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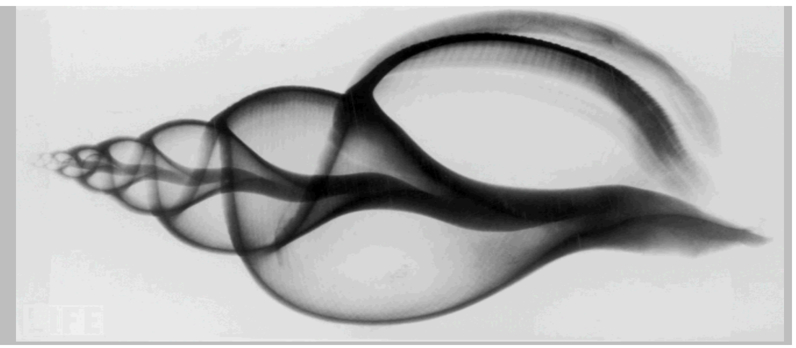

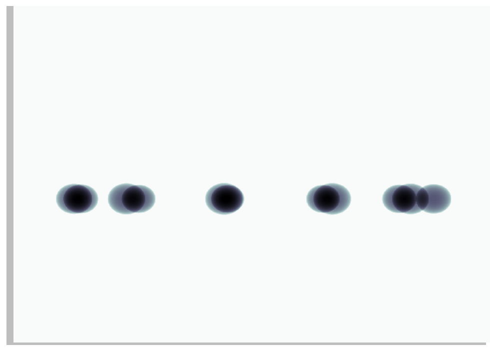

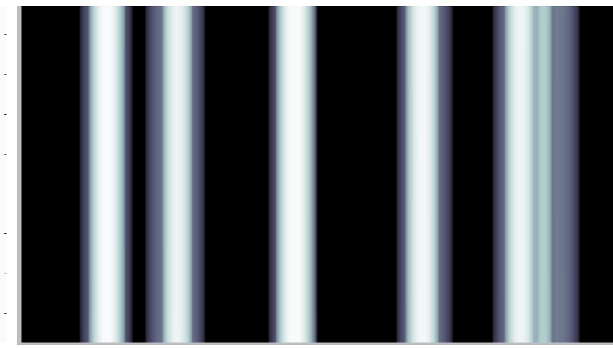

Exploring the Existence of Null Spaces in Mediated-Reality Supplemented Methods to X-ray Attenuation Estimation

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Introduction

- Expansion of exploratory work to investigate feasibility to extract attenuation information.
- For a fully characterized x-ray imaging system:
  - Can the object's attenuation WRT energy be extracted?
  - Are there any "blind spots" in the energy spectrum?
- If null spaces do exist, does this affect estimates?

Introduction Continued

- For this work:
  - Null spaces: Regions or materials in the object space that cannot be resolved for a given x-ray energy.
    - Lack of penetration
    - Lack of absorption

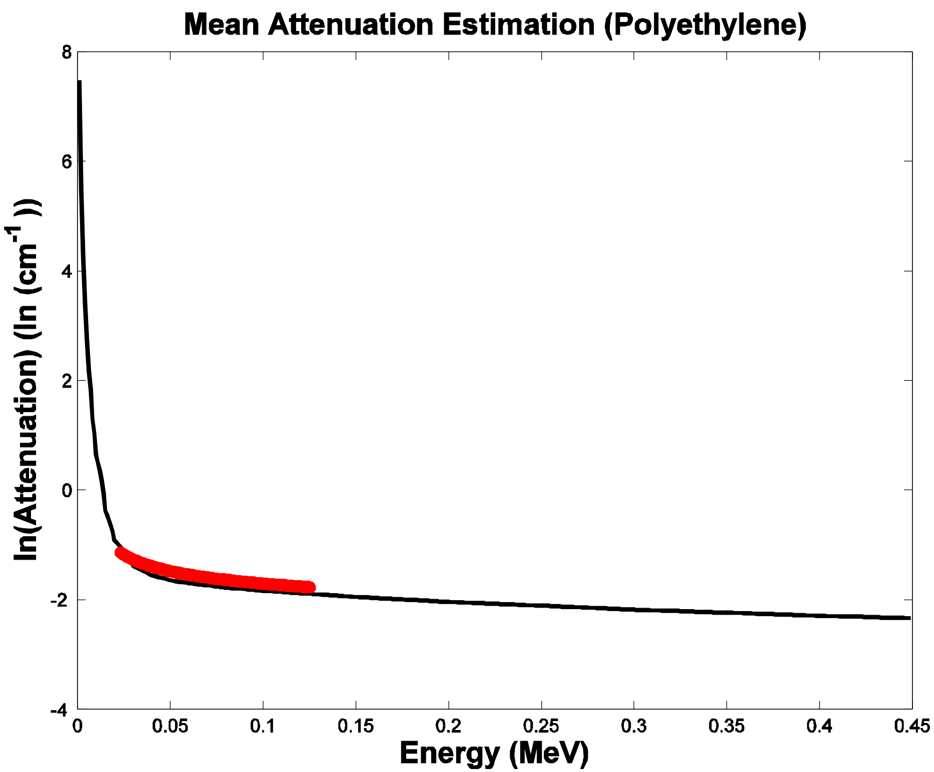
- Consideration must be given to algorithm implementation
  - Numerically sensitive
  - Widely ranging numerical values can lead to instability.

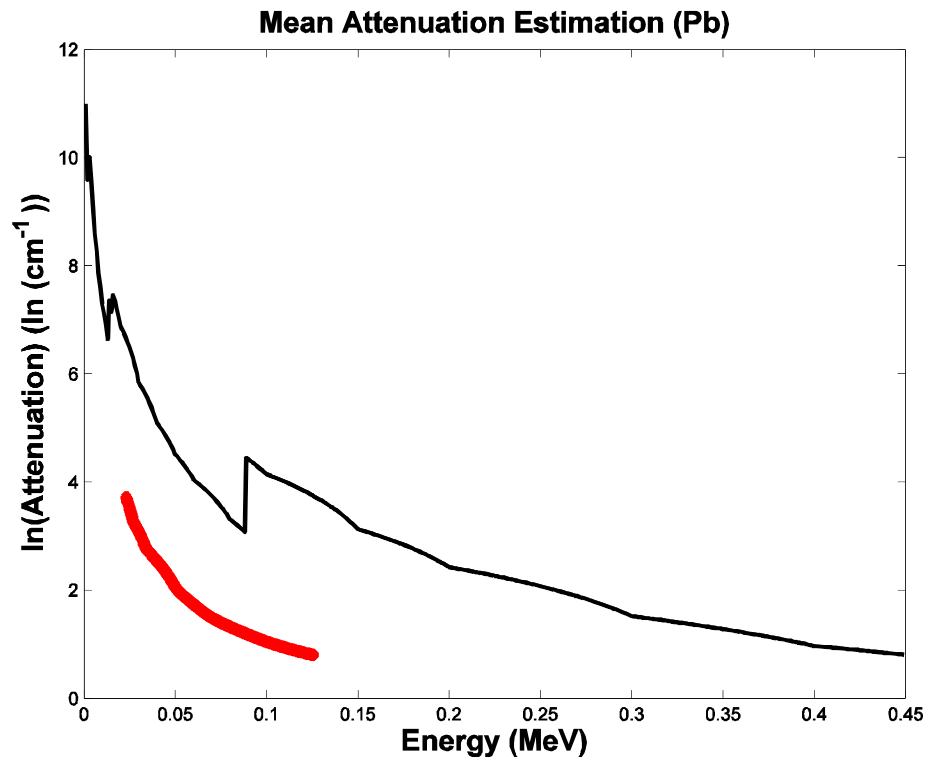
Background

- ASNT Research Symposium 2014
  - Utilization of Virtualized Environments for Efficient X-ray Attenuation Approximation
  - Using a single channel detector, can we estimate $\mu(\varepsilon)$ from images acquired at multiple energy profiles?
  - …sometimes… for low density materials
- SPIE Optics+Photonics 2014
  - Exploring Mediated Reality to Approximate X-ray Attenuation Coefficients from Radiographs
  - Leverage basis-function-based constrained DSM
  - …better…low energy not estimable/globally underestimated.

Background Continued

- Nuclear Science Symposium 2014
  - Object Composition Identification via Mediated-Reality Supplemented Radiographs
  - Use a multi-channel imaging detector and basis-function DSM
  - 10 channels over 450 keV
  - Legendre polynomial basis with Nelder-Mead DSM
  - Much improved estimates!


Mean Attenuation Estimation (Polyethylene)
ln(Attenuation) (ln (cm^{-1}))
Energy (MeV)
8
6
4
2
0
-2
-4
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45


Mean Attenuation Estimation (Pb)
ln(Attenuation) (ln (cm^{-1}))
Energy (MeV)
12
10
8
6
4
2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45

SPIE 2014

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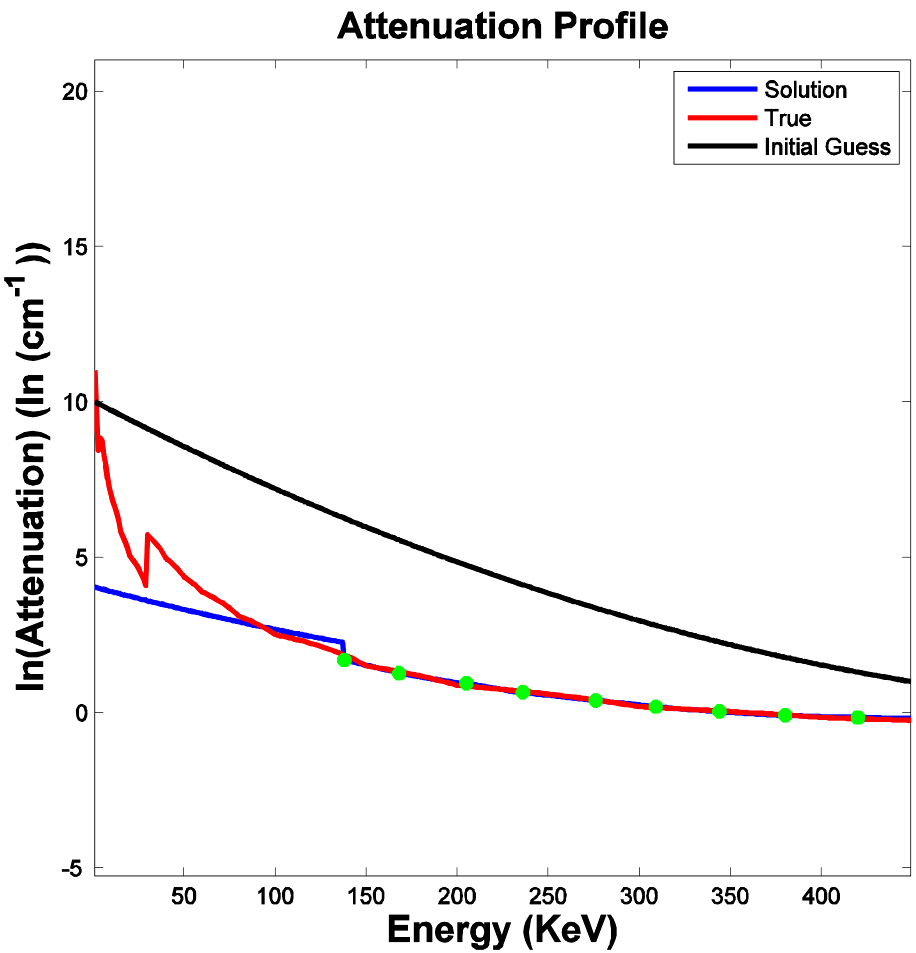
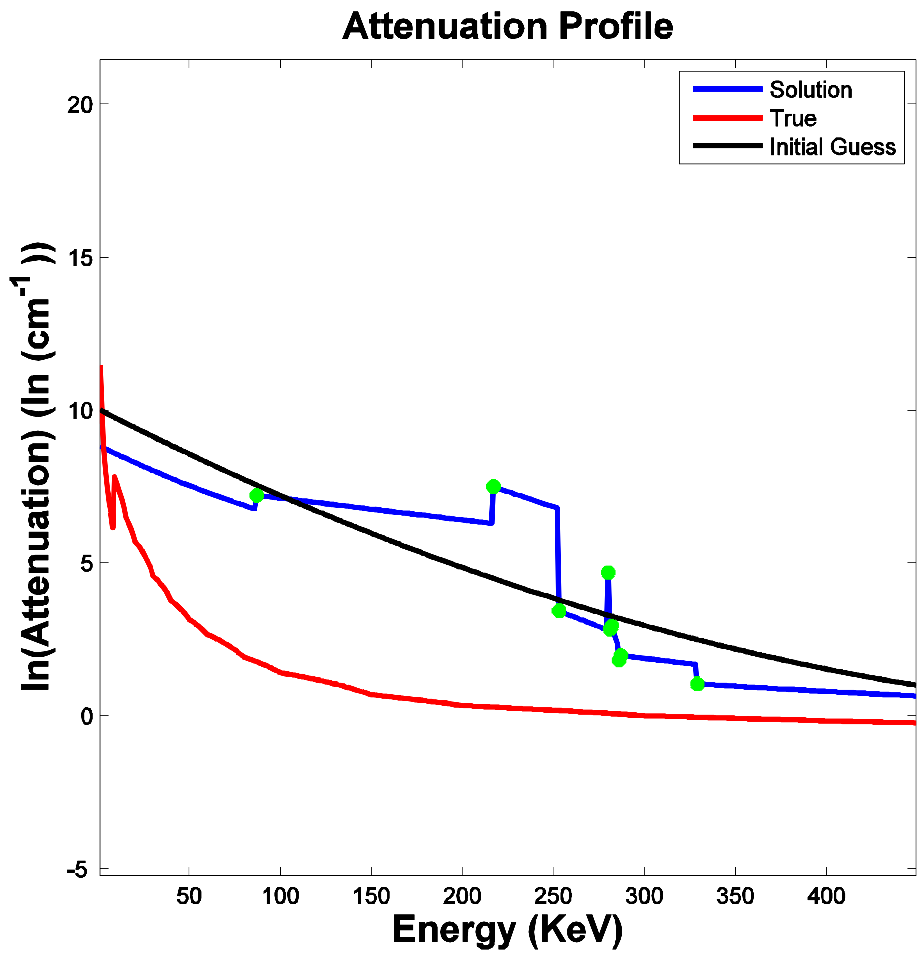
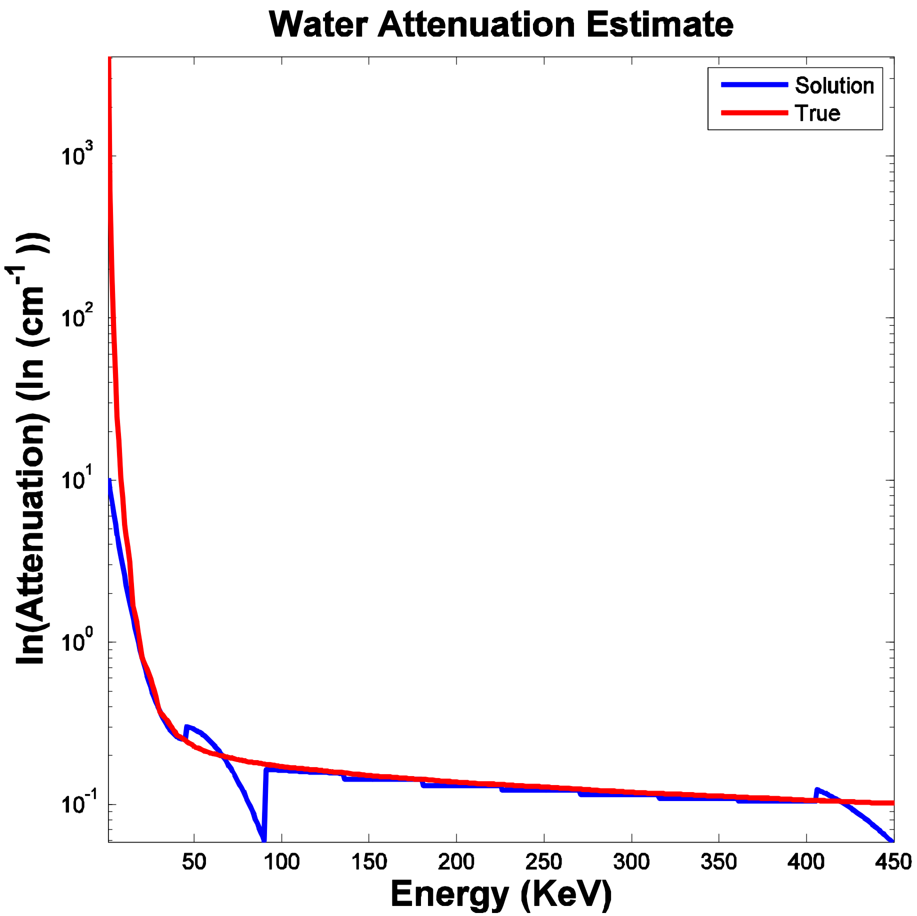
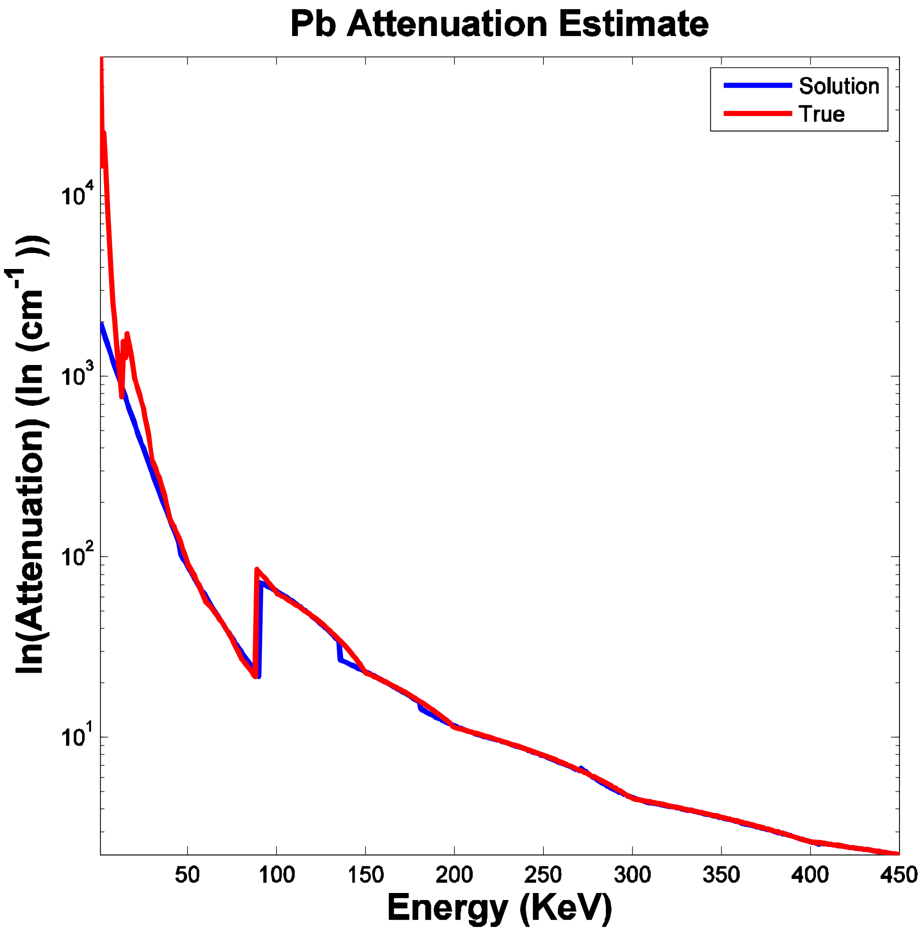




NSS 2014



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



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

Problem

- Direct Search Methods can be particularly sensitive to numerical instability

- Null spaces will mislead search trajectory
  - Will not converge
  - Will converge slowly
  - Will converge to wrong solution

- This work will investigate:
  - Relative error WRT Energy
  - Relative error WRT Thickness
  - Signal absorption WRT Energy
  - Signal absorption WRT Thickness

Approach

- The imaging system is represented as:

$$\vec{g} = \mathscr{H} f(\mathbf{X}, \mu(\mathbf{X})),$$

- Images will be achromatically formed:

$$I_j(\varepsilon) = I_0(\varepsilon)\Delta I e^{-(\mu_a(\varepsilon)x_a + \mu(\varepsilon)x)},$$

- Since this is a study on numerical challenges:
  - Simulation study
  - Noise-free
  - Ideal images

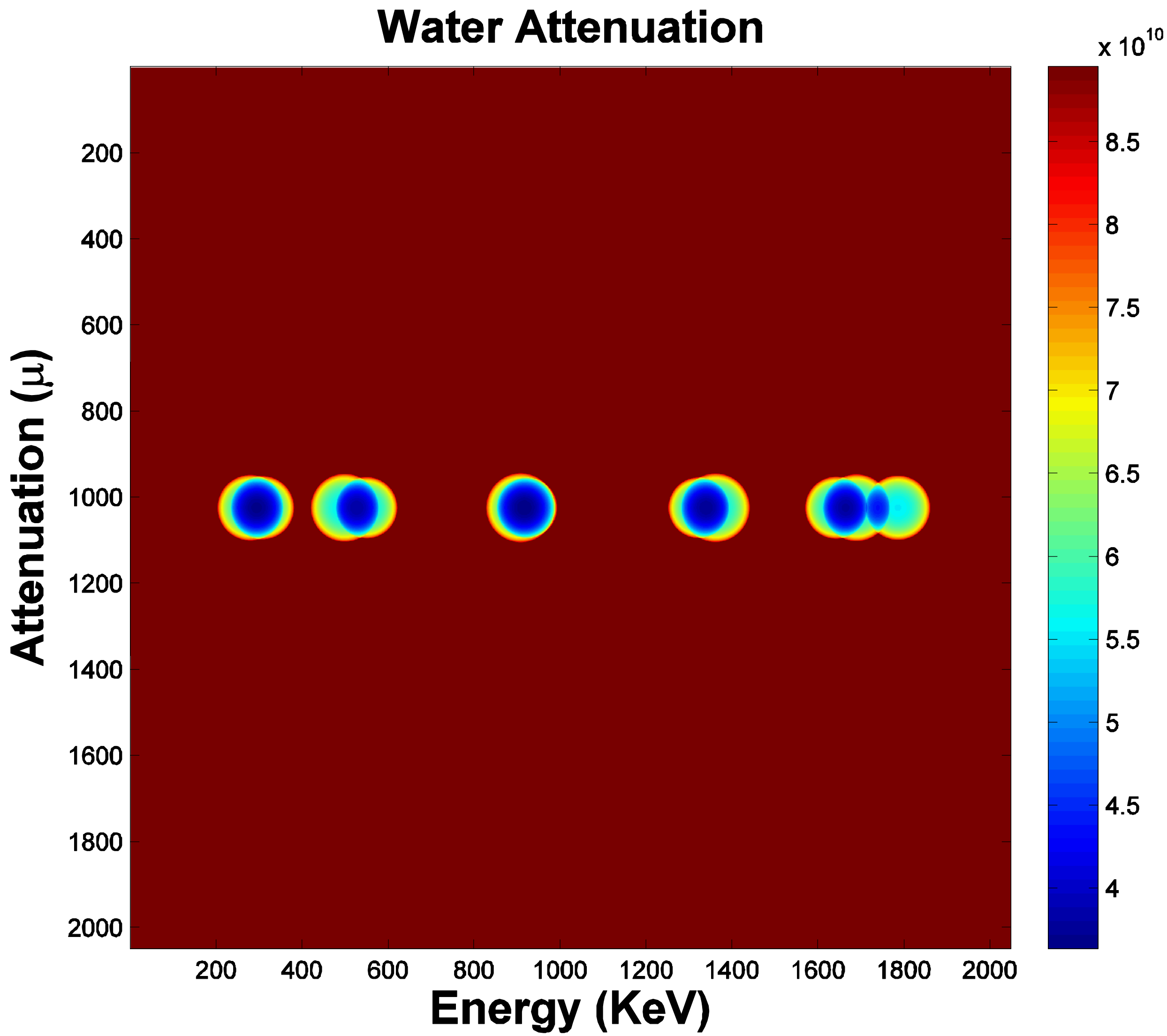
Implementation

- Coded in Matlab R2014a (ver. 8.3.0.532).
- System simulated a 450 keV unfiltered Tungsten target source.
- Each energy bin is 1 keV wide
- 2048x2048 pixel images with 200 um pitch
- Digital phantom is 11 spheres in a circular orientation.

Implementation Continued

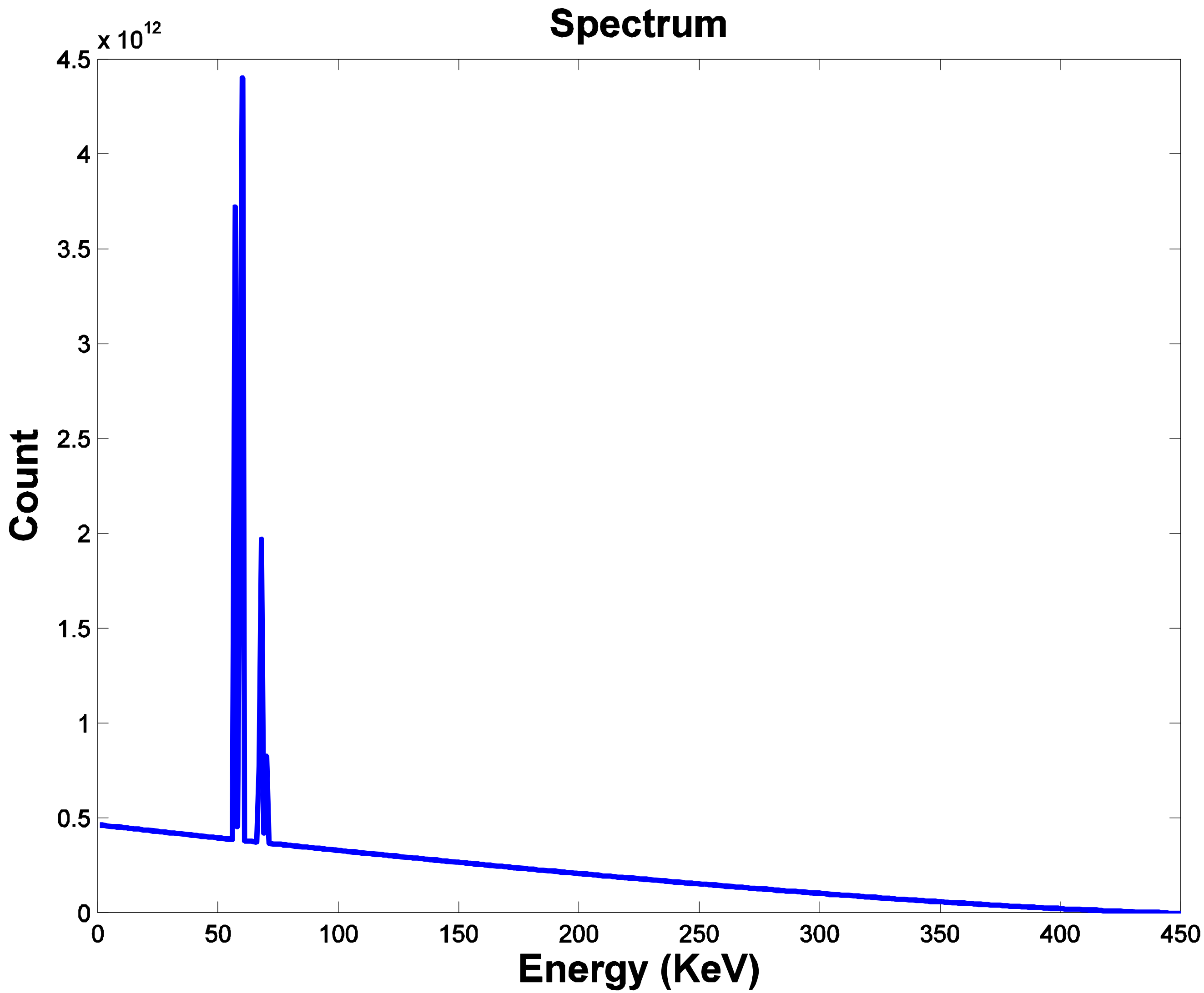
- Source to Detector: 226 cm
- Source to Phantom Center of Mass: 188 cm
- Relative error will be compared to the direct calculation of $\mu(\varepsilon)$ compared to the true value of $\mu(\varepsilon)$.
- Materials imaged:
  - Water
  - Polyethylene
  - Copper
  - Tin
  - Lead

Radiograph



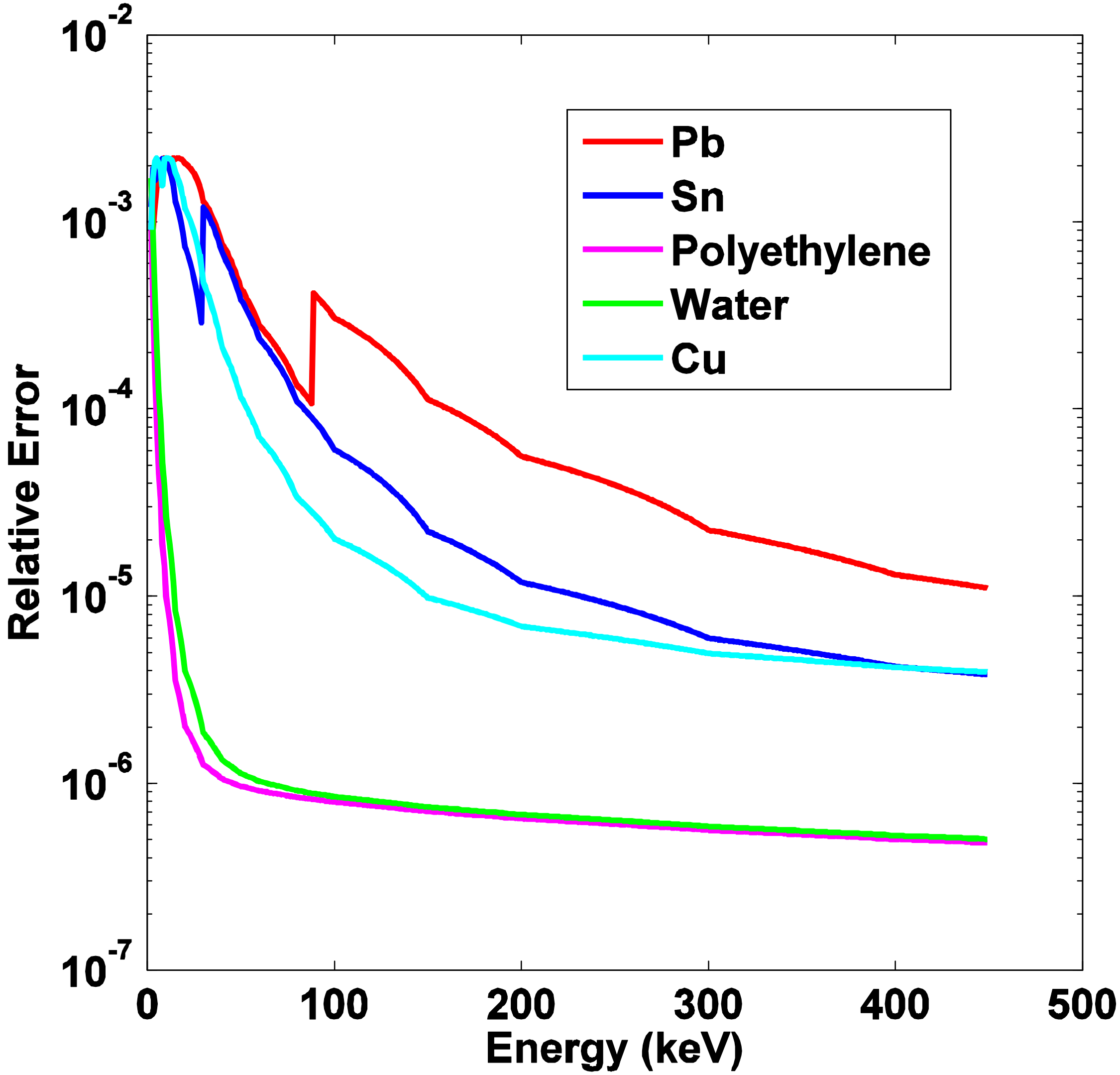
Water Attenuation
Attenuation (μ)
Energy (KeV)
200
400
600
800
1000
1200
1400
1600
1800
2000
x 10^10
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4

Spectrum

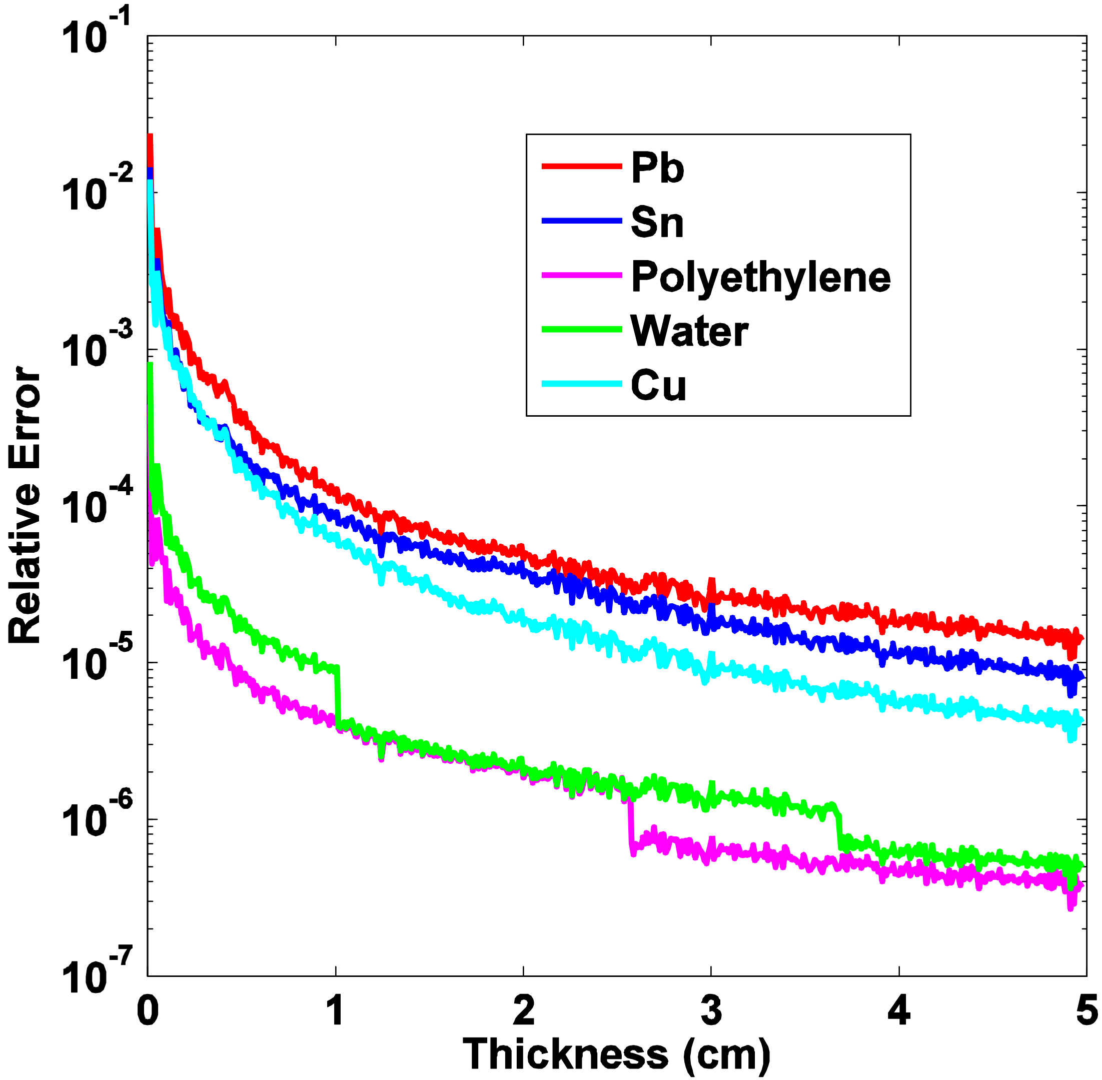


Spectrum
x 10^12
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Count
0
50
100
150
200
250
300
350
400
450
Energy (KeV)

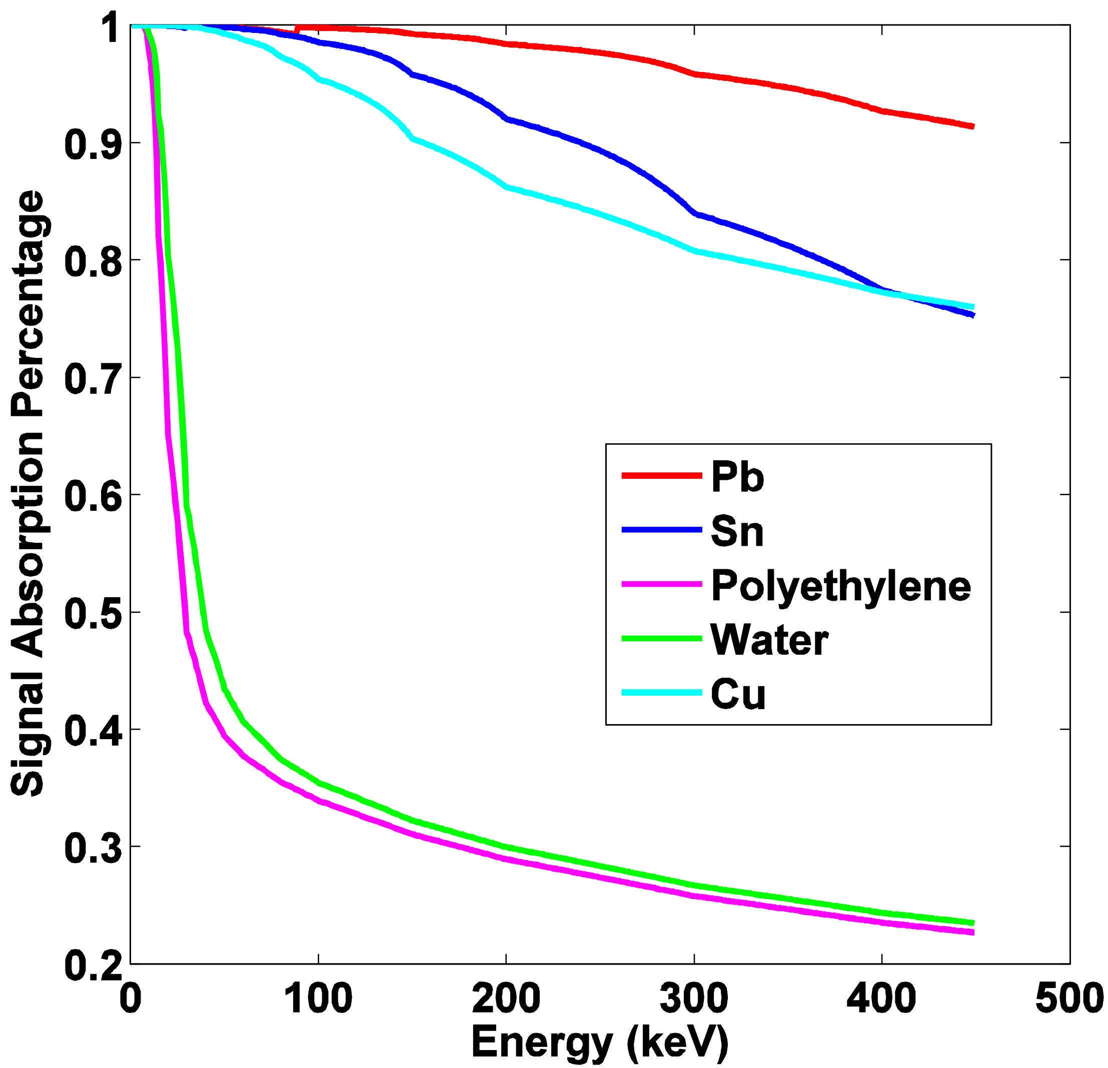
Relative error WRT Energy



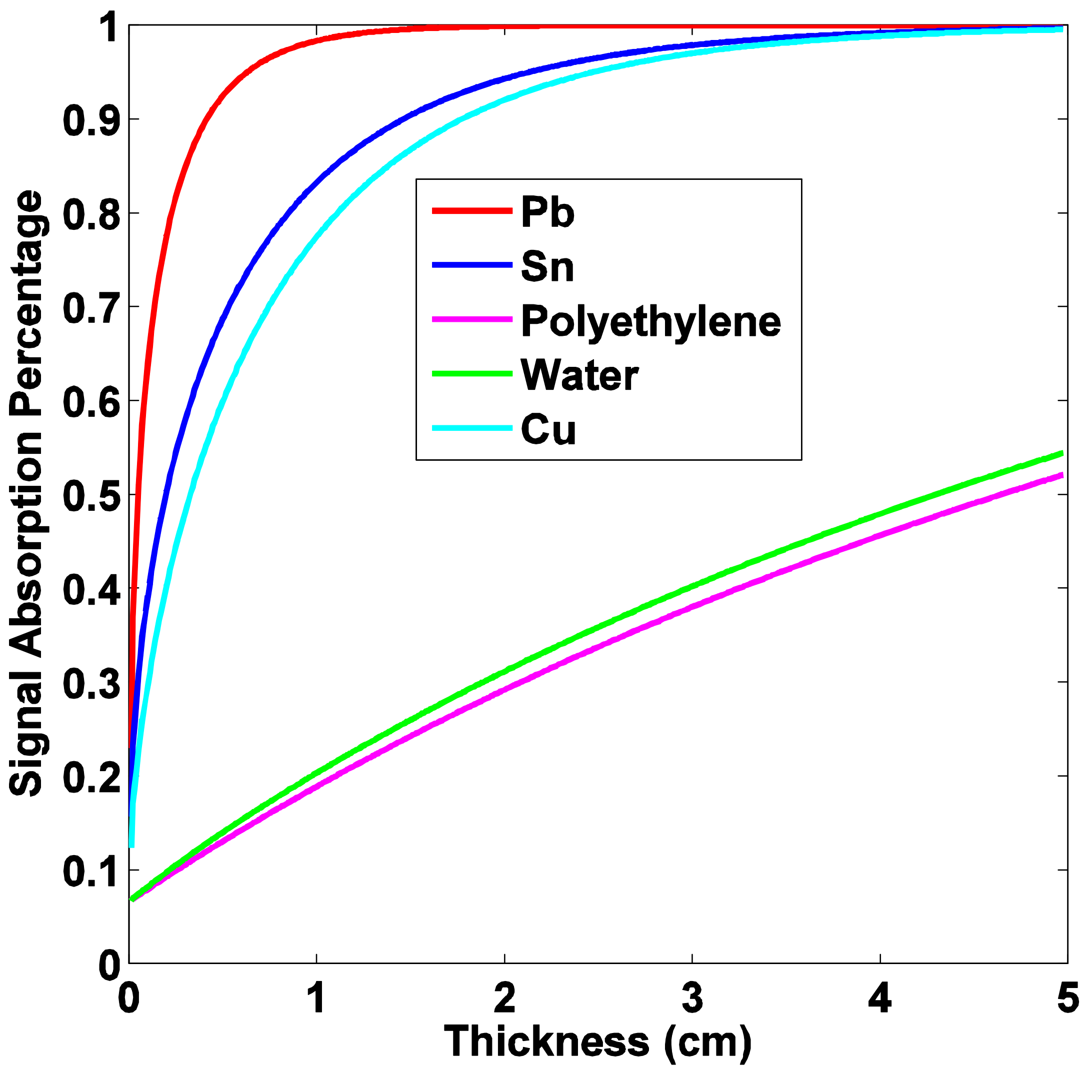
Relative error WRT Thickness



Signal absorption WRT Energy



Signal absorption WRT Thickness



Conclusions

- Elevated error for high Z materials may be a contributor to underestimation.
  - Error around k-edges is problematic.
- Direct calculation of attenuation poses computational challenge.
  - DSM can avoid a direct calculation.
- High Signal absorption can lead to poor SNR
- Can these methods be applied to PCI?