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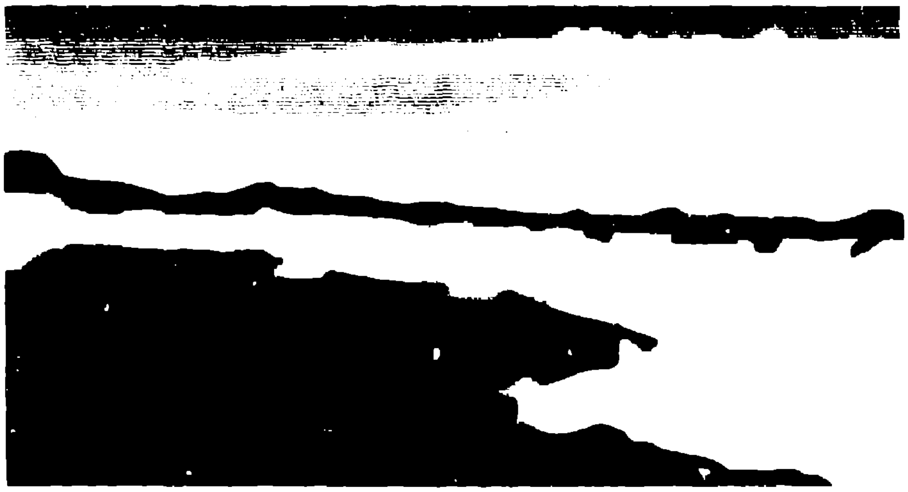

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Integrated Neutron/Gamma-Ray Portal Monitors For Nuclear Safeguards

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Abstract

Radiation monitoring is one nuclear-safeguards measure used to protect against the theft of special nuclear materials (SNM) by pedestrians departing from SNM access areas. The integrated neutron/gamma-ray portal monitor is an ideal radiation monitor for the task when the SNM is plutonium. It achieves high sensitivity for detecting both bare and shielded plutonium by combining two types of radiation detector. One type is a neutron-chamber detector, comprising a large, hollow, neutron moderator that contains a single thermal-neutron proportional counter. The entrance wall of each chamber is thin to admit slow neutrons from plutonium contained in a moderating shield, while the other walls are thick to moderate fast neutrons from bare or lead-shielded plutonium so that they can be detected. The other type of detector is a plastic scintillator that is primarily for detecting gamma rays from small amounts of unshielded plutonium. The two types of detector are easily integrated by making scintillators part of the thick back wall of each neutron chamber or by inserting them into each chamber void. We compared the influence of the two methods of integration on detecting neutrons and gamma rays, and we examined the effectiveness of other design factors and the methods for signal detection as well.

I. INTRODUCTION

Portal monitors for special nuclear materials (SNM) are used in nuclear safeguards to sense the presence of SNM by detecting their emitted gamma rays or neutrons (or both). Examples of SNM are plutonium and highly enriched uranium. Neutron detection is most important for detecting shielded plutonium that is inside a gamma-ray shielding material, such as lead, that is transparent to fast, spontaneous fission neutrons emitted by plutonium. Plastic scintillation detectors offer high sensitivity for fast neutrons, as well as gamma rays. However, another type of detector, the neutron-chamber detector [1], can detect neutrons over a broad range of energies extending from fast neutrons down to the slow neutrons that may emerge from neutron-shielding materials. Its broad sensitivity range makes the neutron chamber detector ideal for detecting plutonium inside gamma-ray and/or neutron shields. The neutron-chamber detectors are also readily combined with plastic scintillators to obtain the very high sensitivity to small amounts of unshielded SNM that is expected of conventional SNM portal monitors.

Pedestrian portal monitors are usually formed by placing a radiation detector or array of detectors on each side of a pedestrian's path to form a portal, and monitoring takes place as a pedestrian walks through. Early neutron portal monitors used large arrays of moderated neutron proportional counters for neutron detection, which was very effective but extremely expensive in comparison to using plastic scintillators for neutron detection. The neutron-chamber detector design greatly reduced the required number of proportional counters, making neutron portal monitors affordable and commercially available. However, because these monitors lacked sensitivity for gamma rays, they could not detect uranium or very small amounts of plutonium. To overcome that problem, neutron portals were first used with a plastic-scintillator portal so that both shielded plutonium and small amounts of unshielded SNM could be detected as pedestrians passed through the two types of monitor. The obvious next step was to reduce the space required and the duplicate costs by combining the two types of monitor. We accomplished this by placing plastic scintillators into slots milled into the thick back walls of two neutron-chamber detectors, as illustrated in Fig. 1. After we evaluated the resulting prototype of the integrated portal and reported the results, TSA Systems, Ltd.,[2] integrated one of their commercial neutron portal monitors by placing plastic scintillators directly into the hollow space of each neutron chamber detector (Fig. 2). To see how well they had achieved our goal TSA Systems loaned us the monitor, designated model NGM-900, and we evaluated it as well.

II. DETECTING NEUTRONS

Plastic scintillation detectors detect fast neutrons through collisions of the neutrons with protons in the scintillator and the subsequent conversion of the proton recoil energy into light and electrical pulses. However, if fast neutrons are slowed by collisions in a moderating material, they may be rendered undetectable in a plastic scintillator. On the other hand, neutron proportional counters are primarily slow neutron detectors, but they can be made to detect neutrons over a broad energy range by placing them in a moderator that can both slow down fast neutrons and admit slow neutrons for detection. The neutron-chamber detector achieves this with a hollow, box-shaped, polyethylene

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[1] This work was supported by the US Department of Energy, Office of Safeguards and Security

[2] TSA Systems, Ltd., 1820 Delaware Pl., Longmont, CO 80501

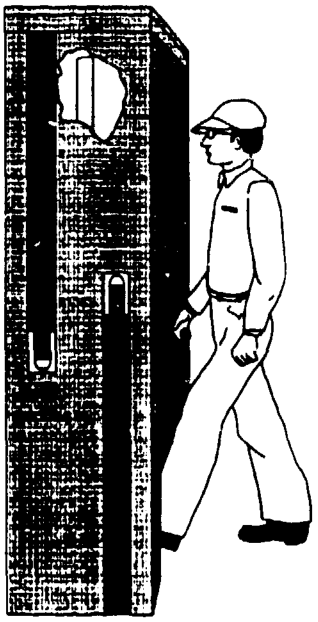

Fig. 1. The LANL-prototype integrated portal monitor replaces part of each neutron chamber's thick back wall with plastic scintillators that are oriented for best coverage from floor to ceiling.

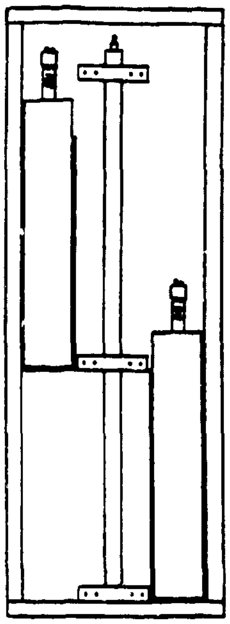

Fig. 2. The TSA Systems NGM-900 has plastic scintillators inserted into the hollow space in each neutron chamber, filling part of it. The scintillator active areas are positioned in the lower three-quarters of the portal height.

moderator that has thick back and side walls for moderating fast neutrons and a thin front wall for admitting neutrons. A neutron proportional counter is centrally located in the hollow portion of the box, and both fast neutrons that enter and have been moderated in the thick walls and entering slow neutrons have a chance to enter and rebound in the hollow space, where they may encounter the proportional counter and be detected.

Another important consideration in detecting neutrons is that signals and background counting rates in neutron portals are relatively small. Whereas background count rates in a plastic scintillator monitor may be thousands of counts per second, neutron backgrounds are more likely to range from a few to a few tens of counts per second. Hence, neutron counting statistics are Poisson distributed in a range that cannot be approximated with a normal (Gaussian) distribution. The alarm thresholds chosen to achieve a particular nuisance-alarm[3] rate in a neutron portal must be derived for each background value; whereas, in gamma-ray portals, a fixed multiple of the standard deviation of a background count achieves that goal. As a result, an integrated portal must use separate decision logic for each type of detector. In our case, the controllers use a look-up table in the firmware for the low count-rate alarm thresholds, and they make a transition to using a multiple of the standard deviation at higher count rates.

III. DESIGN COMPARISONS

The mechanical design of the neutron-chamber detectors in both the Los Alamos National Laboratory (LANL) prototype and the NGM-900 monitor is identical except for their height: the NGM-900 portal ceiling is 5 cm higher than the LANL prototype[4] ceiling. Another difference between the portals is the method used to integrate the plastic scintillators. To elicit detector response differences caused by the detector design or method of detector integration, we made stationary and moving-source measurements along the detectors and through the portals with bare and moderated plutonium sources.

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[3] A nuisance alarm is a monitoring alarm most likely caused by statistical variation in the measurement process [2]. Other causes could be background intensity variation or equipment malfunction. Nuisance alarms are best avoided; however, they are statistically related to the source detection sensitivity, so they must be accepted at some rate.

[4] Nominal portal dimensions are 203 cm high, 66 cm wide, and 71 cm deep. The portal ceiling and chamber walls are 5 cm thick, except for the 1.3-cm-thick entrance wall. The chamber hollow space is 5 cm deep and contains one ^{3}He proportional counter that is 5 cm in diam and has a 183-cm active length and 2 A_g of fill pressure.

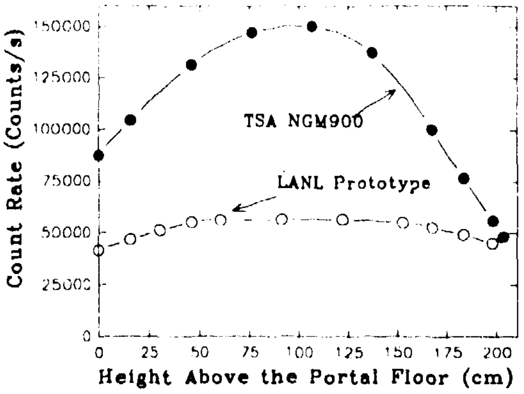

Fig. 3. Vertical scanning results for gamma rays. The least-sensitive regions are the foot region for the LANL portal and head region for the NGM-900.

A. *Gamma-Ray Detector Design*

The LANL plastic scintillators in the LANL prototype are inserted into milled slots in the back polyethylene wall of each neutron chamber. The detectors are oriented to place active detector material as close as possible to the floor and ceiling, as shown in Fig. 1. This orientation places the inactive light pipes and photomultipliers at mid-height, where there usually is excess sensitivity. On the other hand, the NGM-900 detectors are placed as shown in Fig 2. Here, the lower detectors have their active ends at floor level, but the upper ones are positioned very low and are not inverted. Hence, no active detector material is near the portal ceiling, and the gamma-ray sensitivity is lowest in that region. Figure 3 illustrates the monitors' response to scanning a plutonium test source from floor to ceiling. The abrupt rise and extreme drop off in the NGM-900 curve could be reduced by inverting the upper detectors and moving them upward. Other factors that contribute to the large difference in gamma-ray count rate in Fig. 3 are that the NGM scintillators are about 20% larger, and, by being located in the chamber hollow space, they are closer to the source. However, note that the least-sensitive regions, the foot region for the LANL portal and head region for the NGM, have almost identical source count rates. Hence, in the least-sensitive regions, where source testing would take place, the NGM-900 does not benefit from its potential advantages.

B. *Neutron Detector Design*

The plastic scintillator placement also influences the neutron-chamber detector response. The neutron responses of the two monitors to a plutonium test source scanned along a horizontal line through their (horizontal and vertical) center points (Fig. 4) shows the LANL prototype response to be the larger. The area under the NGM-900 curve is only 84% of the LANL prototype area, perhaps because the scintillation detectors in the hollow space absorb neutrons that would otherwise be free to migrate to the proportional counter.

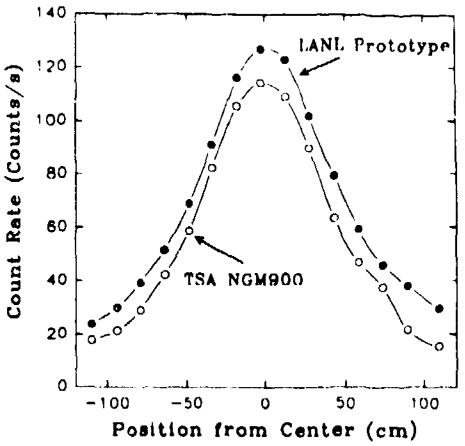

Fig. 4. The neutron response in the two monitors is measured by placing a plutonium test source at intervals along the portal horizontal centerline at mid-height. Each point represents a 60-s average count rate.

The vertical scans through each portal center point (Fig. 5) show a large decrease in response at the top of the NGM-900 portal, its least-sensitive neutron region, and the foot region is the least sensitive in the LANL prototype. There are three reasons for the decrease in sensitivity at the top of the NGM-900 portal: (1) The NGM-900 neutron chambers are 5 cm taller than the LANL prototype chambers, but their proportional counters are not proportionately longer. (2) The NGM-900 proportional counters are actually shorter (by ~ 5 cm) than they should be, and their total length is 183 cm, whereas they should have an active length of 183 cm. (3) The portal ceiling is not 5-cm-thick solid polyethylene, but has been milled out to provide space for cabling and access. Hence, the ceiling is less effective as a neutron reflector, and it is located far from the active regions of the proportional counters.

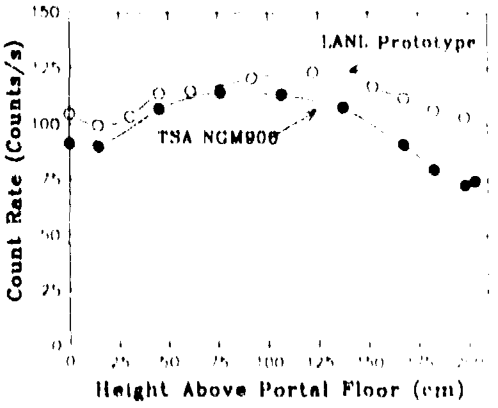

Fig. 5. The vertical source profiles show the least sensitive regions near the floor in the LANL prototype and at the very top of the NGM-900.

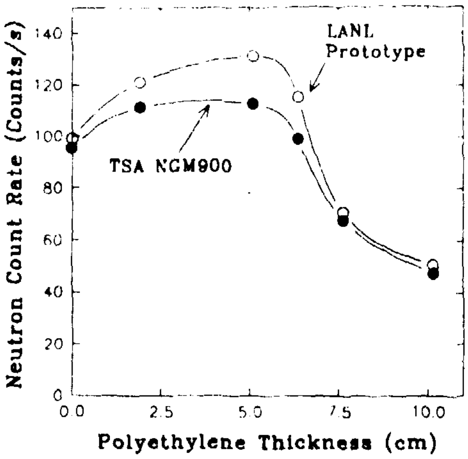

Fig. 6. Moderation by polyethylene around a plutonium source enhances detection of the source over a 6-cm-thick range. Measurements were made near the portal thresholds at center height.

Besides influencing the detection of neutrons from bare plutonium, the neutron detector design also affects the detection of slow neutrons from plutonium inside moderating shields, as illustrated in Fig. 6. Moderate thicknesses of polyethylene shielding around a plutonium source provide additional neutron moderation that makes the neutrons more detectable by a neutron-chamber detector, and the count rates increase in both monitors. At the maximum count rate, at 5-cm-thick polyethylene, the LANL prototype response increases by about 30% and the NGM by a lesser amount, 20%. Thicker polyethylene, more than 6 cm thick, provides overmoderation, and the detector responses decrease and converge. The decreased response of the NGM-900 in the less than 5-cm-thick range also may reflect overmoderation caused by the presence of the plastic scintillators in the chamber hollow space.

IV. PERFORMANCE COMPARISONS

A. Nuisance-Alarm Rates

Detection sensitivity and nuisance-alarm rates are directly related, so any performance comparison must be done as close as possible to the same nuisance-alarm rate. We chose to use a total nuisance-alarm rate of 1 nuisance alarm per 1000 walk-through passages for our comparisons. For the LANL prototype with one neutron and one gamma-ray signal channel, the actual channel rates that we measured were 1 in 3200 passages and 1 in 1500 passages, respectively, for 1 in 1000 passages overall. The different rates in the two channels are a result of using the same control units and monitoring parameters for two channels that operate at greatly different counting rates. TSA Systems supplied detection logic that monitored individual neutron and gamma-ray detectors in 10 combinations, and we calculated alarm thresholds for each that gave them an overall measured rate of 1 per 1056 passages.

B. Walk-Through Testing

We tested both portals separately for gamma-ray and neutron sensitivity by deactivating one type of detector. The significant parameters used in the detection logic for each monitor were as close to the same as we could make them. Nominal backgrounds were 16 counts/s or slightly below for the NGM-900 and 16 counts/s or slightly above for the LANL prototype, and the detection logic updated the stored background counts at 12-2 intervals. Approximately 0.4 s of stored data were used to begin monitoring during each passage, and 0.2-s monitoring counts were analyzed using a five-interval moving average [3] or nominal sequential probability ratio [3] sequence. Individuals passing through the portals during testing transported the source in a holder that allowed it to pass through the least sensitive region. Figure 7 illustrates the source passing through the NGM-900, which had an overhead least-sensitive region. We used different source sizes to identify, with 95% confidence, an SNM mass that could be detected with 0.50 or greater probability. The results are listed in Table I. The less effective neutron detectors in the NGM result in it needing a 30% larger test source to achieve a 0.50 detection probability with 95% confidence. Similarly, the less effective gamma-ray detector arrangement in the NGM prevented it from

Fig. 7. The person is simulating a test passage through the NGM-900.

outperforming the LANL prototype even though the NGM gamma-ray detectors were larger and located closer to the test sources.

Table I. Detection Results[a]				
Monitor	Neutron source		Gamma-ray source	
	Mass (g)	Passages	Mass (g)	Passages
NGM-900	52	36/40	0.5	31/45
LANL	40	32/40	0.5	40/40
[a] At a nuisance-alarm rate of 1 per 1000 passages.				

V. SUMMARY

The results show reasonable performance for both monitors. The neutron performance of the NGM-900 can be improved by removing the scintillators from the hollow space and placing them in the thick wall at the back of each neutron-chamber detector. Using proportional counters with active regions that are 10 cm longer will also help. Any decrease in the sensitivity of the least sensitive gamma-ray region can be made up by arranging the scintillators so that their active portions extend to the floor and ceiling, leaving the inactive portions in the center where there is now excess sensitivity.

VI. ACKNOWLEDGMENTS

Thanks to TSA Systems for lending us the monitor. The many members of the Advanced Nuclear Technology Group who participated in walk-through testing are also much appreciated.

VII. REFERENCES

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