Comparison of MCNP and Experimental Measurements for an HPGe-based Spectroscopy Portal Monitor

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Abstract

The necessity to monitor international commercial transportation for illicit nuclear materials resulted in the installation of many nuclear radiation detection systems in Portal Monitors. These were mainly gross counters which alarmed at any indication of high radioactivity in the shipment, the vehicle or even the driver. The innocent alarm rate, due to legal shipments of sources and NORM, or medical isotopes in patients, caused interruptions and delays in commerce while the legality of the shipment was verified. To overcome this difficulty, Department of Homeland Security (DHS) supported the writing of the ANSI N42.38 standard (Performance Criteria for Spectroscopy-Based Portal Monitors used for Homeland Security) to define the performance of a Portal Monitor with nuclide identification capabilities, called a Spectroscopy Portal Monitor. This standard defines detection levels and response characteristics for the system for energies from 25 keV to3. MeV. To accomplish the necessary performance, several different HPGe detector configurations were modeled using MCNP for the horizontal field of view (FOV) and vertical linearity of response over the detection zone of 5 meters by 4.5 meters for 661 keV as representative of the expected nuclides of interest. The configuration with the best result was built and tested. The results for the FOV as a function of energy and the linearity show good agreement with the model and performance exceeding the requirements of N42.38.

Introduction

Events in the past few years have highlighted the need to ensure that illicit nuclear material is not transported across national borders. The most widely accepted method to accomplish this is to install monitors at places where the vehicles or cargo containers are moving slowly or stationary. This is usually at border crossing, weigh stations or cargo transfer facilities. The early installation of these Portal Monitors were mainly gross counters (no energy selectivity) which detected and alarmed at any indication of high radioactivity passing through the portal. The activity could be in the shipment, the vehicle or even the driver. The Port of New York and New Jersey is now averaging about 150 alarms a day from the RPMs, or approximately 1 in 40 containers, ten times more than was expected[1]. The alarms generated by the detection of legal shipments of sources and NORM, or medical isotopes in patients are called innocent alarms because they are high activity, but allowed in transport. These innocent alarms caused interruptions and delays in commerce while the legality of the shipment was verified. Innocent alarms are not false alarms; false alarms are when the system alarms with no activity of any type present.

To overcome the problem of innocent alarms, which are nuclide specific, DHS supported the development of a Portal Monitor with nuclide identification capabilities, called an Advanced Spectroscopy Portal (ASP) Monitor. DHS also supported the writing of the ANSI N42.38 standard (Performance Criteria for Spectroscopy-Based Portal Monitors used for Homeland Security) to define the performance of this type of Portal Monitor. Several important performance specifications are given in N42.38 for the operation of the ASP. An ASP must be able to collect spectroscopic data, that is, data which shows the energies of the gamma rays from the material, not just the gross count rate. The ASP described here uses High Purity Germanium (HPGe) detectors because of their superior energy resolution. Multiple detectors are used in order to increase the sensitivity as well as increasing the ability to locate the source in the container.

The number and placement of the detectors was modeled using MCNP. The comparison of the calculation and experimental results for a simple test are in good agreement.

The requirements given in N42.38 are the minimum specifications for an ASP that is expected to detect the nature and amount of illicit materials in transit. N42.38 is a performance standard and does not have any requirements on the type or number of detectors. This work is based on the two-sided cargo portal. The cargo portal has the requirement to measure a container of any length and no more than 5 meters wide and 4.5 meters tall. The requirement for uniformity of the response for sources anywhere in the detection zone determines the number and placement of the detectors. MCNP was used to model various configurations and a design was selected based on these results.

The entrance to and exit from the detection zone is recorded by infrared break beams. The speed of the vehicle is expected to be 8 km/hr through the detection zone.

Experimental

<u>Equipment</u>

The Cargo Portal Monitor consists of 4 Panels, of 6 HPGe detectors arranged vertically in each. Two are stacked vertically to obtain the 4.5 meters height and a stack is located on each side of the traffic lane. The cross section of a single panel is shown in Fig. 1 along with the horizontal position of the source. Three detectors are housed in a single manifold and cooled by an electromechanical cooler. The top and bottom manifolds are identical except for the orientation of valves and ports. The HPGe detector crystal has a large front surface and is mounted with the cylindrical axis parallel to the ground. The detectors are evenly spaced at nominally 38 cm from center to center.

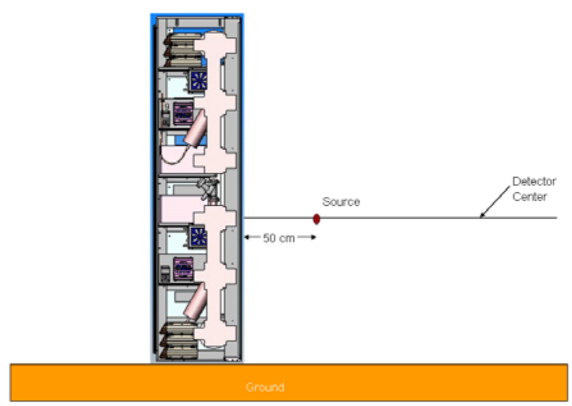

Figure 1 Cross section of a Panel.

The top view of the panel is shown in Fig. 2. The detectors are unshielded in the vertical direction. In the horizontal direction, steel collimators limit the field of view to about 120 degrees. In addition, the sides and back of the detector are shielded to reduce background.

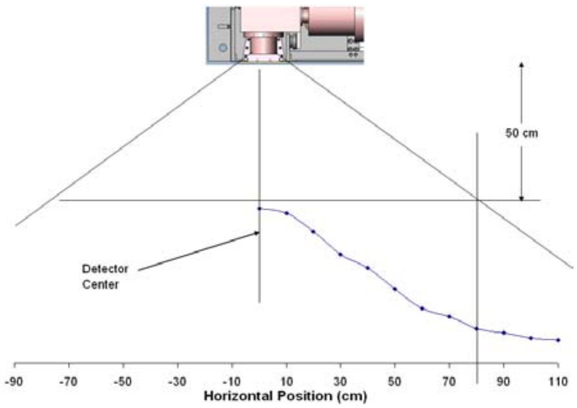

Figure 2 Top View of Detector.

The front of the detector assembly is covered by a protective plastic shield mounted on the surface of the cabinet front. The detector is recessed about 3 cm from the back of the plastic shield.

Break-beam sensors detect the presence of a vehicle in the detection zone. These breakbeam sensors are positioned approximately 1 meter from the center of the panel on each side. The speed is monitored on both the entrance (the time between the front end of the vehicle breaking the entrance and exit beams) and the exit (the time between the rear end of the vehicle breaking the beams). The recorded speed is the average of these two measured speeds.

The data from each detector is recorded separately in list mode with time stamps on each gamma-ray pulse recorded. The time resolution on the time stamps is 20 ms. The separate spectra from each detector are made from the list mode data in 0.24 second intervals. This gives a spatial resolution of about 0.5 meters. That is, a separate spectrum is recorded for each 0.5 meter along the length of the vehicle. Each spectrum is analyzed separately and the result is based on different combinations of these individual results.

<u>MCNP Modeling</u>

The inputs to the MCNP program were the detector crystal dimensions, the cryostat, the manifold, and the steel side shields. The count rate was determined for energies from 20 keV to 3 MeV at 17 energies. The source was moved in 10 cm steps at 50 cm from the detector protective shield along the line shown at the bottom of Fig. 2 from the center at 0 to a distance of 2 meters.

The absolute net peak efficiency at each point is shown in Fig. 3. The efficiency is a combination of the increased distance and the difference in the orientation of the detector relative to the incident gamma rays.

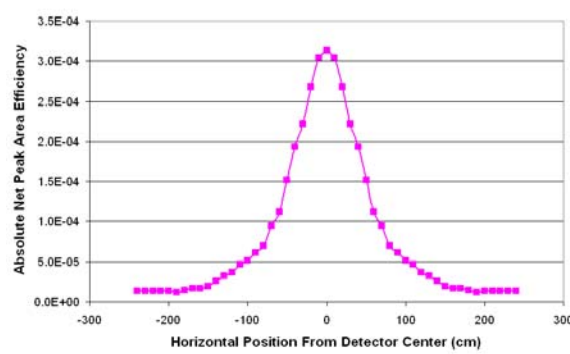

Figure 3 Modeled Efficiency for 137Cs at 50 cm Vertical Distance from Detector Shield..

At the specified speed of 8 km/hr, the source (or any given point in the vehicle) moves 55 cm during 250 ms. Thus the efficiency for gamma rays from the source during the time slice is the average of the efficiency at the MCNP source positions during the 250 ms.

The start of the time slice is based on the time the front of the vehicle triggers the entrance occupancy sensor. In general, the source position is not related to the front of the vehicle, so it is not possible to precisely relate the start of the time slice to the source position. Figure 4 shows different possibilities for the MCNP efficiency points included in a 240 ms time slice. The maximum efficiency is when the center of the time slice is centered on the detector.

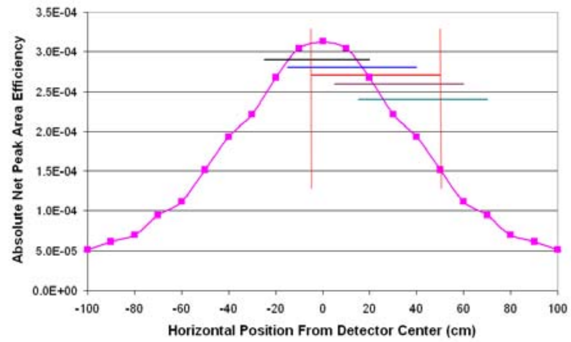

Figure 4 MCNP Efficiency at 662 keV for Various Time Slice Possibilities.

Because of the nearly symmetrical response of the detector from left to right, only the top three slices are relevant. That is, slice 4 would be preceded by a slice similar to slice 3 positioned from -50 to 0. Figure 5 shows the change in the number of counts in the center slice with starting time. The top three slices only vary by 12%. This variation must be taken into account when comparing the MCNP calculation with experimental data.

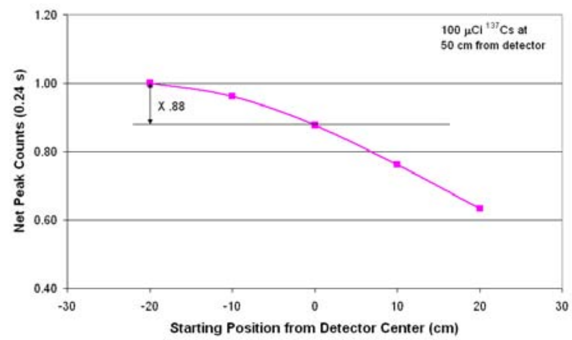

Figure 5 Amplitude of Center Slice for Different Starting Positions.

Source Movement

The source was a 100 µCi ^{137}Cs point source with no shielding. The source was mounted on a laboratory cart at the height of the center of the third detector from the bottom as shown in Fig. 3. Mounted on the cart was material to block the occupancy sensors. The material was longer than the minimum vehicle length specified so that the standard data collection and analysis software could be used. The cart was manually pushed through the portal. The horizontal distance between the source and the detector (see Fig. 6) was manually controlled to be 50 cm. The estimated uncertainty in this distance is 10%. The speed was also manually controlled. The variation in the speed as recorded by the occupancy sensors was from 7.6 to 8.7 km/hr. The average was 8.1 km/hr. Thirteen trials were made for the ^{137}Cs source. Data was collected from all detectors, but only the data from detector 3 is compared to the MCNP calculation, because it is representative of the other detectors and contains the highest counts. All of the trials were in the same direction of travel.

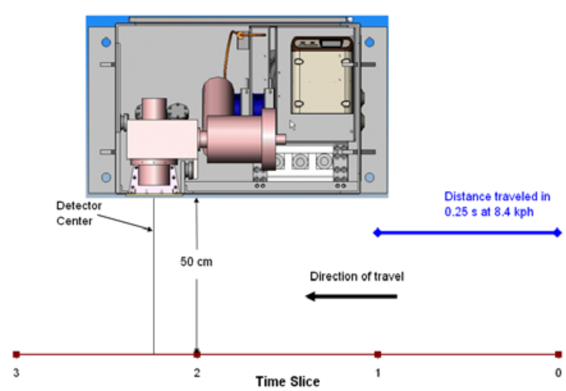

Figure 6 Source Direction of Travel and Distance in Time Slice.

Results

The data from detector 3 for all 13 trials is shown in Fig. 7. The horizontal scale has been adjusted to align the maxima at the center. No correction has been made for the differences in speed. Trial 9 was selected as being a typical run. Trial 9 had an average speed of 7.96 km/hr.

Figure 8 shows the MCNP calculation and the data from Trial 9. The calculation and experiment are in good agreement overall, but the calculation overestimates the overall efficiency, the efficiency at the time slices far from the center and the total width of the collection time.

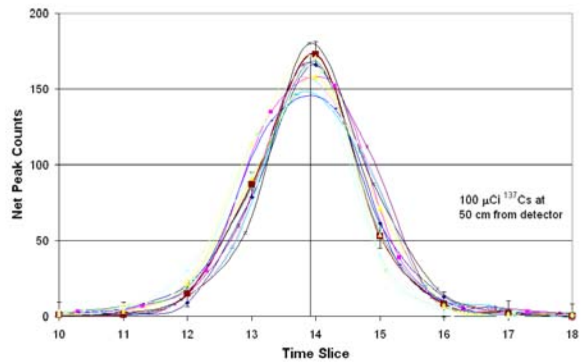

Figure 7 Count Data for All Trials.

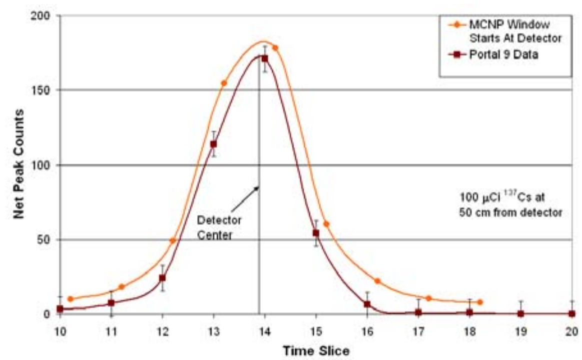

Figure 8 Comparison of MCNP Prediction and Trial 9.

Conclusion

From these data, we conclude that the MCNP model is able to predict the efficiency of the portal monitor detectors for the case of a source moving through the portal. Thus, MCNP can be used to model other configurations to determine corresponding detection performance.

Acknowledgements

The authors would like to acknowledge the assistance of Jesse Ursery, Mark Davis, Mark Allen and Randy Meyers for their help in collecting and analyzing the experimental data.

References

1. BETHANN ROONEY, On Detecting nuclear weapons and radiological materials:How effective is available technology? report to the Subcommittee on Prevention of Nuclear and Biological Attacks and the Subcommittee on Emergency Preparedness, Science and Technology of the House Committee on Homeland Security, June 21, 2005.