Evaluating the Ability of an Artificial Neural Network System to Detect Shielded Depleted Uranium in Intense Photon Fields

T. E. Maurer [1], A. J. Jinia [1], C. A. Meert [1], S. D. Clarke [1], H. S. Kim [2], D. D. Wentzloff [2], S. A. Pozzi [1]

[1] Department of Nuclear Engineering and Radiological Sciences, University of Michigan, 2355 Bonisteel Blvd, Ann Arbor, Michigan 48109-2104

[2] Department of Electrical and Computer Engineering, University of Michigan, 1301 Beal Ave, Ann Arbor, Michigan 48109-2104

S.A. Pozzi, pozzisa@umich.edu

Consortium for Monitoring, Technology, and Verification (MTV)

Introduction and Motivation

- Detection of hidden special nuclear material is key to prevent diversion to clandestine states
- Active interrogation is more robust than passive interrogation
    - Passive interrogation relies on delayed signatures
    - Active interrogation can detect prompt neutrons
    - We performed active interrogation of shielded nuclear material
- Organic scintillators detect neutrons without thermalization, unlike He-3 detectors, which is necessary in these applications
- Stilbene organic scintillators are sensitive to photons and neutrons
- Dual particle sensitivity can present great challenges in high photon flux fields due to the presence of piled-up pulses

Stilbene Organic Scintillator

- Organic scintillators have excellent Pulse Shape Discrimination (PSD) capabilities
- For the same total integral, a neutron will have more tail area than a photon will (Figure 1a,b)
- Piled-up pulses increase tail integrals, presenting challenges for traditional discrimination methods (Figure 1c)

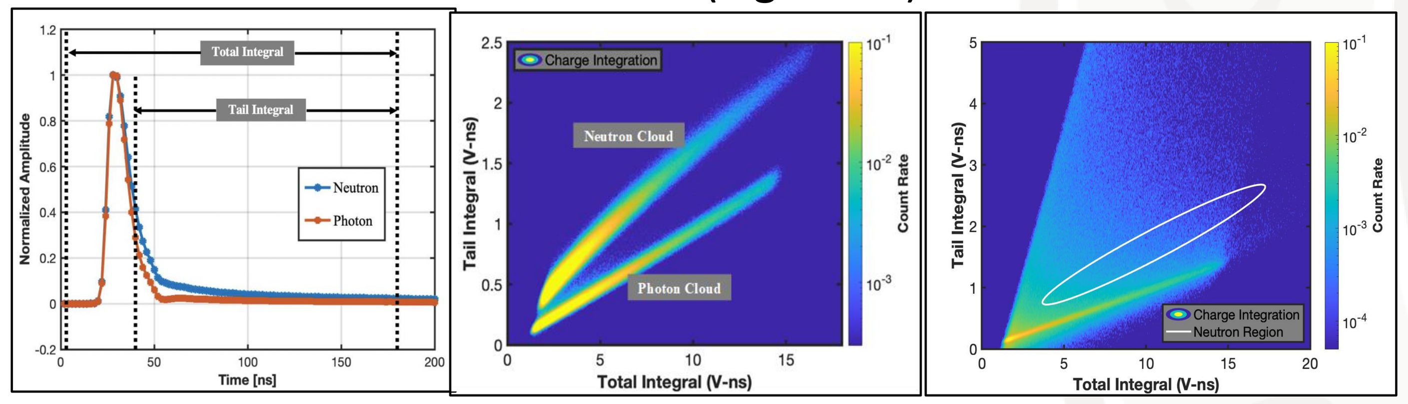

Figure 1 [1]. Single pulses used for a pulse shape discrimination plot. a) Single neutron and photon pulses, b) a clean PSD plot, c) a noisy PSD plot due to piled-ups

- An Artificial Neural Network (ANN) system classifies pulses from organic scintillators with capability to recover piled-ups (Figure 2)

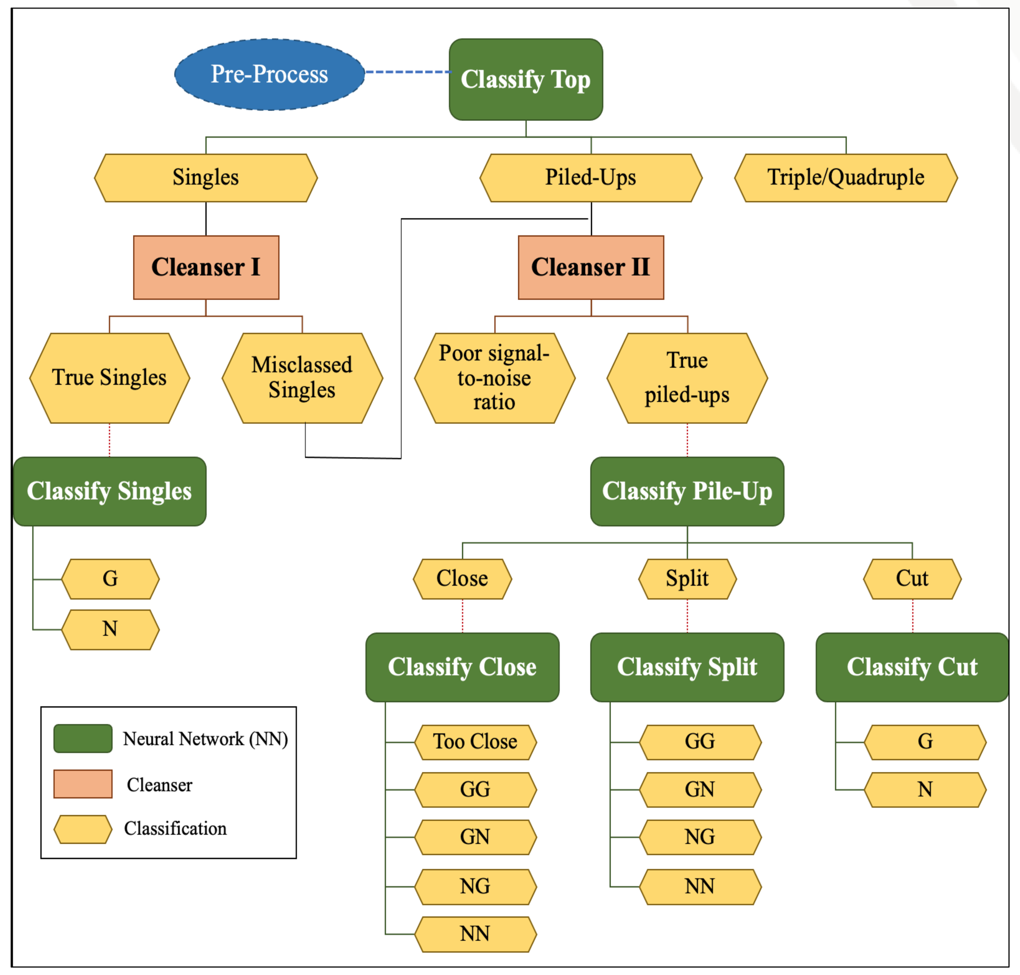

Figure 2. The ANN structure

Technical Approach

- We actively interrogated depleted uranium (DU) with a Varian 9 MeV linac (Figure 3) in four configurations: unshielded, and 1,3,5-inch polyethylene-shielded (Figure 4)
    - Polyethylene is a neutron moderator
- Each configuration was interrogated for one hour
- Each configuration's data set was processed with ANN system to classify neutron and photon pulses

Figure 3. The 9 MeV Varian linac

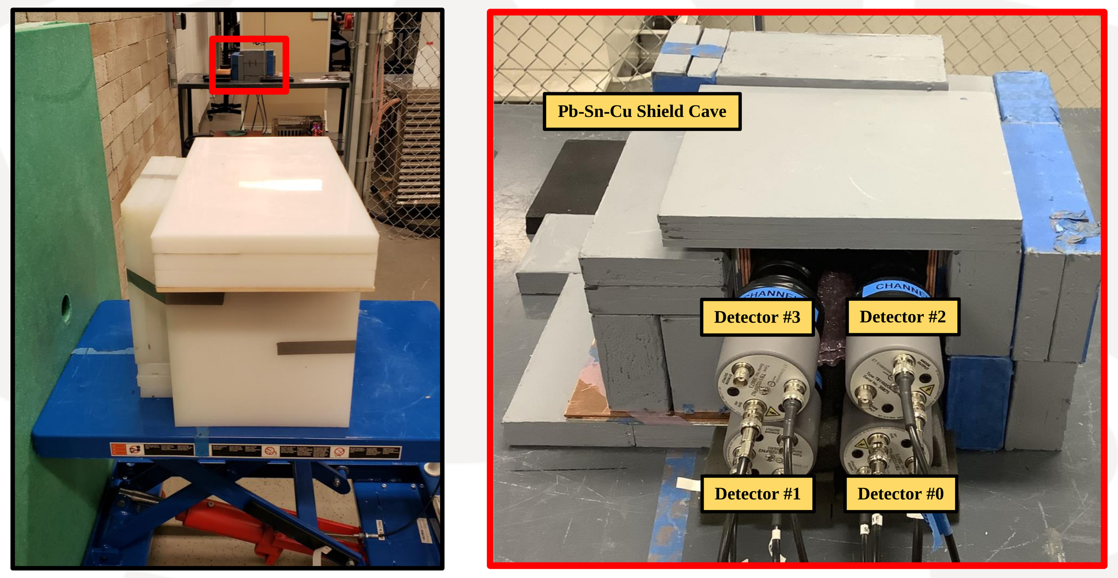

Figure 4. a) A DU cube surrounded by 3 inches of polyethylene, b) the stilbene organic scintillator setup

Mission Relevance and Expected Impact

- Interrogating sources, such as photon beam from a linac, can be used to inspect cargo containers at ports to discourage diversion of nuclear material
- Bare SNM targets are unlikely in inspection systems
- This work marks important step for establishing ANN system's capability in real-world scenarios
- Expands the possibilities for safeguards in photon-flux active interrogation of shielded SNM

References

1. A. J. Jinia, T. E. Maurer , S. D. Clarke, H. S. Kim, D. D. Wentzloff, and S. A. Pozzi, "An Artificial Neural Network System for Special Nuclear Material Detection in Photon Based Active Interrogation Scenarios," *(poster presentation at the 2020 IEEE NSS-MIC Conference)*.
2. A. J. Jinia, K. E. Laferty, S. D. Clarke, H. S. Kim, D. D. Wentzloff, and S. A. Pozzi, "Development an Artificial Neural Network for Special Nuclear Material Detection in a Mixed Photon-Neutron Environment," *(poster presentation at the 2021 NA22 Conference)*.

Results

- High-energy single neutrons (>4 MeV) are present despite shielding (Figure 5)
- Neutron counts decrease with increasing polyethylene shielding (Figure 6), but ANN piled-up recovery offers supplemental information for count rate applications

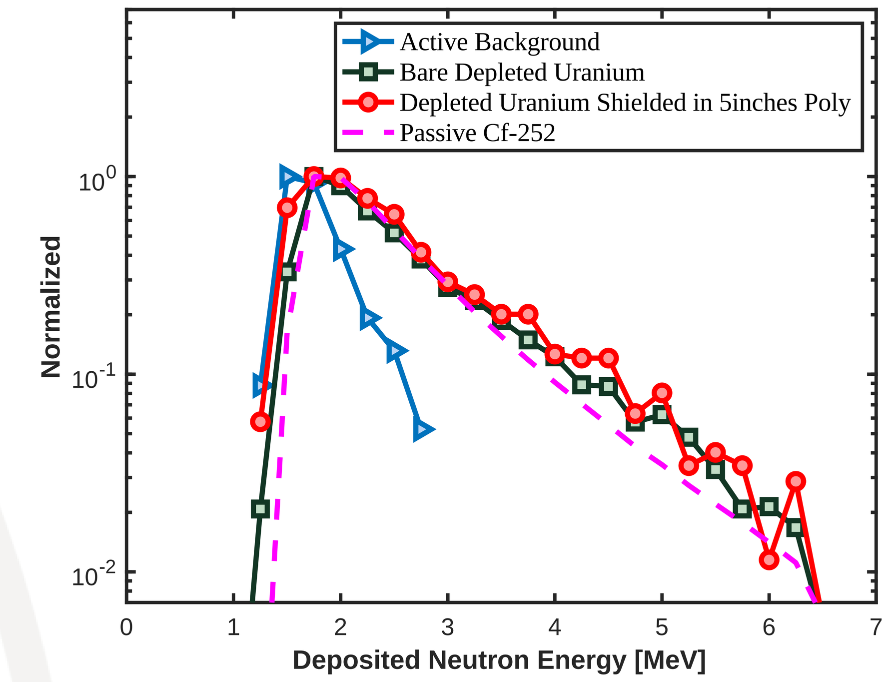

Figure 5. The gross neutron energy distribution plot height normalized.

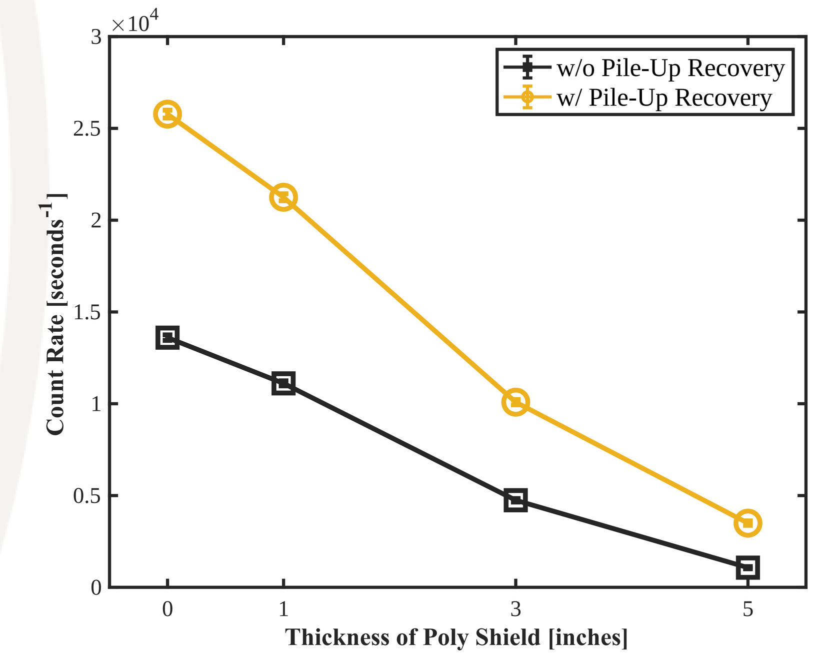

Figure 6. The net neutron count rates of the various shielding configurations

Conclusion

- The neutron energy distribution enhances capability to identify depleted uranium
- Recovered neutrons increase overall neutron counts
- This work demonstrates detection of depleted uranium shielded up to 5 inches of polyethylene is possible
- Promotes NNSA mission of material management and minimization

Next steps:

- Test additional polyethylene shielding thicknesses
- Simulate shielding configurations with MCNP to provide baseline comparisons

This work was funded in-part by the Consortium for Monitoring, Technology, and Verification under Department of Energy National Nuclear Security Administration award number DE-NA0003920

National Nuclear Security Administration