Contribution ID: **57**

Type: **Oral Presentation**

#6-57 Measurement of Neutron Active Interrogation Contraband Signatures Using Organic Scintillators

Tuesday, June 10, 2025 2:00 PM (20 minutes)

Concealed contraband (e.g., explosives, illicit drugs, and special nuclear material) can be detected by neutron active interrogation. For detecting explosives and narcotics, prompt gamma rays from fast neutron inelastic scattering on carbon, nitrogen, and oxygen and delayed gamma rays from thermal neutron capture on hydrogen, nitrogen, and chlorine are the primary signatures. Pulsed accelerator-driven neutron generators are commonly used for activation since the pulse structure allows for the measurement to be divided into a prompt time region, during the neutron pulse when fast neutrons dominate the neutron flux, and a delayed time region between neutron pulses, during which the neutron flux consists of thermalized neutrons. The use of pulsed time gating improves the signal-to-background ratio for signatures based on their timing and the neutron interaction type that produced them. Despite their potential, active interrogation systems are yet to be widely deployed at security checkpoints because the systems require prohibitively long measurement times, can deliver a substantial radiation dose to operators, and are not yet cost-effective. While inorganic scintillators and semiconductor detectors are commonly used for detection of these contraband gamma-ray signatures, organic scintillators offer several advantages. Their fast response times make them pileup resistant, enabling higher neutron fluxes during irradiation. Additionally, organic scintillators are cost-effective and scalable to large volumes to create efficient detection systems. This work explores the use of spectral reconstruction to enhance gamma-ray spectroscopy capabilities of organic scintillators and demonstrates the detection of contraband signatures using fast neutron active interrogation and organic scintillators. Spectral reconstruction is implemented using maximum likelihood estimation maximization, an iterative algorithm that determines the incident gamma-ray spectrum with the highest probability of resulting in the measured light output spectrum, given Poisson counting statistics and a known detector response. The detector response matrix is simulated in the Geant4 framework, using energy deposition convolved with measured energy resolution parameters. The energy resolution parameters are measured by fitting simulation data to measured gamma-ray check source data using a genetic algorithm. The spectral reconstruction algorithm was tested on several gamma-ray check sources and shown to be in good agreement with the known gamma-ray spectrum. Fast neutron active interrogation measurements were conducted using Thermo Scientific P211 DT and MP320 DD pulsed generators and graphite, sugar, salt, and melamine contraband simulants to measure hydrogen, carbon, nitrogen, oxygen, and chlorine contraband signatures. Activation gamma rays were measured using hydrogenous and deuterated liquid organic scintillators. The detection system makes use of a reconfigurable water-based collimation system to reduce the production of activation gamma rays in the environment, which constitute active background, and to shield the detectors from fast and thermal internal neutron activation. We successfully reconstructed the major hydrogen, carbon, nitrogen, oxygen, and chlorine gamma-ray signatures from active background subtracted light output spectra. We additionally show discrimination of contraband simulants and benign activation targets based on the measurement of the ratio of the intensity of carbon and oxygen signatures in reconstructed spectra. We show that time gating on the prompt time region shows an increased signal-to-background ratio for neutron inelastic scattering gamma rays, and gating on the delayed time region improves the signal-to-background ratio for neutron capture gamma rays, evincing the value of pulsed neutron generators. We demonstrated the advantage of short neutron pulses by measuring the signal intensity and signal-to-background ratio for neutron capture gamma ray signatures for various pulse lengths, which were set by adjusting the duty factor of the DD generator. Future work will include the extension of these techniques to measurement of contraband gamma-ray signatures with Cherenkov detectors, which may provide greater pileup resistance but which pose additional unique challenges due to their relatively low light output.

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Session Classification: #06 - Nuclear Safeguards, Homeland Security and CBRN

Track Classification: 06 Nuclear Safeguards, Homeland Security and CBRN