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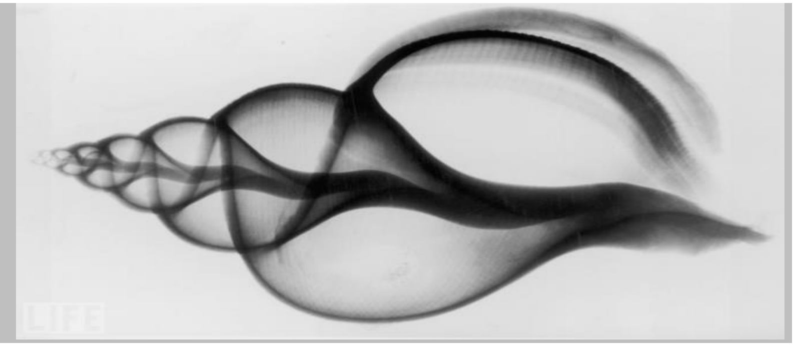

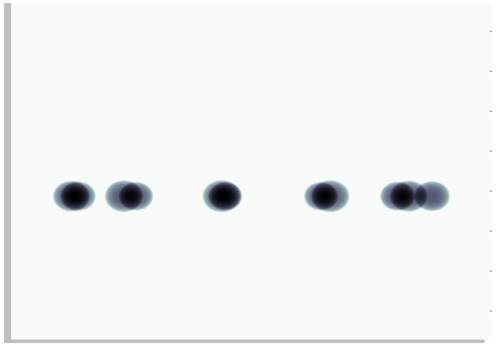

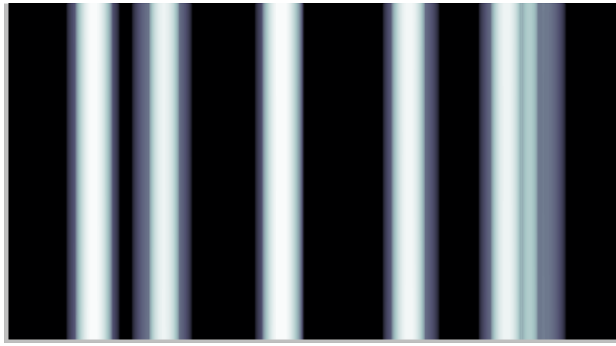

Object Composition Identification via Mediated-Reality Supplemented Radiographs

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Elevator Speech

- Summary:
  - This work presents an exploratory method to post-process radiographs to allow for maximum information extraction. Specifically, can one identify material contain within the field-of-view.
- What benefit could TSA obtain from this technology?
  - Increased detection capacity
  - Reduced false-positive rates
  - Precise material classification
- So what?
  - This technology potentially leads to increased separation between materials with similar properties.
- Who cares?
  - Medical, security, manufacturing, industrial NDT/NDE.

Detection

- Object is scanned
  - X-ray Image(s) produced
  - Displayed on a monitor (LCD-type)

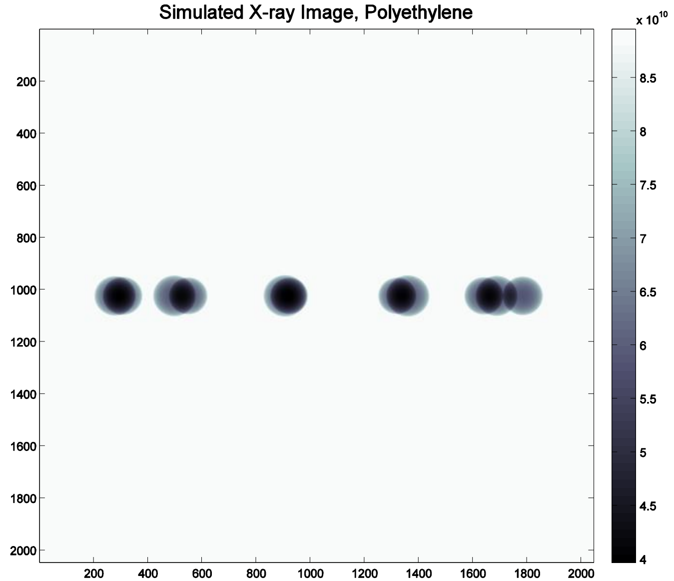
- Image is processed by designated algorithm
  - Pixel Thresholding
    - Usually utilize Dual-Energy Radiography
  - Color coding

Exploratory work

- Avoid the approximation $\bar{I} = \bar{I_0} e^{-\bar{\mu} x}$, and try to estimate $\mu(\varepsilon, x)$ directly.
- Very challenging, is it possible?
- Radiation detection hardware has evolved significantly in recent years.
- Decreasing cost has allowed for new types of data acquisition.

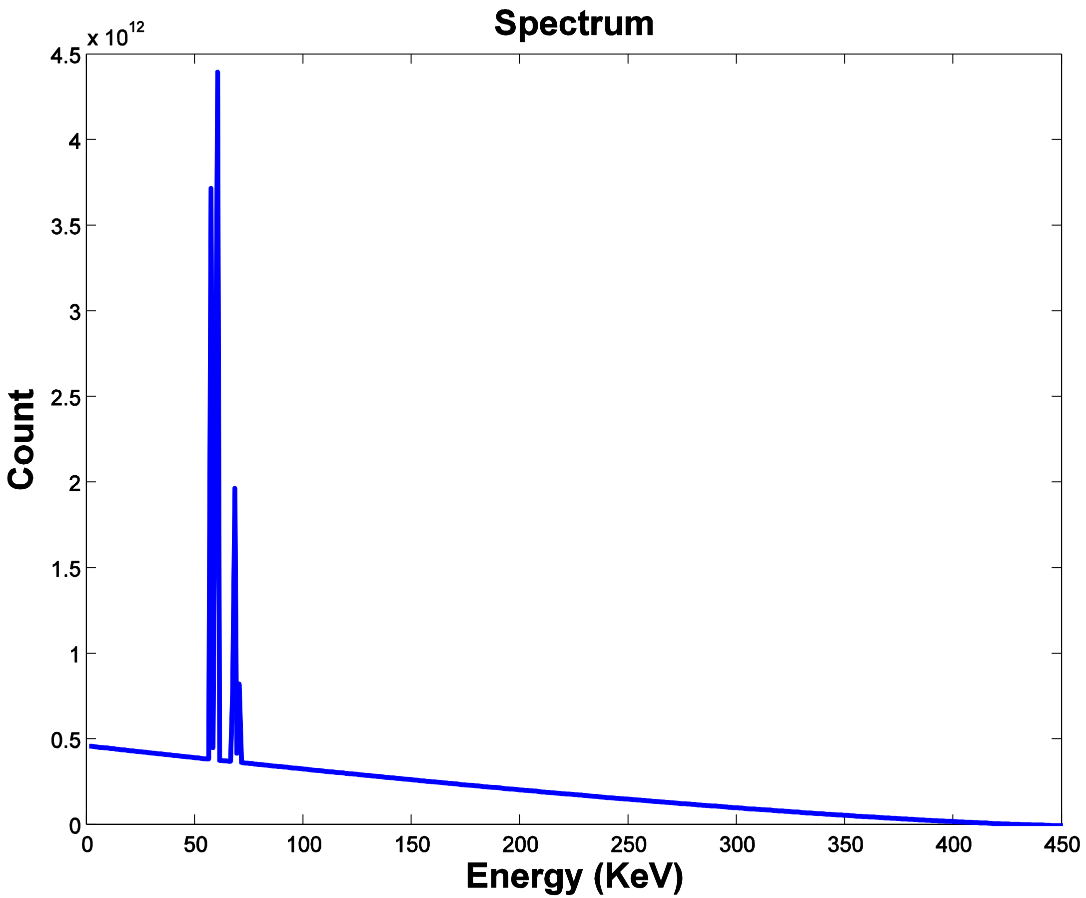
Past Work

- 1st: acquire images at multiple energies, solve effective attenuation (does not work!)
- Next: Approach: Use basis function to create candidate materials, simulate the image and compare it to the acquired image.
  - Limited success



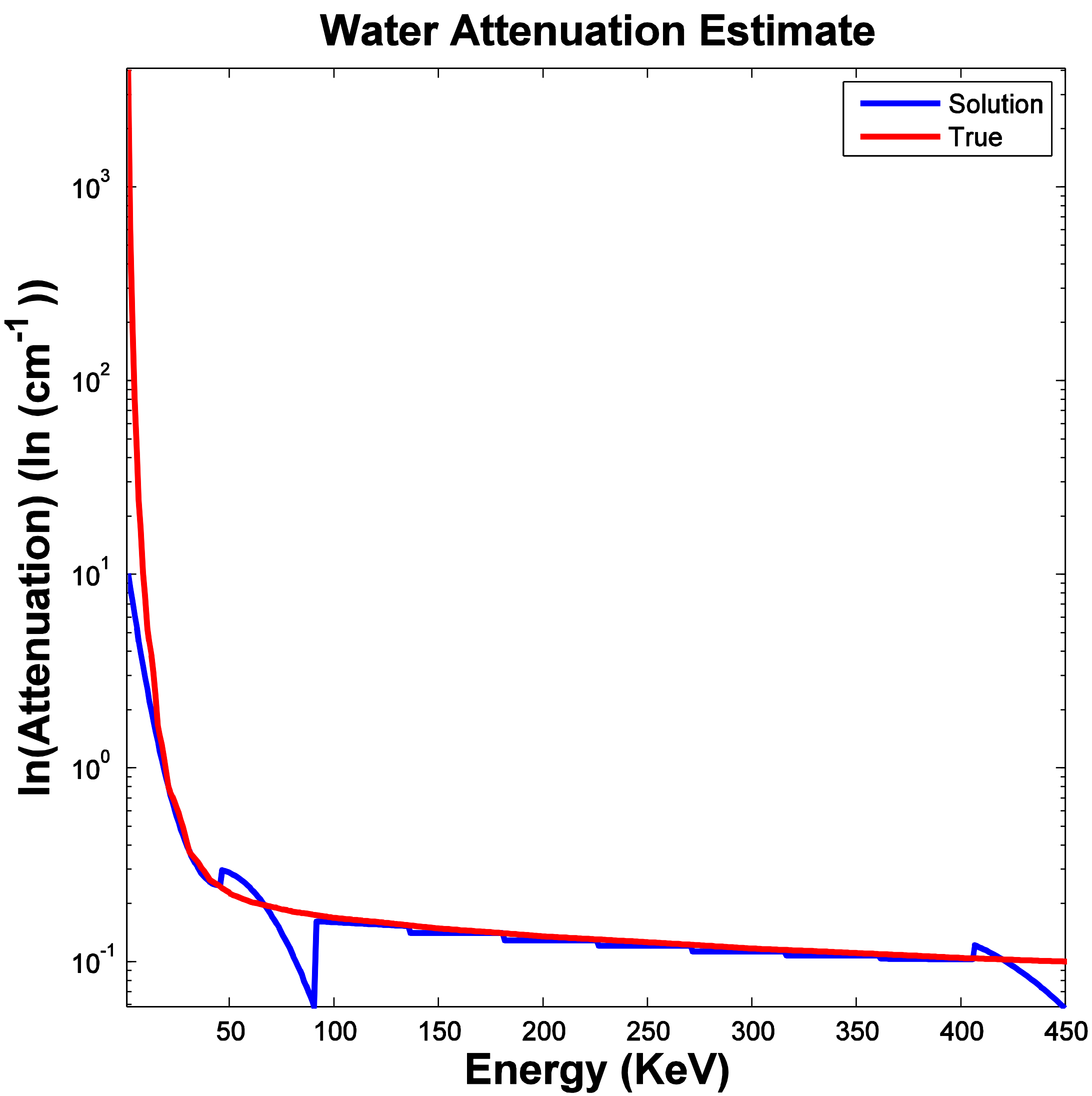
Multi-Energy Attempt

- Acquire images with an energy discriminating detector and apply mediated-reality simulation-based optimization



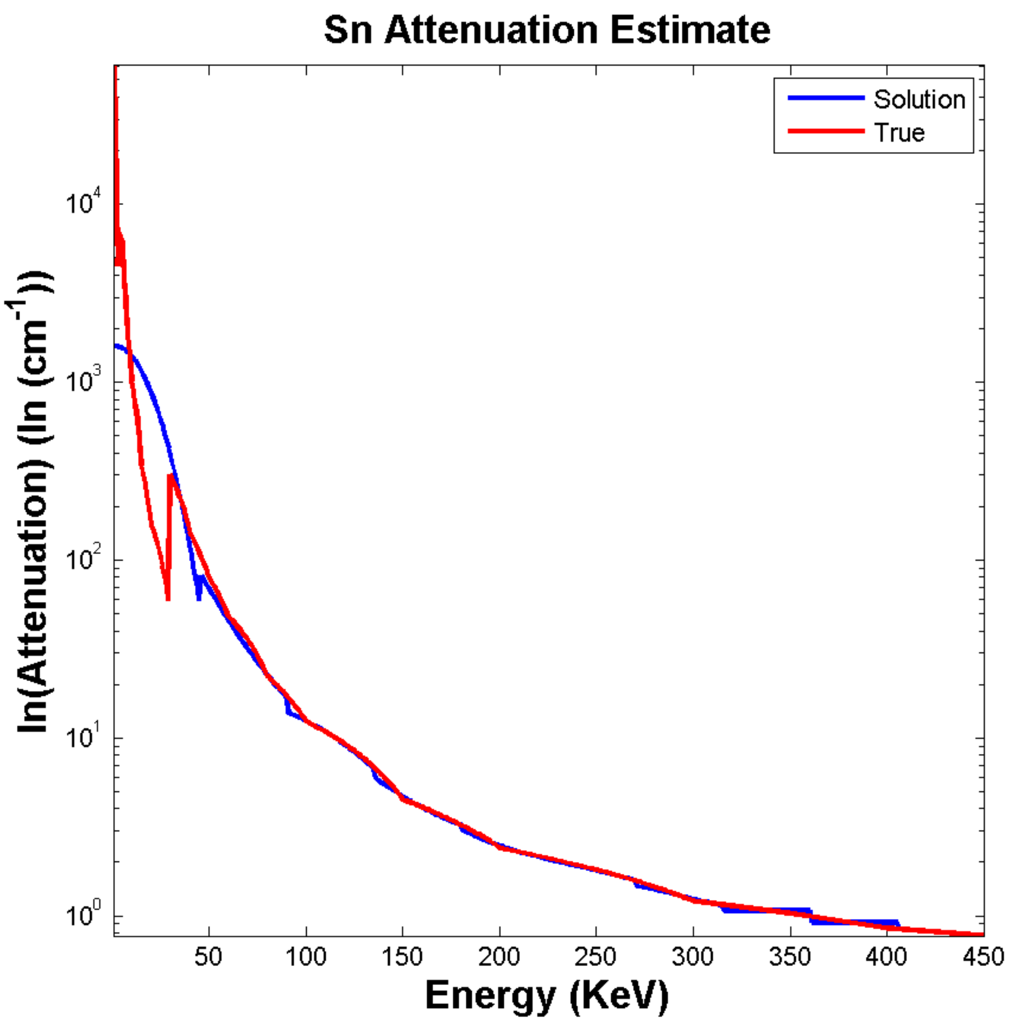
Results

- Water:



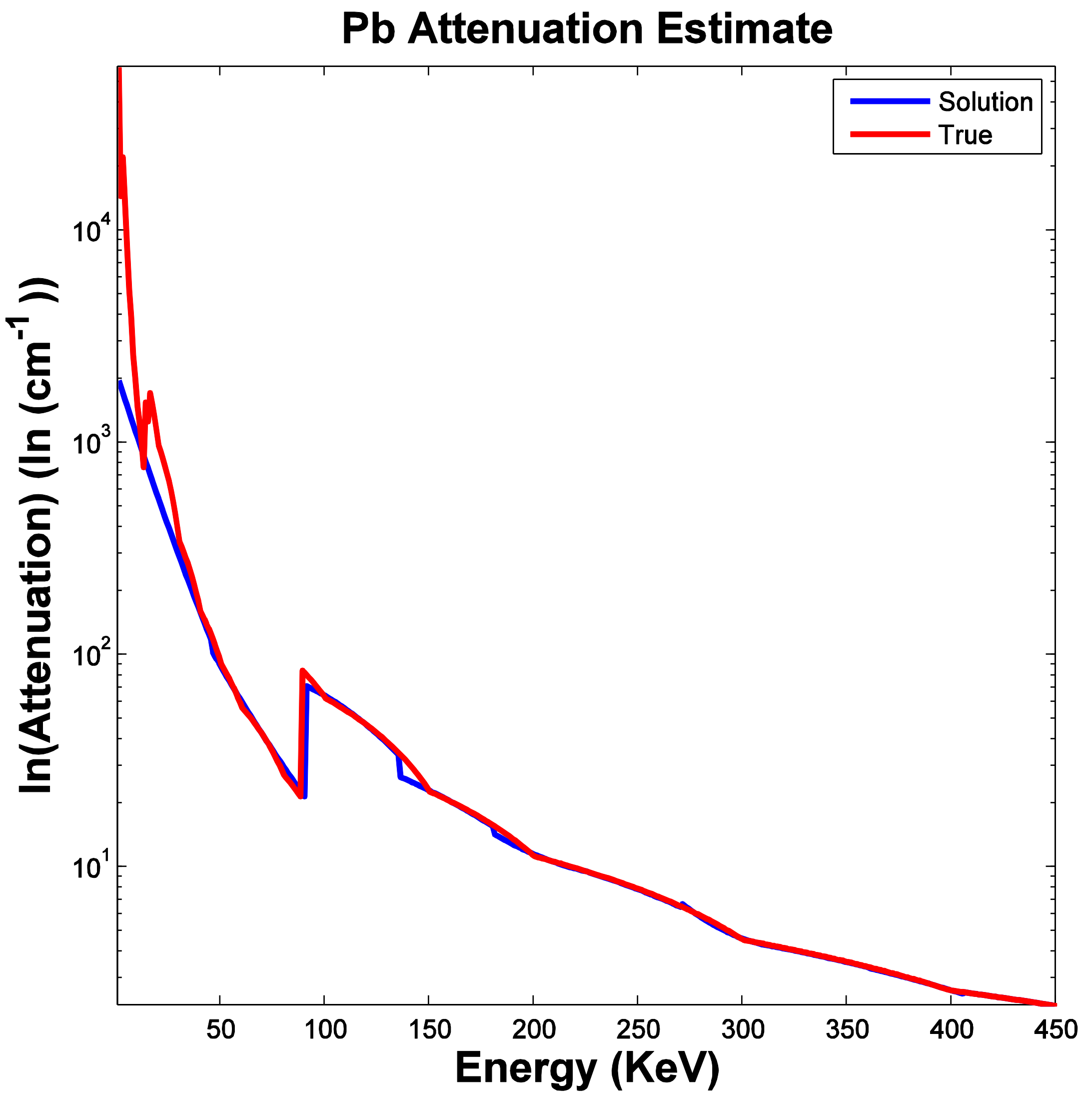
Results:

- Tin:


Sn Attenuation Estimate
Solution
True
10^4
10^3
10^2
10^1
10^0
ln(Attenuation) (ln (cm^{-1}))
50
100
150
200
250
300
350
400
450
Energy (KeV)

Results cont.

- Lead:



Conclusion

- Even for narrow energy ranges, direct evaluation of attenuation values introduce non-trivial error.

- Leveraging simulation-based optimizations could lead to increased numerical stability.

- Future work: Laboratory-based validation experiments underway.

- Thanks! Questions?

Dual Radiography

- X-rays follow Beer's law, for images:
  - $I = \iint_{\varepsilon \epsilon E, x \epsilon X} I_0(\varepsilon) e^{-\mu(\varepsilon,x)x} d\varepsilon dx$
- But, is approximated as:
  - $\bar{I} = \overline{I_0} e^{-\bar{\mu}x}$

- Using this approximation, 2-4 radiographs measured
  - Low energy (object present, absent)
  - High energy (object present, absent)

Continued

- A ratio image of high-to-low energies is created
  - $R = \frac{\frac{I_H}{I_{0,H}}}{\frac{I_L}{I_{0,L}}} \approx \frac{\overline{\mu_H}}{\overline{\mu_L}}$
  - This ratio approximates "effective atomic number"
- This ratio can then be subject to a threshold to separate material types
- Drawback: due to noise and other factors, only general classifications can be made.

SNL Applications

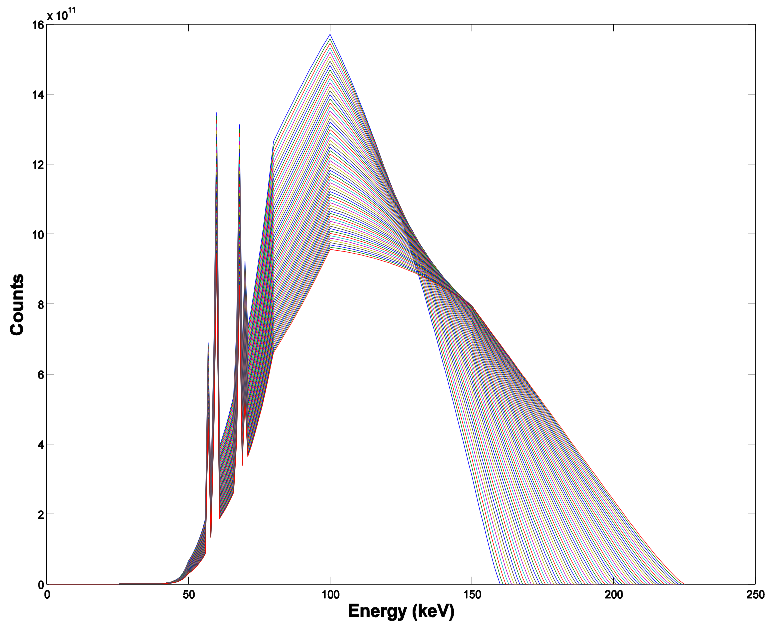
- Current Radiography technology leveraged at SNL
  - 3D Computed Tomography
  - Digital Radiography
  - Computed Radiography
  - Flash Radiography

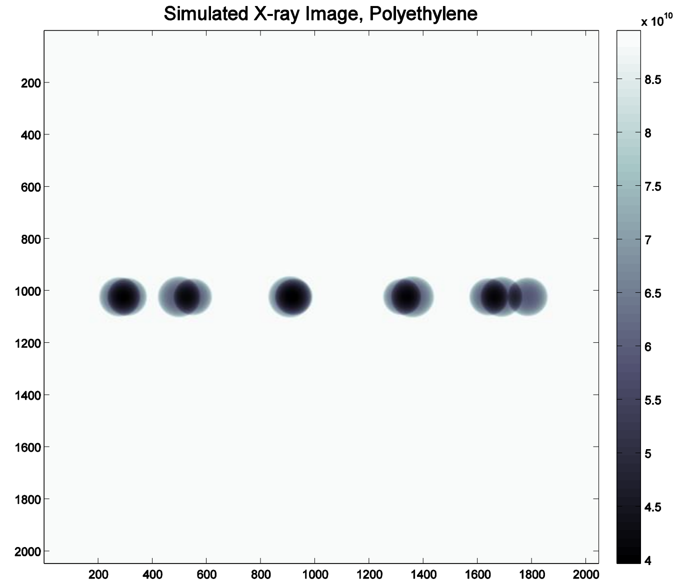
- Applications
  - Defect detection
  - Anomaly detection
  - Materials characterizations
  - Feature extraction

- Sandia National Laboratories has many sources, up to 6 MeV.

First Attempt

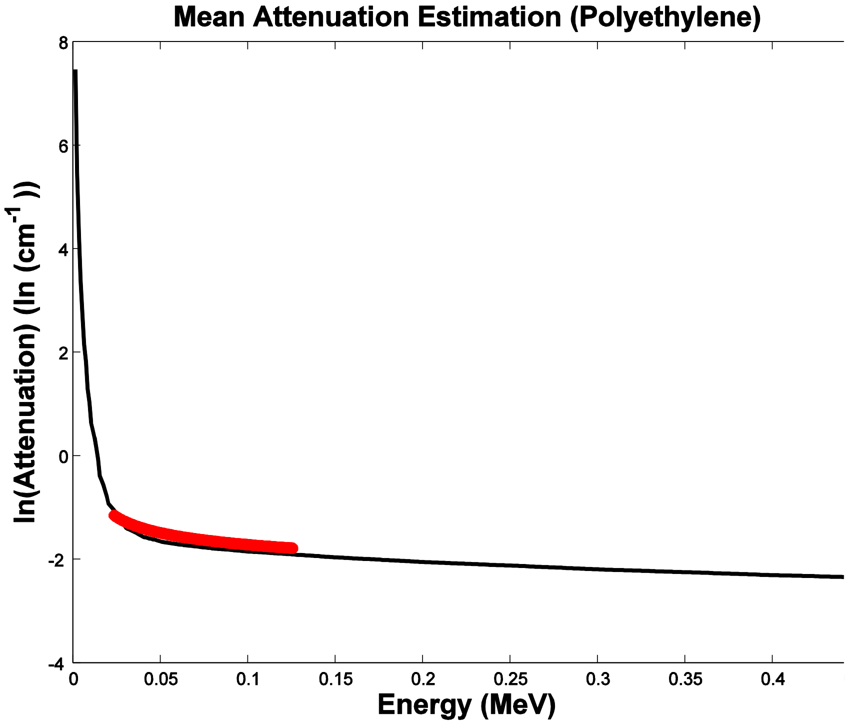
- How far off would we be using approximations?
- Approach: acquire images at multiple energies, solve effective attenuation

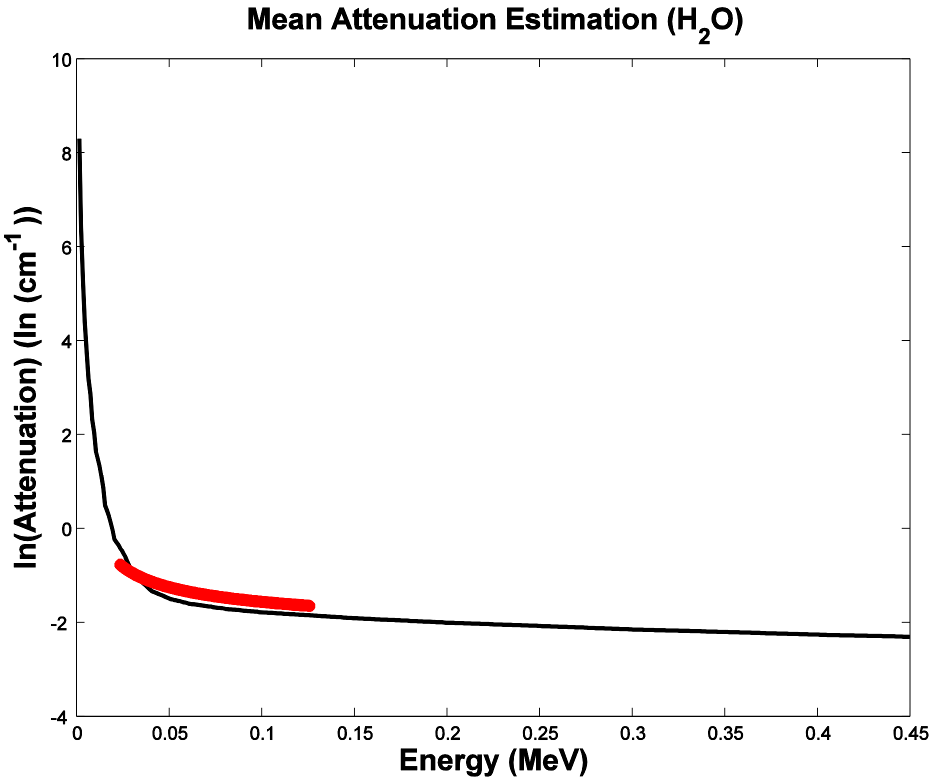




Results

- Polyethylene and Water

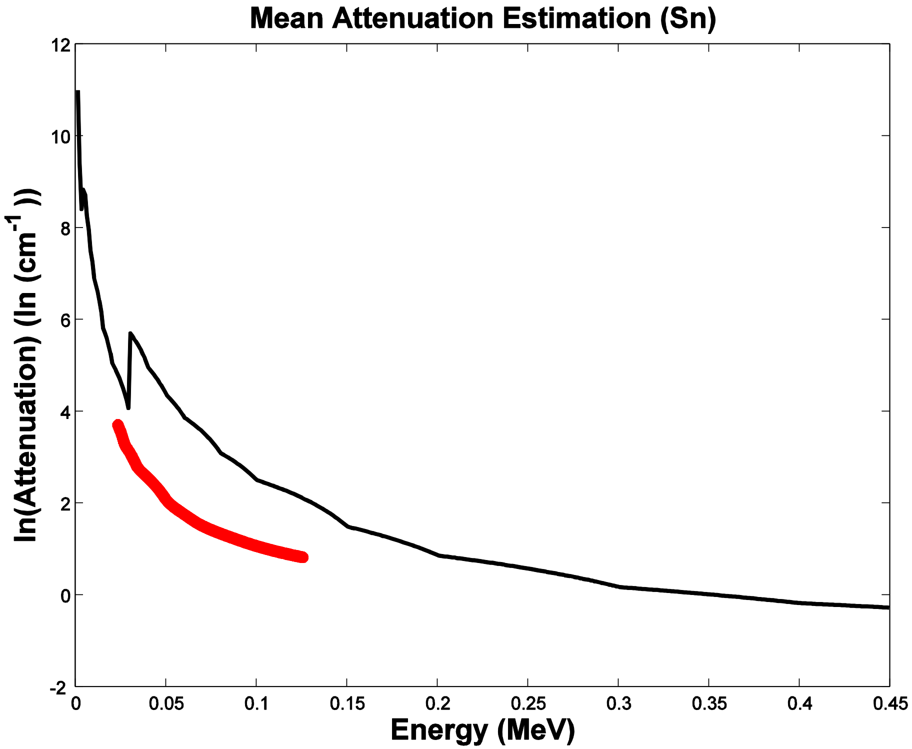


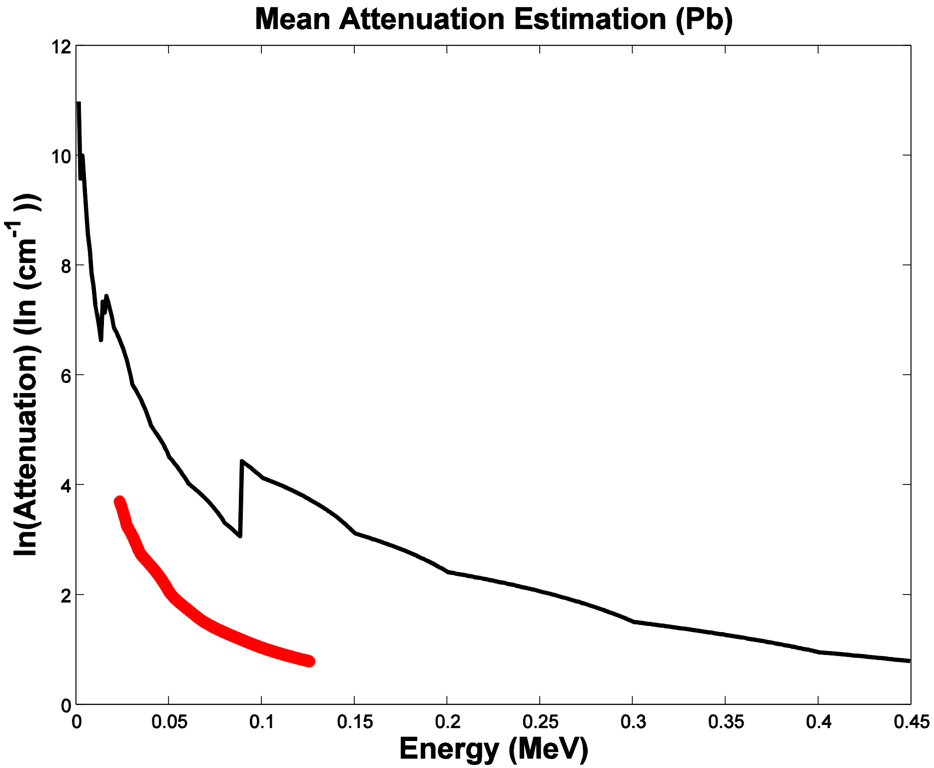


- …not too bad!

Results Cont.

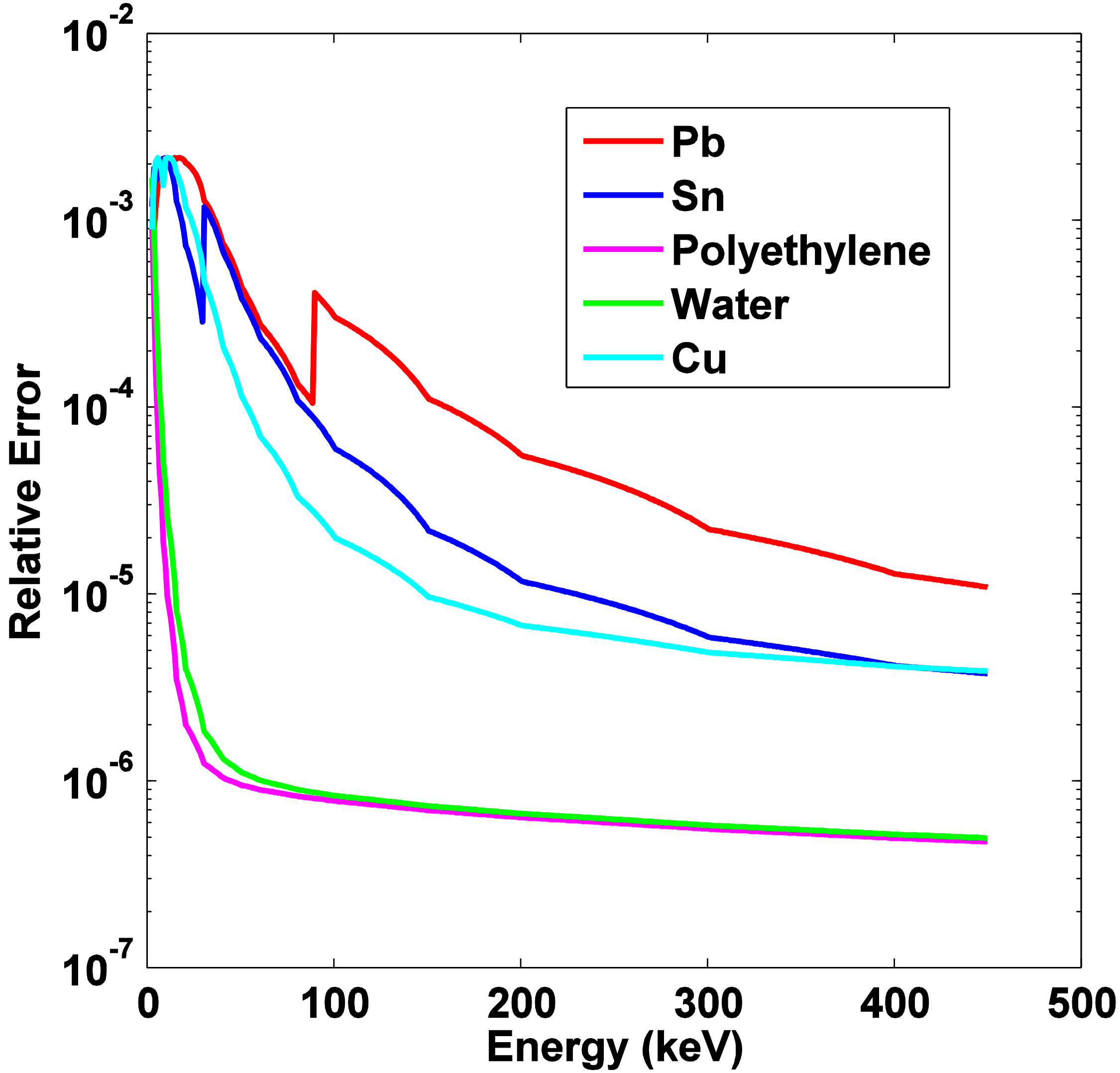
- Tin and Lead



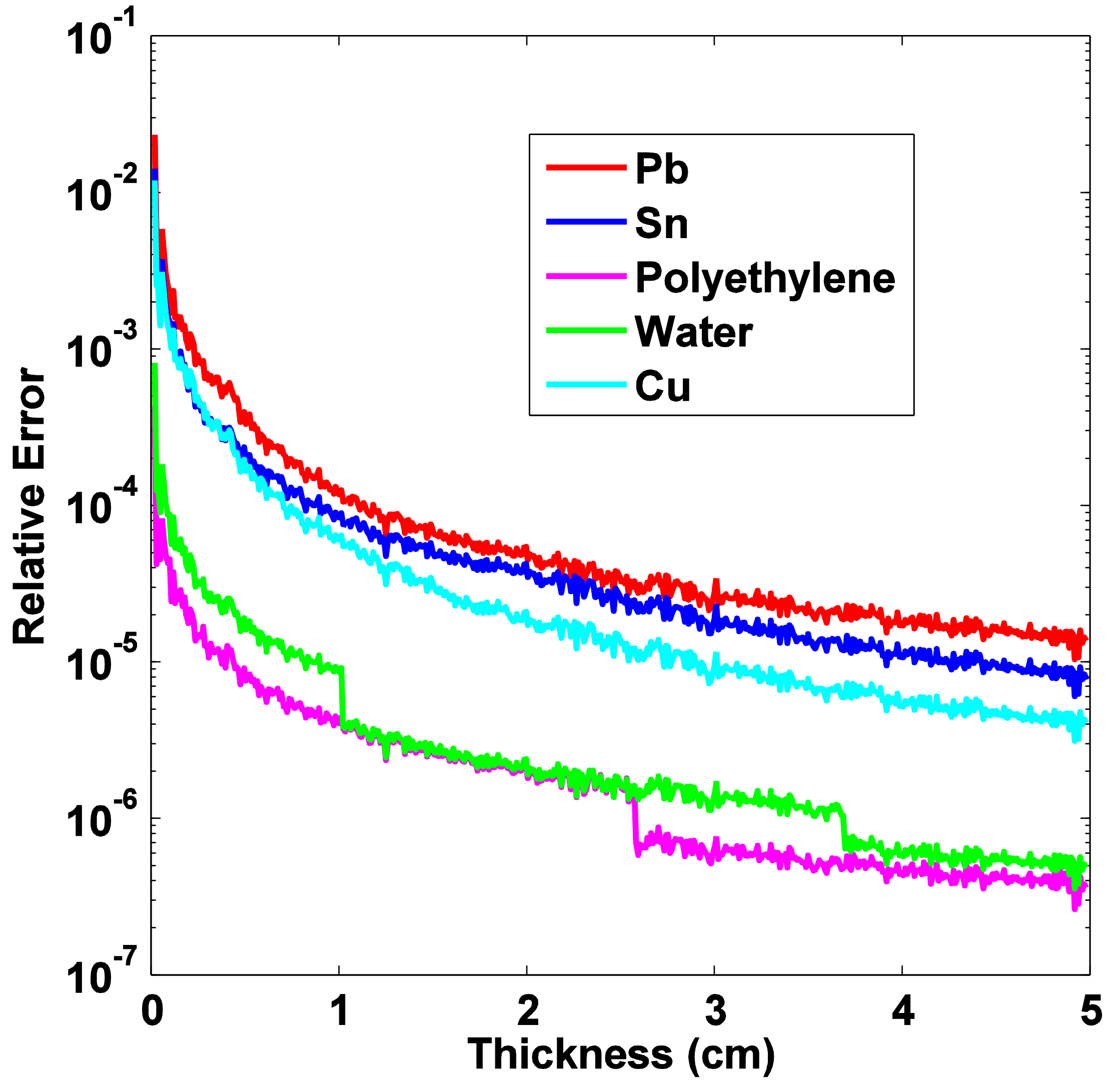


- ....This is problematic

Relative error WRT Energy – Direct Evaluation



Relative error WRT Thickness – Direct Evaluation



Second Attempt

- Mediated Reality and Simulation-based Optimization

- Approach: Use basis function to create candidate materials, simulate the image and compare it to the acquired image.

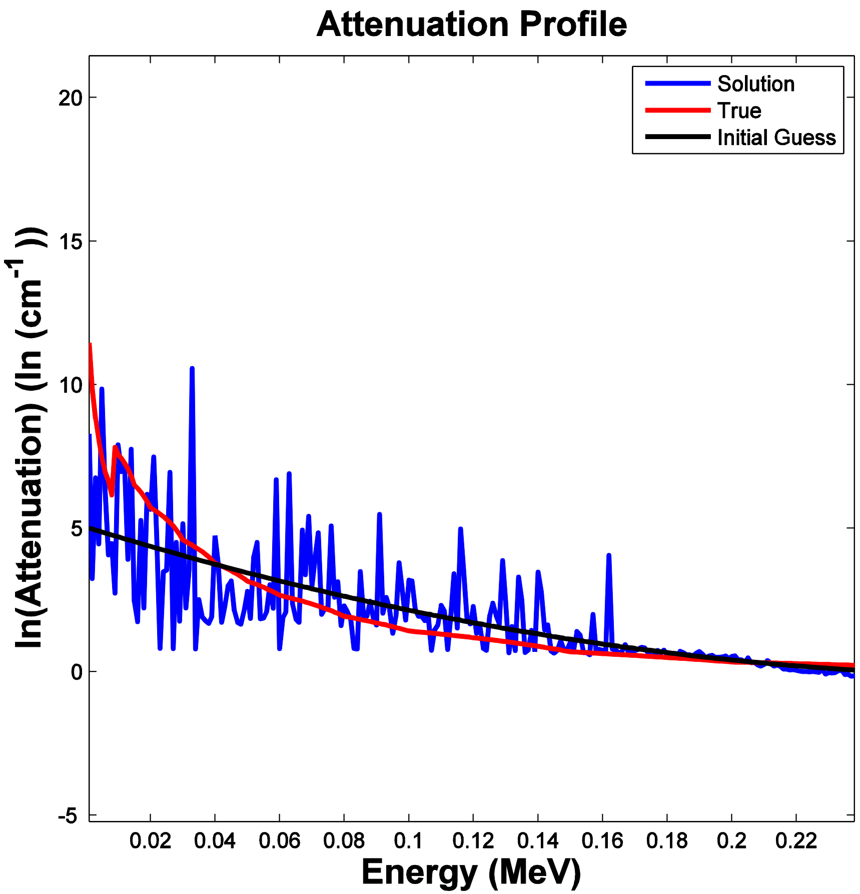
- Goal: Try different basis functions, try to resolve discontinuities in the attenuation profile.

- Optimize:

$$\underset{\hat{\mu}(x,\varepsilon)}{\operatorname{argmin}} \| \log(\overrightarrow{g}_{\mu(x,\varepsilon)}) - \log(\hat{g}_{\hat{\mu}(x,\varepsilon)}) \|_2$$

Results:

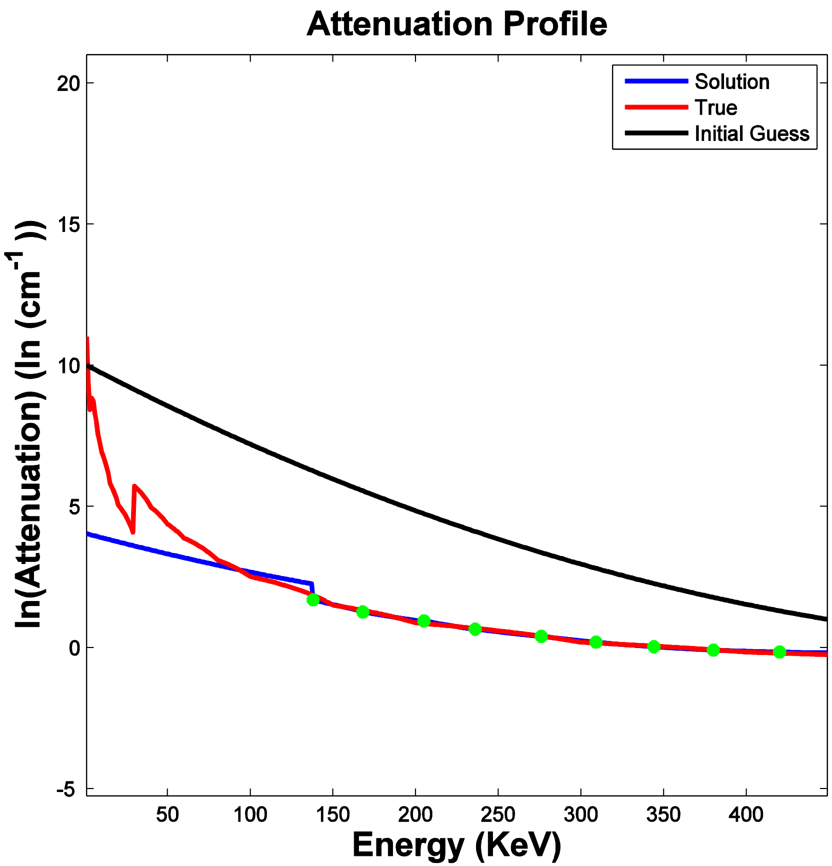
- Using a very large search space (~450 dimensions)
- Copper:



- …Problematic

Results cont.

- Smaller space, interval-based basis functions
- Tin:



- No k-edge resolved…but promising!