

## Alternatives to $^3\text{He}$ for Neutron Detection for Homeland Security

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### Abstract

Neutron detection is an essential aspect of interdiction of radiological threats for national security purposes, since plutonium, a material used for nuclear weapons, is a significant source of fission neutrons. Radiation portal monitoring systems, of which there are thousands deployed for homeland security and non-proliferation purposes, currently use  $^3\text{He}$  gas-filled proportional counters for detecting neutrons. Because of the high usage of  $^3\text{He}$  for neutron scattering science and national security, the supply has dwindled, and can no longer meet the demand. Consequently, a replacement technology for neutron detection is required in the very near future.

**Keywords:** neutron detection; helium-3; radiation detection; homeland security; national security; MCNP

### 1. Introduction

Radiation portal monitoring (RPM) systems currently use  $^3\text{He}$  gas-filled proportional counters for detecting neutrons. These systems are designed for detection of neutrons from thermal to several MeV with almost equal response [Kouzes et al. 2008]. A summary of neutron detection systems in RPMs can be found in Kouzes et al. [2007]. Figure 1 shows an example of an RPM in use at a border crossing.

In addition to alarming on the presence of actual neutron sources, national security applications have a strict requirement for limiting neutron false alarms from a detector, especially in the presence of a large gamma ray-only source [Kouzes 2005]. These same constraints are applicable to any replacement neutron detection.

Because of the  $^3\text{He}$  shortage, a replacement technology for neutron detection is required in the very near future [Kouzes 2009a; Kouzes et al. 2009b; Van Ginhoven 2009]. There are also uses for  $^3\text{He}$  in the oil and gas industry for well logging, medical applications for MRI lung imaging, basic research projects in nuclear and condensed matter physics (e.g., the DOE Spallation Neutron Source), and helium dilution refrigerators. It is estimated that the total  $^3\text{He}$  demand is  $\sim 65 \text{ m}^3/\text{y}$ , while total supply is  $\sim 15 \text{ m}^3/\text{y}$ .

There are three basic requirements for neutron detection for homeland security applications that have developed over the course of large-scale deployments: 1) The absolute detection efficiency for a  $^{252}\text{Cf}$  source located 2 m perpendicular to the neutron sensor shall be greater than 2.5 cps/ng of  $^{252}\text{Cf}$ ; 2) the intrinsic gamma ray sensitivity of the detector shall be less than  $10^{-6}$ ; and 3) the

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detector must retain the same neutron detection efficiency when simultaneously exposed to a gamma ray exposure rate of 10 mR/h [Stromswold et al. 2003; Kouzes et al. 2009c]. In addition, these systems are required to meet all aspects of the ANSI N42.35 standard [ANSI 2004]. For current applications, these detectors must also fit within the footprint of deployed systems.



**Figure 1. Typical RPM scanning a vehicle for radiological material. (Photo By D. Stromswold)**

## **2. Neutron detection technologies**

The primary technology used for thermal neutron detection has historically been based on  $^3\text{He}$ , and previously upon boron trifluoride gas [Segre and Weigand 1947]. Neutron detection is an active area of research and a number of other technologies and devices are currently in use or under development [Peurrung 2000]. Bulk scintillation detectors in general are inappropriate for the large neutron detector requirements of RPMs for national security applications because of their inherent sensitivity to gamma rays. There are numerous scintillating materials being investigated [Milbrath et al. 2008], among them Ce-doped glasses with both Li and B, and Ce-doped lithium borate crystals [Matsumoto et al. 2005]. Liquid scintillator has been used for many years as a neutron detector, where rise time separation of the signal from neutrons and gamma rays is typically used, but adequate separation at high rates is problematic, as well as temperature dependence, as it is for other bulk scintillators.

There is a wide array of composite material-type neutron-sensitive scintillating materials available (see, for example, the list of materials in Koroleva et al. [2005]). These detectors are currently produced in relatively small sizes. There are detectors available that consist of a plastic scintillator material embedded with particles of boron-containing compounds. These detectors can be used for both gamma rays and neutrons, with the particle types distinguished by pulse shape or timing characteristics [Britvich et al. 2005]. The effective neutron detecting area is limited by the need to preserve optical clarity in the scintillating wavelength region. Boron-loaded plastic scintillating fibers and lithium-loaded fibers could also be effective neutron detectors [Ryan et al. 1999].

Another composite material uses large panels of fluorine-doped plastic with lithium phosphate nanoparticles [Ianakiev et al. 2006; Wallace and Allison 2006].

There also are specialized instruments for use in high neutron flux environments, such as those designed for use with the spallation neutron source [Cooper 2004; Engels et al. 2002; Watanabe et al. 2008], and monitoring reactor component dose or fuel performance in fission reactors.

Of the currently commercially available alternative neutron detection technologies, BF<sub>3</sub>-filled proportional detectors [Segre and Weigand 1947; Bolewski 2008], boron-lined proportional detectors [Athanasiaades et al. 2005; Lacy 2006; Dighe 2007], <sup>6</sup>Li-loaded scintillating glass fiber [Bliss et al. 1995; Seymour et al. 2000], or coated wavelength-shifting plastic fiber detectors [Polichar and Baltgavis 2007; Katagiri and Matsubayashi 2007] are the possible replacements for <sup>3</sup>He detector technology in RPMs—if they are proven to have appropriate capabilities [Stromswold et al. 2003]. These four mature, alternative neutron detection technologies have been identified as being currently, commercially available replacements for <sup>3</sup>He and were tested for suitability in RPM systems [Kouzes et al. 2010a]. For each system, the neutron efficiency and gamma ray sensitivity were tested.

The technologies tested included one to four BF<sub>3</sub> tubes (manufactured by LND, Oceanside, NY) filled to 107 kPa placed into an RPM moderator [Ely et al. 2009a; Kouzes et al. 2009d]. General Electric Reuter Stokes (Twinsburg, OH) provided two prototype multi-tube boron-lined detector systems that were tested [Lintereur et al. 2009a]. A Nucsafes backpack lithium loaded glass fiber detector was tested [Ely et al. 2009b]. Two versions of a coated wavelength-shifting plastic fiber system from Innovative American technology (IAT, Coconut Creek, FL) were tested [Lintereur et al. 2009b; Kouzes 2010b].

### 3. Overview of testing results

#### *BF<sub>3</sub> Tubes*

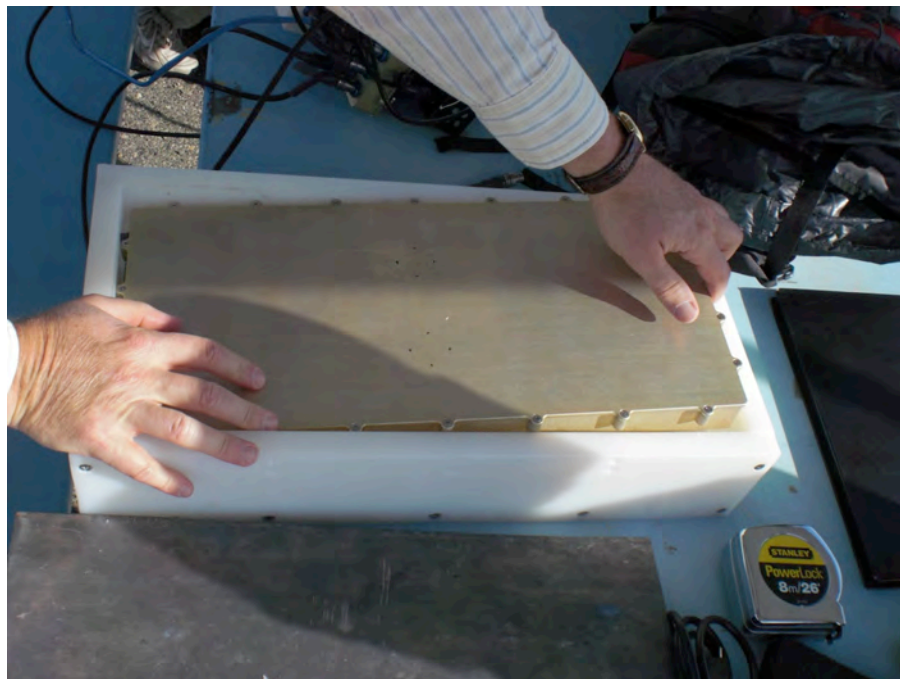
One to four BF<sub>3</sub> tubes were tested in a standard RPM polyethylene moderator box. These results indicate that two BF<sub>3</sub> tubes at 107 kPa can (marginally) meet the required neutron detection efficiency as specified by Stromswold et al. [2003], but three tubes are recommended. This requires more space than currently occupied by <sup>3</sup>He tubes, but three tubes still fit into the existing moderator assembly of RPMs. The BF<sub>3</sub> tubes require a substantially higher operating voltage, about 2200 V, compared to about 900 V for <sup>3</sup>He tubes. Data were taken with a large radiation source to determine the gamma sensitivity of the neutron detectors. The electronics discriminator level for the BF<sub>3</sub> tubes could be set to eliminate the gamma pile up even at exposure rates as high as 100 mR/hr without significantly affecting the neutron detection efficiency. The gamma ray rejection factor for the three-tube BF<sub>3</sub> configuration is  $6 \times 10^{-9}$ . Boron trifluoride is a toxic gas with more transportation restrictions than for <sup>3</sup>He.

#### *Boron-Lined Detector*

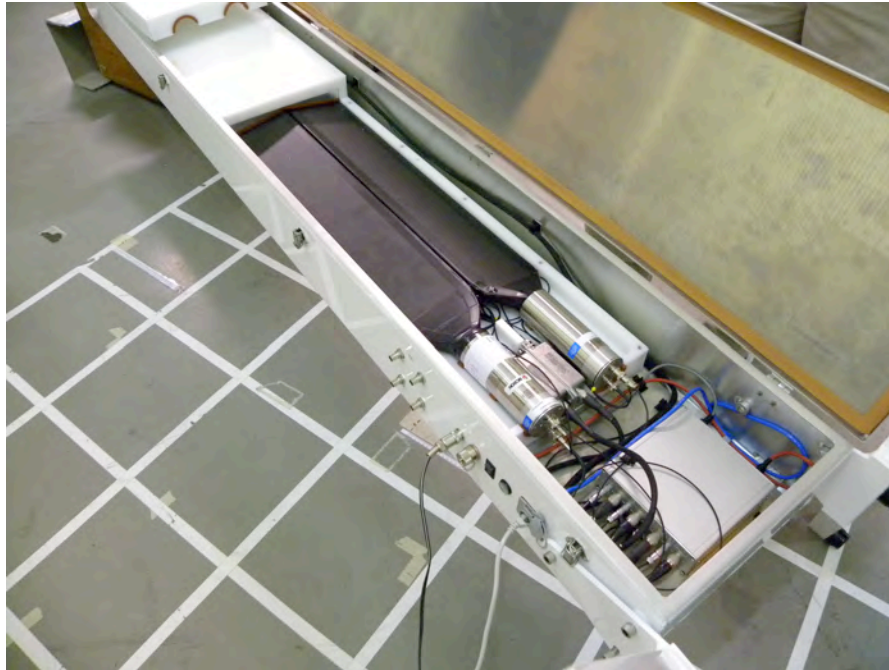
Figure 2 shows the test configuration for the boron-lined system (white box in the background) for neutron detection efficiency in the presence of a large <sup>60</sup>Co gamma ray source. The absolute efficiency for this system was found to be 3.01(18) cps/ng of <sup>252</sup>Cf, which is 24% above the required value (2.5 cps/ng). The intrinsic efficiency for gamma rays detected as neutrons was  $6 \times 10^{-9}$  at 10 mR/hr, and the system met the requirement for detection of neutrons in a gamma ray field.



**Figure 2: Boron-lined detector (in white, rectangular box resting on two ladders) being tested with gamma ray and neutron sources.**



**Figure 3: View of the NuSAFE detector being placed in the moderator box.**



**Figure 4: Internal view showing half of the full-scale IAT detector and electronics.**

#### *Lithium-loaded Glass Detector*

Tests were performed for the absolute neutron efficiency and gamma sensitivity of the lithium loaded glass fiber detectors from NuSAFE (Figure 3). The potential neutron efficiency of the glass-fiber system, scaled in area to the size required for an RPM, had a value of 1.7(6) cps/ng, which is below the required value of 2.5 cps/ng. The detector system tested had intrinsic gamma ray efficiencies on the order of  $10^{-6}$ . However, the system was unable to maintain its neutron detection efficiency in the presence of a large gamma ray source.

#### *Coated Plastic Fiber Detector*

Figure 4 shows two of the neutron detection paddles exposed in the full-scale IAT plastic fiber system. The net efficiency of the system was found to be 2.0(1) cps/ng of  $^{252}\text{Cf}$  with a threshold that provided adequate gamma ray rejection at 10 mR/h. This value falls short of the specified value of 2.5 cps/ng. The IAT detector tested had intrinsic gamma ray efficiency on the order of  $10^{-7}$  for  $^{60}\text{Co}$  exposure rates up to 10 mR/hr and thus meets the gamma ray rejection requirement. The IAT detector was able to maintain its neutron detection efficiency in the presence of a gamma ray exposure rate of 10 mR/hr.

## **4. Conclusions**

Four commercially available detectors have been tested as possible alternative neutron detection technologies for use in RPM systems for national security applications. These technologies are: boron trifluoride-filled proportional counters, boron-lined proportional counters, lithium-loaded glass fibers, and coated wavelength-shifting plastic fibers.

Table 1 summarizes the results of testing the various neutron-detection technologies, where green means it meets the requirement and yellow means it does not. Although this testing indicates that

two of the alternative technologies can meet the basic neutron detection requirements, and the coated fibers technology also appears promising, additional considerations should be given to the selection of a technology for further development and integration into RPMs. The BF<sub>3</sub> tubes are attractive for their neutron efficiency, but the gas is toxic, potentially causing problems in shipping, installation, and long-term use, and the tubes have a significantly higher operating voltage. The boron-lined system has good neutron detection efficiency and gamma ray insensitivity. The coated wavelength-shifting plastic fibers show promise, but do not yet meet the sensitivity requirements. The scintillating glass fibers currently do not meet the sensitivity requirements. Both fiber vendors are investigating improvements to their technologies. The cost of alternative neutron detectors is significantly greater than historical costs for <sup>3</sup>He, but the actual cost remains to be determined when the technologies progress into large-quantity production.

Technology	Efficiency	$\gamma$ - discrim.	Comments
<sup>3</sup> He			<b>Gold standard</b>
BF <sub>3</sub>			<b>Toxic, high operating voltage, more space</b>
Boron-lined			<b>Meets requirements</b>
Coated Plastic Fiber			<b>Issues with neutron efficiency</b>
Glass Fiber			<b>Issues with neutron and gamma ray efficiency</b>

**Table 1: Summary of test results where green is passing and yellow is failing.**

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