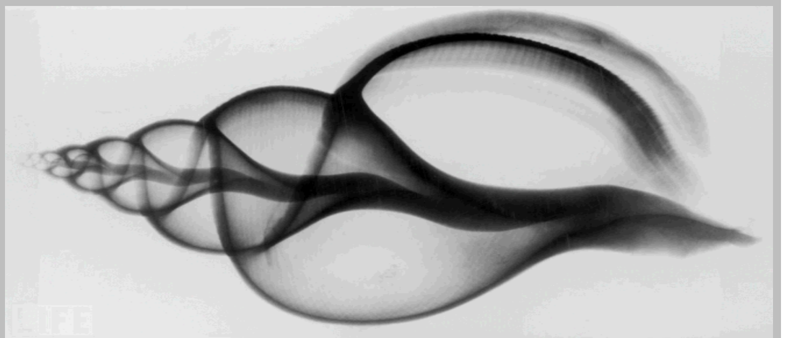
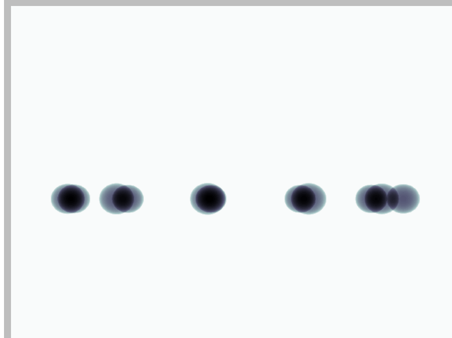
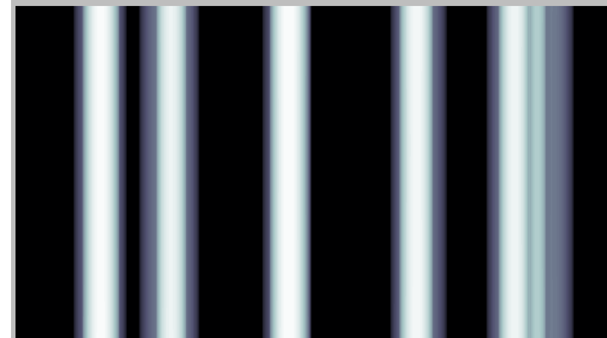
Exceptional service in the national interest

SAND2014-17157PE

Sandia National Laboratories







Exploring Mediated Reality to Approximate X-ray Attenuation Coefficients from Radiographs

Edward S. Jimenez, Laurel J. Orr, Megan L. Morgan, and Kyle R. Thompson

Penetrating Radiation Systems and Applications XV at SPIE Optics+Photonics 2014

August 2014

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.

Introduction

- This is an exploratory project:
  - Feasibility of material identification from 2D Radiograph
  - Expands on an investigation in approximating x-ray attenuation properties.
  - Effective attenuation is not sufficient to identify a material in a radiograph.
- This work will expand on the characterization of the imaging system.
  - Information leveraged along with a direct search method.
- Mediated reality based approaches have been successfully leveraged in imaging applications.

Background

- Ignoring noise, the intensity of pixel j is:

$$I(j) = \int_{\varepsilon \in E} \int_{l_j} I_0(\varepsilon) e^{\mu(x,\varepsilon)x} \, dx \, d\varepsilon$$

- Leveraging the mediated reality information of the imaging system:
  - Source profile
  - Energy Range
  - Geometry of Hardware

Background Cont.

- Leveraging all the above and a given image, optimize:

$$\underset{\hat{\mu}(x,\varepsilon)}{arg\ min} \left\| \vec{g}_{\mu(x,\varepsilon)} - \hat{g}_{\hat{\mu}(x,\varepsilon)} \right\|_p$$

- The data is represented as vector g.
  - Pixel basis is no longer required.
  - Parameterizations can be considered.
  - In this work p=2.

Approach

- Due to the non-linear nature of imaging with polychromatic radiation, a direct search algorithm will be used.

- Nelder-Mead Simplex Algorithm
  - No gradients needed.
  - For n dimensions, n+1 vertices on the simplex.
  - Modify simplex based on evaluation of objective function.

- Although Nelder-Mead can fail, it typically does not.

- Drawback: Very slow convergence for high dimensional domain

Implementation

- Three approaches will be investigated:

- Full Nelder-Mead
  - Spectrum is discretized
  - At 450 keV, 450 dimensions
  - Allows for discontinuities at k-edges

- Legendre Polynomials
  - Drastically reduces dimensionality of domain
  - 5 polynomials
  - Does not allow for discontinuities

$$\hat{\mu}(\varepsilon) = \sum_{i=0}^{4} c_i p_i(\varepsilon)$$

Implementation Cont.

- The third approach attempts to resolve the edges while reducing dimensionality.
  - Partition energy support into 10 sub-intervals
  - Fit 5 Legendre polynomials in each interval
  - 59 dimensions instead of 450.
  - Allows for up to 10 discontinuities.
  - The intervals can dynamically increase or decrease in length.
    - Constrained to the size of support of the initial profile.

- All images contain objects of a homogeneous material.
  - Digital phantom of 11 spheres 2.5 cm in diameter.
  - Circular arrangement perpendicular to detector plane.

Implementation Cont.

- In the interest of performance and accuracy:
  - Profile is generally decreasing
  - Generally concave up
  - Lowest energy has highest attenuation
  - Highest energy has lowest attenuation

- If any conditions above are violated then error is forced to be maximal.

- Constraints above could potentially hinder the algorithm.

Evaluation

- Compare performance of each approach described.
- Each will run until minima is reached or 96 hours elapse.
- Candidate profiles will be compared to:
  - Profiles yielded from the other approaches.
  - Initial guess
  - True profile
- Five materials:
  - Copper
  - Lead
  - Tin
  - Polyethylene
  - Water

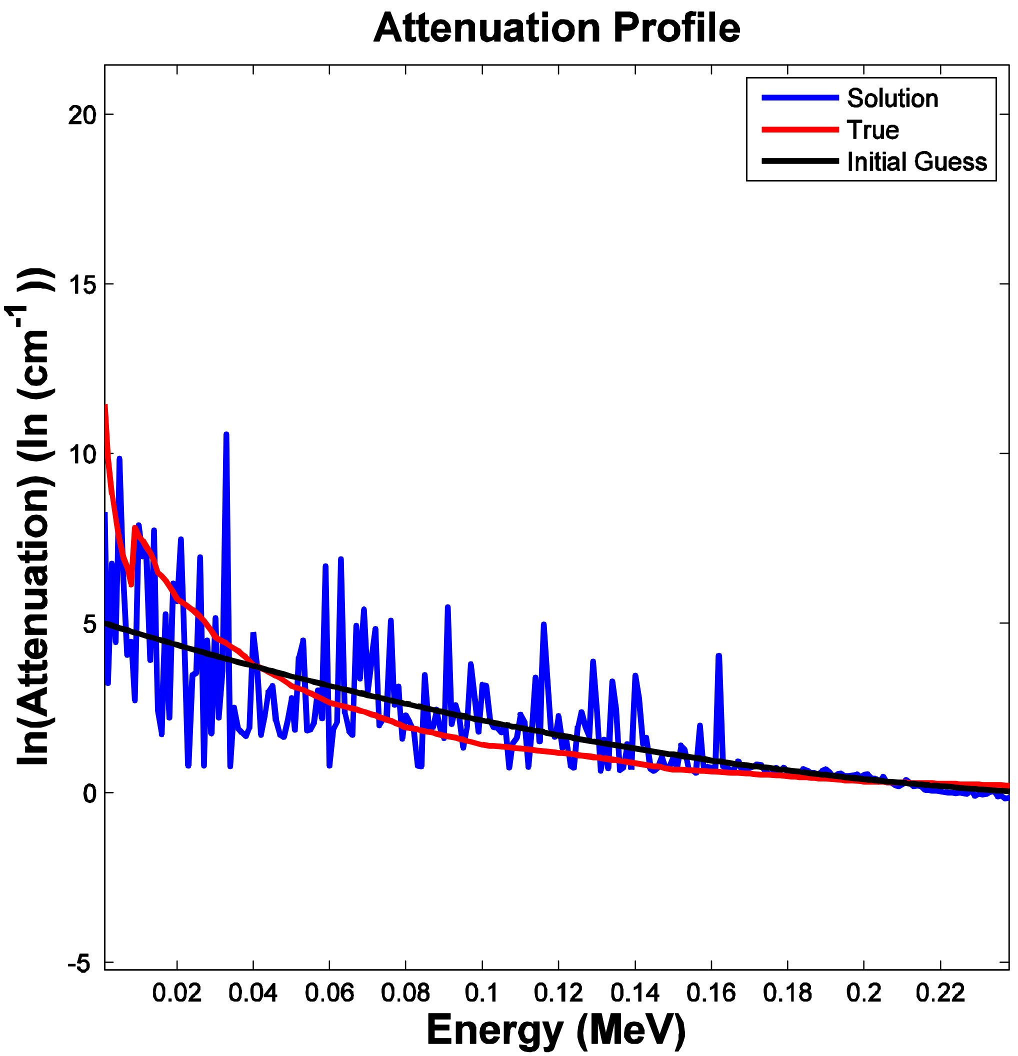
Evaluation Cont.

- Imaging system:
  - Simulated in Matlab.
  - 450 keV Bremsstrahlung profile (Tungsten target).
  - Object is 11 spheres of homogeneous material.
  - Ideal Detector at 2048x2048 pixels (0.02cmx0.02cm)
  - Detector to Source: 226cm

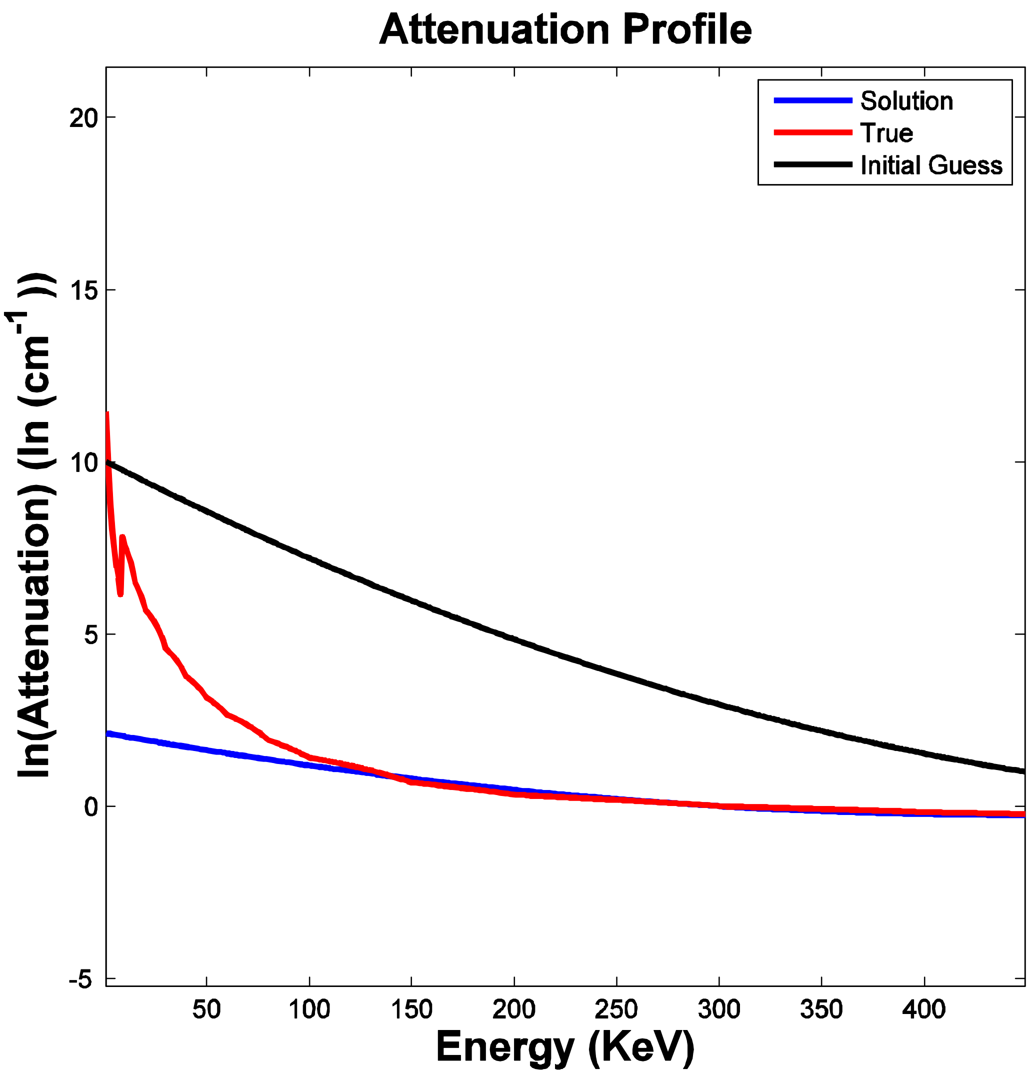
- To improve numerical stability, the objective function is:

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

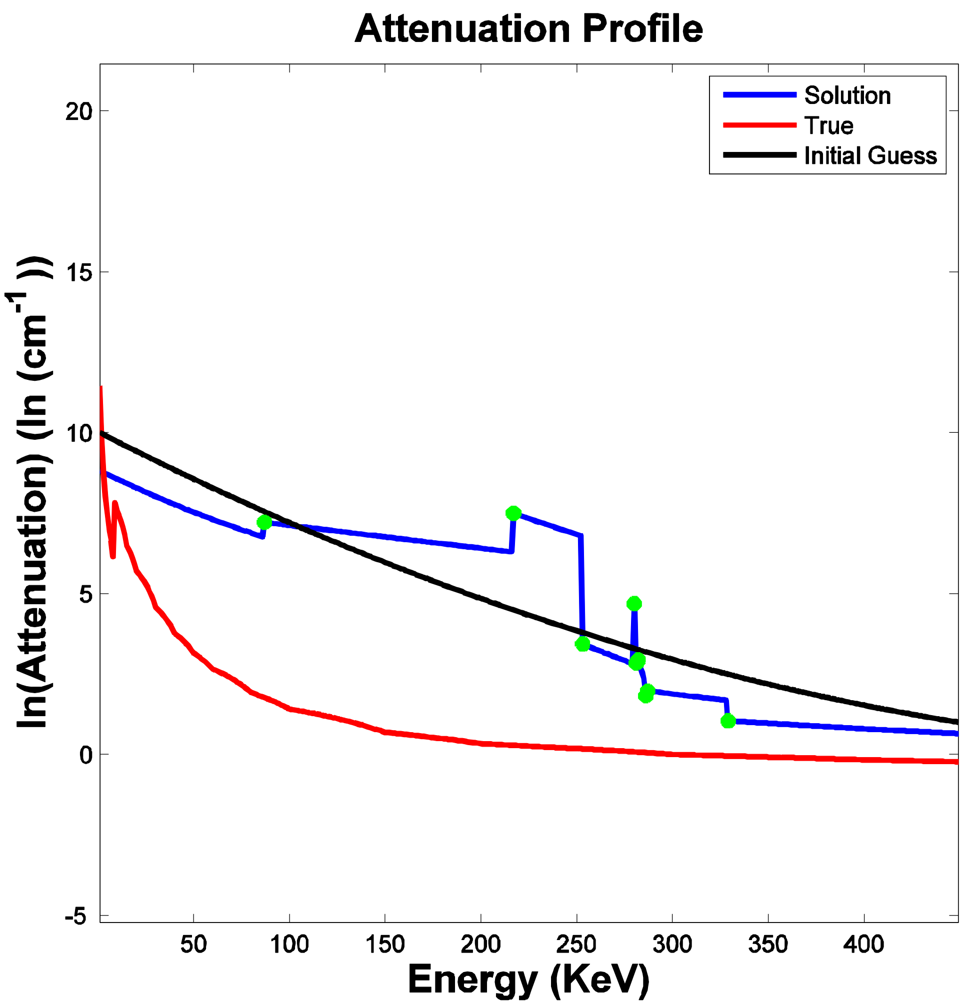
Results: Full Nelder-Mead (Cu)



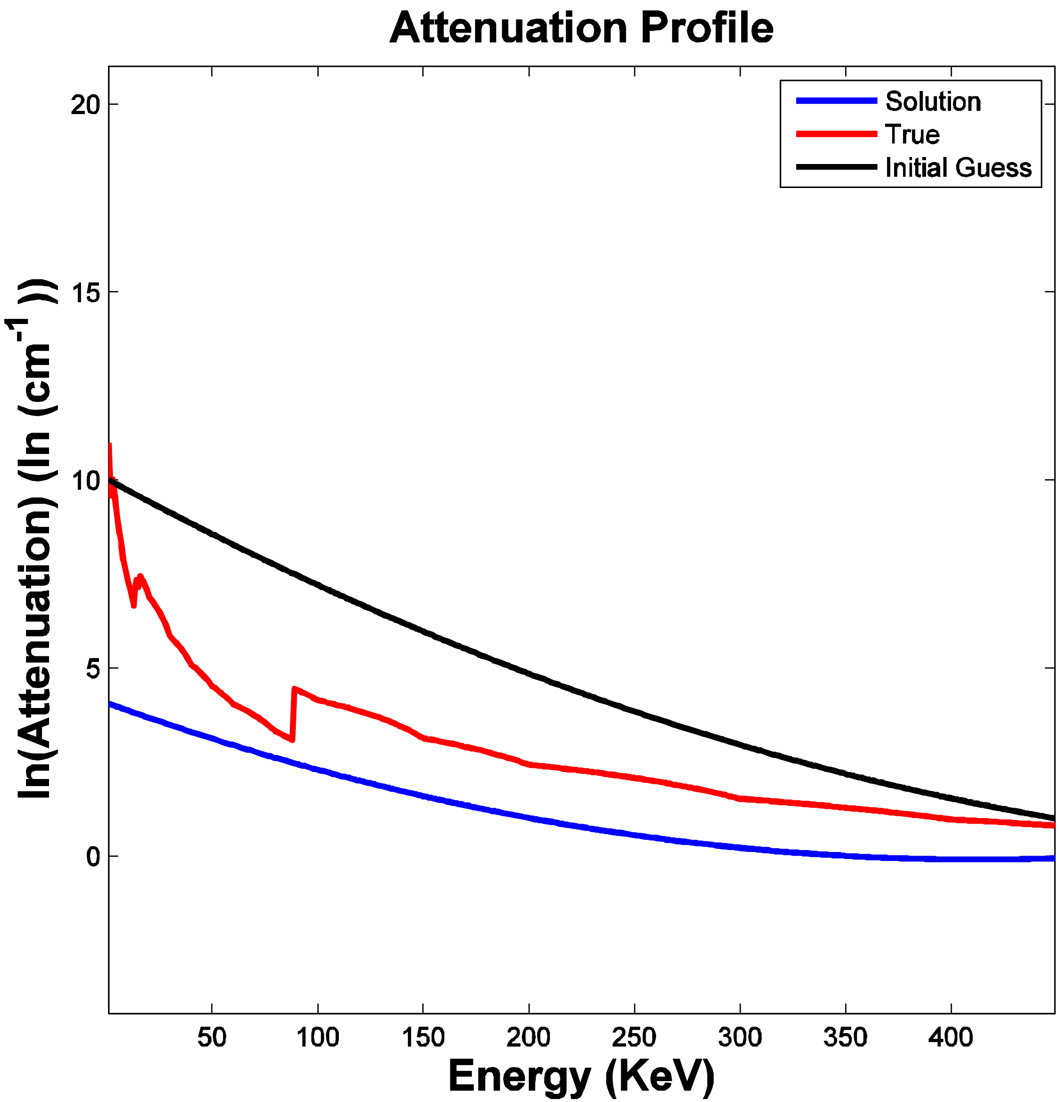
Results: Legendre Polynomials (Cu)



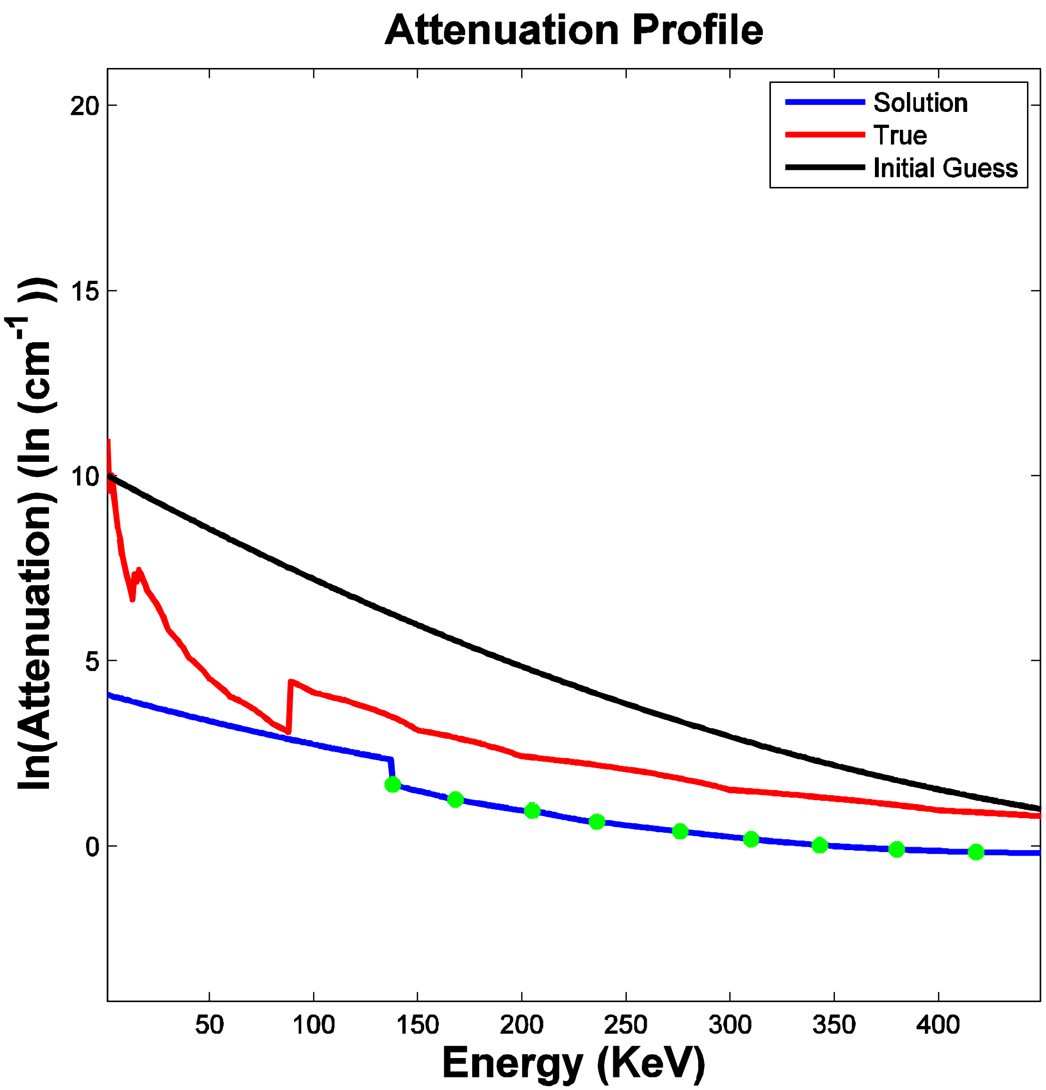
Results: Multi-Intervals (Cu)



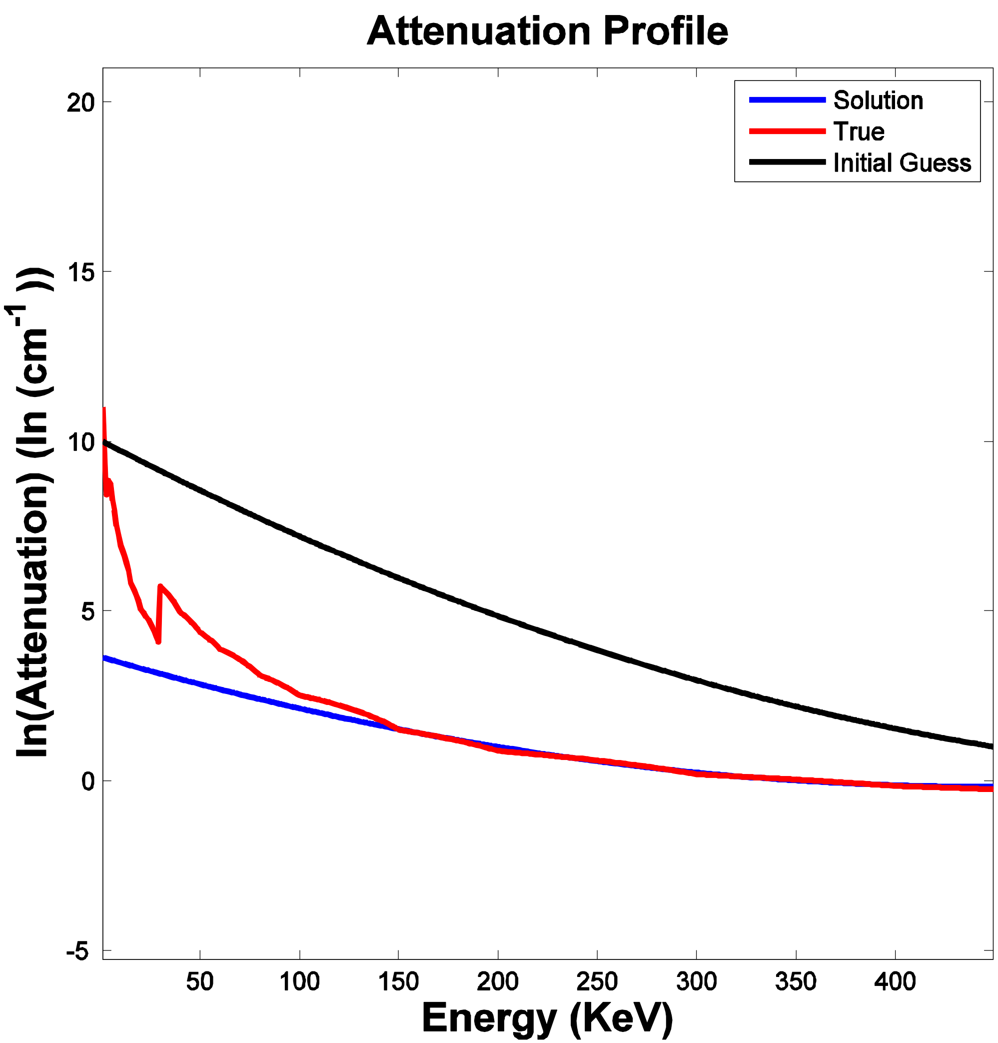
Results: Legendre Polynomials (Pb)



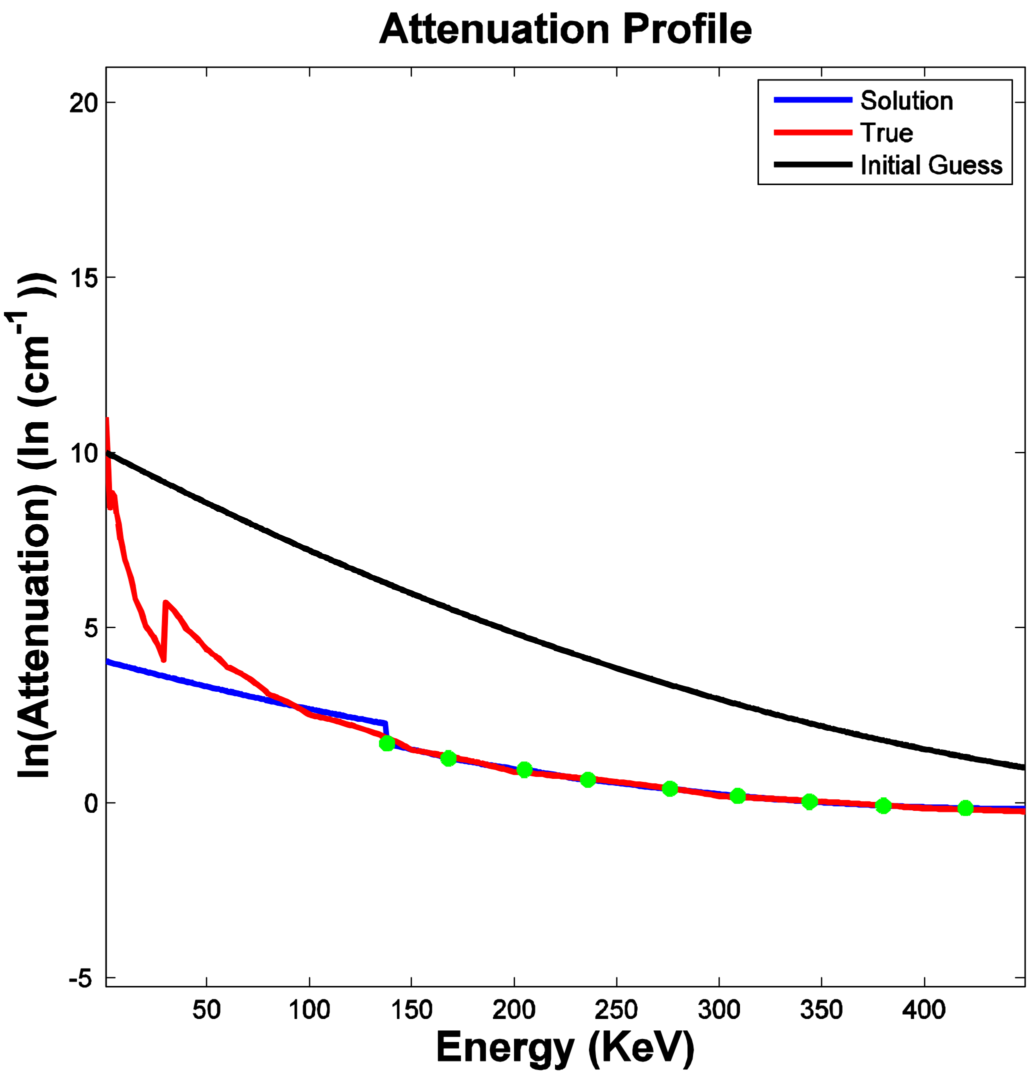
Results: Multi-Intervals (Pb)



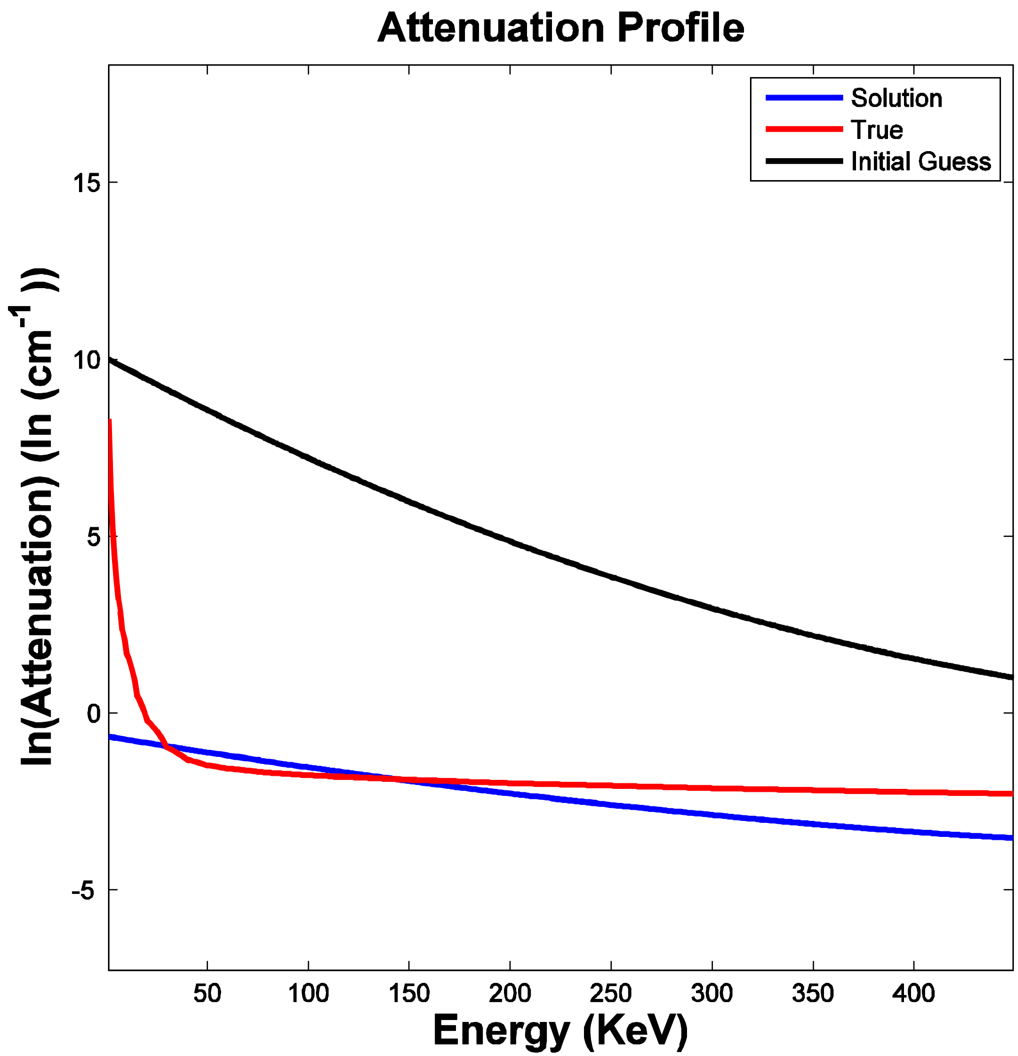
Results: Legendre Polynomials (Sn)



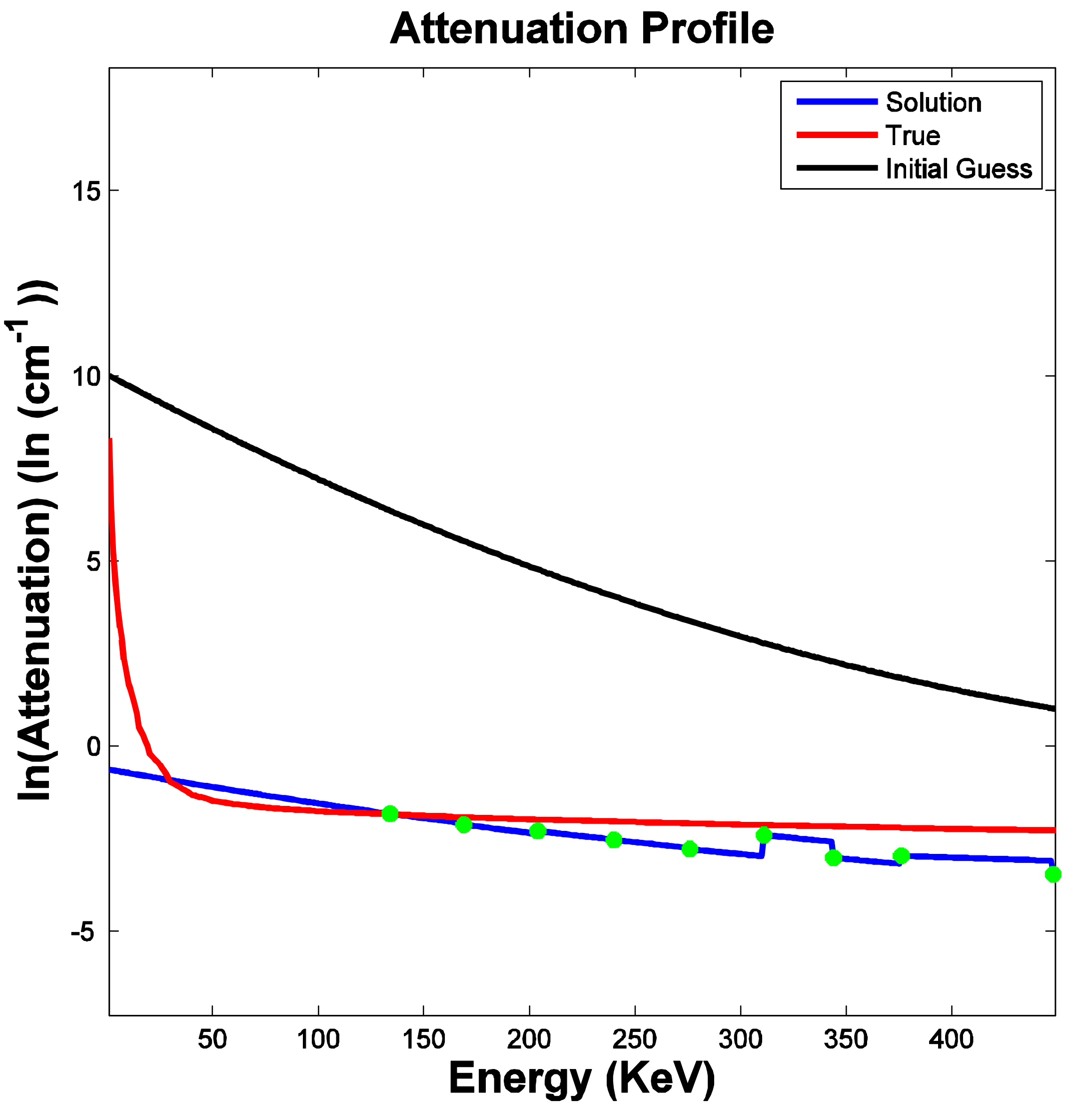
Results: Multi-Intervals (Sn)



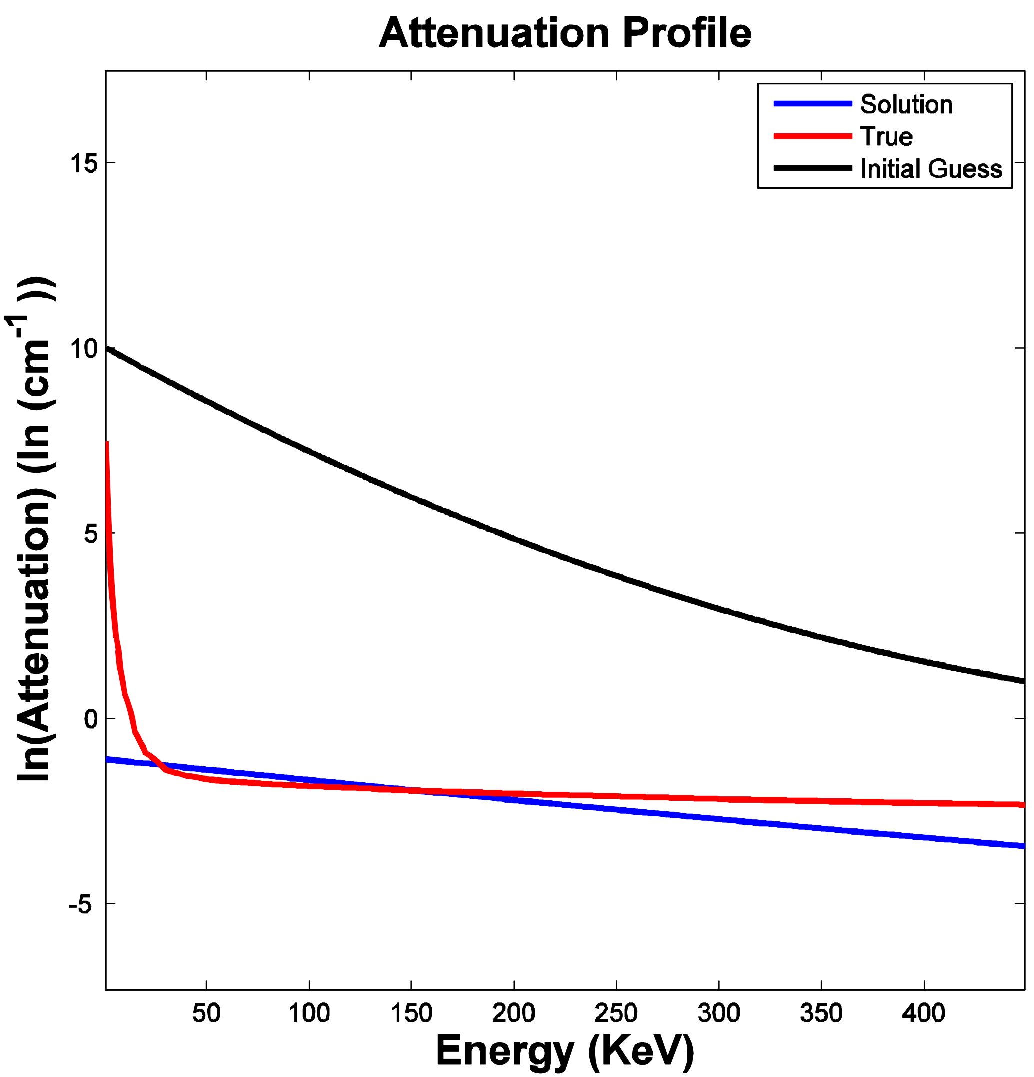
Results: Legendre Polynomials (Water)



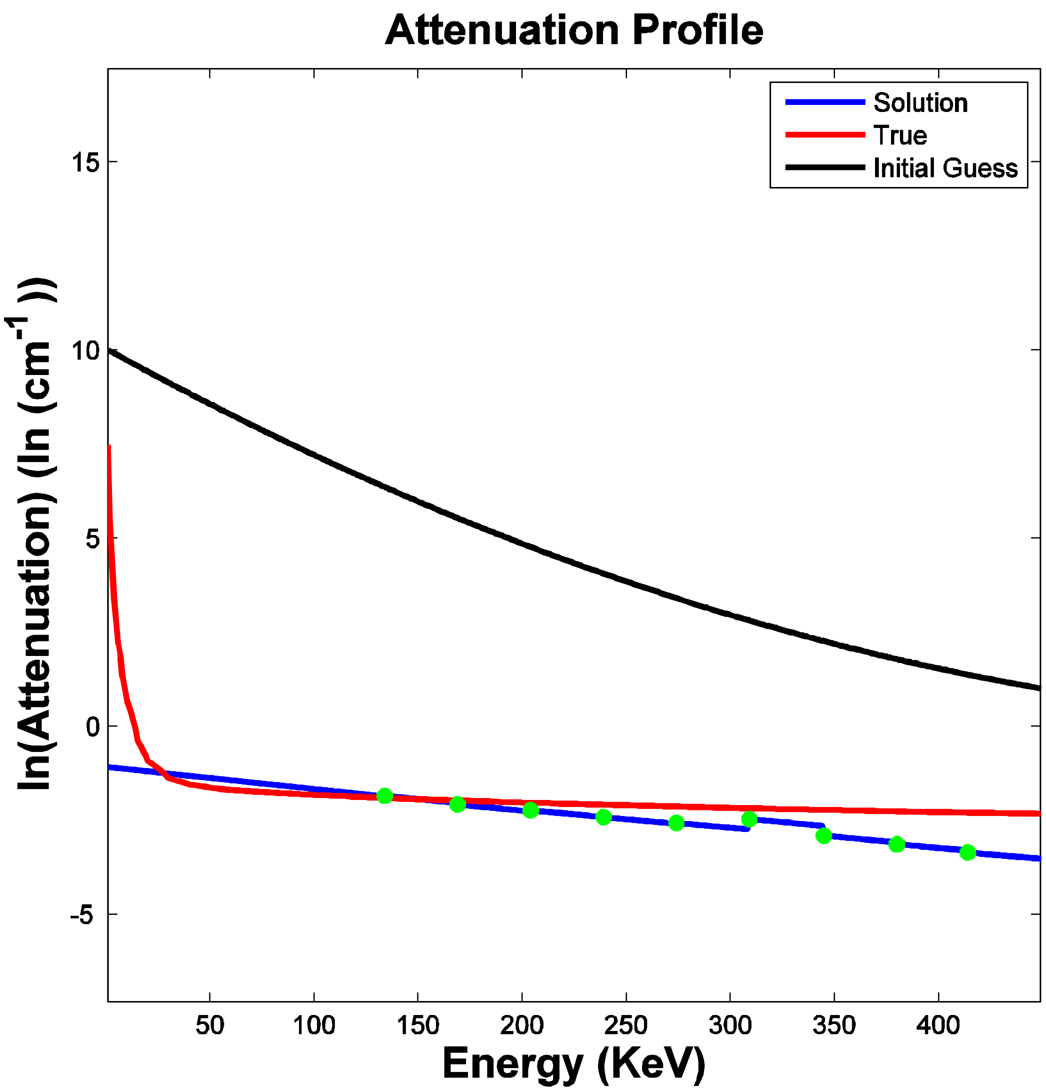
Results: Multi-Intervals (Water)



Results: Legendre Polynomials (Polyeth.)



Results: Multi-Intervals (Polyeth.)



Conclusions

- Improvements in the estimation task over previous work.
- Unfortunately, none resolved K-edges.
- The domains exhibit apparent local minima.
- The presence of null spaces may be hindering search.
- Future work holds promise.
- Ability to identify material in Radiographs is potentially disruptive.