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Image Reconstruction of Shielded Mixed-Oxide Fuel Using a Dual-Particle Imaging System

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Detection for Nuclear Nonproliferation Group

Abstract – The dual-particle imaging (DPI) system being developed at the University of Michigan was brought to the Joint Research Centre located in Ispra, Italy for performance testing on various samples of special nuclear material. A 1150 g mixed-oxide (MOX) fuel sample was measured with various shielding configurations to determine how the presence of lead and/or polyethylene shielding degrades the system's ability to localize a source via neutron and photon imaging. Three two-hour measurements were taken with the source shielded by an: a) 8 mm lead sheath and 5.1 cm lead bricks, b) 8 mm lead sheath and 6.5 cm polyethylene bricks, and c) 8 mm lead sheath, 5.1 cm lead bricks, and 6.5 cm polyethylene bricks. A 'bare' measurement was also made by using only the 8 mm lead sheath, but the unexpected presence of additional sources has rendered the measurement unsuitable for comparison. The 8 mm lead sheath was used in all cases to reduce the measured photon count rate to a manageable level. The resulting images show that neutrons are less susceptible to degradation due to shielding than photons despite having a much lower count rates. The reconstructed energy spectra are also analyzed for perturbations caused by shielding material. Conclusions are drawn on the usefulness of bimodal imaging techniques in nuclear safeguards and security applications that require detection and localization of sources in the presence of intervening material.

Motivation and Objectives

Motivation

- Imaging systems can be used to determine the spatial distribution of radioactive material within a field of view.
- Sensitivity to both photons and neutrons increases the probability of source localization when shielding materials are present.

Objectives

- Measure a MOX sample with various shielding configurations at the PERLA facility at the Joint Research Center (JRC) located in Ispra, Italy.
- Assess the impact of polyethylene and lead shielding on neutron and photon simple-backprojection images and reconstructed energy spectra.

Image Reconstruction

Simple Backprojection

- Use physics of Compton scattering or neutron elastic scattering to project cones of possible source locations onto a sphere surrounding the imaging system. Overlapping projections will converge to locations where sources are present.

$$\cos^2\theta_{n1} = \frac{E_{n1}}{E_{n0}} \qquad E_{n1} = \frac{m_n}{2} \times \frac{d^2}{TOF^2} \qquad \cos\theta_{\gamma 1} = 1 - \frac{m_e c^2 \times E_{d1}}{E_{d2}(E_{d1}+E_{d2})}$$

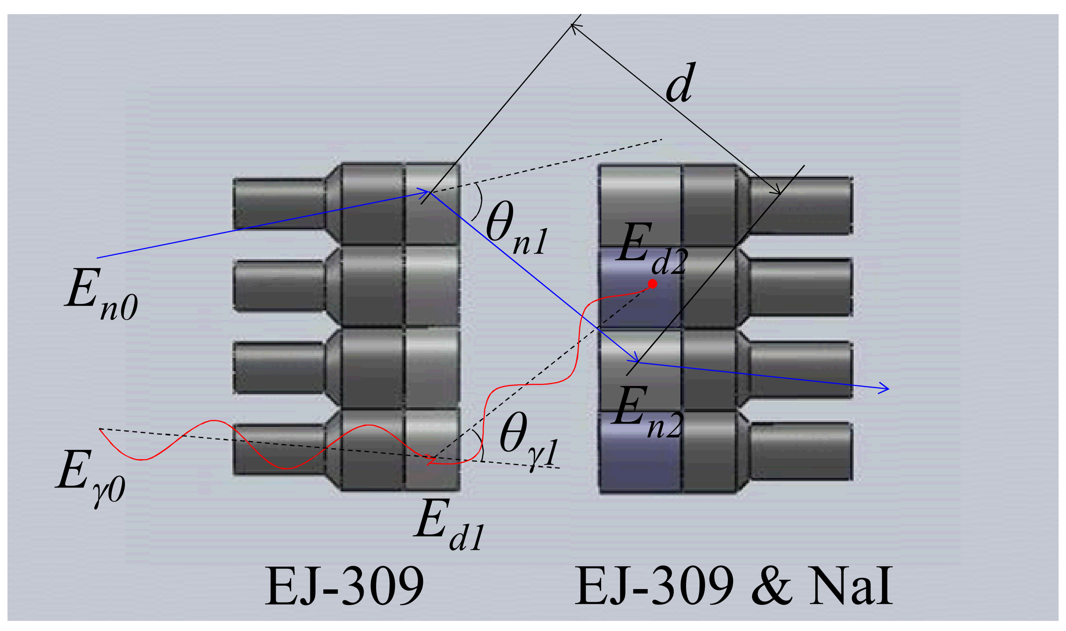

Figure 1. Schematic of the DPI showing the quantities used to compute the backprojection cones.

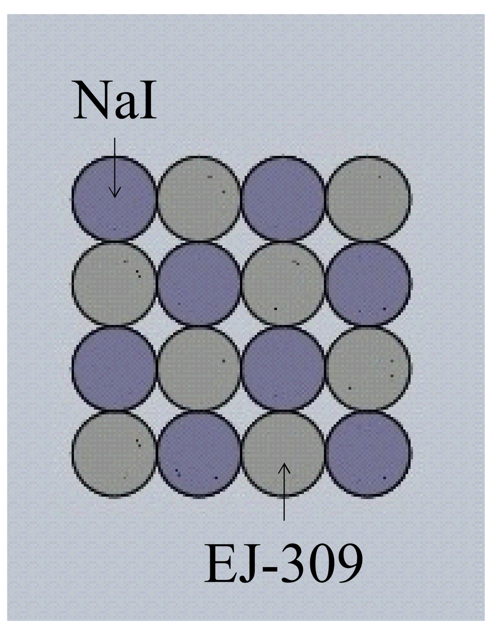

Figure 2. Cross-sectional view of the second plane of the DPI.

Measurement Setup

- Single 1,150 g mixed-oxide (MOX) fuel sample with 10.9 wt% ^{239}Pu, 4.6 wt% ^{240}Pu, 66.8 wt% ^{238}U, 0.5 wt% ^{235}U, and 16.1 wt% ^{16}O.
- Sample activity of 28,000 fissions per second and 31,000 (α,n) reactions per second.
- Canister located 2.5 m from system at (90°, 90°).
- Shielding configurations consisted of a wall of 5.1 cm lead bricks and/or 6.5 cm polyethylene bricks.
- Additional 8 mm lead sheath utilized in all cases.
- Canister measured for approximately 120 minutes.
- Measurement performed at PERLA facility at the JRC located in Ispra, Italy.

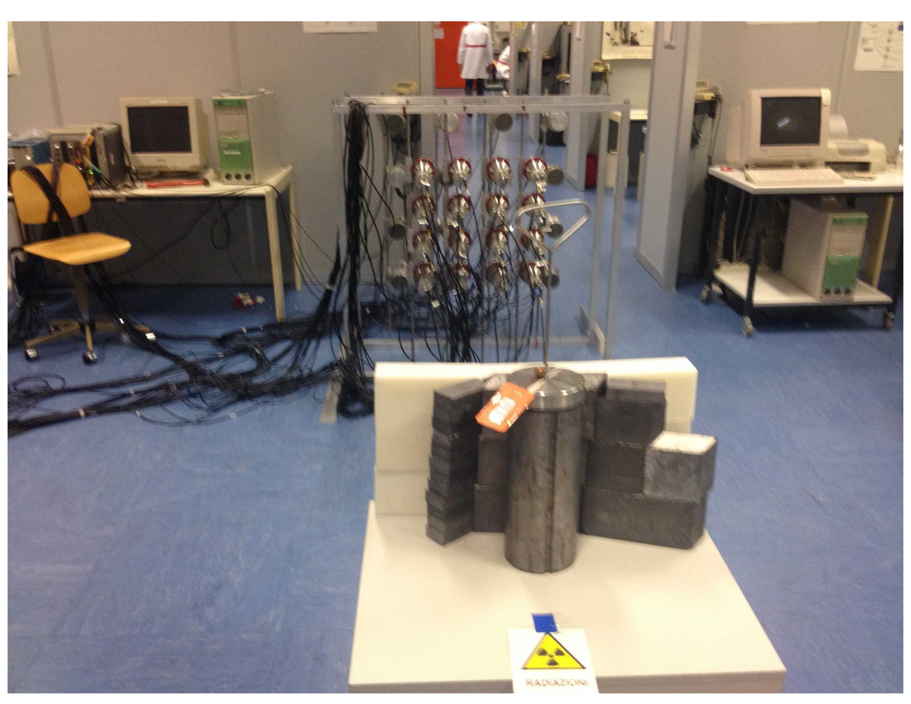

Figure 3. Photo of MOX canister being measured directly in front (90° 90°) of DPI. Canister is shielded by both lead and polyethylene bricks.

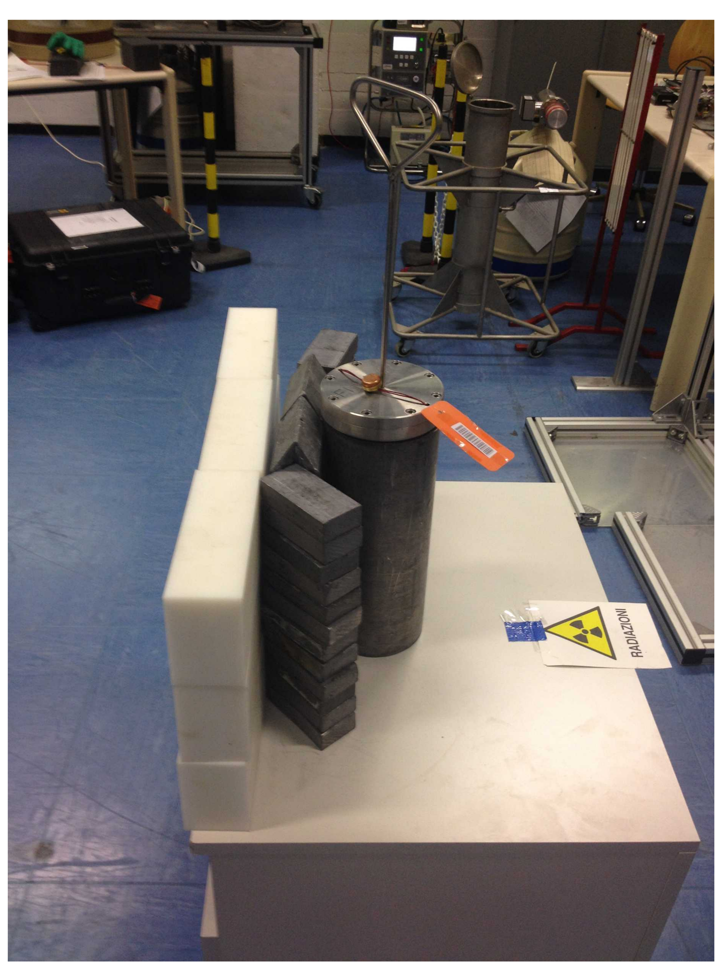

Figure 4. Photo of MOX canister in the combination lead and polyethylene shielding configuration. Lead bricks are 5.1 cm thick and polyethylene bricks are 6.5 cm thick.

Measurement Results

Reconstructed Images

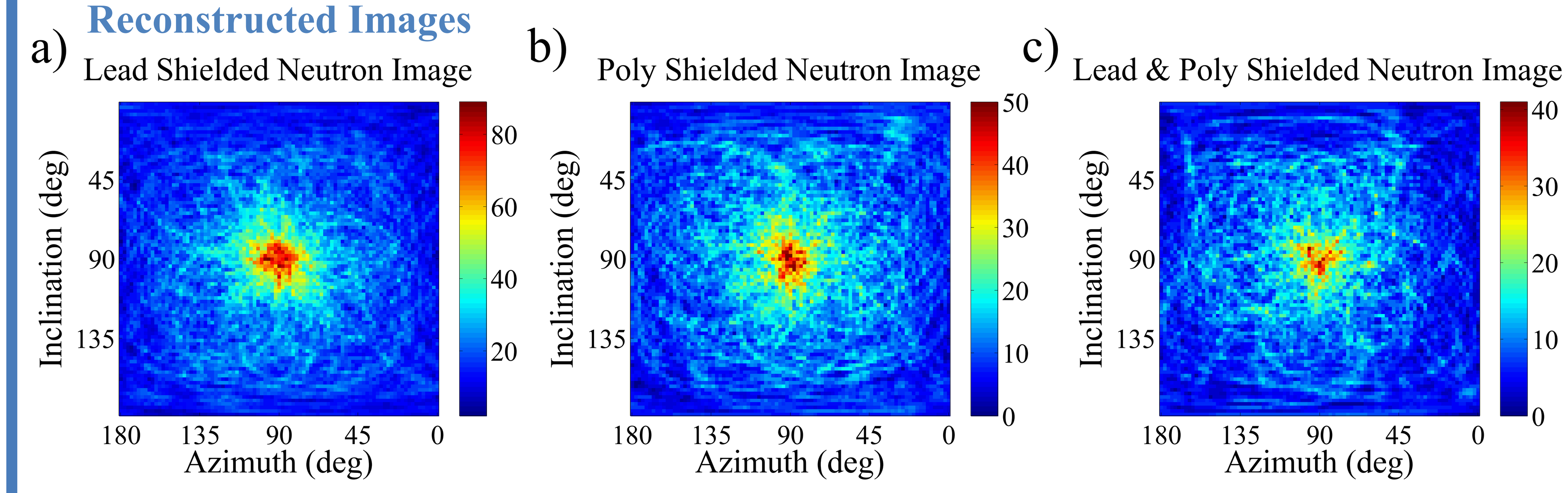

Figure 5. Neutron backprojection images for the lead (a), polyethylene (b), and lead and polyethylene (c) shielded MOX canister measurements. MOX canister is correctly located in all three scenarios.

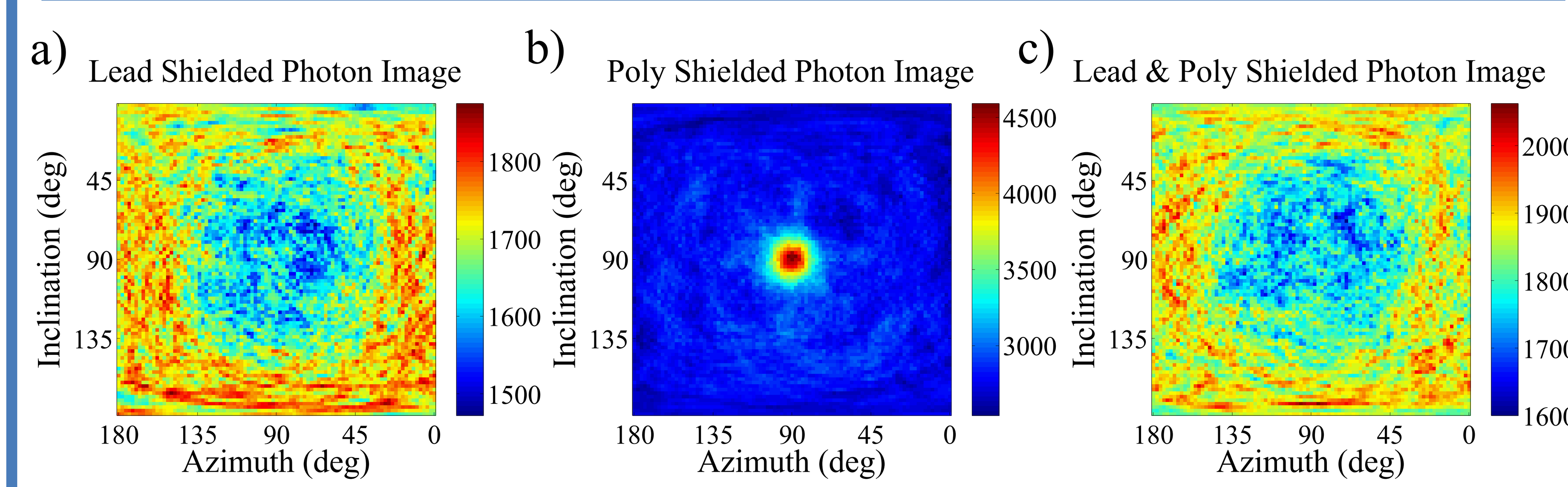

Figure 6. Photon backprojection images for the lead (a), polyethylene (b), and lead and polyethylene (c) shielded MOX canister measurements. MOX canister is only located in the polyethylene shielded scenario, while background counts dominate the lead and mixed shielding scenarios.

Count Rates

Table 1. Neutron and photon count rates for each of the three shielding scenarios.

	Lead Shielded	Poly Shielded	Lead & Poly Shielded
Neutrons/second	0.1605	0.0833	0.0614
Photons/second	69.49	96.81	69.59

Reconstructed Energy Spectra

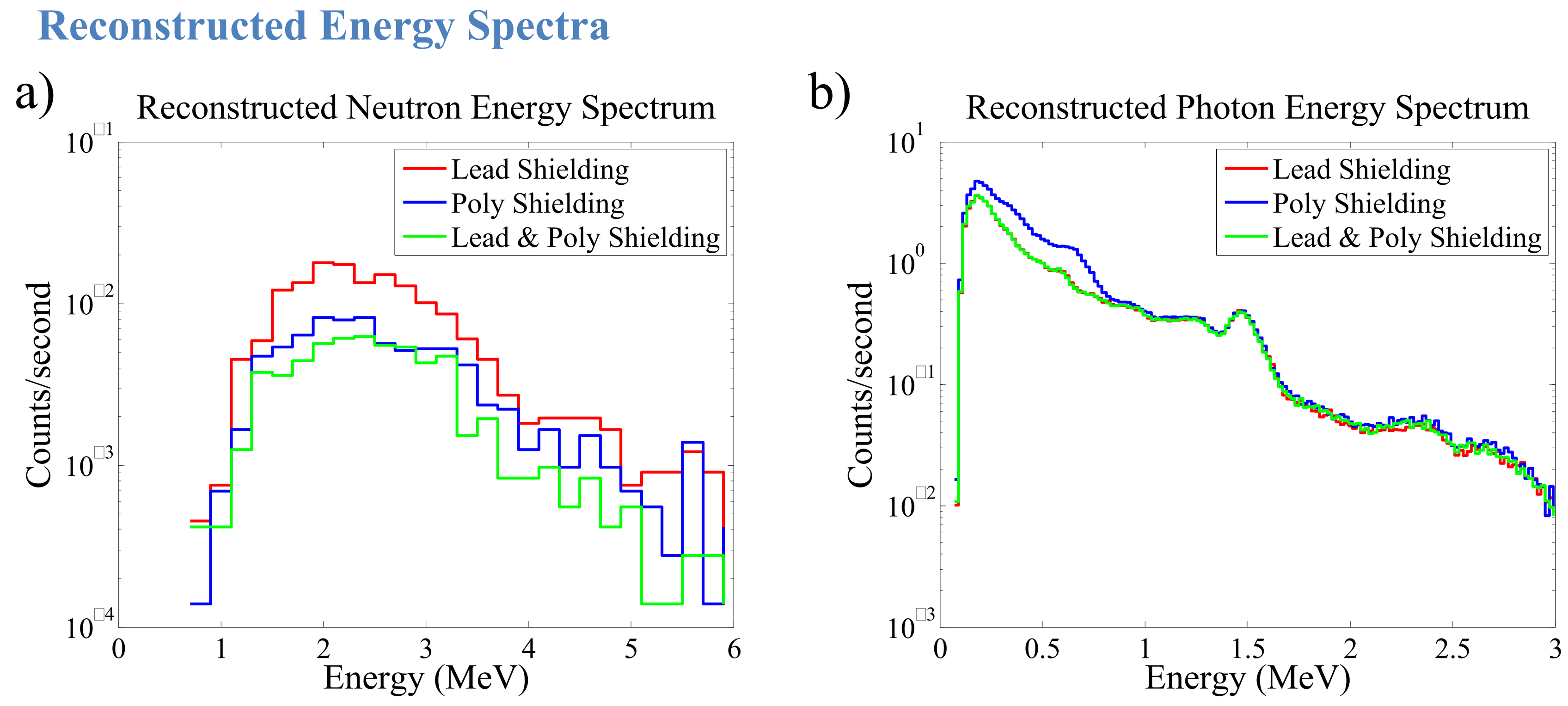

Figure 7. Reconstructed neutron (a), and photon (b) energy spectra for each of the three shielding scenarios. Neutrons are shielded by polyethylene and scattered by lead. Photon spectra are dominated by background counts. Polyethylene shielded photon spectrum varies significantly from lead and mixed shielded photon spectra below ~1 MeV.

Conclusions

- Neutron imaging can locate MOX canister in the presence of both lead and polyethylene shielding despite low count rates.
- Photon imaging is susceptible to degradation from shielding and relatively high background count rates.

Ongoing Work

- Investigation of maximum-likelihood expectation-maximization (MLEM) for image and energy spectrum reconstruction.
- Development of algorithms for computing location specific energy spectra.
- Analysis of energy spectra to estimate the amounts and types of shielding present.

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8 Update release number
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10 Should I add Kai's home university?
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