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# Utilization of Virtualized Environments for Efficient X-ray Attenuation Approximation

**Edward S. Jimenez[1], Kyle R. Thompson[2], and Laurel J. Orr[1]**

Sandia National Laboratories
[1]Software Systems R&D
[2]Structural Dynamics and X-ray/Non-Destructive Evaluation
PO Box 5800
Mail Stop 0933
Albuquerque, NM 87185-0933
(505) 284-9690; fax (505) 844-2018;email esjimen@sandia.gov

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## 1 ABSTRACT

The acquisition of true x-ray attenuation information of an object typically requires a mono-energetic x-ray source and computed tomography (CT) where many radiographs are acquired and reconstructed with a computationally complex reconstruction algorithm. This approach is prohibitive for use in applications where CT is not feasible, either from the number of objects, the geometry of the objects, the speed of the inspection, or the lack of a mono-energetic source. This work proposes an approach where a virtualized environment of the known scan geometry and object dimensions are used to calculate accurate path lengths through the object and applied to a radiograph or set of radiographs acquired from an identical configuration to allow an effective attenuation (averaged over the x-ray beam spectrum) to be reasonably approximated. This approach can be utilized for applications where many objects need to be inspected in the same configuration efficiently. Additionally, a single radiograph is needed instead of several and a trivial calculation is performed as opposed to a complex reconstruction calculation.

## 2 INTRODUCTION

This exploratory work investigates the feasibility of approximating effective attenuation of objects when exploiting the knowledge of the system, scan geometry, and dimensions of the object. Virtually replicating a digital phantom of the object will allow one to extract exact distances that each ray path travels through the object. The ray path, along with knowledge of the spectrum emanating from the source, may be used to extract effective attenuation information.

Digital phantoms have been utilized for the extrapolation of quantitative measures in the past [4]. Additionally, calibrating a system and measuring radiation output, although tedious, can be accomplished for a given source. One example for total system calibration is the PhD thesis work conducted by Chen at the University of Arizona in which an entire imaging operator was approximated numerically for a small animal SPECT system for the purpose of tomographic image reconstruction [2].

## 3 APPROACH

Our approach requires that a radiograph of the object of interest be acquired. Next, we create a digital phantom in the exact configuration as it was imaged. Let us represent the image as the vector $\vec{I}$. The exact digital representation will allow for the exact ray path distances from the x-ray source to each pixel on the x-ray detector to be determined. Additionally, we can determine if the ray path intersects the object as well as the length(s) of the intersection(s). Let us represent the coincident distances as the vector as the vector $\vec{x}$ and the total ray path distances as the vector $\vec{d}$, both vectors have the same length as $\vec{I}$.

For simplicity, let us assume that object consists of a homogeneous material of uniform density. The effective attenuation can be approximated by first approximating the scalar $i_0$ from the pixels that correspond to paths that do not intersect the object and then correcting for attenuation through air over the corresponding distances in $\vec{d}$. Next, for each pixel, $I_j$, that corresponds to a ray path that intersects the object, an effective scalar $\mu$ can be calculated as:

$$\mu_{\varepsilon_E, j} = -\frac{\ln\left(\frac{I_j}{i_0}\right)}{x_j}, \text{for every } x_j > 0.$$

The effective energy $\varepsilon_E$ is calculated as the center of mass of the initial energy spectrum emanating from the x-ray source:

$$\varepsilon_E = \left(\sum_i I_0\left(\varepsilon_i\right)\right)^{-1} \left(\sum_j \varepsilon_j I_0\left(\varepsilon_j\right)\right).$$

The initial spectrum can be approximated from a calibration measurement of the source that was used to acquire the x-ray image. This will yield a point estimate of the attenuation profile of the material of interest. If multiple images are acquired using differing energy profiles and/or filtering of the x-ray beam, then multiple estimates at different effective energies can be acquired. This can be done as many times as feasible; however, limitations in filtering and the maximum performance parameters of the source could severely restrict one to a small interval of effective energy.

# 4 IMPLEMENTATION

Our experiments were executed numerically by simulating x-ray images from Bremmstrahlung radiation of a digital phantom of 11 identical spheres all made from a material of interest. Figure 1 is an example of a simulated image of Polyethylene taken at 450 KeV. Our simulations were implemented in MATLAB. We acquired images for a variety of spectra ranging from 70 KeV to 450 KeV for each material and attempt the calculation described above. The materials of interest are Water, Polyethylene, Copper, Lead, and Tin. Attenuation values were retrieved from the National Institute of Standards and Technology website for x-ray mass attenuation coefficients [3]. Typical densities at room temperature for each material is assumed. As this is a preliminary experiment, ideal conditions are assumed, i.e. scatter-free images, and the absence of a null space from the continuous-to-discrete imaging operator [1]. Future work will investigate the effect of imaging and numerically related inaccuracies.

# 5 PRELIMINARY RESULTS

Figures 2 and 3 show the calculated effective attenuations at various energies for water and polyethylene respectively. It seems as if the approximations are fairly close to the true attenuation values at the effective energies. Figures 4, 5 and 6 show the calculated effective attenuations at various energies for copper, lead, and tin respectively, not only is the approximation poor, but the peaks are not resolved. It seems that the general trend is depicted in the materials of higher attenuation, but there may be a miscalculation in $i_0$ or the energies utilized did not penetrate the material sufficiently potentially creating a poor environment causing instability, this requires further investigation.

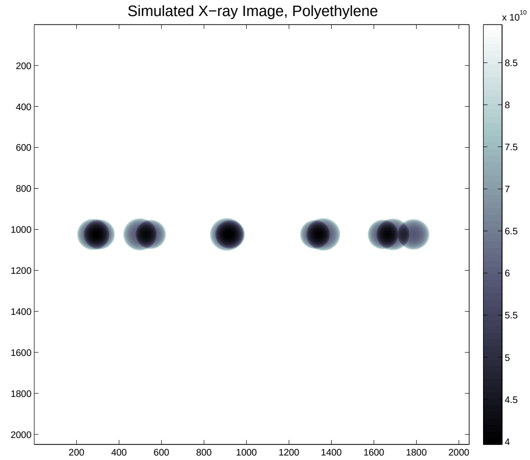


Figure 1: Simulated x-ray image of Polyethylene at 450 KeV.

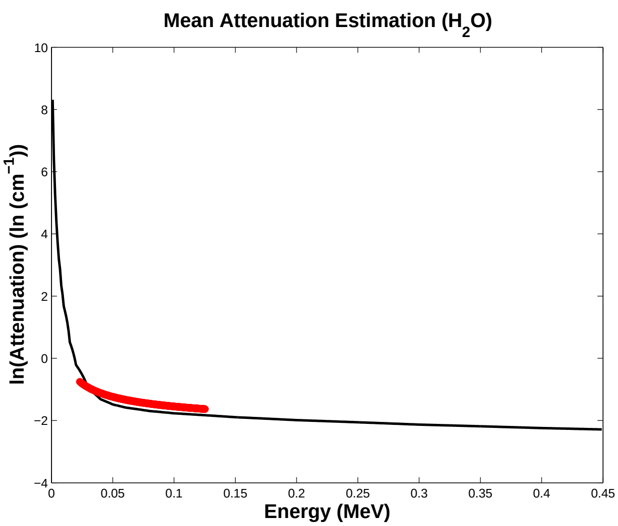


Figure 2: Effective attenuation approximations for $H_2O$ (red) compared to the true attenuation

# 6 CONCLUSION

We have presented a very preliminary attempt to extract exact attenuation values from radiographs created from Bremmstrahlung radiation efficiently and simply. Although approximations for low attenuation material were fairly accurate, the high attenuation material had poor approximations. Further work needs to be

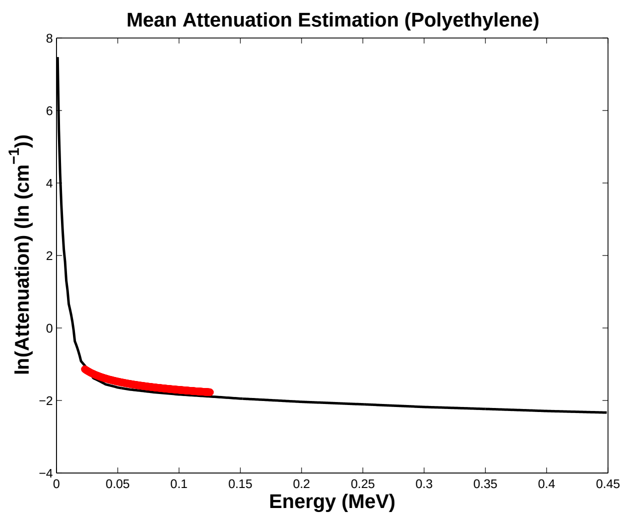


Figure 3: Effective attenuation approximations for Polyethylene (red) compared to the true attenuation

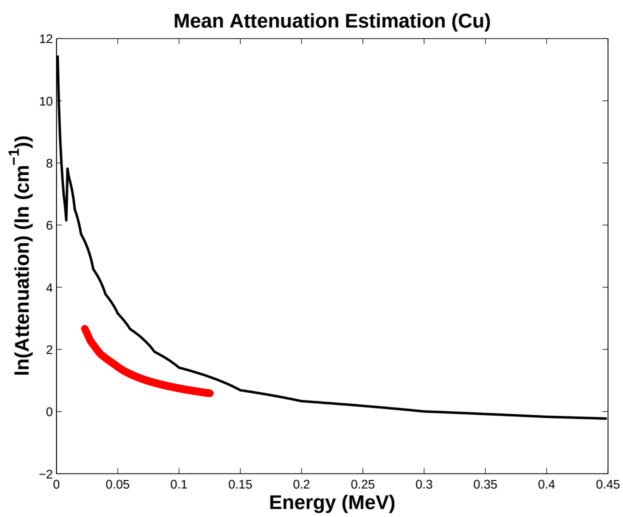


Figure 4: Effective attenuation approximations for Copper (red) compared to the true attenuation

conducted to acquire improved approximations as well as investigations into the feasibility of resolving the k-edges of the attenuation curves. Future work includes investigating iterative solutions as well as methods to approximate the entire attenuation curve as opposed to single points from a single or small set of images. The ability to accurately identify material in x-ray images is an ongoing topic with wide applications in quality control, security, and inspection.

# 7 ACKNOWLEDGEMENTS

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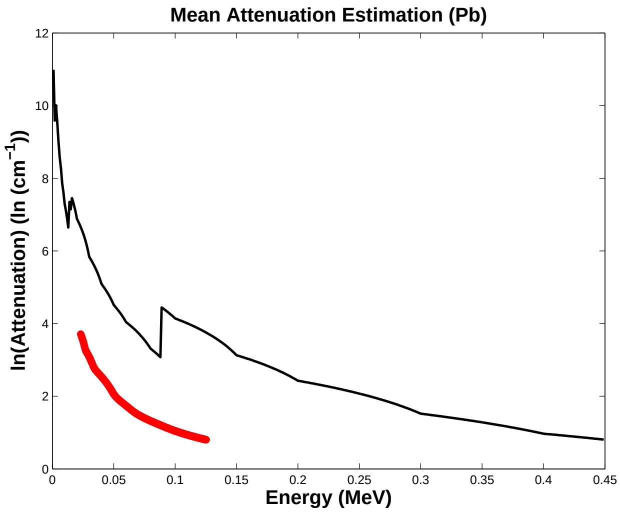


Figure 5: Effective attenuation approximations for Lead (red) compared to the true attenuation

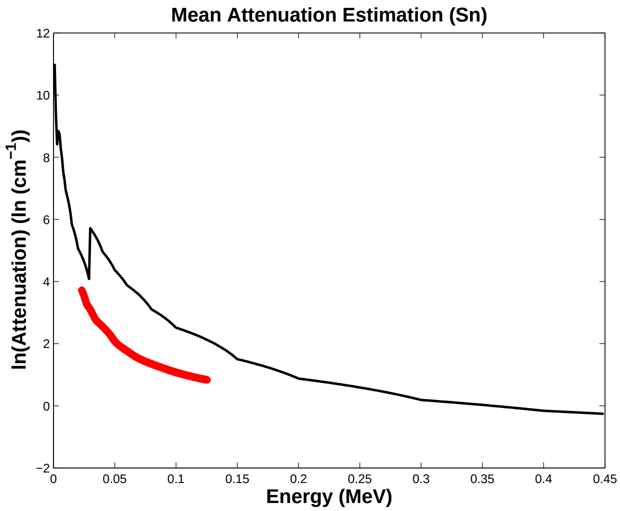


Figure 6: Effective attenuation approximations for Tin (red) compared to the true attenuation

# References

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