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#6-16 Advancements in Illicit Material Detection Using Active Photon Interrogation and Photoneutron Spectrometry: Proof of Concept and Application to Homeland Security

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The growing threat posed by the trafficking of illicit materials, including explosives, narcotics, and chemical weapons, requires the development of robust, non-intrusive detection techniques capable of providing fast and accurate on-site assessments. In this context, active photon interrogation methods have shown potential interest but have remained underexplored in applications not related to actinide detection [1]. Over the past two years, we achieved significant progress in the development of a novel approach using active photon interrogation combined with photoneutron spectrometry to address this challenge. This paper presents a comprehensive update on the research, demonstrating its successful transition from early-stage simulations and fundamental measurements to the proof of concept and its validation through realistic detection scenarios with direct relevance to homeland security.

Traditional non-intrusive inspection techniques, often based on neutron-induced reactions [2], rely heavily on gamma-ray spectrometry, which presents significant limitations due to high levels of background noise and the complexity of interpreting spectra in real-time. In contrast, active photon interrogation offers a promising alternative, particularly when applied to the detection of conventional explosives, narcotics, and other illicit materials containing light elements such as nitrogen, oxygen, and carbon. These elements can undergo photo-nuclear reactions when exposed to high-energy photons, producing photoneutrons whose energy spectra can be analyzed allowing the identification of the material's composition.

Two years ago, preliminary work on this method was presented at the 2023 ANIMMA conference [3], where Monte-Carlo simulations using FLUKA, GEANT4, MCNP and PHITS codes were used to explore the feasibility of the application based on photo-nuclear reactions for the detection of illicit materials. These initial studies demonstrated significant differences in the modeling of light elements' nuclear levels across the simulation codes and highlighted the need for improved experimental validation and data-driven methods for interpreting photoneutron spectra. Since this initial contribution, substantial progress has been made in the experimental and analytical development of the proposed method, allowing the transition from theoretical simulations to practical applications, leveraging both the photon source based on our Varian TrueBeam medical accelerator and deep learning algorithms, in order to detect illicit materials in very realistic, and consequently challenging scenarios.

A series of experiments were conducted using a Varian TrueBeam medical accelerator, specially adapted to fulfil our needs, to generate photon beams with energies up to 22 MeV. The resulting beams were directed on various target materials, inducing photo-nuclear reactions at the origin of measurable photoneutron spectra. To ensure accurate results, we employed a carefully designed detection set-up. EJ309 and BC-501-A liquid organic scintillators were calibrated and successfully used to measure the fast photoneutron spectra in the very challenging mixed short-pulsed fields with intense photon flashes generated during the irradiations. Multiple types of unfolding techniques were used to accurately reconstruct the photoneutron energy distributions [4].

The proof of concept is presently successfully provided through a series of detection experiments involving realistic scenarios for homeland security applications. One of the key breakthroughs was the detection of melamine, an explosive simulant material with high nitrogen content, hidden in various complex and realistic environments. The first case was a suitcase filled with clothing interrogated using our active photon method. Despite the presence of a high quantity of non-threatening materials (10 kg of clothes), we successfully identified the presence of melamine, as indicated by the characteristic photoneutron signatures from the reactions on nitrogen. The second case was a more complex scenario where melamine was concealed inside a large wooden freight box containing copper cables and electronic equipment weighting more than 10 kg. Even with the highly attenuating copper and high photoneutron contribution from metallic parts, our method was able to detect also in this case the presence of melamine, showcasing the robustness of the approach for real-world applications.

The experimental results achieved validate the potential of the active photon interrogation combined with photoneutron spectrometry in detecting illicit materials in complex environments and therefore extending the use of active photon interrogation to the detection of threats other than actinides. Future work will focus on expanding the range of detectable materials, refining the machine learning models for enhanced accuracy, and conducting additional field trials to further validate the system's performance in operational environments. This research lays the groundwork for a new generation of non-intrusive inspection techniques capable of addressing the evolving threats posed by illicit material trafficking.

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[3] C. Besnard-Vauterin, V. Blideanu, B. Rapp, "Development of a new method for the detection of illicit materials based on the active interrogation method and photoneutron spectrometry", in Proc. of 8th Int. Conf. Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), Lucca, Italy, June 12–16, 2023.
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