Megaelectron Volt Computed Tomography at Site 300

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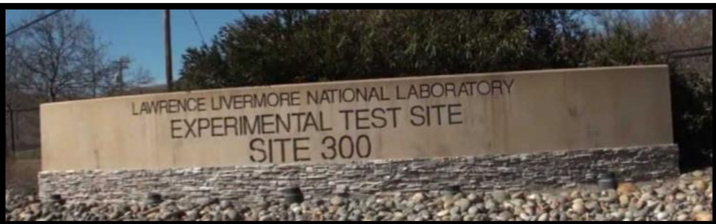
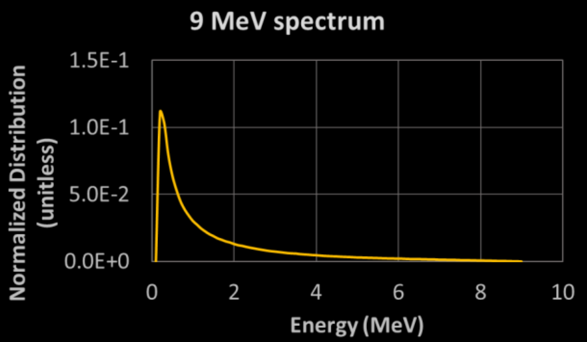
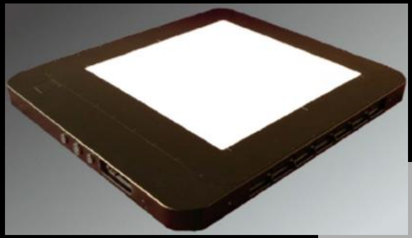
X-ray computed tomography at Site 300

- X-ray computed tomography (CT) is a nondestructive imaging modality that requires x-ray projections at various orientations to reconstruct an object
- At Site 300 we use Megaelectron Volt (MeV) CT to diagnose operation of conventional weapons
- The Site 300 system uses a dual capability (6 MeV or 9 MeV) x-ray source with a digital detector panel
- MeV x-ray CT systems are used to image radiographically dense objects
- Concern: As x-ray energy increases, (1) image contrast decreases and (2) safety considerations increase due to expanded radiation dose fields
- *Our interest is examining Monte Carlo methods, specifically MCNP, to characterize image contrast and radiation dose field with the objective of maximizing image quality and minimizing radiation field*







Varex XRD 1621 detector panel

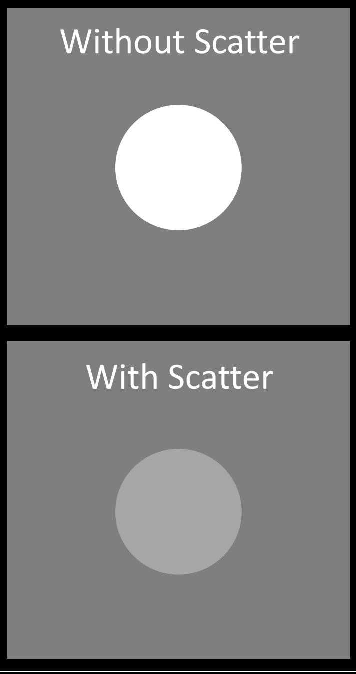
Varex Linatron M9

Three concerns motivate our investigation

Concern 1:
Contrast is reduced with higher energy x-ray systems

Dzierma et al (2014)

Concern 2:
Contrast is reduced by object scatter, which becomes more significant with increasing energy



Concern 3:
High radiation doses

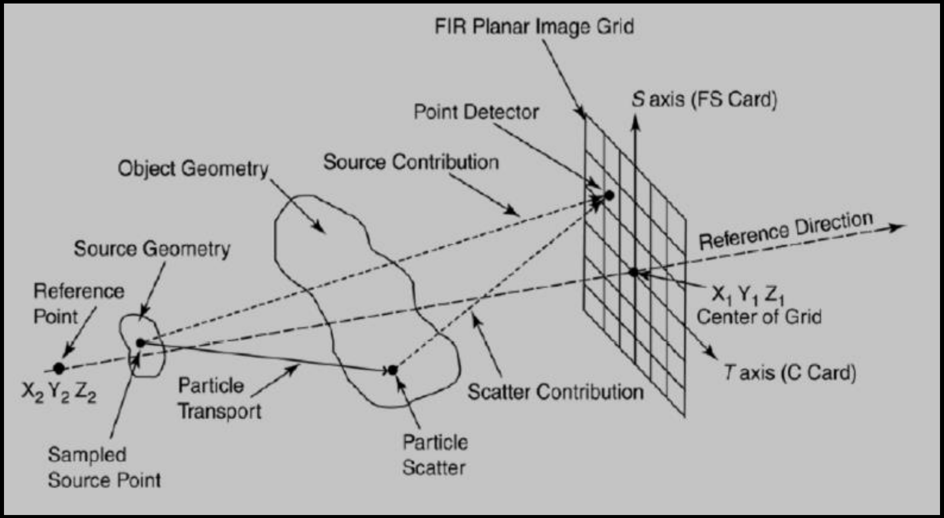
- LD50 is the amount of a material, given all at once, which causes the death of 50% (one half) of a population
- The LD50 for x-ray radiation is 5 Gy
- The x-ray system at Site 300 can produce 30 Gy per minute 1 meter from target. Dose is reduced by:

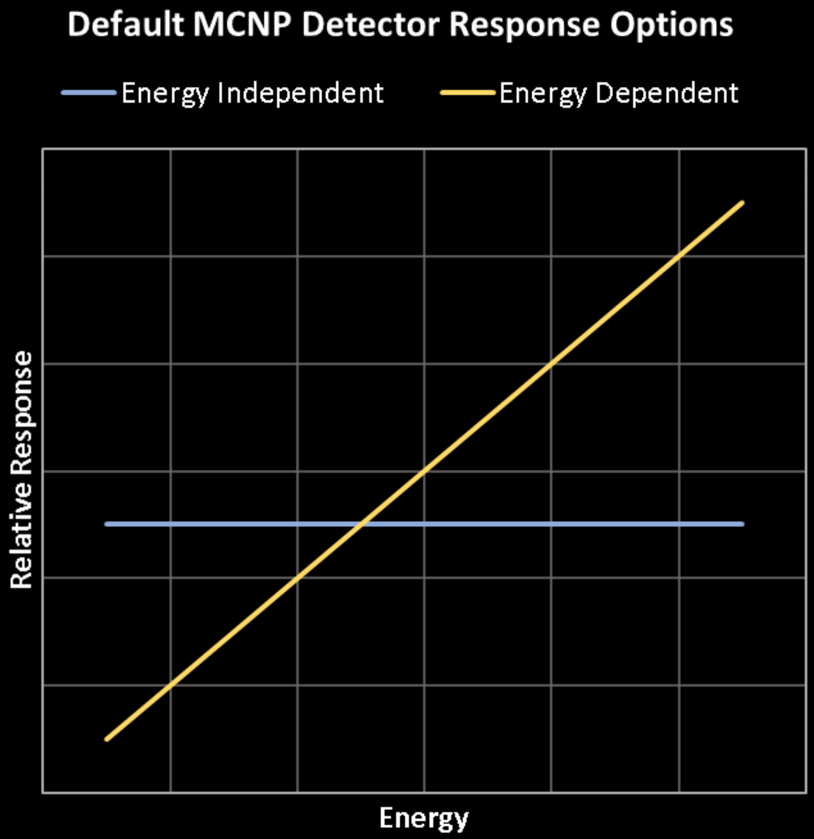
Distance
Shielding
Time

Goal: Simulate MeV CT system design to maximize the image quality and minimize radiation dose field

MCNP6 is a general-purpose Monte Carlo code used to simulate neutron, photon, electron, or coupled neutron/photon/electron transport

MCNP has a built-in framework for Monte Carlo radiographic simulation to accelerate convergence





Framework allows for scatter evaluation

Simulation Performed

1. How well does the MCNP simulation match the measurements?

2. How much of an improvement in image quality does MCNP predict from scatter reduction?

3. How well can we simulate the radiation field at site 300?

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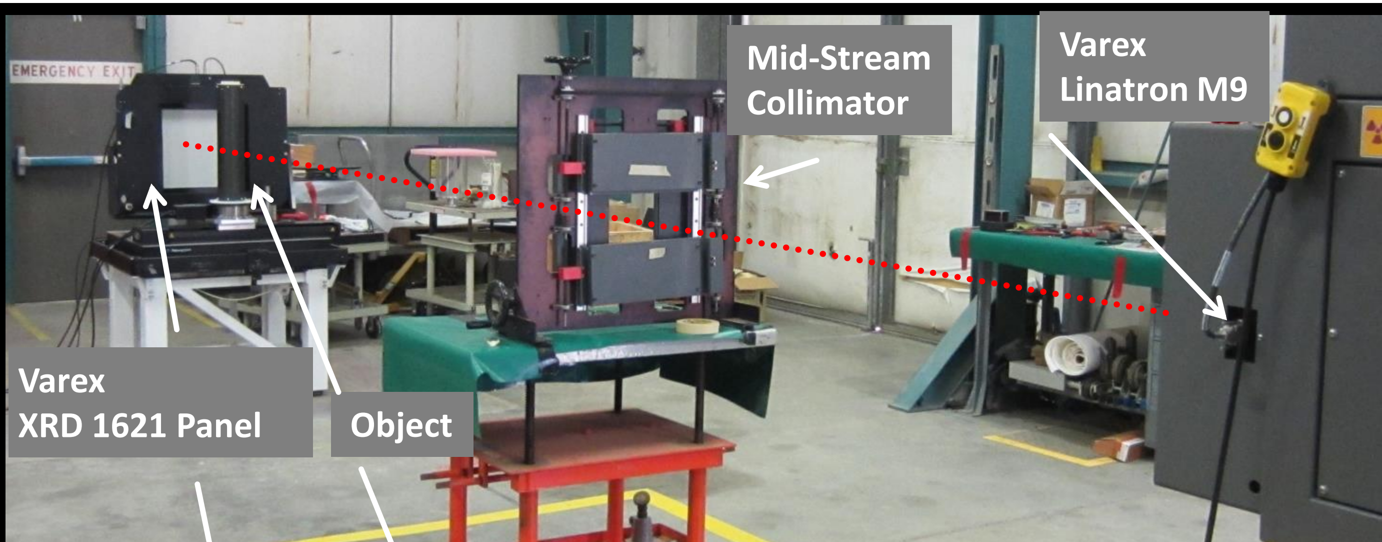
Measurement data was taken using a 6 MeV x-ray spectrum



Object:
Cylindrical munition component principally composed of HMX, tungsten and aluminum encased in carbon fiber

X-Ray Spectrum:
6 MeV spectrum filtered with 3.175 mm of tantalum

Measured and simulated radiographs were processed to compare attenuation

1. Measured images (I_m) were processed as follow:

$$I_m = -ln\left(\frac{(I - I_d)}{(I_o - I_d)}\right) = \int \mu \, dL$$

where

I : Image with x-rays on and object in field of view

I_o : Image with x-rays on but no object in the field of view

I_d : Image with x-rays off

μ : Linear attenuation coefficient (mm^{-1}), which is a function of atomic number, density and x-ray energy

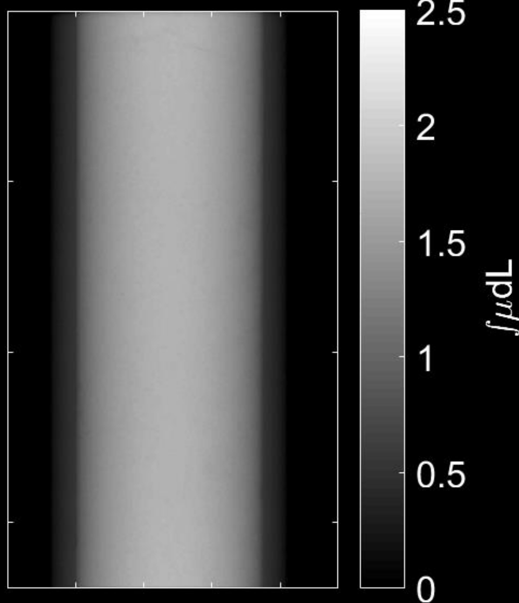
L : Material thickness (mm)

2. Similarly, simulated images (I_s) were process as:

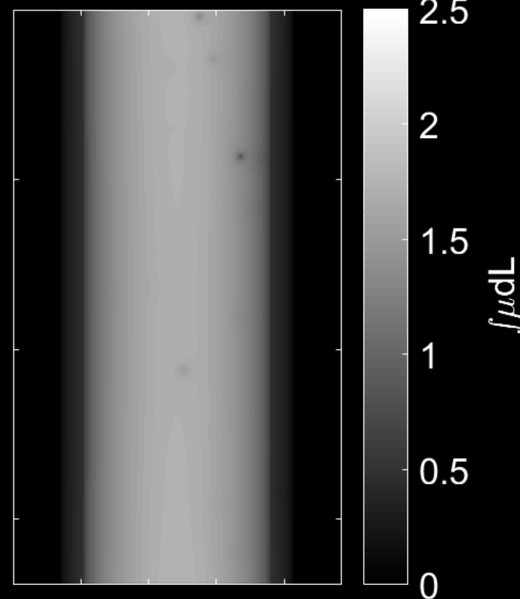
$$I_s = -ln\left(\frac{I}{I_o}\right) = \int \mu \, dL$$

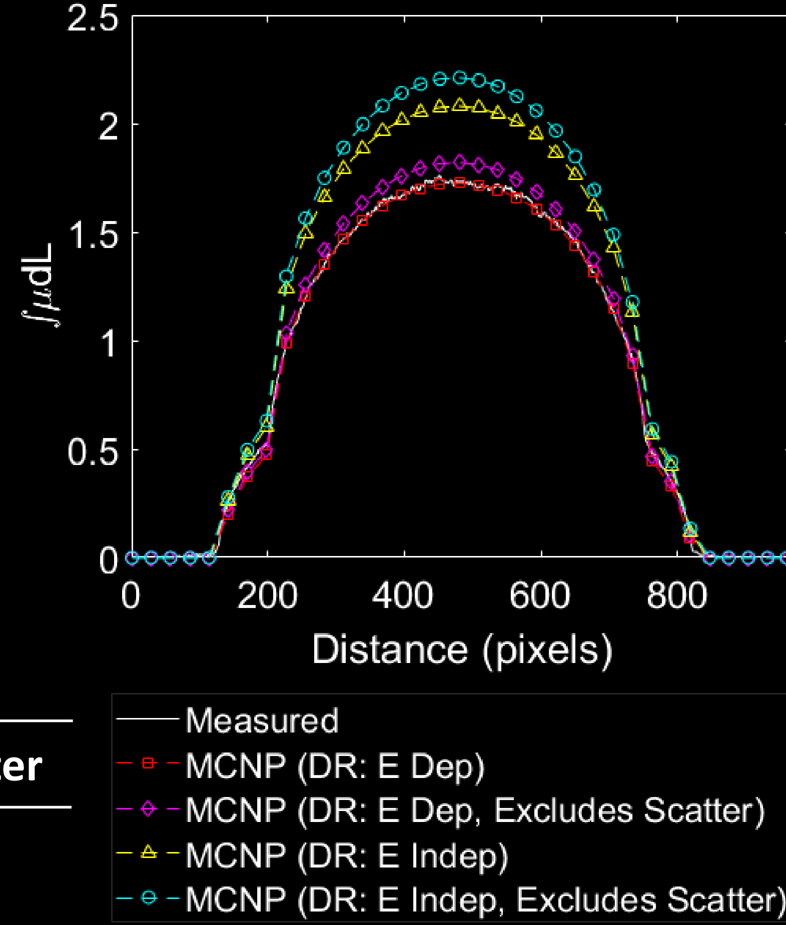
Simulation that includes an energy dependent detector response and scatter best approximates measurement

Measurement



Simulation

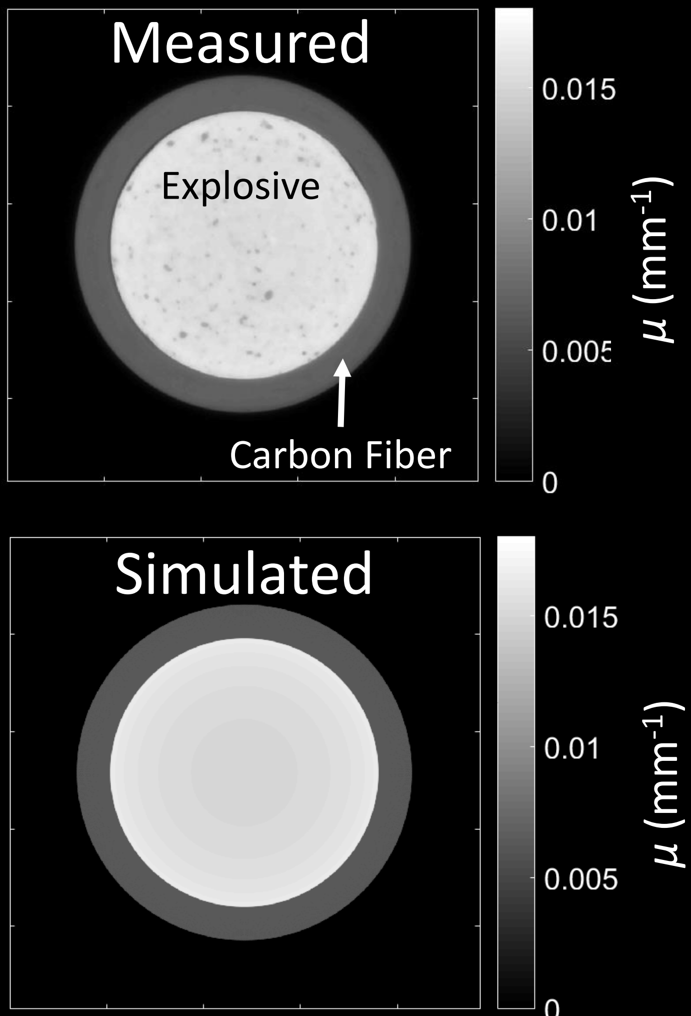


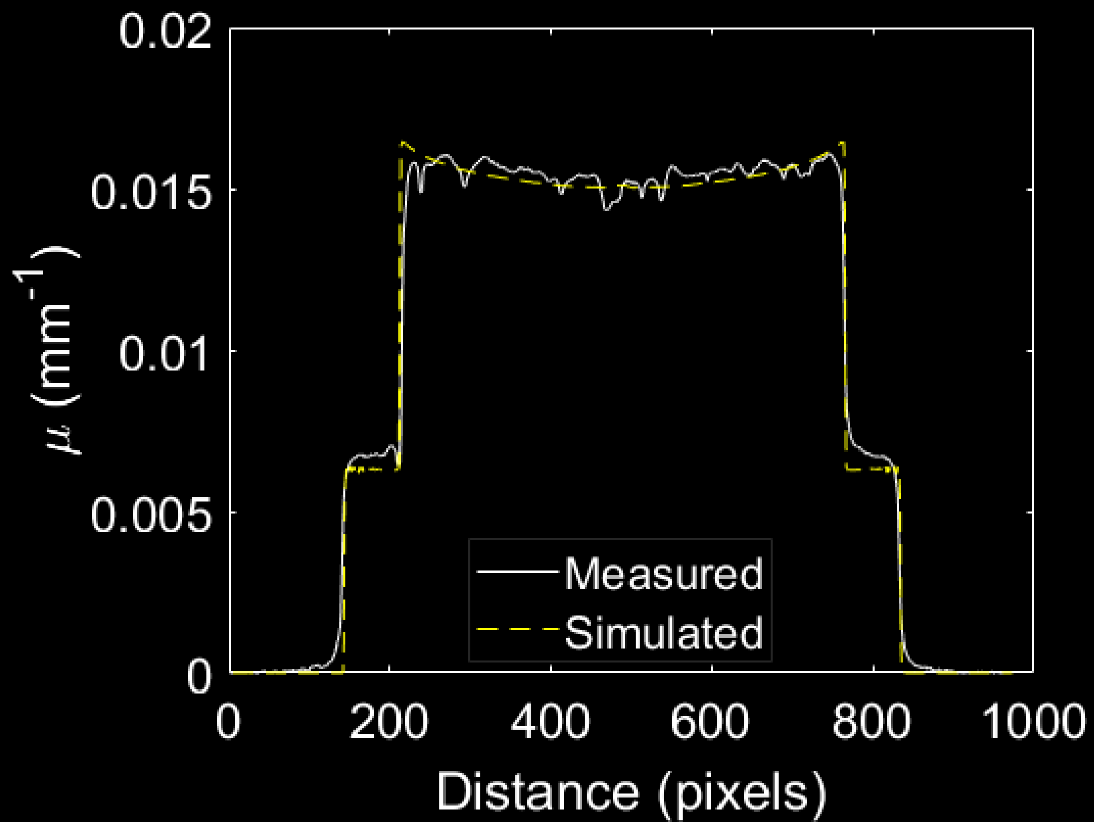


Percent deviation from measurement (%)

Detector Response (DR)	Primary	Primary and Scatter
Energy Independent (EI)	27	20
Energy Dependent (ED)	5	0.6

Simulated reconstruction deviates by < 1 %





Simulation assumes energy dependent detector response and includes scatter

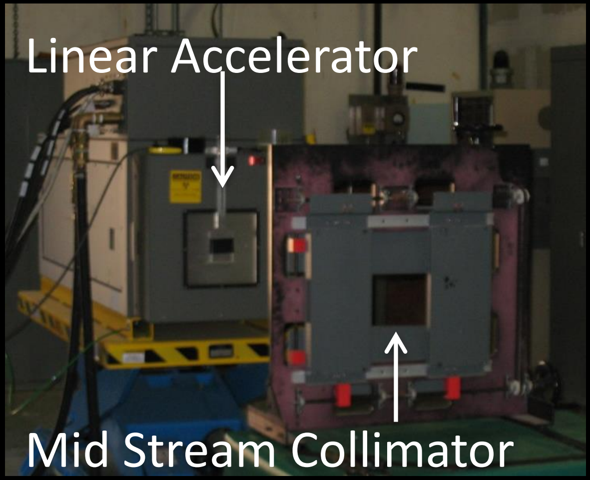
Simulation Performed

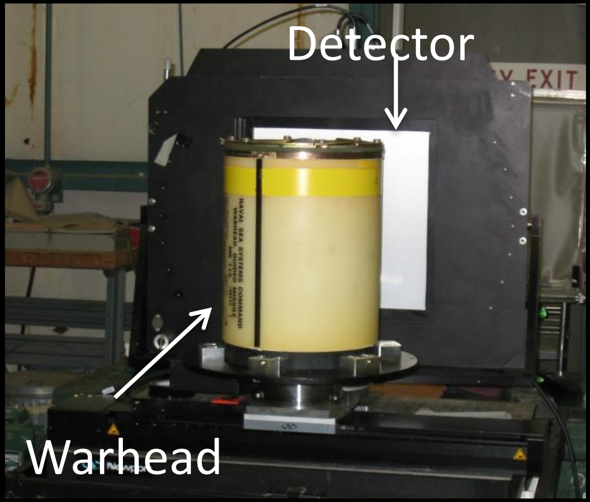
1. How well does the MCNP simulation match the measurements?

2. How much of an improvement in image quality does MCNP predict from scatter reduction?

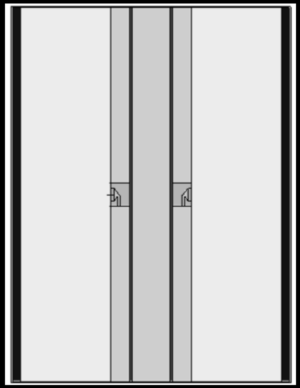
3. How well can we simulate the radiation field at site 300?

At Site 300 we acquired CT data of a conventional explosive warhead using a 9 MeV spectrum



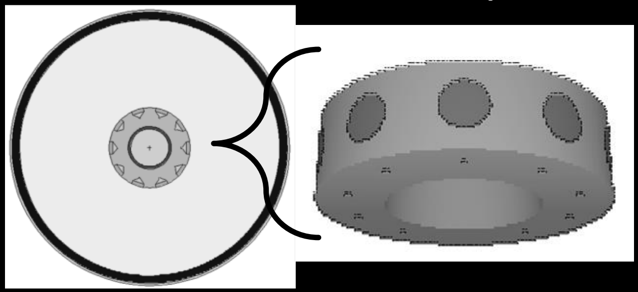


Longitudinal Cross Section



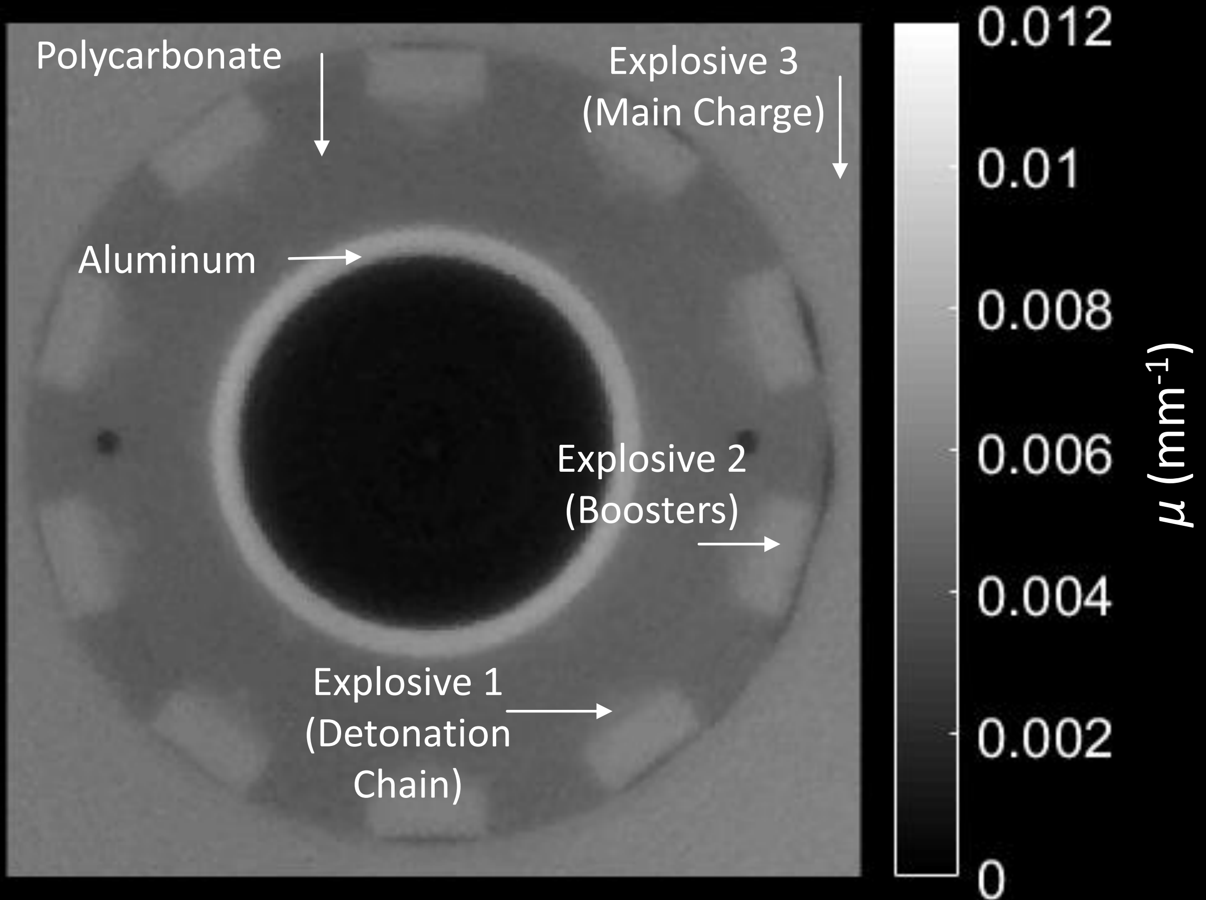
Transverse Cross Section

Rendering of radial plate



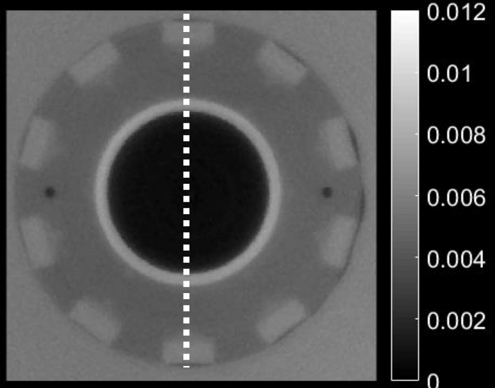
Focus of analysis was on radial plate

Measured CT slice through radial plate

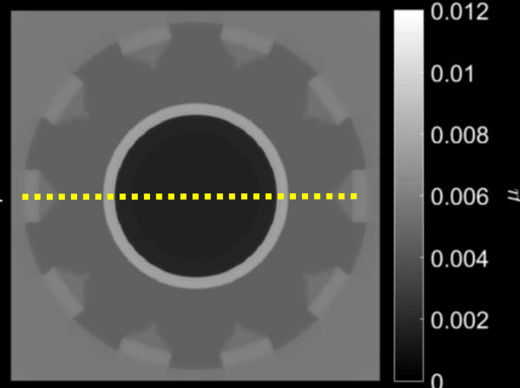


Simulation 1 considers primary and scatter

Measurement

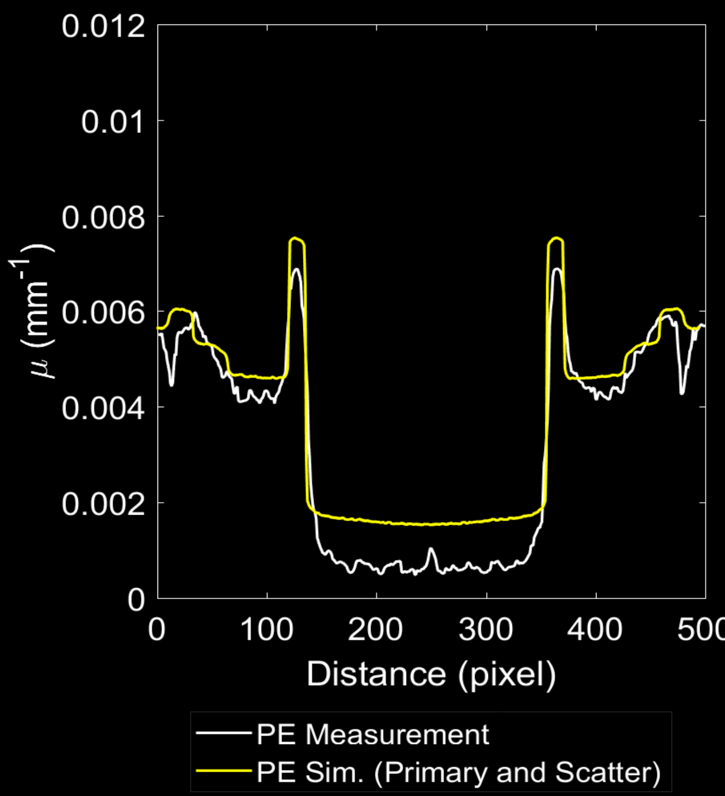


Simulation 1
(Primary and Scatter)



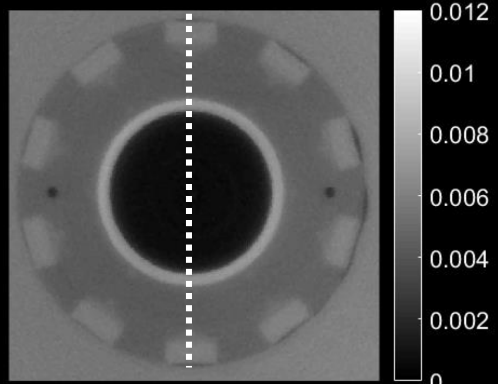
Provided models:

1. Energy spectrum
2. Detector response

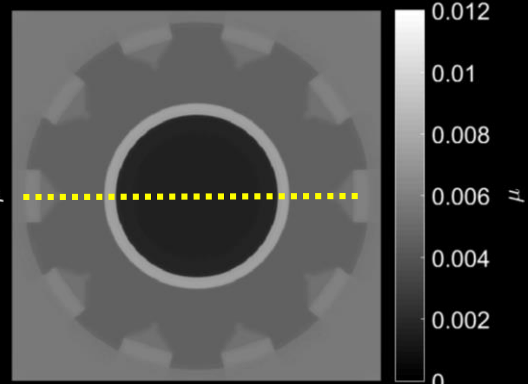


Simulation 2 considers only primary

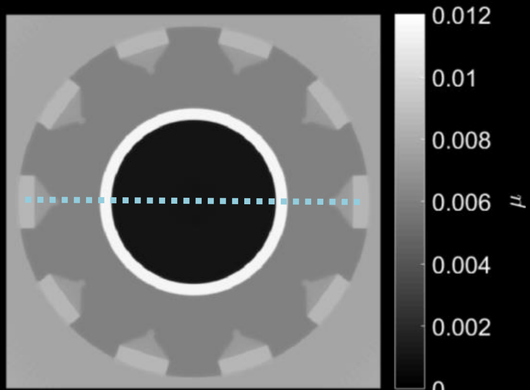
Measurement



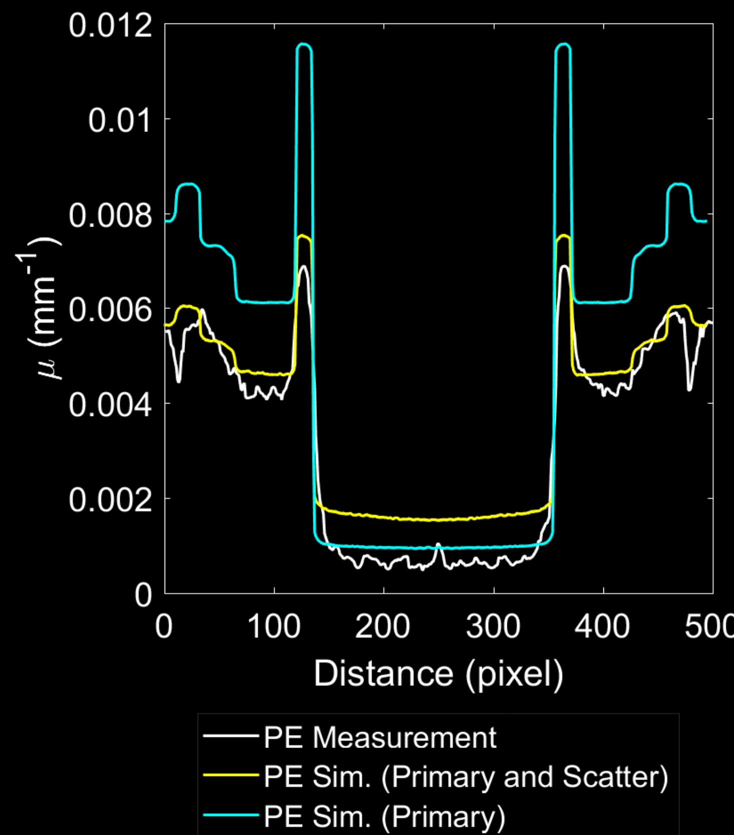
Simulation 1
(Primary and Scatter)



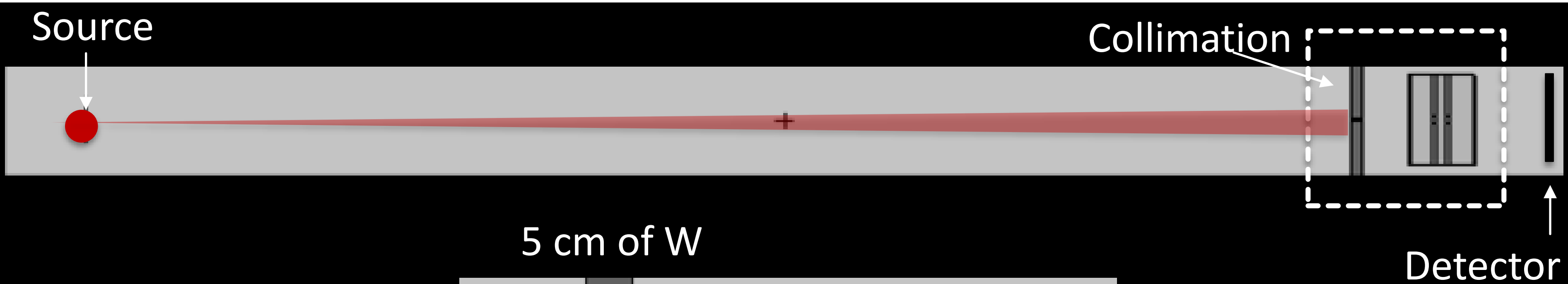
Simulation 2
(Primary only)

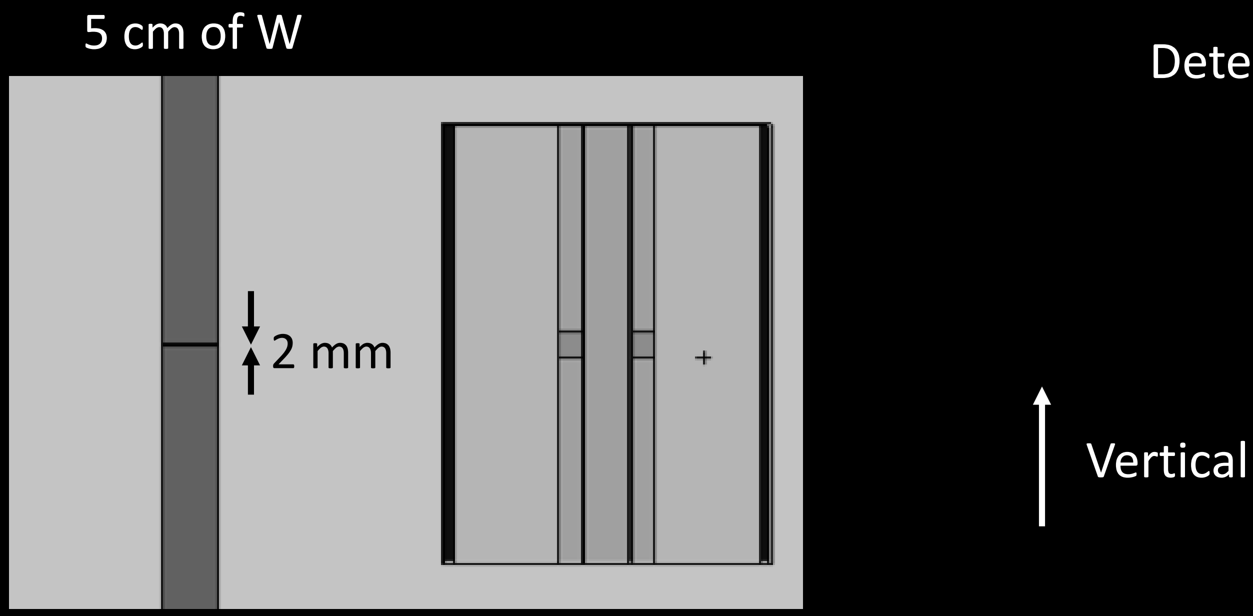


Scatter reduces linear attenuation values (μ) for all materials near and within the radial plate.



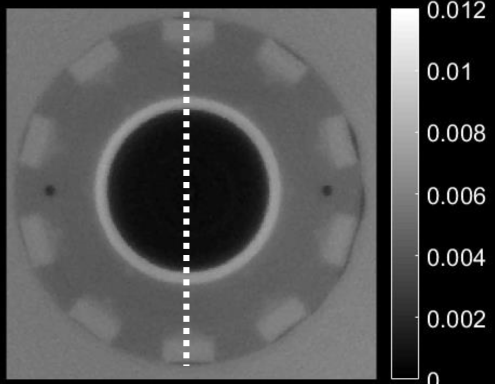
Slit collimation was simulated to evaluate effect on contrast



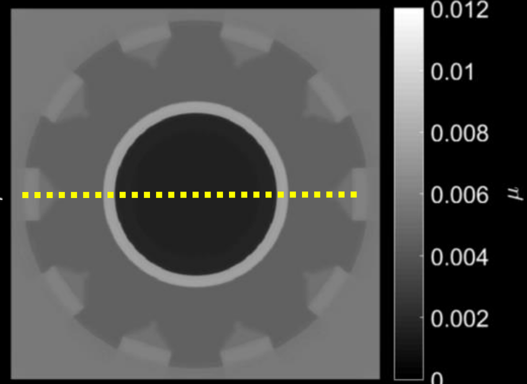


Slit aperture effectively reduces scatter

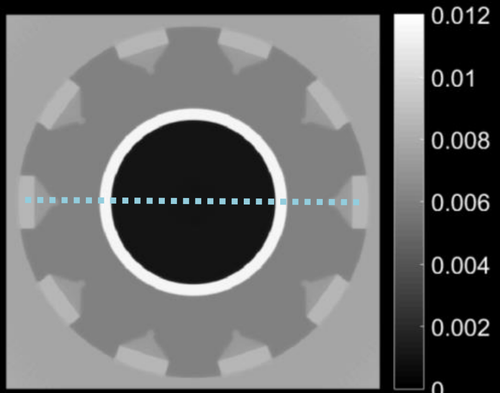
Measurement



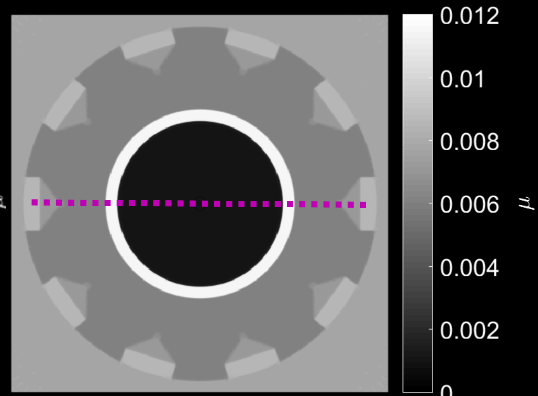
Simulation 1
(Primary and Scatter)



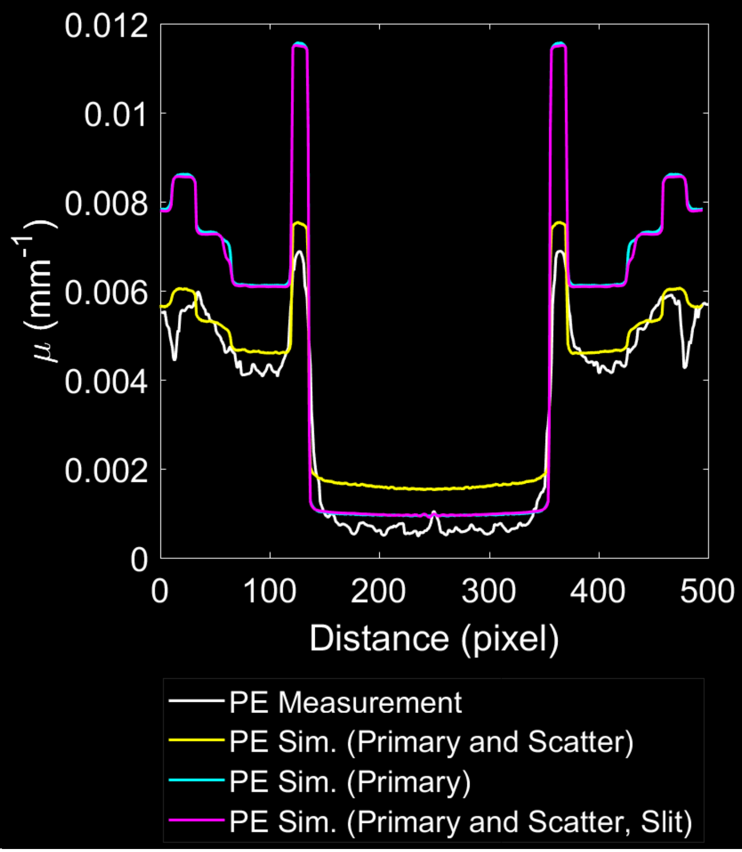
Simulation 2
(Primary only)



Simulation 3
(Primary and Scatter, Slit)

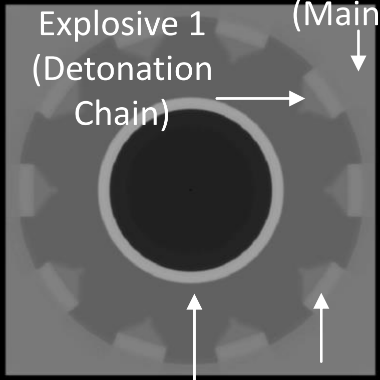


Profile of simulation 3 (primary and Scatter, Slit) overlaps simulation 2 (primary only)



Slit collimator can recover reduced contrast due to object scatter

Simulation



$$Contrast = \frac{ROI_2 - ROI_1}{ROI_2 + ROI_1}$$

Note:
ROI_i: region of interest in material i

Contrast Results:	**Polycarbonate to Explosive 1**	**Polycarbonate to Explosive 2**	**Polycarbonate to Explosive 3**
PE Simulation 1 (P & S)	0.0691	0.1313	0.1079
PE Simulation 2 (P)	0.0889	0.1691	0.1254
Percent Change (%)	29	29	16
PE Simulation 3 (P & S, slit)	0.0878	0.1677	0.1246
Percent Change (%)	29	29	15

Summary

- Site 300 uses MeV CT to diagnose operation of non-nuclear weapon components
- MeV CT enables interrogation of items that may be too radiographically dense for keV systems
- Three concerns when using MeV CT:
  1. contrast is reduced with higher energy x-ray systems
  2. contrast is reduced by scattered radiation which becomes more significant with higher energy x-rays
  3. high radiation fields
- Goal of this work is to simulate MeV CT system to optimize design that maximizes image quality and minimizes radiation dose field
- Currently, we are using the MCNP Monte Carlo radiation transport code to evaluate:
  1. radiographic framework to assess detector response and scatter
  2. benefits of scatter reduction techniques
  3. radiation field at Site 300

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