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ScienceDirect
Nuclear Instruments and Methods in Physics Research B 261 (2007) 351–355
NIM B Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Signals and interferences in the nuclear car wash

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Available online 1 May 2007

Abstract

The screening of sea-going cargo containers for highly enriched uranium (HEU) and other fissile material is a challenging problem. This is due in part to the cargo itself, which acts as an attenuator to any radiation that might signal its presence. In the nuclear car wash, β-delayed high-energy γ-rays following neutron-induced fission are utilized as this signal. The delayed γ-rays above 3 MeV are highly penetrating and have energies above natural background radiation. In addition, the half-lives of most fission products emitting γ-rays at these energies are less than 160 s, making it feasible to construct decay curves on a time scale which preserves the flow of commerce through the port. A particular goal of the project is to understand the rate of false alarms. To this end, experiments are underway to investigate possible interferences, and to understand variations in the overall γ-ray background. The experiments and preliminary results are discussed. Work performed under the auspices of the DOE by the UC LLNL W7405Eng4,UCRL-PROC-224803.
Published by Elsevier B.V.

PACS: 25.85.Ec; 23.40.−s; 29.40.Mc; 89.20.Bb

Keywords: Active neutron interrogation; n-Induced fission; β-Delayed radiation; Plastic scintillators; SNM

1. Introduction

In the fight against terrorism at our nation's ports, active cargo container interrogation can confirm the presence of fissile material in the assessment of a possible threat. At Lawrence Livermore National Laboratory, one such system 'the nuclear car wash' [1–4] is currently undergoing feasibility testing. The system employs active neutron interrogation, using neutrons to induce fission, and then taking subsequent β-delayed high-energy γ-rays as the signal that fissile material has been stowed in the cargo. In some cases, the decay of delayed neutrons is used in conjunction with that of the delayed γ-rays as this signature. One goal for the system is to limit the scanning time per container to 1 min while retaining 95% detection and 0.1% false alarm rates.

A system prototype has been set up to facilitate tests with hydrogenous and metallic cargos. Recent experiments designed to test the effects of incident neutron attenuation, examine the γ-ray background, and measure the severity of several possible signal interferences, show that the method is successful, and has the potential to play a major role in reducing the false alarm rates in any combined-method scanning apparatus that may be implemented at the seaports.

2. β-delayed radiation signals fissile material

The nuclear car wash uses β-delayed radiation to signal the presence of fissile material in cargo. It has been shown that after thermal-neutron induced fission, β-delayed γ-rays with $E > 3$ MeV are a unique signature for ^{235}U and ^{239}Pu [5]. Many of these fission products have half-lives ranging $1\ s < t_{1/2} < 30\ s$ and also have high Q-values to β-decay [6]. This indicates that there is a chance for

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0168-583X/$ - see front matter Published by Elsevier B.V.
doi:10.1016/j.nimb.2007.04.264

many decays within the 1 min per scan goal, and that in these decays there is an equally important chance that a high-energy γ-ray will be emitted, and because of its energy, escape full attenuation by the cargo. While the number of high-energy γ-rays emitted by a particular fission product per fission may be small, the sum of these γ-rays over the wide mass distribution of fission products is large enough to consider. Consequently, and because significant natural background γ-radiation falls below 2.6 MeV, this summed number of high-energy β-delayed γ-rays becomes a workable signal for the presence of fissile material in thick cargo.

3. Experimental setup

The experiment setup (Fig. 1) consists of a broad spectrum 7 MeV neutron source, eight large area plastic scintillators for γ-ray detection, and 14 ^{3}He tubes to count delayed neutrons. Smuggled nuclear material is represented with a sample of HEU (U_3O_8) placed at various locations within 0.55 g/cm^3 mock hydrogenous cargo (plywood), and separately in a 0.6 g/cm^3 mock metallic cargo (steel pipes). The dimensions of the mock cargos are 229 cm × 122 cm × 178 cm.

Neutrons are produced in a d(d, n) reaction. A 4 MeV deuteron linac from Accsys Technologies accelerates deuterons horizontally to 4 MeV. The deuteron beam direction is then bent 90° upward by a high-energy beam transport system and is delivered to the 1 atm, 60 cm long, D_2 gas target cell at currents of 10–65 μA nominally (100 μA maximum). A 10 μm Mo window slows the beam to approximately 3.27 MeV upon entry into the cell where the incident deuterons are completely stopped.

Neutrons escape through the floor of the high bay via a polyethylene collimator with a 15° opening angle. Delayed γ-rays produced by the *n*-induced reactions are then detected in 4 – 61 × 61 × 25.4 cm, 2 – 61 × 61 × 15.2 cm and 2 – 61 × 122 × 15.2 cm plastic scintillators which have energy resolutions of approximately 35% at 898 keV. The data presented here will represent the summed spectra for four 25.4 cm thick detectors. In addition to γ-ray detectors, 14 ^{3}He tubes were used to detect delayed neutrons during experiments with steel cargo. The ^{3}He tubes are 5.08 cm in diameter, 91 cm long, are filled with 4 atm ^{3}He and embedded in 10.16 cm thick polyethylene for moderation.

Experiments are performed by placing a sample of HEU (U_3O_8), either 221.1 g or 376.5 g ^{235}U, at varying depths within a mock cargo. The neutron generator is then cycled on for 30 s to induce fission and to allow sufficient build up of fission products with 1 s $< t_{1/2} <$ 30 s. Neutrons are then turned off, and gamma and neutron counters are allowed to count their respective β-delayed radiations for another 100 s.

4. γ-Ray background

System goals of 95% detection and 0.1% false alarm rates correspond to a signal strength 5σ over ‘active background’, γ-rays counted after irradiation of the cargo only (no HEU). Variation in the active background must be understood in order to properly define the standard deviation (σ). A preliminary study shown here investigates the dependence of the variation of the active background on deuterium current.

Fig. 2 shows the active background for different deuterium beam currents measured at the entrance of the D_2 gas cell. The ‘passive background’, taken without n-irradiation, has been subtracted. Data is displayed as a decay curve, the number of γ-rays with energies from 3 to 5 MeV taken in 1 s time bins plotted over 100 s after a single 30 s irradiation. Poisson 2σ error bars are shown. The variation between curves of different beam current is significantly greater than $N^{1/2}$, where N is the number of counts

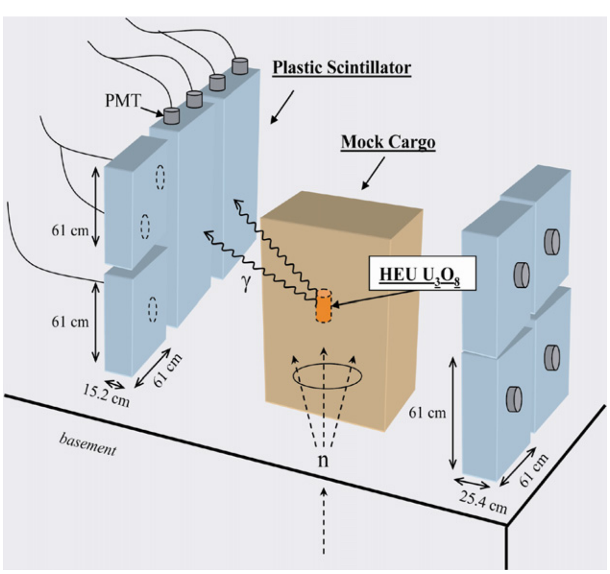

Fig. 1. The nuclear car wash experiment setup.

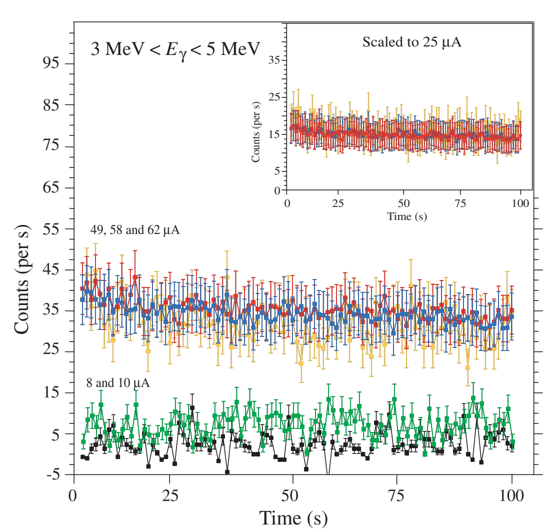

Fig. 2. Active γ-ray background for varying deuterium currents. The inset is scaled to 25 μA.