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AUTHOR(S) Paul E. Fehlau, N-2
Henry F. Atwater, N-2
Kenneth L. Coop, N-2

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Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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NEUTRON-CHAMBER DETECTORS AND APPLICATIONS*

Paul E. Fehlau, Henry F. Atwater, and Kenneth L. Coop

Group N-2, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

ABSTRACT

Detector applications in Nuclear Safeguards and Waste Management have included measuring neutrons from fission and (alpha,n) reactions with well-moderated neutron proportional counters, often embedded in a slab of polyethylene. Other less-moderated geometries are useful for detecting both bare and moderated fission-source neutrons with good efficiency. The neutron chamber is an undermoderated detector design comprising a large, hollow, polyethylene-walled chamber containing one or more proportional counters. Neutron-chamber detectors are relatively inexpensive; can have large apertures, usually through a thin chamber wall; and offer very good detection efficiency per dollar. For 10% of the cost, a neutron-chamber detector may give one-half the total detection efficiency of a slab detector for detecting neutrons from a distant, bare source. A nuclear safeguards pedestrian monitor detects concealed plutonium using two such chamber detectors to form a walk-through portal. Neutron-chamber detectors have also been used for monitoring vehicles and for assaying large crates of transuranic waste. Our Monte Carlo calculations for a new application (monitoring low-density waste for concealed plutonium) illustrate the advantages of the hollow-chamber design for detecting moderated fission sources.

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1. Introduction

The neutron emission of nuclear materials is a useful attribute for nuclear safeguards monitoring and for waste-management assay applications. Neutron backgrounds are usually low, and neutrons emitted by nuclear materials can often penetrate containers to give a signature related to the contained mass. Moderated proportional counters filled with ^3He or BF_3 gas have been used as neutron detectors for safeguards and waste-assay purposes. Conventional assay instrument designs embed the proportional counters in solid polyethylene (slab detector) to moderate incident neutrons from spontaneous fission and (α, n) reactions. Moderators can be designed to obtain a desired response to different energy neutrons for a particular application [1]. For special-nuclear-material (SNM) monitoring and some waste-assay measurements, the desired response is good sensitivity for detecting neutrons from either bare or moderated sources.

2. Evolution of Detector Designs

Neutron detector designs that are sensitive to both bare and moderated neutron sources stem from the U. S. Department of Energy's Nuclear Emergency Search Team (NEST) program. NEST experiments comparing slab detectors to other designs led to using bare proportional counters (facing the neutron source) backed with an albedo layer of polyethylene [2]. Monte Carlo calculations later optimized this detector design with a 5.08-cm-thick polyethylene albedo layer that was scalloped to surround the proportional counters to one-half

their diameter. This concept soon found application for nuclear safeguards monitoring.

A polyethylene-walled tunnel lined with many ^3He proportional counters was conceived [3], as a detector that would more uniformly monitor large vehicles for contained nuclear material than was possible with gamma-ray detectors. This technology was later evaluated for pedestrian monitoring in a polyethylene-walled booth [4], which had neutron proportional counters located in its ceiling and floor. The concept was later made modular and portable for another application: assay of large transuranic-waste crates. The modular detector units [5] were hollow, polyethylene chambers containing several ^3He proportional counters (Fig. 1); the detector units were stacked around crated waste to assay the neutron-emitting contents. These modular, neutron-chamber detector units were easily evaluated for other applications.

One possible application for the units was to monitor vehicles for concealed plutonium. Evaluation showed that the modules were effective for detecting both bare and shielded plutonium being transported in vehicles. A prototype neutron-detection-based monitor [6] developed for monitoring vehicles used chambers having 5-cm-thick walls, except for the 1.3-cm-thick, neutron-entrance wall. The entrance-wall thickness was chosen to optimize detection of moderately shielded (5-15 cm of polyethylene) fission neutron sources. The hollow chamber (112 cm high, 254 cm wide, and 5 cm deep) contained four, evenly spaced, 2-Atm pressure, ^3He proportional counters, each 5 cm in diameter and having an active length of 183 cm. Two similar but taller and narrower neutron-chamber detectors (180 cm high and 60 cm wide), each containing

a single proportional counter, were later used to form the portal (Fig. 2) for a prototype walk-through pedestrian monitor [7] that is now commercially available.

3. Detector Comparisons

A major difference between slab and neutron-chamber detectors is that slab detectors generally use more proportional counters for the same detector aperture. But even with fewer counters, the neutron-chamber detectors can still achieve relatively good intrinsic detection efficiency. To make a comparison, one slab detector [8] and one neutron-chamber detector [9] use the same active volume of ^3He , a major contributor to detector cost, and the same moderator thicknesses, 1.3 cm (front) and 5 cm (back). Their other parameters, shown in Table 1, are quite different. Although source distances and ground effects are not necessarily identical, it is safe to say that the neutron chamber has almost half the intrinsic efficiency (counts per incident neutron) of the slab detector. At the same time, it has 7.8 times the active detector area. As a result, it counts 3.5 times as many neutrons from a distant source at a lower cost. The lower gas pressure halves the ^3He cost, and fewer proportional counters to fabricate offsets the increased cost of polyethylene in the larger detector.

Another comparison (Fig. 3) uses detector count rates for a ^{252}Cf source being scanned, in contact, across the width (perpendicular to the proportional-counter axes) at the center of two nearly equal-size detectors, 200 cm long and 70 cm wide. One detector is a slab detector with a solid moderator 10 cm thick and having a central hole for the proportional counter. The other is a neutron chamber with walls 5 cm

and 1.3 cm thick and a chamber void, 5 cm thick and 60 cm wide. Its proportional counter also is centrally located. Each scan width is over the middle 60 cm of the detector's 70-cm width. The qualitative difference between the two scans is that the embedded proportional counter effectively detects neutrons incident within about 5 cm of the counter wall; whereas the chamber proportional counter detects incident neutrons across the entire chamber width. At a greater source distance (1 m), the total detection efficiency for a bare ^{252}Cf source is 0.22% for the slab detector and 0.26% for the chamber detector. The total detection efficiency for the same source in 5-cm-thick polyethylene is decreased to 0.15% for the slab detector and increased to 0.28% for the chamber detector. To further study the differences, we used Monte Carlo calculations of candidate detectors proposed for a low-density waste monitor that would be used to detect plutonium.

4. Low-Density Waste Monitor Detectors

Figure 4 shows the source-detector geometry for one of our Monte Carlo calculations. The neutron-chamber detector, containing two ^3He proportional counters, is one of four that form the top, bottom, and side walls of a detector array, which surrounds waste packages in a proposed, low-density waste monitor. The front and back walls of the monitor are solid-polyethylene entry and exit doors. Waste packages are automatically moved through the monitor by conveyor. To compare the neutronics of detection for candidate designs, we calculated two versions of the detector and monitor: one using the neutron-chamber design shown and the other using a similar slab design with solid moderator. Our results are listed in Table 2. Although an individual

chamber detector is less effective (by 16%) than a slab for detecting bare sources, an individual chamber is more effective than a slab when placed on concrete (by 4%) or when it is part of a complete waste monitor (by 40%). A chamber detector is also more effective than a slab, both as an individual detector (by 23%) and in a monitor (by 95%), when the source is moderated with polyethylene, 5 cm thick. Concrete offers no improvement when the source is moderated because low-energy neutrons are more likely to be absorbed than scattered in concrete.

As part of the Monte Carlo calculations, we compared the time histories of neutrons between emission by bare and moderated sources and detection in each detector design. Figure 5 is for a bare source, and Fig. 6 is for a moderated source. In each case, the response is initially greater in the slab design, but as time progresses, the neutron dieaway in the slab is more rapid. For the bare source, the integrated response in the slab is also greater than for the chamber design, but for the moderated source it is less. The results suggest that the increased detection efficiency in the neutron-chamber design results from the freedom of low-energy neutrons to repeatedly scatter in a chamber or monitor enclosure until some are detected. Correspondingly, in the slab design, low-energy neutrons are more quickly absorbed in the moderator before they can be scattered near a proportional counter and be detected.

5. Summary

Monitors that use neutron-chamber detectors are not easily defeated by moderately thick, neutron-shielding materials. When used in applications that enclose neutron-emitting items within moderating walls or detector assemblies, there is a great advantage to the neutron-chamber design. Even for individual detectors, such as those used in vehicle and pedestrian monitors, the increased sensitivity of neutron-chamber detectors for detecting moderated sources overshadows their slightly reduced bare-source sensitivity. Neutron-chamber detectors seem to be the best choice for applications that require economical detection of both bare and moderated sources.

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Figure captions

Fig. 1. The first modular, neutron-chamber detectors had front and back chambers with interior sub-divisions. In this illustration, the side and front walls have been removed to show the interior details.

Fig. 2. A neutron pedestrian portal is formed by two neutron-chamber detectors, each containing a single ^3He proportional counter.

Fig. 3. The better response uniformity of neutron-chamber detectors is illustrated here by scanning a fission-neutron source across slab and chamber detectors. The source is moved, in contact, across the active width of each detector.

Fig. 4. We used Monte Carlo calculations to compare slab and neutron-chamber detector designs for detecting a plutonium fission source, S_n , located 30 cm away. We calculated the response for three detectors: one in free space; one resting on concrete; and one installed in a waste monitor.

Fig. 5. The time response for neutrons from a bare plutonium source detected in neutron-chamber (solid line) and slab (dashed line) detectors.

Fig. 6. The time response for neutrons from a moderated (5 cm of polyethylene) plutonium source detected in neutron-chamber (solid line) and slab (dashed line) detectors.

Table 1

Parameters for Two Neutron Detectors with Equal ^3He Volume

Detector	Number of Proportional	^3He Pressure	Area	Intrinsic Detection
<u>Type</u>	<u>Counters</u>	<u>(A_s)</u>	<u>(cm^2)</u>	<u>Efficiency^a</u>
Slab	8	4	3800	.093
Neutron chamber	4	2	29700	.042

^aFor ^{252}Cf fission neutrons.

Table 2

Relative Response^a to Different Source Conditions of Two Detector
 Designs, Individually and in a Waste Monitor

<u>Detector Type</u>	<u>Bare Source</u>	<u>Bare Source with Concrete Reflector</u>	<u>Moderated Source (5 cm thick)</u>
Individual			
Slab	1	1.08	0.94
Neutron chamber	0.84	1.04	1.23
Waste monitor			
Slab	1	--	1.19
Neutron chamber	1.40	--	1.95

^aResponse normalized to 1.0% total efficiency for the individual slab
 design and 6.21% total efficiency for the slab waste monitor.

Fig 2

Fig 3

Fig 4

Fig 5

Fig 6