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An Optimized International Vehicle Monitor
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INTRODUCTION

The security plans for many DOE facilities require the monitoring of pedestrians and vehicles to control the movement of special nuclear material (SNM). Vehicle monitors often provide the outer-most barrier against the theft of SNM. Automatic monitors determine the presence of SNM by comparing the gamma-ray and neutron intensity while occupied, to the continuously updated background radiation level which is measured while the unit is unoccupied. The most important factors in choosing automatic vehicle monitors are sensitivity, cost and in high traffic applications total monitoring time. The two types of automatic vehicle monitors presently in use are the vehicle monitoring station and the drive-through vehicle monitor. These two types have dramatically different cost and sensitivities. The vehicle monitoring station has a worst-case detection sensitivity of 40 g of highly enriched uranium, HEU,¹ and a cost approximately \$180k. This type of monitor is very difficult to install and can only be used in low traffic flow locations. The drive-through vehicle portal has a worst-case detection sensitivity of 1 kg of HEU and a cost approximately \$20k.

The world's political situation has created a pressing need to prevent the diversion of SNM from FSU nuclear facilities and across international borders. Drive-through vehicle monitors would be an effective and practical nuclear material proliferation deterrent if their sensitivity can be improved to a sufficient level. The goal of this project is to evaluate different detector configurations as a means of improving the sensitivity of these instruments to achieve a vehicle monitor that is economical, practical to install, and has adequate sensitivity to be an effective barrier to illegal transportation of SNM.

BACKGROUND

Commercially available vehicle drive-through SNM portals generally consist of two vertical cabinets containing both large plastic scintillators and decision-making electronics. These scintillators continuously measure the gamma ray background intensity and adjust the alarm threshold to maintain a constant nuisance alarm rate. The sensitivity of an SNM vehicle monitors varies for different types of vehicles and depends on the size, spacing, and number of detectors. For an individual detector configuration and vehicle, two of the dominant sensitivity factors are the occupancy background suppression and shielding provided by the components of the vehicle.²

For an average vehicle, the occupancy background suppression can decrease the sensitivity of the monitor by a factor of two. Figure 1 shows a background suppression profile for the half-ton Chevrolet van used for these measurements when it passes through a commercially available SNM vehicle monitor. The normal alarm threshold is four times the square root of the background or 4σ . Thus, as shown in this figure the occupied counting rate must increase by over 8σ before an alarm occurs. This is the

reason why simply moving the pillars closer together does not always increase the sensitivity of the monitor. Therefore, improvements to the monitors sensitivity must not increase the effects of this parameter.

Figure 1. A occupancy background suppression profile for a commercially available vehicle SNM monitor.

Three of the most severe shielding positions are illustrated in Figure 2, between the door posts, above the engine block, and below the engine. The shielding effects of these components of the vehicle on a normal two pillar system are shown in Figure 3. With these sensitivity profiles the minimum detectable mass at each of the these positions can be calculated. The minimum detectable mass varies from 173 g above the engine block to 985 g below the engine block. This variation in sensitivity can be dramatically improved by using a more comprehensive detector configuration.

EXPERIMENTAL PROCEDURE

The variation in sensitivity due the gamma ray shielding of vehicle components can be minimized by placing more detectors around the vehicle. Besides the standard side detectors, we added detectors above and below the vehicle. The detector configuration is shown in Figure 4. The scintillation detectors used were all the standard size 79 cm long, 15 cm wide, and 3.81 cm thick. Each pillar in the configuration contains two detectors. The response of each detector was set-up so that their $S/\sqrt{B}$ values for a standard HEU source were in good agreement. S is the counts per second minus

background, B, achieved when the HEU is placed on each detector. These measurements were performed in a background of 20 to 25 μR . This configuration

Figure 2. A sketch showing the positions where the SNM source was placed in the vehicle

Figure 3. Profiles illustrating the variation in the sensitivity of standard vehicle SNM monitor when the source is placed a different locations in the vehicle.

is essentially placing one of the normal side pillars above and below the vehicle. The two side pillars were consider as one detector group and were spaced 4.47 meters apart. The

overhead detector was positioned at 3.66 meters. The lower detector was placed on the surface of the pavement and aluminum ramps were used to allow the vehicle to pass over the detector.

The SNM source used in these measurements was a 987 g HEU metallic right cylinder with a diameter of 4.1 cm. The enrichment is 93 % ^{235}U with less than 0.25 % impurities. This is an SNM source having the maximum self attenuation of its emitted radiation. The source was placed at different locations in the vehicle and the vehicle was moved through the monitor in 0.5 meter steps. The response of the two side, the overhead, and the lower detectors was recorded at each position. This data was used to simulate the vehicle passage response of each monitor component. Calculations were then performed to determine the minimum count rates for which the individual and combinations of monitor components achieve a 0.50 or greater detection probability with 95 % confidence at a nuisance alarm rate of less than one per thousand occupancies. The minimum detectable masses were then calculated. Since the mean free path of 186-keV photons in uranium metal is 0.04 cm, the gamma emission rate is assumed to be proportional to the surface area of the cylinder.

Figure 4. A sketch the four pillar detector configuration that was tested.

EXPERIMENTAL DATA

The occupancy background suppression profile for the three individual detector groups is shown in Figure 5. The lower detector has the largest background suppression because it is closest to the vehicle. Since all the data was taken with the source inside the vehicle, the occupancy background suppression is reflected in all the data.

The response of the three detector groups varied dramatically for the three source positions inside the vehicle. An example of this variation is show in Figure 5. These profiles were taken with source between the two door posts, position B in Figure 1. In

this position the sensitivity of the side detectors was very poor but the sensitivity of the lower detector was high. However, with the source above the engine block the situation was

Figure 5. The occupancy suppression profiles for the three detector groups.

reversed. The summary of all data is presented in Figure 6 and Table 1. The key to interpreting the data is find the largest minimum detectable mass for each detector configuration at any source position in the vehicle. For the commercially available configuration which is the side detectors only, this value is 1 kg of HEU when the source is placed below the engine block. While the lower detector has very high sensitivity for the positions A and B, its worse case sensitivity is only 1.5 kg at position C. The overhead detector has reasonable sensitivity for positions A and C but its sensitivity when source was below the engine block was so poor that the 1 kg mass did not yield positive count rates and therefore, the detectable mass could not be determined. The most sensitive combination is, as expected, the sum of all three detector groups. This is true not just because this configuration has the maximum number of detectors, but because the detector positions compliment each other. The worst case for the side and overhead detectors, blow the engine block, is the highest sensitivity for the lower detector. Similarly, the side and overhead detectors have high sensitivity for the lower detector's worst case, above the engine block. Another important feature of this data is that summing certain detector groups is actually detrimental to the sensitivity.

Figure 6. The variation in the minimum detectable mass for different detector configurations and source positions in the vehicle. Position A is between the door posts. Position B is below the engine block and position C is above the engine block.

Minimum Detectable Masses in Kilograms							
Source Position	Side	Lower	Over head	Side + Overhead	Side + Lower	Lower + Overhead	All Three
A. Between door posts	0.4	0.04	0.5	0.3	0.06	0.06	0.06
B. Below engine block	1.0	0.01	>2.0	1.9	0.3	0.02	0.04
C. Above engine block	0.2	1.5	0.6	0.2	0.2	0.5	0.2

Table 1. Minimum detectable masses calculated from the measured response profiles.

CONCLUSION

The original design of two side pillars is more sensitive than just the lower detector or the just the overhead detector. The addition of the overhead detector to the to the side detectors does not increase the worse case sensitivity. Summing the count rates of the side and lower detectors decreases the minimum detectable mass from 1.0 kg to 0.3 kg. However, the best performance is achieved when all three detector groups are summed. This configuration reduces the worst-case minimum detectable mass to 200 g. The difference in sensitivity between the vehicle monitoring station and the commercially available drive-through vehicle monitor is a factor of 25. If the lower and overhead detectors are added this is reduced to a factor of 5. This sensitivity is measured in an

arbitrary laboratory environment to determine the relative sensitivities of the different detector configurations. The sensitivity at any nuclear facility would depend on the operational environment. This new detector configuration improves the sensitivity of the drive-through vehicle monitor by a factor of 5 while not changing the nuisance alarm rate.

¹ P. E. Fehlau, "An Applications Guide to Vehicle SNM Monitors," Los Alamos National Laboratory report LA-10912-MS (Mar. 1987).

² P. E. Fehlau, C. Garcia, Jr., R. A. Payne, and E. R. Shunk, "Vehicle Monitors for Domestic Perimeter Safeguards," Los Alamos National Laboratory report LA-9633-MS (Jan. 1983).