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A Survey of Special Nuclear Material Vehicle Monitors for Domestic and International Safeguards

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ABSTRACT

Special nuclear materials vehicle monitors, including gateside vehicle monitors, hand-held personnel-vehicle monitors, and a new tunnel monitor concept for very large vehicles, are discussed. The results of a comparison of effectiveness of monitors for domestic application are presented. The results of calculations and small scale prototype measurements are given for a tunnel-like neutron monitor for monitoring at the perimeter of an enrichment plant subject to International Safeguards.

I. INTRODUCTION

Group Q-2 of the Los Alamos Scientific Laboratory (LASL) has as its primary function the development and utilization of instrumentation for the detection and identification of special nuclear materials (SNM) in application to problems in domestic and international nuclear fuel cycle safeguards. In connection with our work in instrumentation for domestic perimeter safeguards, we were asked by the Department of Energy (DOE) Office of Safeguards and Security (SS) to investigate the effectiveness of SNM vehicle monitors. At the same time, a parallel effort dealing with instrumentation that might be applicable to perimeter safeguards applied by the International Atomic Energy Agency (IAEA) at a centrifuge enrichment plant was undertaken and the need for monitoring very large vehicles for undeclared feed material arose. As a result, we are investigating, through calculation and measurement on mock up and full scale working models, the effectiveness and performance of a number of detector systems for bad vehicle monitoring.

II. MONITOR TYPES

SNM vehicle monitoring began at the DOE Rocky Flats Plant with a vehicular gate monitor[1] that resembles a personnel SNM doorway monitor except that it was installed at a two lane vehicle gate. The specifications for this monitor have been used by others to procure vehicle monitors.

In our studies we have used two monitors in a gateside geometry. One is a system sold by Tom Scurry Associates that follows the specifications mentioned above using four 5.08-cm diam by 2.54-cm thick NaI scintillators, two on each side of the gate vertically separated by 1.6 m. The second gateside monitor was constructed from components of a LASL-personnel doorway monitor[2] that utilized plastic scintillators. This unit had four 5.08-cm diam by 91-cm long solid organic scintillators (NE-110), with two on each side of the gate. These gateside monitors were used to carry out static count rate measurements on a source-containing vehicle at gate widths up to 7.3 m separation between detectors.

In order to minimize the separation between the detectors and the vehicle without obstructing traffic, we have constructed a roadbed gate monitor as shown in Fig. 1. This roadbed monitor utilizes a pit to house its array of eight NaI detectors that are optimized for the detection of shielded plutonium.[3] Aluminum diamond plate and grating are used for vehicle support to minimize absorption of gamma radiation, and moisture problems are minimized through a gravity drain in the pit and waterproof encapsulation of the detectors.[4] Signal conditioning electronics for the monitor located in the guard station, as well as controllers for current loops located in the roadbed, are used for occupancy and traffic direction data. A microwave electronic vehicle identification system[5] also has its electronics housed in the guard station. The identification data, along with all of the detector counting data, is transmitted by overhead lines to an adjoining building and is input to a Data General MicroNOVA minicomputer

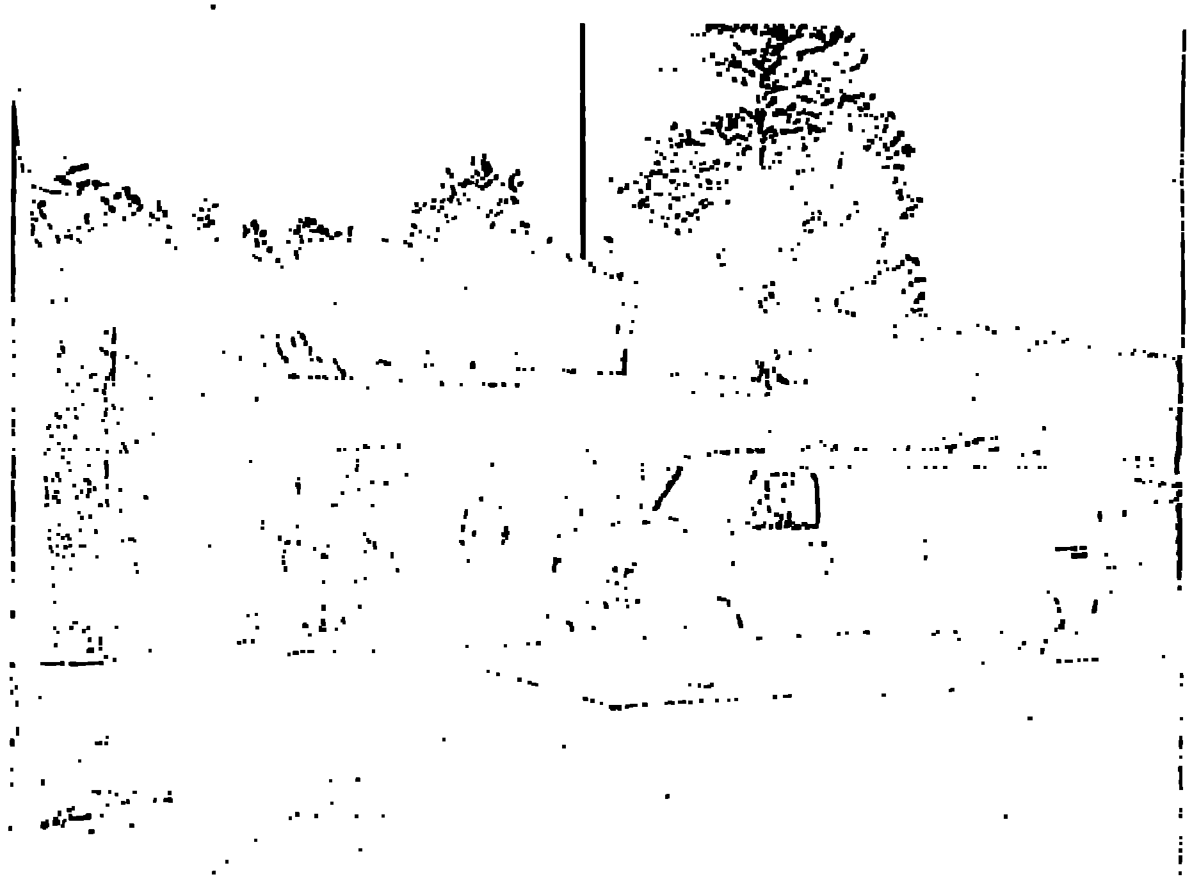

Fig. 1. LASL Q-2 SNM Vehicle Roadbed Monitor.

serving all logic and control functions for the monitor. Also on top of the adjoining building is a background monitor used to detect site-produced background conditions that interfer with monitor operation. We used this monitor for static measurements on the same source-containing vehicle, the one-ton Ford van, as we used in the gateside monitor. The roadbed monitor detector pit also contains an array of 48 BF_3 proportional counters[4] used to make neutron measurements for comparative purposes.

A third vehicle monitor that has been in use at LASL and other DOE installations is the hand-held monitor.[6] This monitor was developed at LASL Q-2 to provide an instrument capable of detecting small changes in gamma radiation count rate without requiring a great deal of operator training and experience. To this end, the package contains logic circuitry in addition to the usual battery-operated power supplies, signal conditioning electronics, and NaI scintillation detectors. Figure 2 shows the hand-held monitors in two forms. The original unit, which we call a personnel-vehicle monitor (PVM), has a logic circuit that calculates an alarm level that is a mean background count plus a selectable fraction of the background. For instance, a commonly used selection is to alarm when the count in a count interval exceeds 1.4 times the mean background. The second instrument, the delta rate monitor (DRM) that is just now being

Fig. 2. The PVM and DRM Hand-Held Monitors.

procured in quantity, utilizes an alarm circuit that adds a switch selectable number to the mean background to obtain the alarm level. In using this instrument the operator varies the switch setting so as to obtain 2-6 alarms per minute from statistical variation. The essential difference between the PVM and DRM is that, in an increasing background, the signal required to alarm the monitor increases directly with the background in the PVM, while in the DRM the increase is not as great. In practice, acceptable performance is achieved at Los Alamos at approximately 3 times normal background for the PVM and at approximately 10 times normal background for the DRM.

The tunnel monitor for large vehicles[7] was designed to meet the need to detect undeclared feed material entering a uranium enrichment plant and it is a neutron detector system that looks for neutrons produced in spontaneous fission of ^{238}U or ^{240}Pu and (α,n) neutrons in UF_6. The tunnel approach shown in Fig. 3 was used to maximize the detector solid angle to achieve the necessary total efficiency to detect a rather low source strength material that could be heavily shielded in a large truck or railway freight car. The overburden shown reduces cosmic ray-produced neutron background and the tunnel has a polyethylene lining that serves to thermalize neutrons originating inside the monitor, trapping them there until detected by ^3He proportional counters mounted on the walls. While the full scale railway car monitor may be too expensive for immediate application, the concept of lining high neutron albedo walls with a few proportional counters to produce a high total efficiency neutron detector has already been applied in a personnel monitor.[8] At LASL we have constructed a small vehicle mockup that has been used for measurements to validate calculations of efficiency and scaling laws.

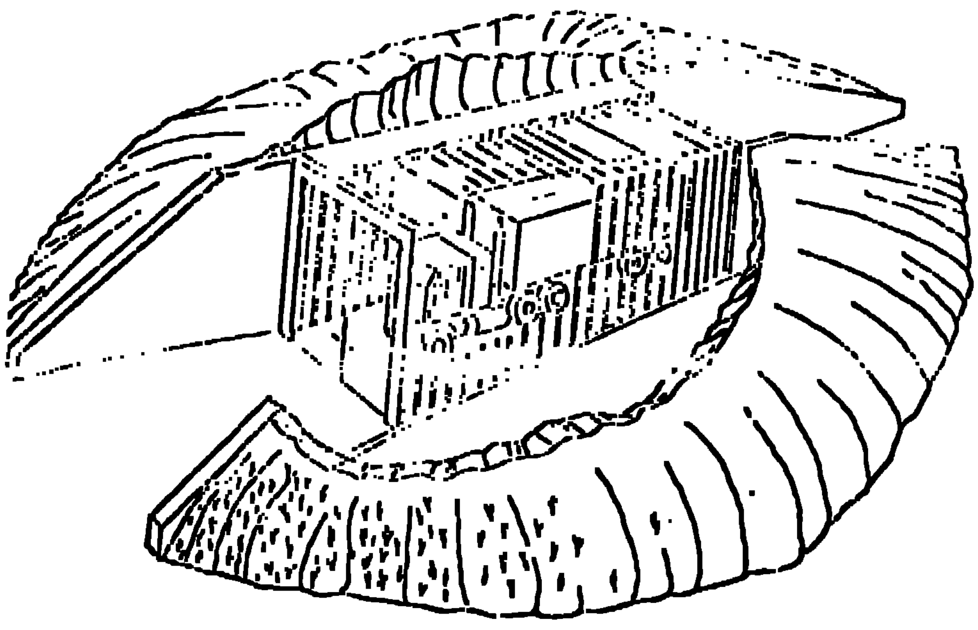

Fig. 3. The Tunnel Neutron Detector.

III. EFFECTIVENESS

In order to make a comparison between domestic monitor types, we have made static measurements using a particular vehicle and source set. It should be emphasized that these are laboratory measurements made under a controlled environment and the equipment is not in routine monitoring use. The sources used for comparison were: 1) a 25-g weapons grade plutonium sample in the form of PuO_2 with low ^{241}Am content; 2) a 1-kg high enriched uranium (HEU) metallic sample. Both sources were in the form of height-equal-to diameter cylinders and the plutonium was doubly encapsulated in thin stainless steel. The measurements were made with the source located in the vehicle at a position that gave minimum response for that particular monitor. The positions were between the front seat backs on the floor with the door posts in line with the detectors for the gateside monitor, and near the roof above an ONAN gasoline motor generator and voltage regulator for the roadbed monitor.

To make a comparison, we have calculated the counting time necessary to just detect the source using as an alarm level the mean background plus four standard deviations. A complicating factor is that the presence of the vehicle suppresses the background count rate to a significant extent. But here we assume that an occupancy monitor is used and a correction is made in the monitoring algorithm to compensate. The results given in Table I indicate that for plutonium monitoring there are only minor differences between gamma monitors, while the neutron system is clearly inferior.

Table I

Monitor	Minimum Time Required to Detect* 25-g Pu as PuO_2	1-kg HEU metal
NaI gateside	6.2 s	20.0 s
Plastic gateside	1.5	7.7
Roadbed – gamma ray	3.5	160.0
Roadbed – neutron	50.0	-----

*Minimum count time required to detect specified sources in stationary vehicle monitors.

This question will be explored further to see if the conclusion holds for more heavily shielded material. The results for HEU are more divergent because the transmission of the softer radiation from uranium is lower through the vehicle materials. Here, the performance of the roadbed monitor clearly suffers from its one-sided nature. A supplementary detector array on a canopy above the vehicle would improve performance. In both cases, the plastic gateside monitor shows better performance. The reason is the gateside monitors' detectors are designed to give equal performance for unshielded sources, while in vehicle monitoring, the softer radiation is attenuated by the vehicle materials and we are looking at shielded materials. The efficiency of the NaI detectors decrease with gamma-ray energy, while the plastic actually increases in the upper end of the energy region used.

We have not included data on the hand-held units because the effectiveness includes the performance of the human operator in addition to the instrument. We do know that the samples can be detected from outside the vehicle without opening doors or hood in a walkaround that takes approximately 20 seconds. We also know that when the doors and hood are opened and the instrument is used to scan the interior, much smaller samples can be detected. However, we need to study the mean performance of the guard force to determine a threshold detectable source and mean search time in order to make an adequate comparison. We intend to do this.

In order to include a comparison of the tunnel monitor, we have studied its characteristics and how they vary with monitor size through Monte Carlo calculations and verifying measurements in a mockup monitor that lacked only the overburden. The calculations show the detector response is relatively independent of source position and the efficiency of the detector scales with the ratio of projected proportional counter area to enclosure surface area. Backgrounds are simply proportional to detector projected area and shielding provided, and we have found that the time to detect at an alarm level as used above is given by the expression:

$$T = 39\,A_t^2/(N^2 A_{pc} S)$$

The parameters are: At - size in m^2, N - neutron source strength in n/s, A_{pc} - projected counter area in m^2, S - a cosmic ray shielding factor, and T - the time to detect in seconds. For a monitor of this type that would contain cars and small trucks up to typical flat-bed truck size, the parameters are: At = 82 m^2, 30 - 0.05 m x 1.83 m proportional counters, S = 1.4 (0.25 m concrete), N = 3 x 10^3 n/s for our plutonium sample, and the resultant count time = 0.007 s. Thus, this monitor is not only superior to the roadbed monitor neutron system, it also surpasses the gamma system performance. On the other hand, the neutron source strength of the HEU is so low, at most 2 n/s for our 1-kg sample, this monitor is not capable of detecting it. For comparison, in its intended use for undeclared feed material, 1 kg of UF_6 feed would require about 40 seconds to detect.

IV. OTHER CONSIDERATIONS

A most important consideration for monitors is cost and we find that the least expensive monitor, the hand-held type at an estimated cost of $1000 each, is quite effective but its use is time consuming when vehicles [illegible] inspection and trained personnel are needed. [illegible] be considered in addition to training costs.

Gateside monitors are more expensive, approximately $20,000 each, installed with occupancy monitor. The roadbed monitor with the vehicle identification package is estimated between $50-80,000 each. These monitors have an advantage in performing their task uniformly and, for the most part, unfailingly without a supervisor present. They also do not require opening the vehicle and can monitor tall vehicles. The roadbed monitor, through its identification system and computer, can do bookkeeping using accumulated results for vehicles that pass frequently and achieve a higher sensitivity. This technique has been described in personnel monitoring by C. N. Henry and

J. C. Pratt[9] and is effective in detecting less than single-pass-detectable quantities of material removed during many passages. This technique will allow us to do a better job of monitoring the vehicles that make frequent use of the gate.

The tunnel monitor is the most expensive and ranges from a cost estimate of $\$1 \times 10^6$ for a railway-semitruck size to $\$2 \times 10^5$ for one that might apply for trucks up to the size we have been considering. For plutonium or undeclared feed monitoring, its cost is balanced by its effectiveness. In domestic safeguards where uranium is usually of interest, it is not applicable.

V. SUMMARY

Our task is not complete, but the emerging conclusions indicate that a good job can be done in vehicle monitoring for plutonium with short count times. For uranium, the times required are longer whether they be count times or the time required for opening vehicle access points for manual search. In our continuing effort we will study the manual search as well as obtain operational experience with the modified monitor in single and multiple-pass monitoring.

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