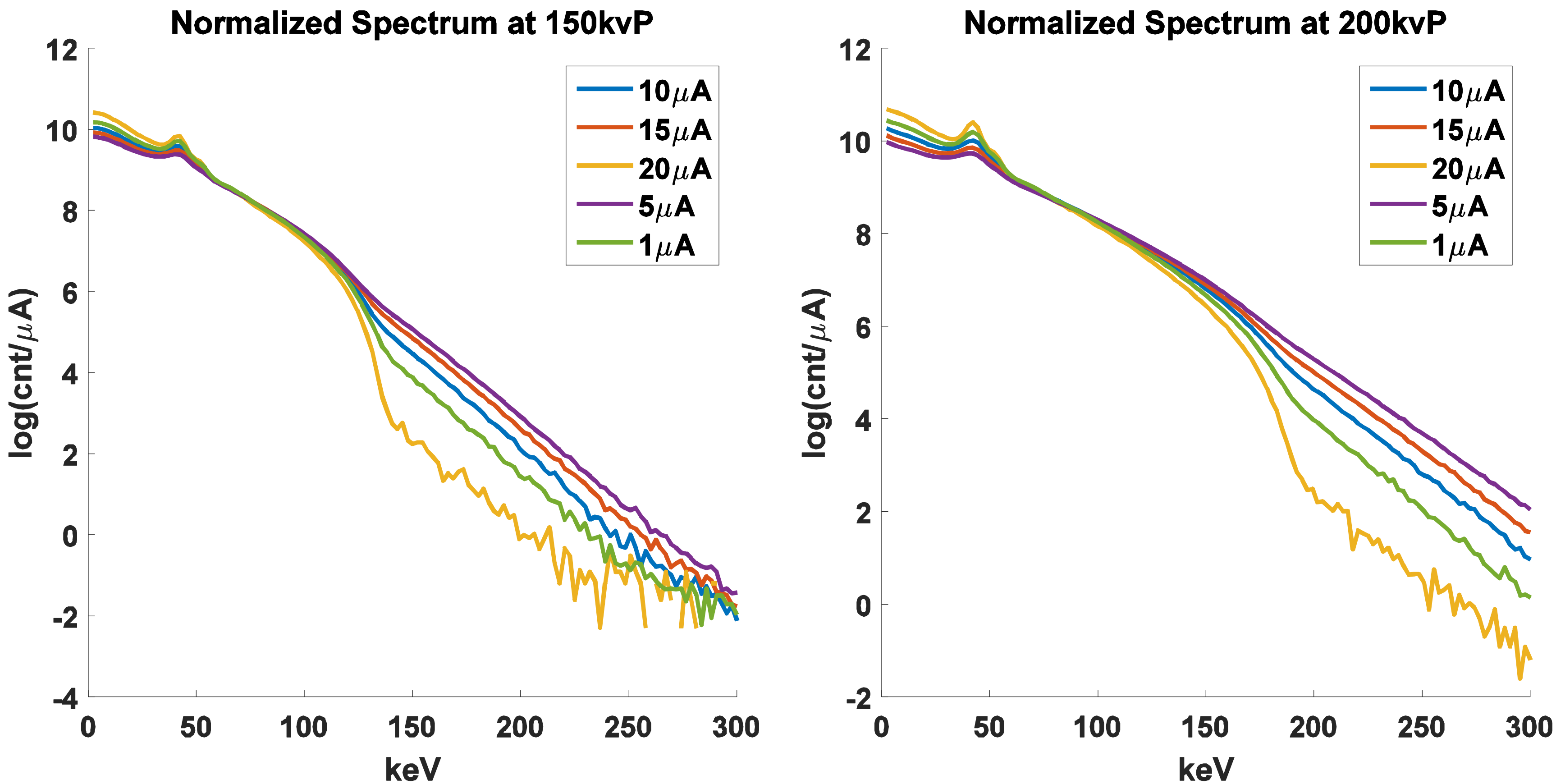


Normalized Spectrum 50 & 100keV

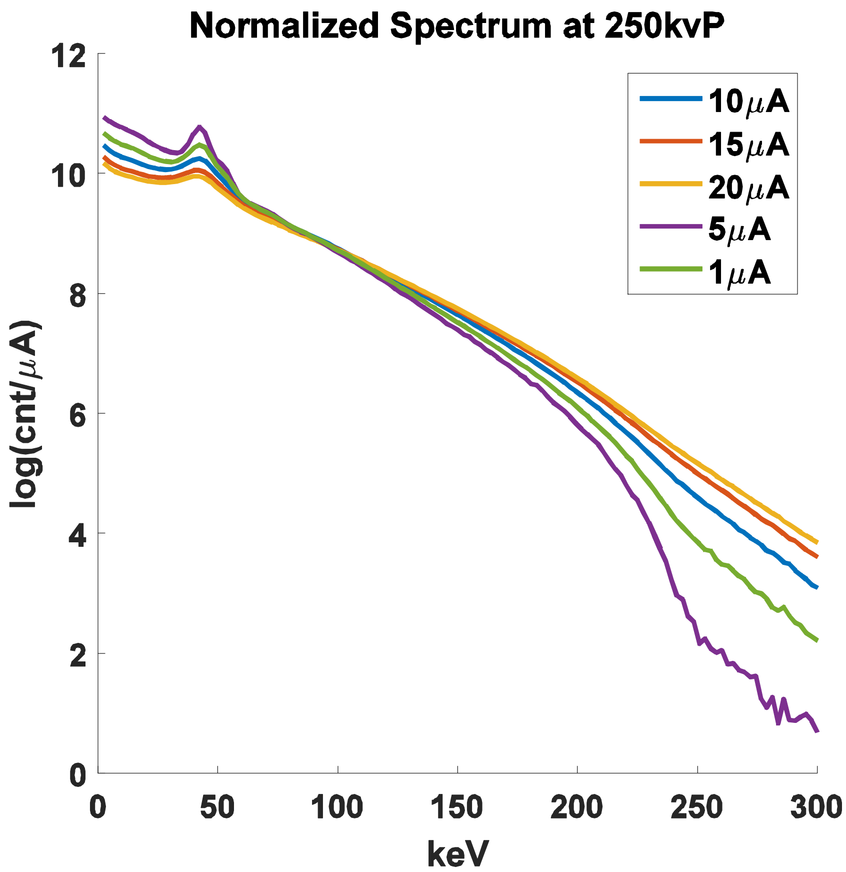


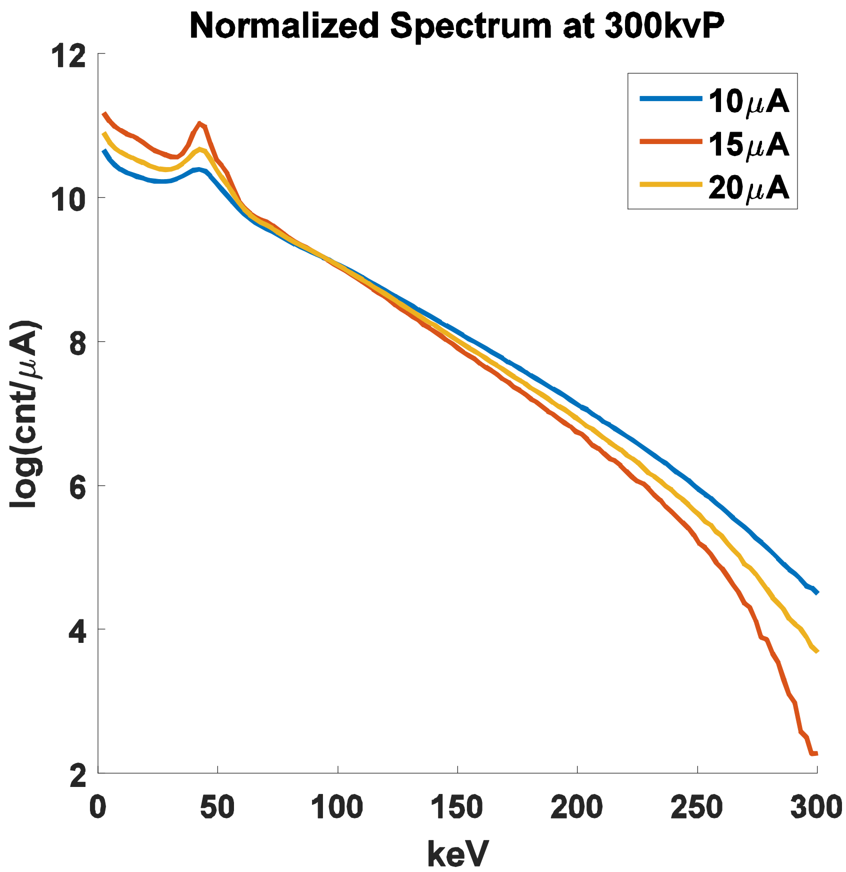


…150keV & 200 keV

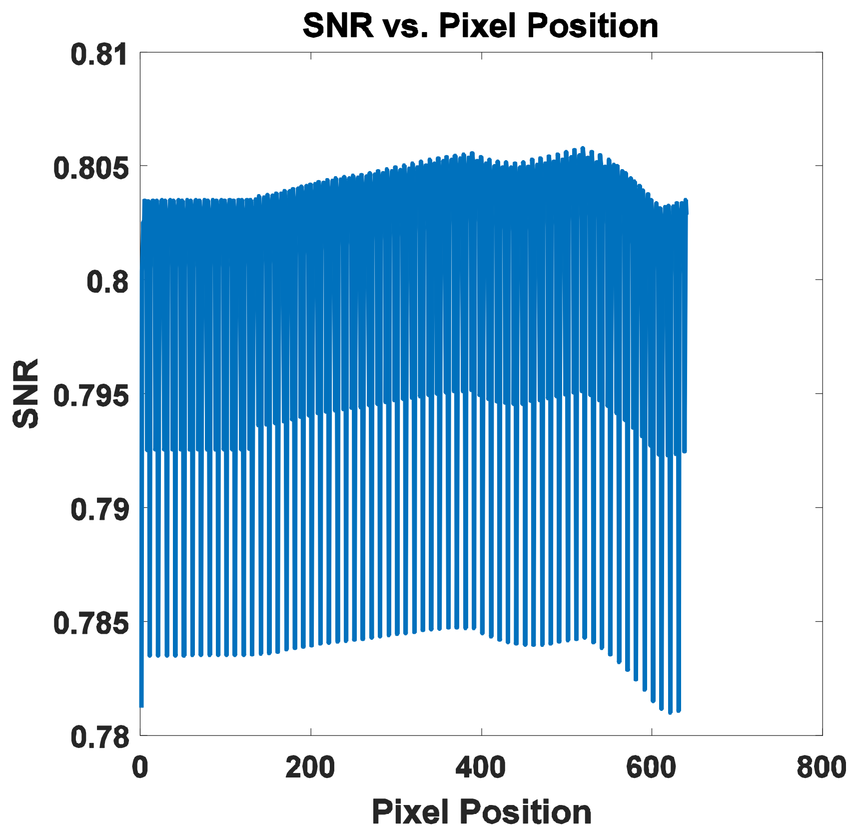


…250keV & 300keV

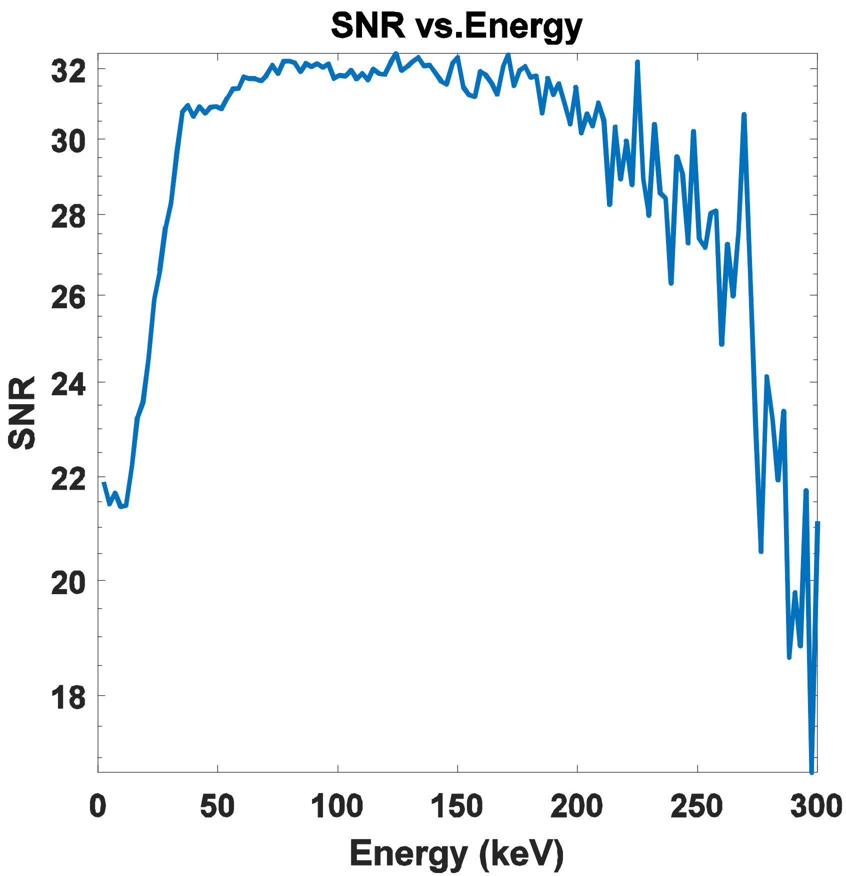




SNR



SNR vs. Pixel Position
SNR
0.81
0.805
0.8
0.795
0.79
0.785
0.78
0
200
400
600
800
Pixel Position



SNR vs.Energy
SNR
32
30
28
26
24
22
20
18
0
50
100
150
200
250
300
Energy (keV)

Discussion

- Count Rate:
  - Multix exhibits great scalability for 50 to 300keV
  - Across array over 100M counts per second achieved
  - Crucial for 2D Imaging and CT
  - Detector did not seem to saturate with our maximum current

- Materials Identification
  - More work needed
  - Low energy attenuation estimation
    - Noise and Scatter?
    - Consistent with Amptek
  - High energy attenuation estimation
    - Generally overestimated
    - Detector efficiency causing overestimate?

- LLNL Metric
  - More consistent/tighter clustering possible?
  - Could dramatically improve performance of multiple systems
  - Need to test with more thicknesses

- Normalized Spectrum
  - Inflection point around 100keV?
  - Pulse-pileup is visible for kVP settings below 300kVP
  - Ideal detector should have perfect overlap of normalized spectrums

- SNR
  - Pixels: Cyclical SNR correlated with submodules?
  - Energy: ~50 to ~160keV yield best SNR?
    - Possibly expected as this was the original specification

Future Work

- Develop Software for more complex Scans
  - 2D Images
  - Computed Tomography Datasets

- Spectrum Corrections

- Issues Encountered:
  - Design issues
  - Alignment
  - Hyper- and Hyposensitivity
  - SDK Issues

Thank you

- Our team appreciates the opportunity to present our work.
- Questions?