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ScienceDirect

Physics Procedia 66 (2015) 206 – 215

Physics Procedia

C 23rd Conference on Application of Accelerators in Research and Industry, CAARI 2014

Mixed Source Interrogation of Steel Shielded Special Nuclear Material Using an Intense Pulsed Source

C. Hill*, C. D. Clemett, B. Campbell, P. N. Martin, J. Threadgold, J. O'Malley

AWE, Aldermaston, Reading Berks RG7 4PR United Kingdom

Abstract

This paper explores the benefits of using a mixed photon and neutron radiation source for active detection of special nuclear material. More than fifty irradiations were performed using an 8 MV electron accelerator employing and induction voltage adder (IVA). The experiments used a high atomic number converter to produce a Bremsstrahlung photon spectrum which was then used to create a neutron source via a nuclear interaction with heavy water (deuterium oxide, D_2O). This mixed particle source was used to irradiate a depleted uranium (DU) sample, inducing fission in the sample. Several thicknesses of steel shielding were tested in order to compare the performance of the mixed photon and neutron source to a Bremsstrahlung-only source. An array of detectors were fielded to record both photons and neutrons emitted by the fission reactions. A correlation between steel shielding and a detection figure-of-merit can be seen in all cases where the Bremsstrahlung-only source was used. The same relationship for the mixed photon-neutron source is less consistent. The data collected from the fielded detectors is compared to MCNP6 calculations and good agreement is found.

Keywords: Active detection; photofission; neutron induced fission; IVA; uranium

1. Introduction

Photons with energies higher than ~5 MeV, and neutrons of any energy, can induce fission in special nuclear materials and, in turn, the products can be detected and identify the material as fissile or fissionable. The

* Corresponding author. Tel.: +44118985677
E-mail address: cassie.hill@awe.co.uk

doi:10.1016/j.phpro.2015.05.027

experiments discussed here used a high atomic number converter to produce an 8-MeV endpoint energy Bremsstrahlung photon spectrum which was then used to irradiate a D_2O insert which produces a 2-3 MeV endpoint neutron spectrum for a small measurable loss in photon fluence. This mixed interrogation source is potentially favourable for non-hydrogenous shielding configurations which are highly attenuating to photon beams. However, neutrons add significant complexity both operationally in terms of radiation dose and, also, for analysis in discriminating fission signals due to high backgrounds and activation products. The added performance benefits must outweigh these complications if the neutron component of the source is to be deployed. To assess these effects, a depleted uranium plate was irradiated and induced-fission signatures were measured as a function of the thickness of steel shielding surrounding the target. This was performed with the accelerator operating in normal Bremsstrahlung mode with a D_2O insert to generate neutrons and with a H_2O insert to measure the relative photon attenuation of the secondary converter. The non-fission related radiation background produced during an interrogation (the active background) was also measured and characterised. This will support an understanding of the level of complexity the neutron component introduces.

2. Experimental Setup

The experiments were performed at the Mercury facility at the Naval Research Laboratory, Washington DC. In total, more than 110 shots were fired investigating several different parameters pertinent to active detection, of which a subset of 52 shots was used for the present analysis. As shown in Table 1, three families of shots were analysed. These relate to the radiation converter target used, i.e., bremsstrahlung, D_2O and H_2O. In the case of the Bremsstrahlung source, the converter used was the standard high-Z tantalum diode [2] used in previous active detection campaigns [3]. A deuterated water insert was included in the collimation to produce a fast neutron component via the $^{2}H(\gamma,n)^{1}H$ process. As a control measure, the D_2O insert was replaced with a H_2O insert for a small number of shots in order to understand the photon attenuation of the heavy water converter. For each of the three converter configurations, a number of stainless steel shielding thicknesses were investigated. Stainless steel was chosen due to its abundance in shipping cargos [4] and because of its high photoneutron threshold and low relative yield in comparison with other high-Z materials such as lead and tungsten. If a low photoneutron threshold material had been used, the additional neutrons produced by the shielding material may contribute to the induced fission and confuse the analysis of these experiments. Table 1 also shows the shielding thicknesses used and their corresponding areal masses. Most configurations were repeated at least once to ensure repeatability in the results.