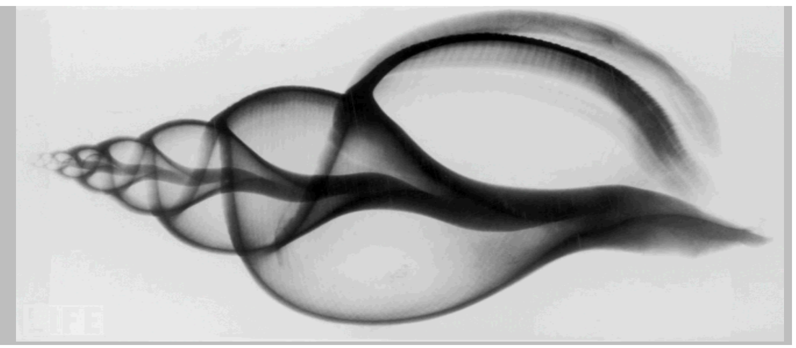
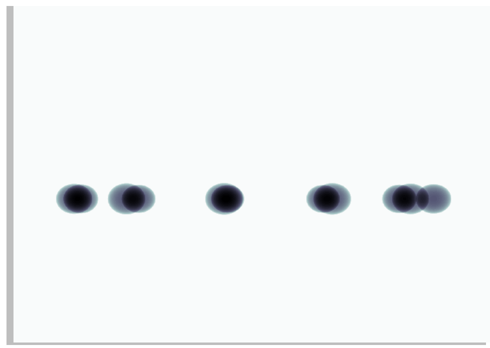
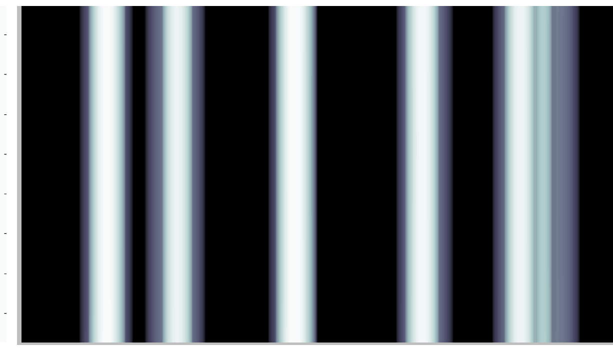
SAND2015-1016PE

Exceptional service in the national interest

Sandia National Laboratories







Exploring Computational Methods to Identify Materials in X-ray Images

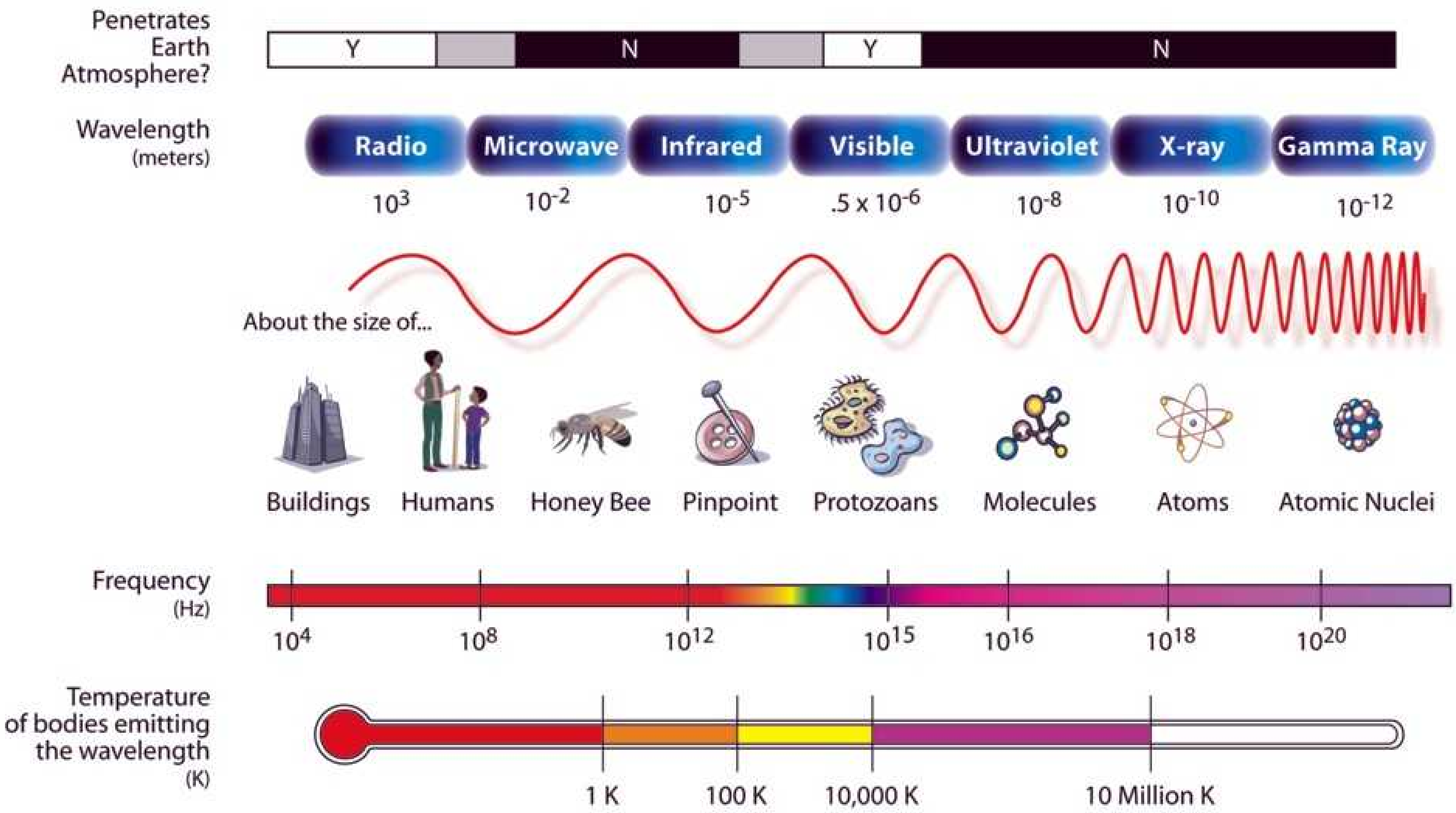
Dr. Edward Jimenez

U.S. DEPARTMENT OF ENERGY

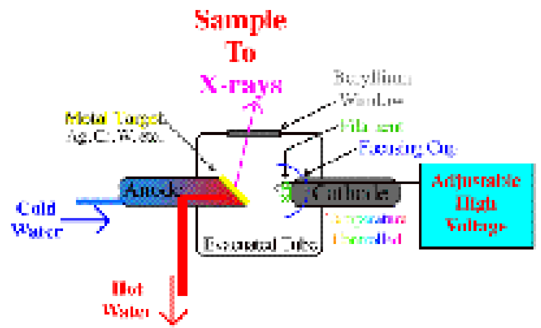
NNSA National Nuclear Security Administration

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

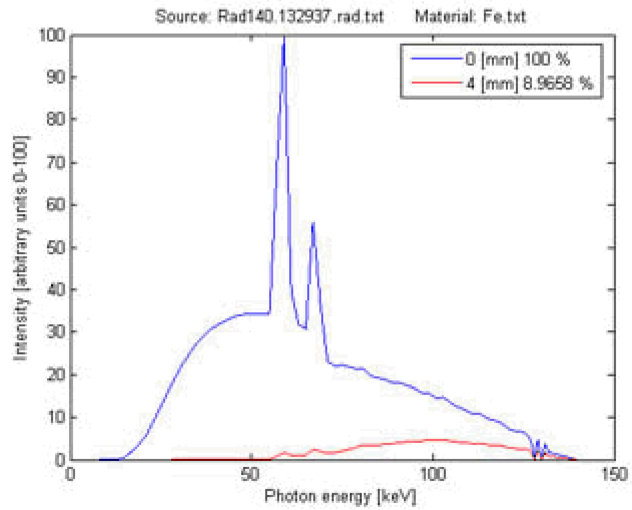
THE ELECTROMAGNETIC SPECTRUM

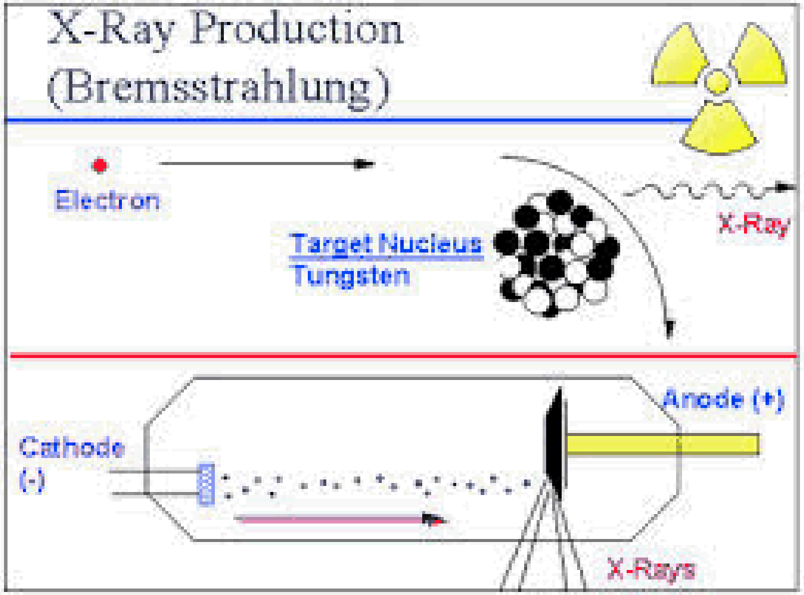


Where do X-rays come from?

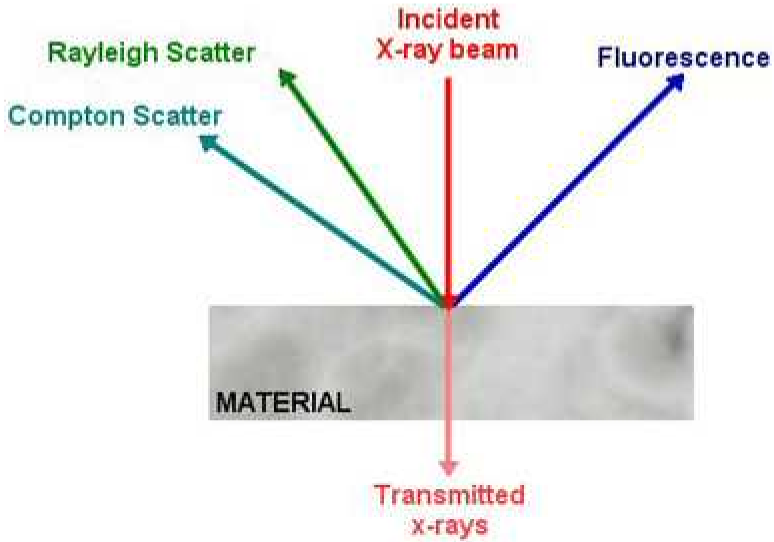


X-Ray Source





Interaction with materials?



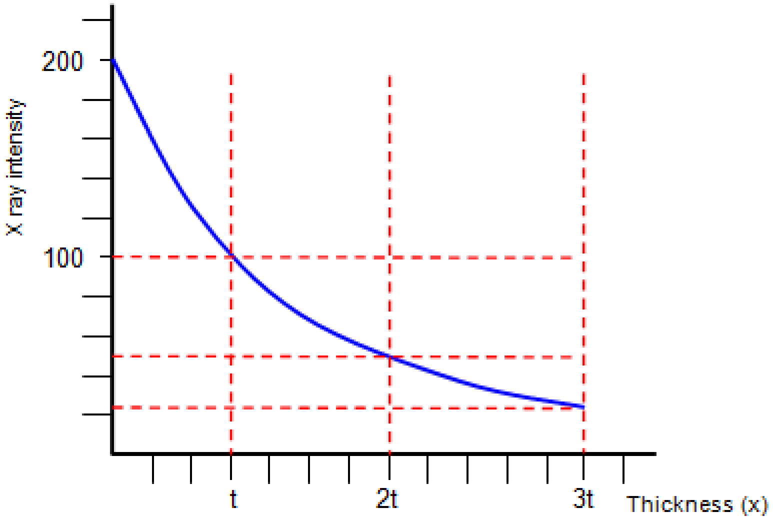
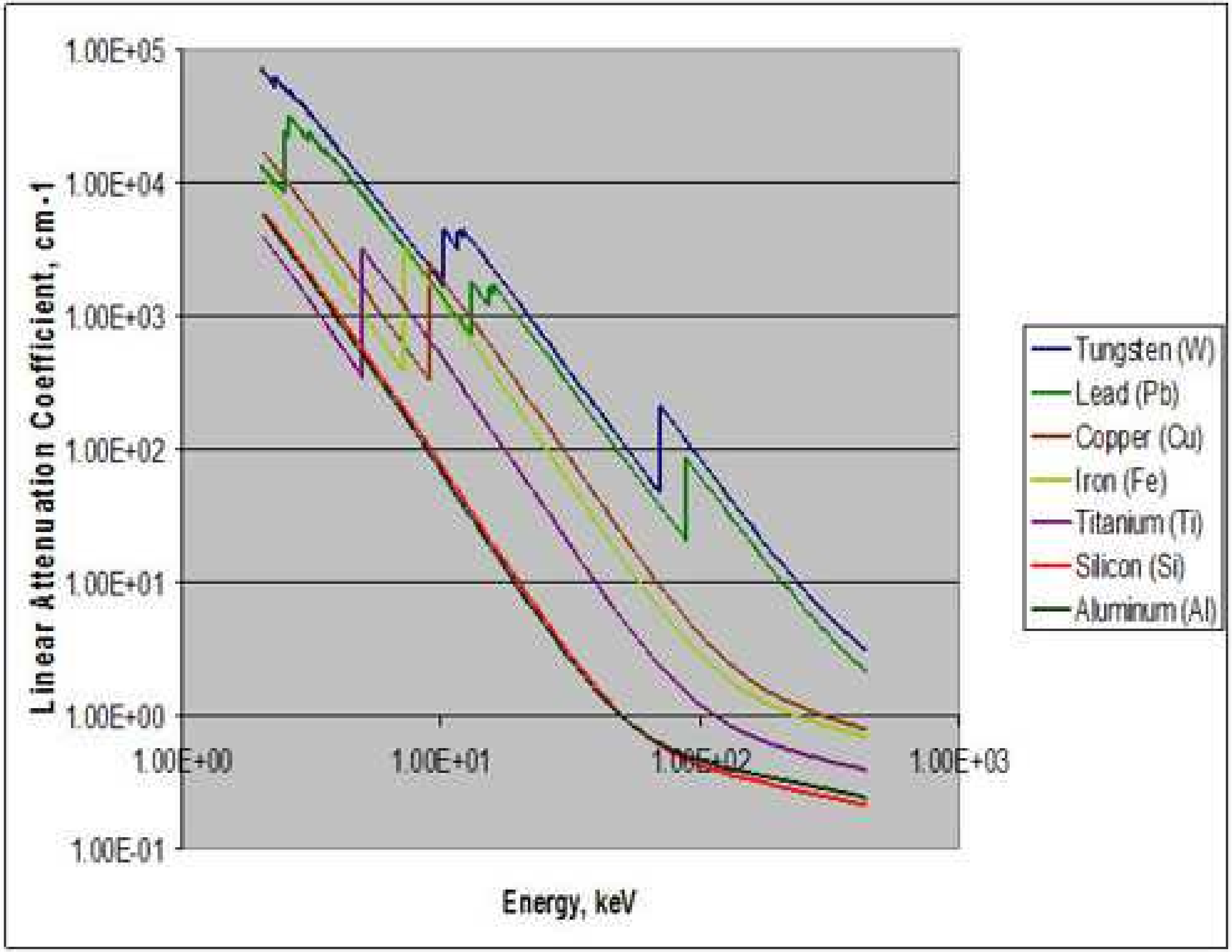


Figure 3

How they interact with materials?



SNL Applications

Sandia National Laboratories

- Current Radiography technology leveraged at SNL
  - 3D Computed Tomography
  - Digital Radiography
  - Computed Radiography
  - Flash Radiography
- Applications
  - Defect detection
  - Anomaly detection
  - Materials characterizations
  - Feature extraction

Medical Applications

- One of the largest concerns with medicine is dose
- Maximum information extraction
- Focused delivery of dose
- Typical energies around 160keV
- CT datasets on the order of millions of voxels

Industrial Applications

- With most imaged objects, dose not a concern
  - Exception example: Sensitive electronics
- Not typically limited to medical-scale energies
  - @SNL up to 6MeV or 6000keV
- Since dose can be increased
  - Larger detectors with smaller pixels
  - BigData CT
  - Computation complexity

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

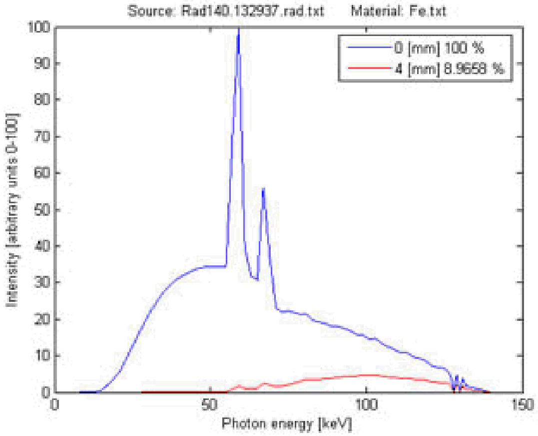
Another Use of Dual-Energy Radiography

•Two images at different energy spectrums are acquired.

•The images are then weighted and subtracted from each other.

•Allows, enhancement of either low or high attenuation regions.

•Used in medicine, being studied for security applications.



http://www.upstate.edu/radiology/education/rsna/radiography/dual.php

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

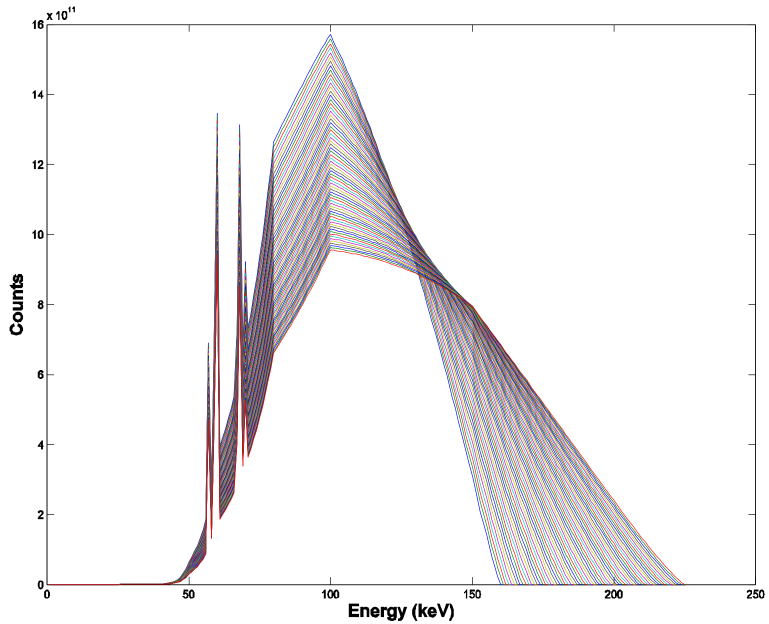
- A ratio image of high-to-low energies is created
  - $R = \frac{\frac{I_H}{I_{0,H}}}{\frac{I_L}{I_{0,L}}} \approx \frac{\overline{\mu_H}}{\overline{\mu_L}}$
  - This ratio approximates “effective atomic number”
- This ratio can then be subject to a threshold to separate material types
- Drawback: due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

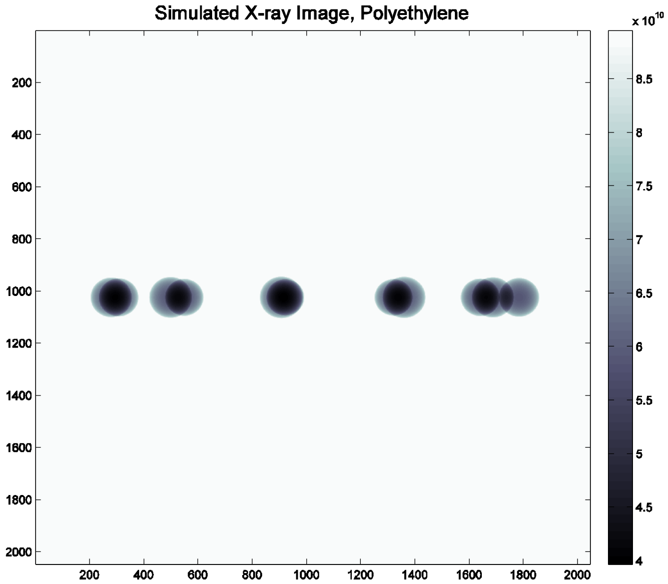
Exploratory work

- 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.

First Attempt

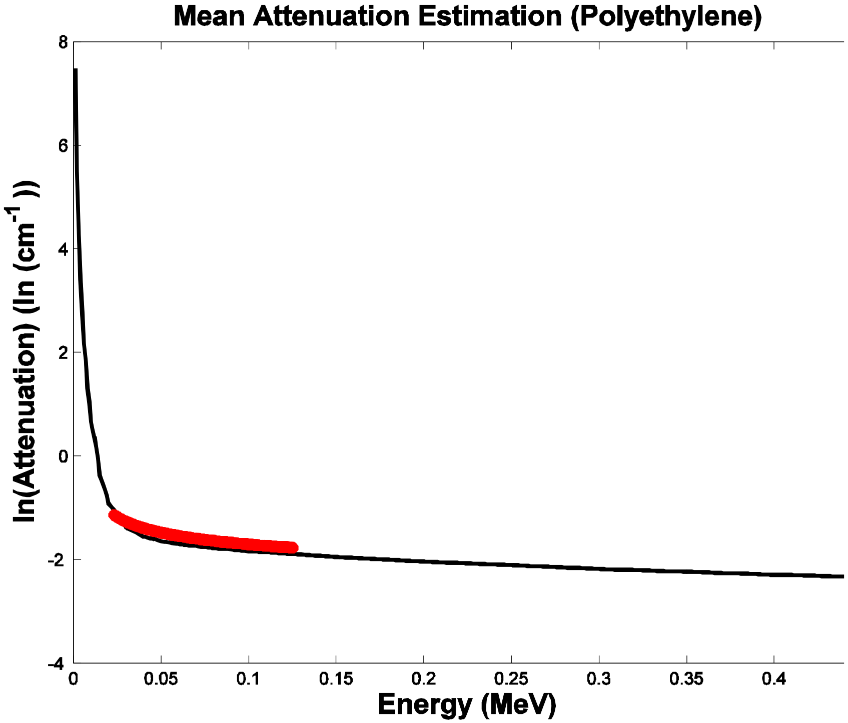
- How far off would we be using approximations?
- Approach: acquire images at multiple energies, solve effective attenuation

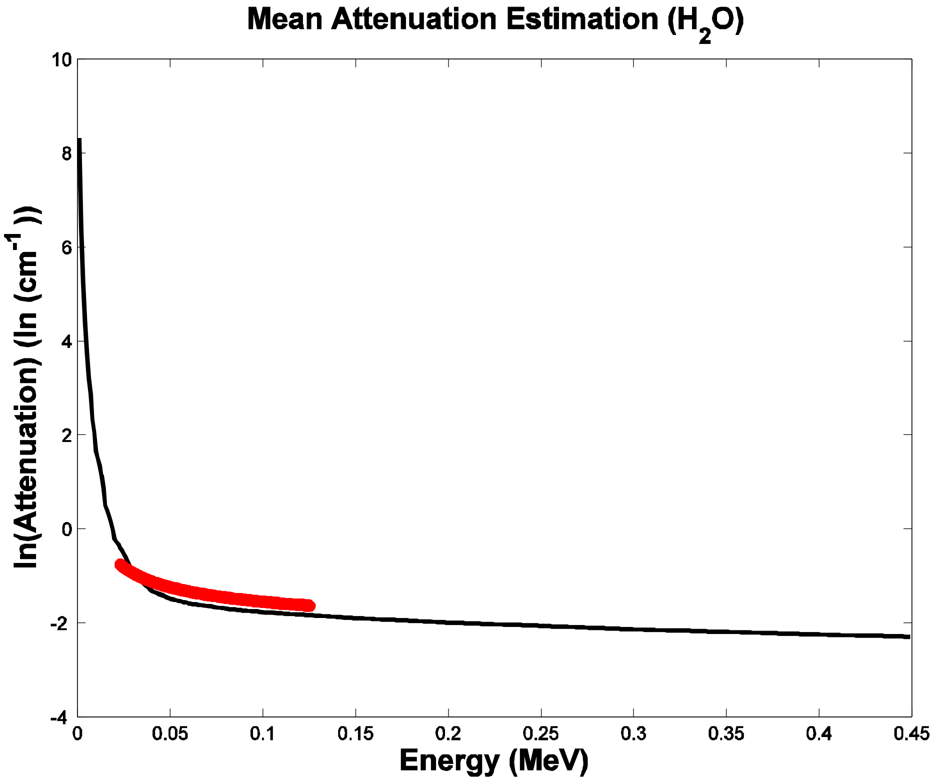




Results

- Polyethylene and Water

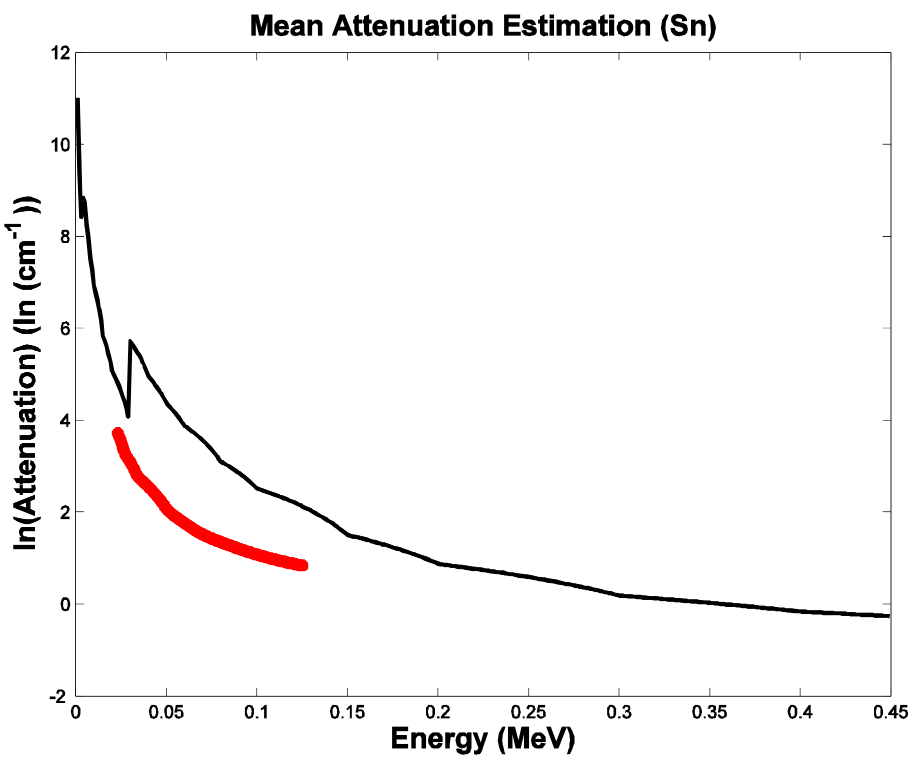


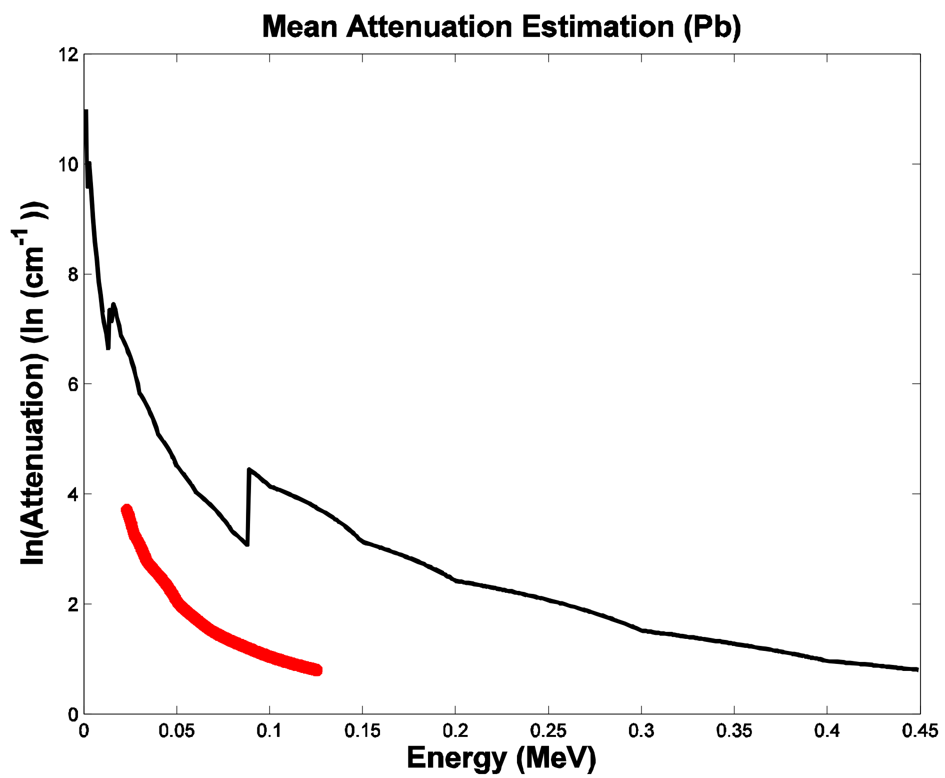


- ...not too bad!

Results Cont.

- Tin and Lead





- ….This is problematic

Second Attempt

Sandia National Laboratories

- Mediated Reality and Simulation-based Optimization

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

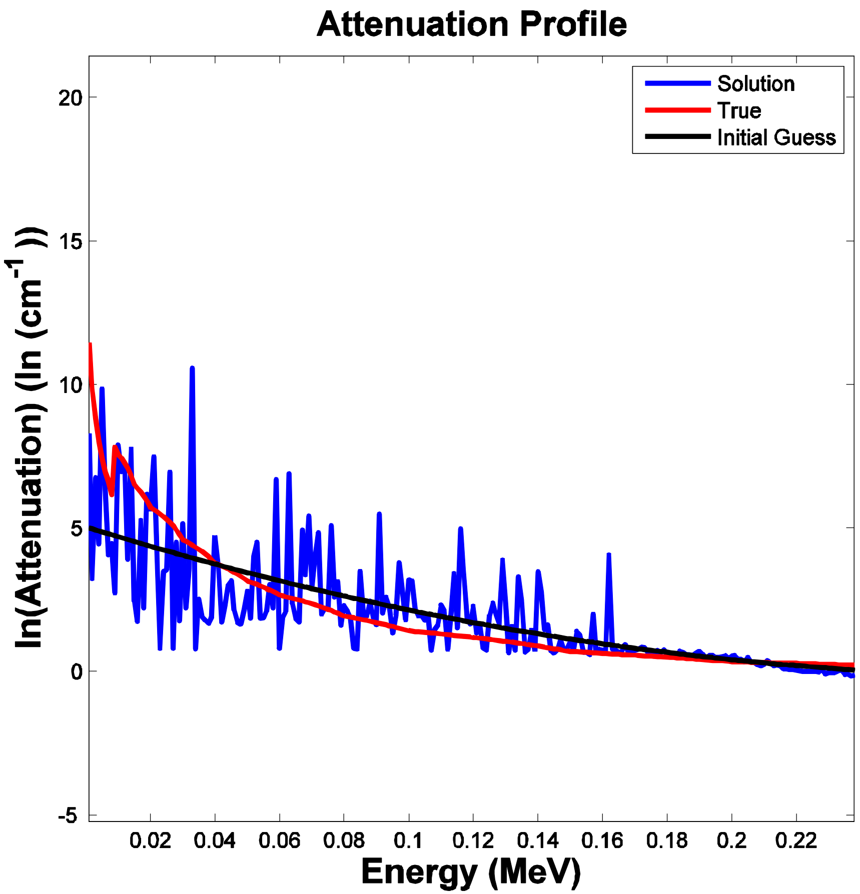
- Goal: Try different basis functions, try to resolve discontinuities in the attenuation profile.

- Optimize:

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

Results:

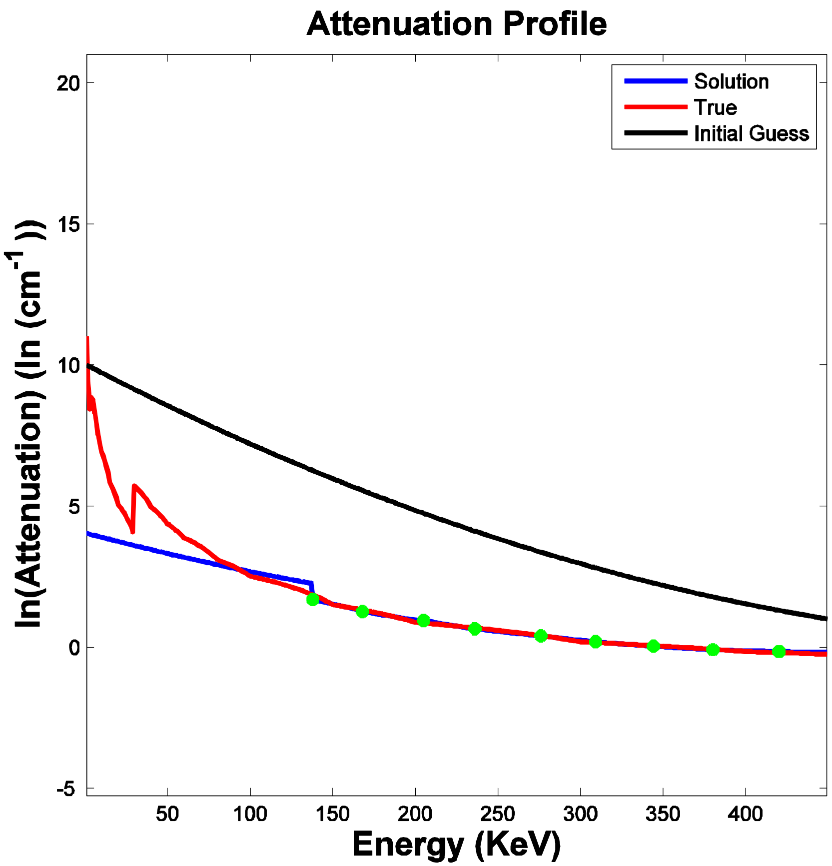
- Using a very large search space (~450 dimensions)
- Copper:



- …Problematic

Results cont.

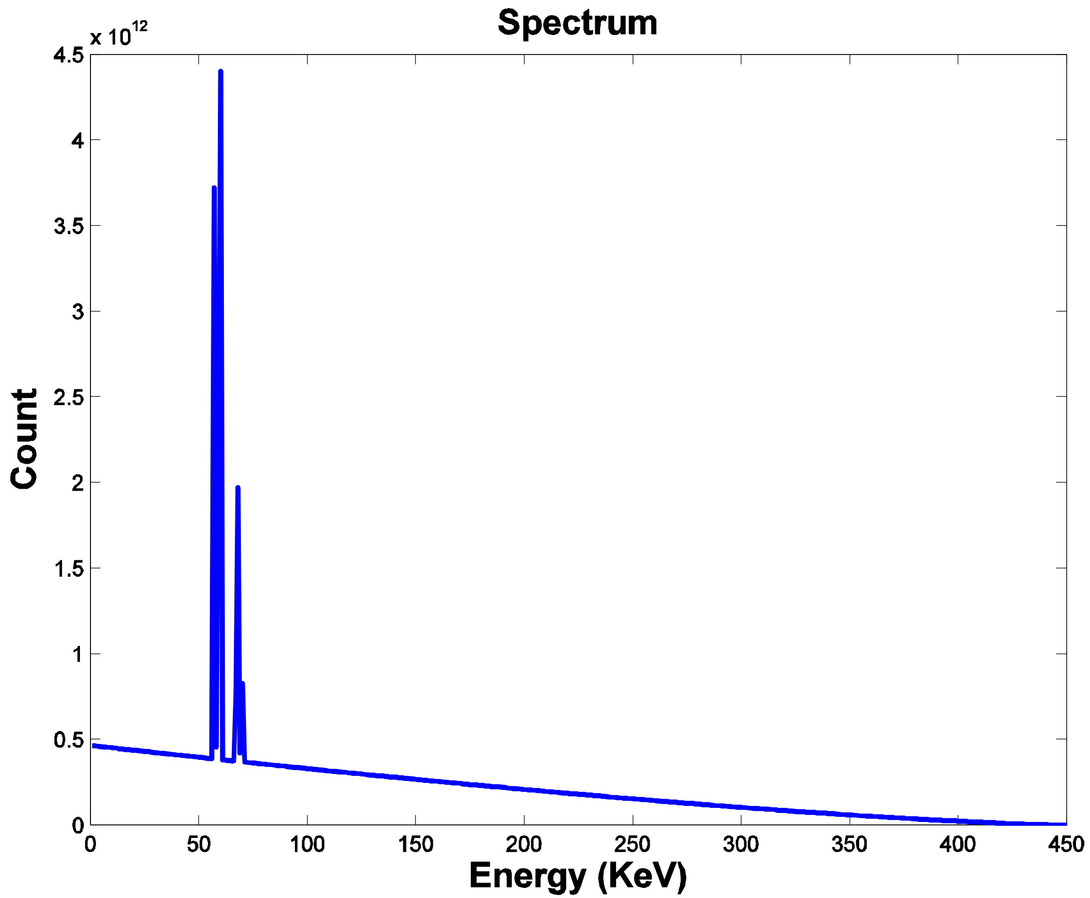
- Smaller space, interval-based basis functions
- Tin:



- No k-edge resolved…but promising!

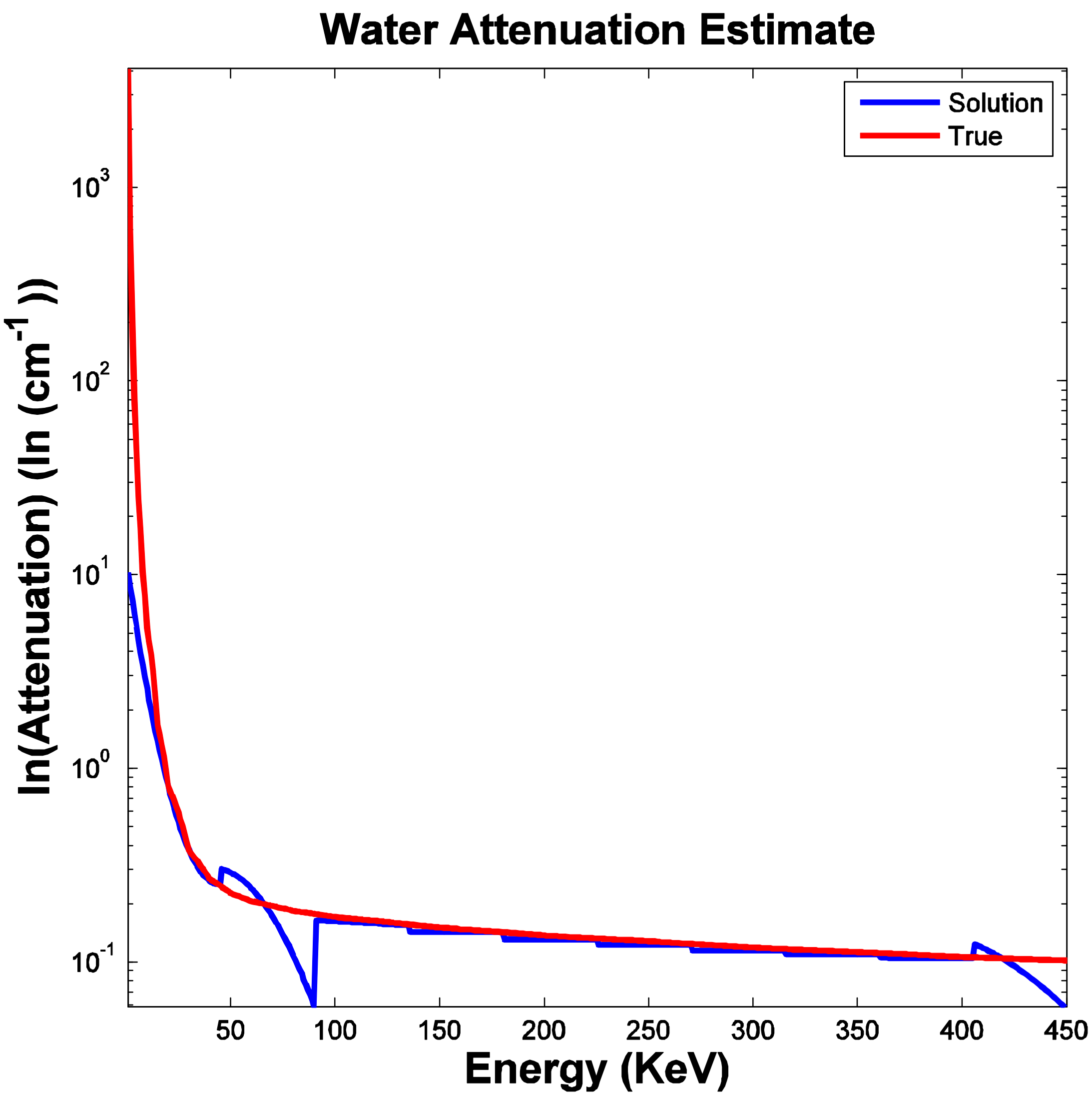
Third Attempt

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



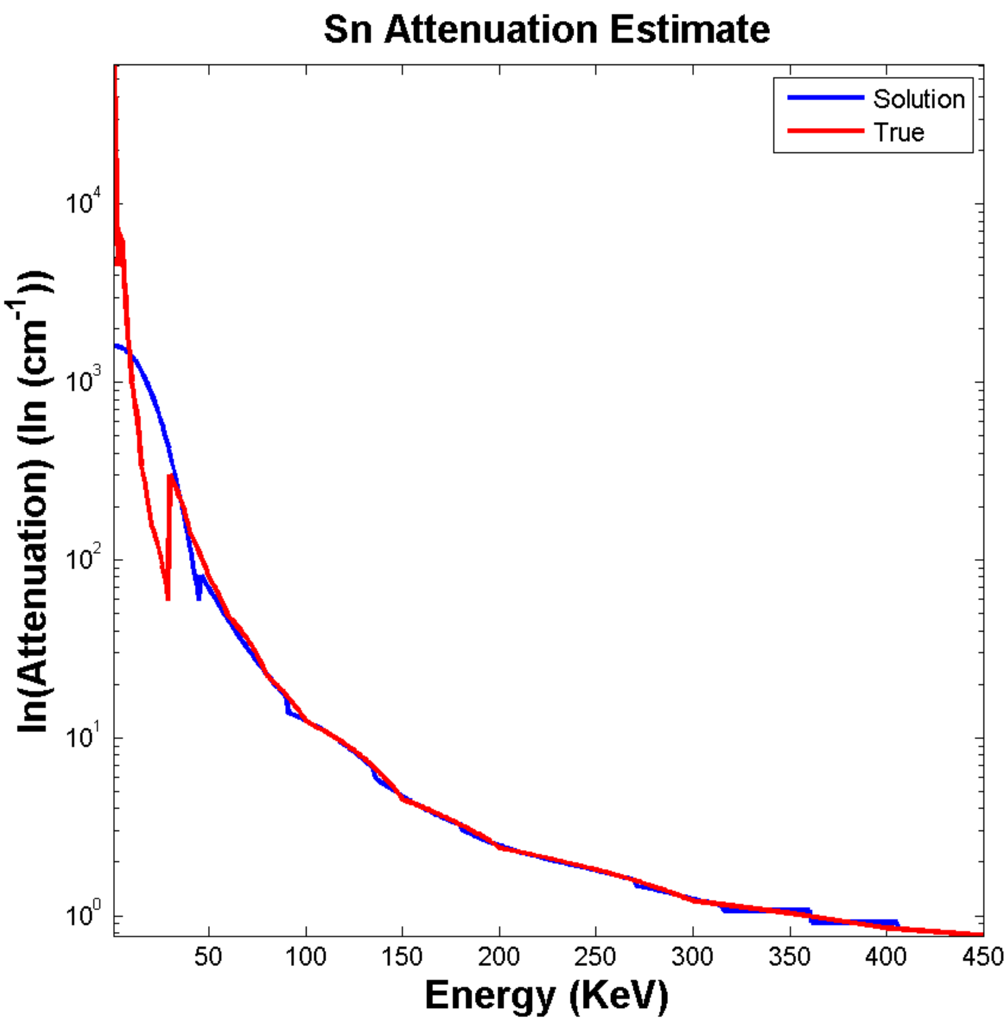
Results

- Water:



Results:

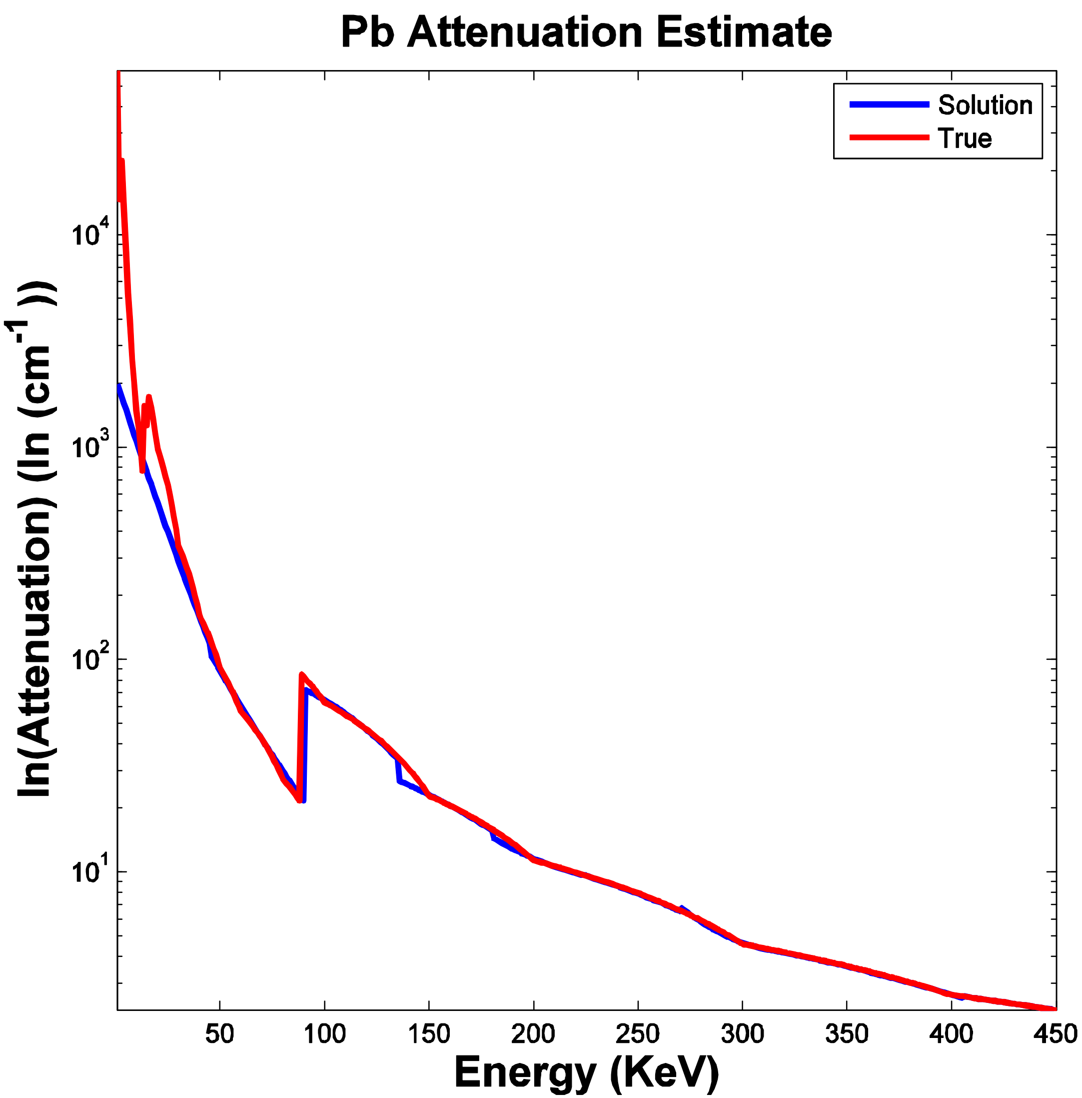
- Tin:



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

Results cont.

- Lead:



Conclusion

- Radiography, although a well-studied technology, there is still much to learn.
- Evolution of radiation detection and computational technology, new approaches can be studied.
- Sandia National Laboratories must take a leading role as this effort as it has many applications in areas of interest to SNL.
- Thanks! Questions?