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An Optimized International Vehicle Monitor

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Abstract

This is the final report of a one-year, Laboratory Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). The goal of this project was to evaluate detector configurations to achieve a vehicle monitor that is economical, practical to install, and has adequate sensitivity to be an effective barrier to illegal transportation of special nuclear materials. We designed a new detector configuration that improves the sensitivity of available drive-through vehicle monitors by more than a factor of 5 while not changing the nuisance alarm rate.

INTRODUCTION

The security plans for many Department of Energy (DOE) facilities require the monitoring of pedestrians and vehicles to control the movement of special nuclear material (SNM). Vehicle monitors often provide the outermost 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 that is measured while the vehicle monitor 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 costs and sensitivities. The vehicle monitoring station has a worst-case detection sensitivity of 40 g of highly enriched uranium (HEU) and costs approximately \$180,000. 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 costs approximately \$20,000.

The world's political situation has created a pressing need to prevent the diversion of SNM from the former Soviet Union nuclear facilities and across international borders. Drive-through vehicle monitors would be an effective and practical nuclear material

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proliferation deterrent if their HEU sensitivity can be improved to a sufficient level. The goal of this project was to evaluate more complex 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 portal monitor 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 the shielding provided by the components of the vehicle. For an average vehicle, the occupancy background suppression in a vehicle portal can change the gamma-ray intensity necessary to cause an alarm by as much as 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 portal 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 value increases with proximity and is the reason why simply moving the pillars closer together does not always increase the sensitivity of the monitor. Therefore, improvements to the monitor's sensitivity must avoid increasing this effect.

Three of the most severe structural shielding positions in a vehicle are illustrated in Figure 2 (between the door post, above the engine, and below the engine). The shielding effects of these vehicle components on a normal two-pillar portal's response to an SNM source are shown in Figure 3. With these source sensitivity profiles, the detectable mass at each of these positions can be estimated by calculations. The worst-case minimum detectable HEU 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.

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

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 at different locations in the vehicle.

EXPERIMENTAL PROCEDURE

The variation in sensitivity due to the gamma-ray shielding of vehicle components can be reduced by placing more detectors around the vehicle. In addition to 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 a standard size, 79-cm long, 15-cm wide, and 3.81-cm thick. Each pillar in the configuration contains two detectors. The repines of each detector were 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 is essentially adding one of the normal side pillars above and below the vehicle. The two side pillars were treated as one detector group and were spaced 4.47 meters apart. The overhead detector was positioned at 3.66 meters above the ground. The lower detector was placed on the pavement surface, and aluminum ramps were used to pass over the detector.

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

The SNM source used in these measurements was a 1061 g HEU metallic right cylinder with a diameter of 4.1 cm. This source with a 93% ^{235}U enrichment and less than 0.25% impurities corresponds to 987 grams of ^{235}U . This is an SNM source having the maximum self attenuation of its emitted radiation. The source was placed at three different locations in the vehicle and the vehicle was moved through the monitor in steps of 0.5 meters. The response of the two sides, 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 detected count rates for which the individual and combinations of monitor components achieve a 0.50 or greater detection probability at a nuisance alarm rate of less than 0.001. The corresponding 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 in the calculation.

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 subsequent 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 shown in Figure 6. These

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

Figure 6. Profiles showing the different responses of the detector groups when the source was placed between the door posts.

profiles were taken with the source between the two door posts, position B in Figure 2. 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 reversed.

The summary of all the measurement and calculations is presented in Figure 7 and Table 1. The key to interpreting the data is to find the largest minimum detectable mass for each detector configuration at any source position in the vehicle. For the commercially available portal, 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 1.5 kg at position C. The overhead detector has reasonable sensitivity for positions A and C but its sensitivity when the 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,

below 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 7. The variation in the minimum detectable mass for different detector configurations and source positions in the vehicle. Position A is above the engine block. Position B is between the door posts and position C is below the engine block.

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

Minimum Detectable Masses in Kilograms							
Source Position	Side	Lower	Overhead	Side + Overhead	Side + Lower	Lower + Overhead	All Three
A. Above engine block	0.17	1.48	0.57	0.16	0.19	0.52	0.16
B. Between door posts	0.36	0.04	0.52	0.26	0.06	0.06	0.06
C. Below engine block	1.0	0.01	>2.0	1.93	0.03	0.02	0.04

CONCLUSION

The original portal design of two side pillars is more sensitive than just the lower detector or just the overhead detector. The addition of the overhead detector 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 0.2 kg. However, the best performance is achieved when all three detector groups are summed. This configuration reduces the worst-case minimum detectable mass to 160 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. Thus, this new detector configuration improves the sensitivity of the drive-through vehicle monitor by more than a factor of 5 while not changing the nuisance alarm rate.

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