Unclassified Unlimited Release (UUR) Executive Summary (60-word maximum)

This is a high-risk effort to leverage knowledge gained from previous work, which focused on detector development leading to better energy resolution and reconstruction errors. This work seeks to enable applications that require precise elemental characterization of materials, such as chemical munitions remediation, offering the potential to close current detection gaps.

Summary of Key R&D Accomplishments (300-word maximum)

This work involved the design and performance of a proof-of-concept 32 channel material identification system. Our system is based on the energy-dependent attenuation of fast neutrons for four elements: hydrogen, carbon, nitrogen and oxygen. The system's performance as a function of time-of-flight energy resolution is explored using a Geant4-based Monte Carlo. Our results indicate that, with the expected detector response of our system, we will be able to determine the molar density of all four elements to within a 20-30% accuracy in a two-hour scan time. In many cases this error is systematically low, thus the ratio between elements is more accurate. This degree of accuracy is enough to distinguish a sample of water from a sample of pure hydrogen peroxide: the ratio of oxygen to hydrogen is reconstructed with an error of $8 \pm 0.5\%$. Finally, with future algorithm development that accounts for backgrounds caused by scattering within the sample itself, the accuracy of molar densities, not ratios, may improve to the 5-10% level for a two-hour scan time. The response of an experimental system was characterized and demonstrated to meet the requirements based on the simulation work. Experimental performance in terms of material characterization was evaluated with various thicknesses of polyethylene. Digitization errors appear to be dominating the time-of-flight spectrum, preventing accurate reconstruction, although overall agreement between the expected and measured spectrum was reached. This motivates either improved digitization or analog acquisition, as well as improved PMT response. In addition, sample scattering may be contributing to poor performance. Although a background to the neutron attenuation signature, sample scattering is also dependent on the elemental constituents of the sample, and therefore could be included in the reconstruction for improved accuracy. Additional investment would be required to realize the benefits of including sample scattering into the reconstruction.

Significance of Results and Impacts (100-word maximum)

This work addresses the Department of Homeland Security's Strategic Plan, Goal 1.2: Prevent the unauthorized acquisition or use of chemical, biological, radiological, and nuclear materials and capabilities. It responds to current and emerging threats by potentially detecting not just known explosives in transit, but also materials that, as indicated by their elemental composition, could be rejected as benign material. We also directly respond to Goal 2.1: Secure U.S. Air, Land, and Sea Borders with the detection of explosives and illegal. This project demonstrated the expected performance given particular parameters of a laboratory system, and sought to experimentally demonstrate these findings.