

Detection of shielded nuclear material in a cargo container[☆]

James L. Jones^{a,*}, Daren R. Norman^a, Kevin J. Haskell^a, James W. Sterbentz^a,
Woo Y. Yoon^a, Scott M. Watson^a, James T. Johnson^a, John M. Zabriskie^a,
Brion D. Bennett^a, Richard W. Watson^a, Cavin E. Moss^b, J. Frank Harmon^c

^aIdaho National Laboratory, P.O. Box 1625, MS 2802, Idaho Falls, ID, 82415-2802, USA

^bLos Alamos National Laboratory, P.O. Box 1663, MS B228, Los Alamos, New Mexico 87585

^cIdaho State University, 1500 Alvin Ricken Dr., Pocatello, ID 83201, USA

Available online 3 March 2006

Abstract

The Idaho National Laboratory, along with Los Alamos National Laboratory and the Idaho State University's Idaho Accelerator Center, are developing electron accelerator-based, photonuclear inspection technologies for the detection of shielded nuclear material within air-, rail-, and especially, maritime-cargo transportation containers. This paper describes a developing prototypical cargo container inspection system utilizing the Pulsed Photonuclear Assessment (PPA) technology, incorporates interchangeable, well-defined, contraband shielding structures (i.e., "calibration" pallets) providing realistic detection data for induced radiation signatures from smuggled nuclear material, and provides various shielded nuclear material detection results. Using a 4.8-kg quantity of depleted uranium, neutron and gamma-ray detection responses are presented for well-defined shielded and unshielded configurations evaluated in a selected cargo container inspection configuration.

© 2006 Elsevier B.V. All rights reserved.

PACS: 25.20.-x

Keywords: Nuclear smuggling; Cargo containers; Active interrogation; Photofission; Neutron signature; Gamma-ray signature

1. Introduction

The Idaho National Laboratory (INL), along with Los Alamos National Laboratory (LANL) and Idaho State University's Idaho Accelerator Center (ISU/IAC), has been developing a high energy photon interrogation system for non-intrusive inspections of air-, rail-, and maritime cargo containers [1,2]. This energetic photon inspection technology is referred to as the Pulsed Photonuclear Assessment (PPA) technology and is supported by the Department of Homeland Security. The PPA technology development is addressing one of our homeland security's most important concerns—terrorism associated with the transportation of

weapons of mass destruction (WMD), specifically weapons employing nuclear materials, such as highly enriched uranium (HEU). While all aspects of cargo container transportation and security is important, the focus of this paper is with shielded nuclear material detection in maritime cargo containers (or trucks) since these represent the most common mode of commercial transportation. This paper briefly describes the prototype PPA inspection system and then presents detection results from a selected cargo container inspection configuration. The photonuclear-induced, radiation signatures are presented for a nominal 10-MeV photon interrogation of a 4.8-kg depleted uranium (DU) sample that is located within well-defined shielding configurations (i.e., INL "calibration" pallets) that are then positioned in the center of the inspected cargo container. This center-positioned DU, and/or the "calibration" pallet, provides relatively challenging detection scenarios because it results in the largest DU-to-detector distances.

[☆]Supported in part by the Department of Homeland Security under DOE Contract No. DE-AC07-05ID14517.

*Corresponding author. Tel.: 208 526 1730; fax: 208 526 5208.

E-mail address: james.jones@inl.gov (J.L. Jones).

2. Inspection technology

The PPA inspection technology uses pulsed, energetic photons to induce photofissions (and neutron-induced fissions) in shielded nuclear materials. The main features of the PPA inspection system include a pulsed electron accelerator (the photon source), a neutron and gamma-ray detection system [1,2], and an inexpensive gray scale mapping system for cargo loading characterizations [2]. Note, the PPA “mapping” component will not be discussed in this paper.

The pulsed photon source for the PPA prototype is the INL Varitron [3]. The Varitron is a mobile accelerator system capable of generating electron pulses of 2–12 MeV electrons at rates up to 500 Hz with an on-board, electron beam current and energy monitoring capability. All signature emission data presented in this paper are provided with a nominal 10-MeV, 125-Hz operation producing about 3–4 μA (avg.) beam current.

The prototype neutron and gamma-ray detection system consists of a transportable stand consisting of an array of nine detector pairs at various elevations. Each collocated pair consist a neutron and gamma-ray detector. Fig. 1 shows a detector assembly positioned along side a maritime-cargo container in a testing device at the IAC that provides container motion.

Neutron detection is accomplished with the patent-pending Photonuclear Neutron Detector (PND) design [1] that operates within intense pulsed, photon-flash environments and differentiates prompt and delayed fission neutrons emissions between every accelerator pulse. The unique PND design allows for the detection of 0.1-keV to 1.0-MeV neutron since this energy range is representative of almost all delayed fission neutron emissions.

Gamma-ray detection is accomplished with the use of standard, 1.6-cm, 27.3-cm Geiger–Müller tubes (model LND 719) collocated with each PND. A figure-of-merit (FOM)-type parameter is used to characterize the induced-gamma-ray emissions. This FOM is a ratio of the time-

dependent responses of a GM tube and the thermal neutrons in a bare helium-3 tube.

3. Inspection configuration

The selected PPA inspection configuration for the maritime-cargo container assessment is shown in Figs. 2 and 3. This configuration was selected to keep each detector assembly axis perpendicular to the long axis of the cargo container and to allow an angular alignment between the accelerator beam axis and the detector assembly axis. For this inspection evaluation, an angle of about 42° is selected with a 250-cm standoff distance from the photon source to the center of the cargo container. As shown in Fig. 3, the interrogating photon beam axis is 122 cm from the ground level.

4. “Calibration” pallets

To characterize the radiation shielding effects from a cargo container, a set of well-defined cargo loadings have been assembled [2]. This representative set of cargo loadings is referred to as the INL “Calibration” Pallets.

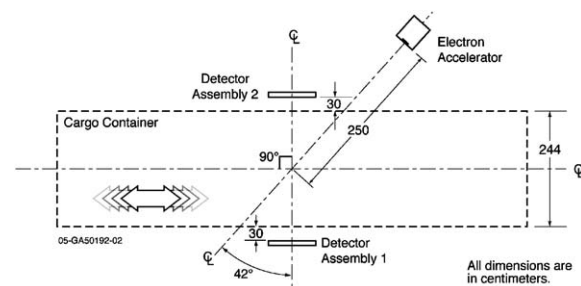


Fig. 2. Top view of the cargo container inspection configuration.

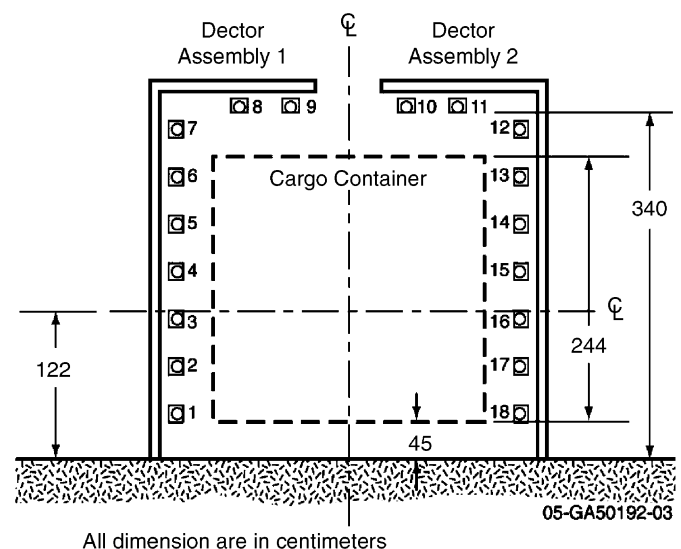


Fig. 3. End view of the cargo container inspection configuration.



Fig. 1. Deployed PPA detector assembly.

Table 1
Calibration pallet designs

Pallets	Mass (kg)	Primary Material	Material Density (g/cc)
Empty	46	Aluminium	2.70
Celotex	90	“Celotex”	0.05
Borated Polyethylene	1012	5%-Borated polyethylene	1.05
Polyethylene	923	Polyethylene	0.95
Wood	482	Plywood	0.48
Lead	254	Lead	10.80
Iron	890	Iron	7.80

Table 2
Selected neutron detection responses

Pallets	Neutron counts/Electron (120 s inspection)			
	Detector #3		Detector #16	
	No DU	With DU	No DU	With DU
Empty	$2.30 \pm 0.29 \text{ E-14}$	$9.97 \pm 0.19 \text{ E-13}$	$2.31 \pm 0.29 \text{ E-14}$	$5.62 \pm 0.14 \text{ E-13}$
Celotex	$1.88 \pm 0.26 \text{ E-14}$	$9.11 \pm 0.18 \text{ E-13}$	$2.46 \pm 0.28 \text{ E-14}$	$8.44 \pm 0.17 \text{ E-13}$
Borated polyethylene	$1.94 \pm 0.30 \text{ E-14}$	$2.06 \pm 0.31 \text{ E-14}$	$2.03 \pm 0.31 \text{ E-14}$	$1.84 \pm 0.29 \text{ E-14}$
Polyethylene	$2.61 \pm 0.35 \text{ E-14}$	$1.97 \pm 0.29 \text{ E-14}$	$2.83 \pm 0.35 \text{ E-14}$	$1.99 \pm 0.29 \text{ E-14}$
Wood	$2.56 \pm 0.31 \text{ E-14}$	$5.95 \pm 0.48 \text{ E-14}$	$1.89 \pm 0.26 \text{ E-14}$	$6.86 \pm 0.51 \text{ E-14}$
Lead	$2.57 \pm 0.34 \text{ E-14}$	$1.08 \pm 0.07 \text{ E-13}$	$3.08 \pm 0.38 \text{ E-14}$	$8.33 \pm 0.62 \text{ E-14}$
Iron	$3.00 \pm 0.37 \text{ E-14}$	$6.46 \pm 0.56 \text{ E-14}$	$3.33 \pm 4.01 \text{ E-14}$	$5.36 \pm 0.51 \text{ E-14}$

Table 1 summarizes some key characteristics of these “Calibration” Pallet designs.

All pallet designs provide shielding completely around a centrally located nuclear material. The Wood, Celotex, Borated Polyethylene, and Polyethylene Pallets are rectangular in shape and have a 1.07-m depth, a 0.86-m width, and a 1.02-m height. The Lead and Iron Pallets are cylindrical in shape and have radial shield thickness of 5.08 and 16.51 cm, respectively. When the rectangular-shaped pallets are placed within a cargo container, they are aligned with their long (depth) dimension parallel with the long container axis. This alignment allows a standard two-wide, two-high pallet loading in the cargo container.

5. Results

Tests were performed with (and without) a 4.8-kg, ~14-cm square DU sample in each of the INL “Calibration” Pallets located at the center of the cargo container configuration as indicated in Figs. 2 and 3. All tests involved a 120-s data acquisition.

Table 2 presents the neutron detection response at detector positions #3 and #16 while Table 3 presents gamma-ray FOM parameter data from all gamma-ray detector positions. Italic entries represent nuclear material detection based on the following threshold settings: 4E-14 neutron counts/e (neutron) and a FOM = 14 (gamma).

Table 3
Gamma-ray FOM detection responses

Pallets	Gamma Detection FOM for both detector assemblies	
	No DU	With DU
Empty	13.18 ± 0.16	31.17 ± 0.25
Celotex	13.16 ± 0.16	33.24 ± 0.32
Borated polyethylene	16.03 ± 0.22	16.14 ± 0.21
Polyethylene	12.06 ± 0.16	14.98 ± 0.18
Wood	12.27 ± 0.15	21.14 ± 0.21
Lead	13.56 ± 0.17	13.84 ± 0.18
Iron	15.22 ± 0.20	14.80 ± 0.19

6. Summary

A photonuclear-based inspection technology, referred to as the PPA technology, is being developed and sponsored by the Department of Homeland Security for the detection of shielded nuclear material in air-, rail-, and maritime-cargo containers. Using a representative nuclear material (4.8-kg DU) and some well-defined shielding configurations positioned within the center of a selected cargo container inspection configuration, the PPA technology with its integrated neutron and gamma-ray detection capability did successfully detect the nuclear material within 120 s whenever it was present. These results are

very encouraging since it is anticipated that the detection capability will further improve when the pallets are actually loaded in their normal positions along the cargo container side, hence, effectively decreasing the DU-to-detector distances.

The neutron detection capability correctly detected the nuclear material in all pallet scenarios, except the Borated Polyethylene and Polyethylene Pallet cases, with no false positive responses. The simple gamma ray-detection capability correctly showed positive nuclear material detection in all scenarios but the Lead Pallet case. For the latter case, detection is observed when integrating the neutron-based detection data. However, the gamma ray data did also provide false positive detections with the Borated Polyethylene and Iron Pallet cases. It should be noted that these two pallet cases are representative of very significant

neutron attenuation/absorbing scenarios that should probably justify some additional inspection attention anyway, such as with radiographic imaging. Additional work is needed to better characterize/improve the simple gamma-ray detection system, to develop detection responses for off-beam- axis locations, to characterize multiple “calibration” pallet loading configurations.

References

- [1] J.L. Jones, et al., Photofission-based, Nuclear Material Detection: Technology Demonstration, INL Report 02-01406, December 2002.
- [2] J.L. Jones, et al., Pulsed Photonuclear Assessment (PPA) Technique: CY04 Year-end Progress Report, INL Report 05-02583, February 2005.
- [3] J.L. Jones, et al., Pulsed Photoneutron Interrogation: The GNT Demonstration System, INL/WINCO Report 94-1225, October 1994.