Performance of a Small Portal Using Integrated Germanium Detector Modules

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ABSTRACT
Portal monitors and mobile search systems are most effective in positive identification when constructed with high resolution detectors. To satisfy the need for this type of detector, an integrated gamma ray spectrometer, incorporating a germanium detector with integral mechanical cooling, digital signal processing electronics, MCA, and communications has been developed. This modular subsystem has been used in a several different applications, including use in stationary and mobile systems for the detection and identification of radioactive materials. To have the sensitivity needed for these applications the detectors must have good low and medium energy detection efficiency coupled with excellent spectral peak resolution. The high resolution is needed to remove peak overlaps and overcome the problems of masking of SNM with common nuclides. In either situation where the spectrometer and the source are moving relative to one another, the Field of View (FOV) determines the time the radioactive material contributes to the data in the spectrum. The absolute efficiency and background (i.e., signal-to-noise ratio) determine the minimum detectable or identifiable quantity for the material in the FOV. The uniformity of the performance of several units over the energy range of 80 keV to 1.8 MeV was previously reported. A portal monitor was constructed with 8 detectors and the performance measured for several common test nuclides. The total height of the detection zone is 2 meters with 4 detectors uniformly spaced on each side. In this portal, the horizontal FOV is limited by steel collimators. The vertical FOV was not collimated. The background was measured in low background and elevated (NORM) background situations. The measurements presented show this unit can be applied to a wide variety of monitoring situations for the detection of illicit material.

Keywords: radioisotope; integrated systems; germanium detectors; HPGe; illicit trafficking; monitoring

INTRODUCTION
The control of radioactive materials in transportation and the detection of stored materials are important to limit the threat of improper use. Portal monitors and mobile search systems are being developed for positive identification in these situations. These systems are most effective when constructed with high resolution detectors because of the superior signal-to-noise ratio in the spectrum. To satisfy the needs of this type of system, an integrated gamma ray spectrometer, incorporating a germanium detector with integral mechanical cooling, digital signal processing electronics, MCA, and communications has been developed (Interchangeable Detector Module – IDM). This modular subsystem has been used in a several different applications, including use in stationary and mobile systems for the detection and identification of radioactive materials.

The nuclides of interest have gamma rays in the 100 to 600 keV energy range. To have the sensitivity needed at these energies, the detectors must have good energy detection efficiency coupled with excellent spectral peak resolution. The high resolution is needed to remove peak overlaps and overcome the problems of masking of SNM with common nuclides in addition to improving the signal-to-noise ratio.

In any situation where the spectrometer and the source are moving relative to one another, the Field of View (FOV) determines the time the radioactive material contributes to the data in the spectrum.

The absolute efficiency, background (i.e., signal-to-noise ratio), transit speed, and the allowed limits for false negatives and false positives determine the minimum detectable or identifiable quantity for the material in the FOV.

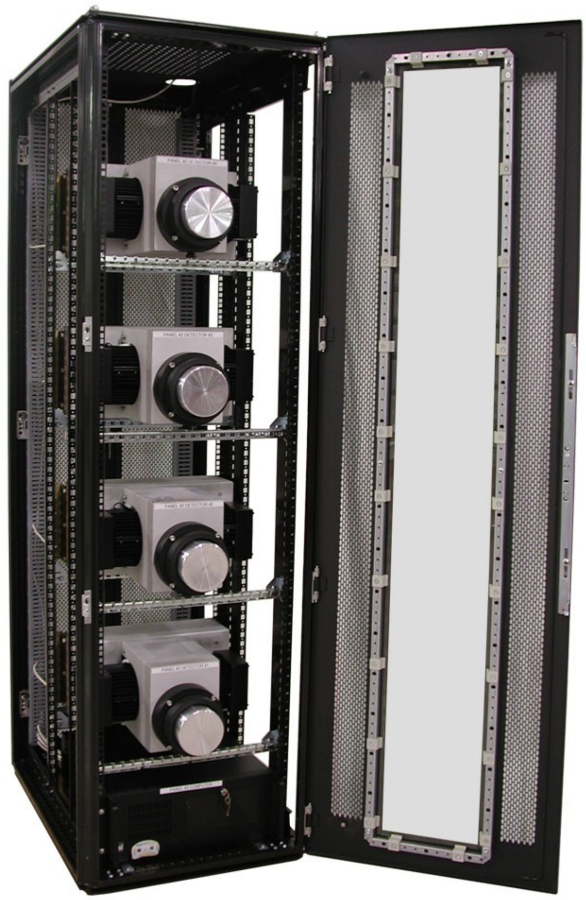

Figure 1. Stationary Monitor

To evaluate the performance of this type of system, a portal monitor was constructed with 8 detectors and the performance measured for several common test nuclides. The total height of the detection zone is 2 meters with 4 detectors uniformly spaced on each side. The width of the detection zone is 4 meters. Such a system could be used to monitor air cargo containers. The transit speed is specified in various documents [1, 2].

Figure 2. Interchangeable Detector Module (IDM)

Equipment

The equipment consists of 8 IDMs, mounting hardware, control computer, and software. The high-resolution germanium detector is 85 x 30 mm and constructed of p-type material. The IDM has been described in detail in previous work [3] and is shown in Fig.2

To reduce the general background and radiation from adjacent containers, side shields were added to the existing back shield as shown in Fig. 3. The side shields are 13 mm thick steel plates and extend in front of the detector module to limit the FOV to about 120º for low-energy gamma rays.

The system was constructed and the background measured in a building with concrete floors and minimal internal walls.

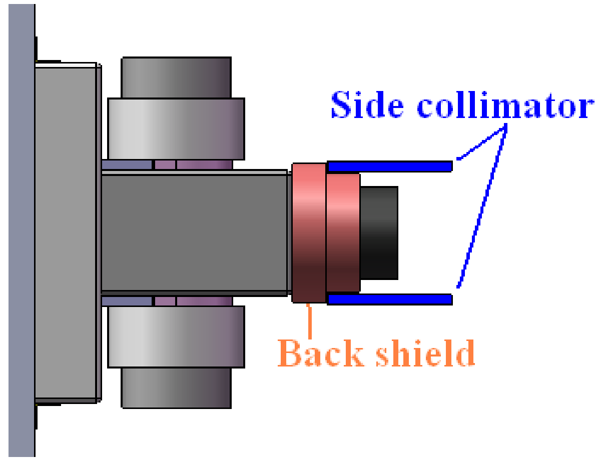

Figure 3. IDM with Shielding to Limit Background

The schematic of the total system is shown in Fig. 4. The background was increased by placing approximately 8 kg of mineral sand on the side of the detection zone near panel 1. This increased the background by a factor of two in the panel 1 detectors.

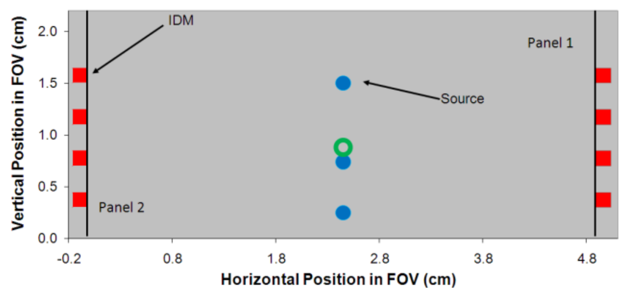

Figure 4. Test System Showing IDMs and Sources

The test sources are NIST traceable point sources of ^{133}Ba, ^{60}Co and ^{137}Cs of various activities. They were placed on an automated positioner so that they could be moved through the detection zone at the top, middle, and bottom of the zone, corresponding to a height from the floor of 25, 100, and 175 cm.

To maximize the signal-to-noise ratio and eliminate any reduction in spectrum quality, the data for each spectrum peak from each detector are processed and then summed to make the composite result. The data are processed every 250 ms in a sliding window of 6 sec, the approximate time a point source would be in the field of view at the specified transit speed. The background is calculated on the spectrum collected during the object transit through the FOV so that it represents the actual background in the spectrum and is not affected by changes in the NORM or background suppression [4] by the object.

The detection and identification are based on the peak quality factor (Q), defined as the quotient of the net peak area and the uncertainty in the net peak area [5]. When the Q value for a peak is above a threshold, the peak is marked as found. The nuclide is identified based on the gamma-ray signature of the nuclide.

RESULTS

The background spectrum for a typical detector for the low background level is shown in Fig. 5 and for the high background level in Fig. 6. These backgrounds are typical of the background in a portal or package monitor. The background in the object spectrum affects the peak detection and identification performance, which impacts the minimum identifiable activity (MIA).

The FOV for 356 keV for 4 IDMs when the source passes through the center (both vertically and horizontally) is shown in Fig. 7. For lower energies, the FOV is narrower because the side shielding is more effective, while for higher energies, the FOV is wider because of higher penetration of the shield material by the high-energy gamma rays.

The FOV for the source at the 175 cm position vertically is shown in Fig. 8. In this case the bottom detectors do not contribute significantly to the total data.

In addition to the processing of the sliding time slices, the software processes many different combinations of detectors simultaneously and reports the result with the highest confidence level on a nuclide-by-nuclide basis both for the time slices and combinations in an occupancy. That is, each time slice is processed for all nuclides in different groups of detectors and the result for each nuclide in an occupancy is based on the group and time slice with the highest confidence for that nuclide.

The sources (^{133}Ba, ^{60}Co and ^{137}Cs) of different activities were passed through the detection at the three heights at the transit speed of 0.28 m/s. Figure 9 shows the median Q results for different activities when the sources were at different positions in the detection zone. Four

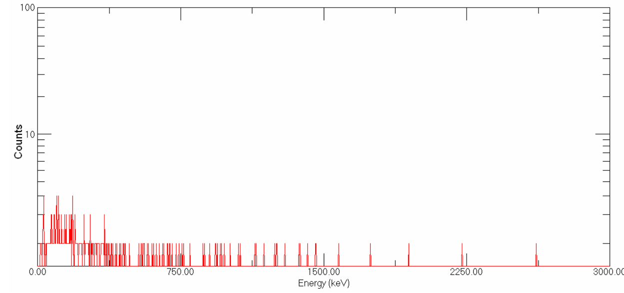

Figure 5. IDM Background Spectra for Low Level

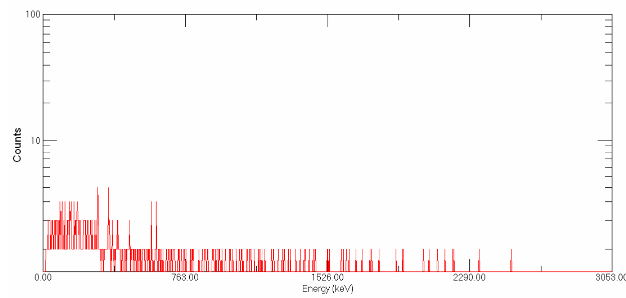

Figure 6. IDM Background Spectra for High Level

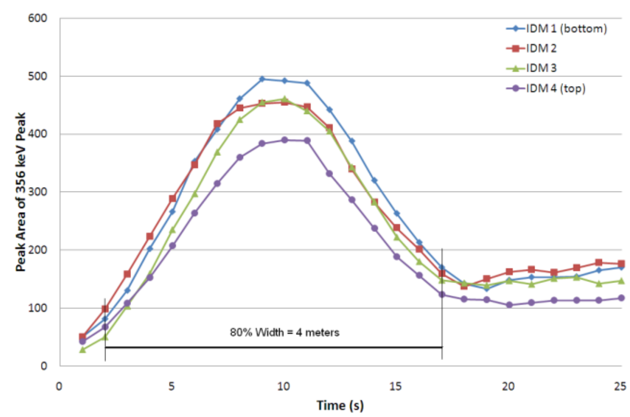

Figure 7. FOV for Panel 1 at Center of an 8 IDM System.

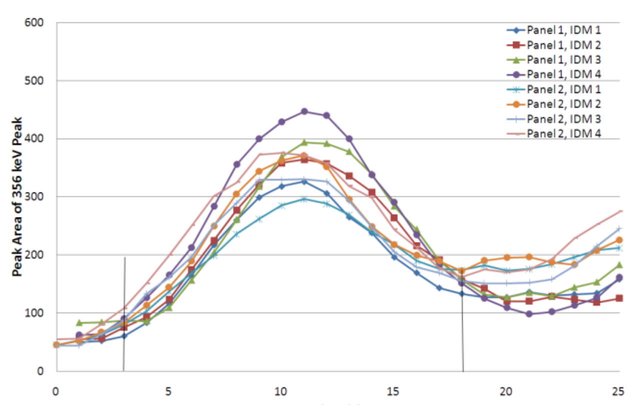

Figure 8. FOV at Top of 8 IDM System

situations are compared. The first, blue, had all three nuclides at the center of the detection zone and high background. The second, red, was the same sources with the background reduced by 50%. The third was with ^{133}Ba and one ^{60}Co source at the 175 cm position and ^{137}Cs and one ^{60}Co source at the 25 cm position. The fourth was the same combination of sources rotated to the horizontal such that the ^{133}Ba and ^{60}Co passed through the detection zone 1.5 m before the ^{137}Cs and ^{60}Co. The high background decreased the Q value slightly for all nuclides, with ^{133}Ba being the most affected due to the background increasing most at the lower energies. The confidence levels on the identification are not significantly different for the different source distributions.

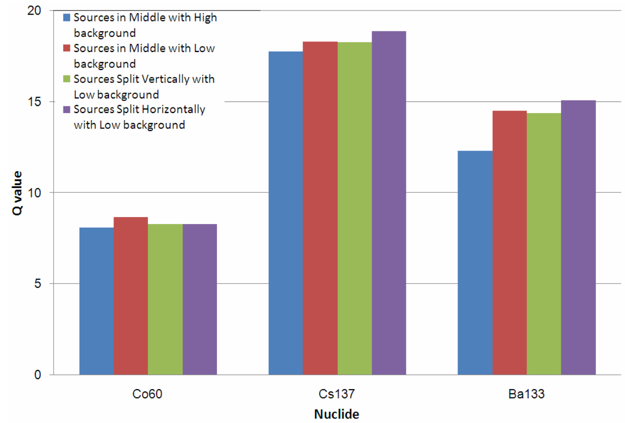

Figure 9. Q Value for Several Sources at Different Arrangements and Background

Figure 10 shows the Q values of ^{133}Ba and ^{137}Cs for different activities passing through the center of the detection zone. The MIA is based on the threshold of the peak quality factor (Q) [5] set to the value determined above for the 1:10000 FP and the Q value of the nuclide peak for known activities in the expected scenario. Extrapolating the ^{133}Ba and ^{137}Cs Q values to the threshold for these cases gives an MIA of about 200 kBq for ^{133}Ba and ^{137}Cs. This compares favorably with the N42.38 requirement of 330 kBq for ^{133}Ba and 600 kBq for ^{137}Cs.

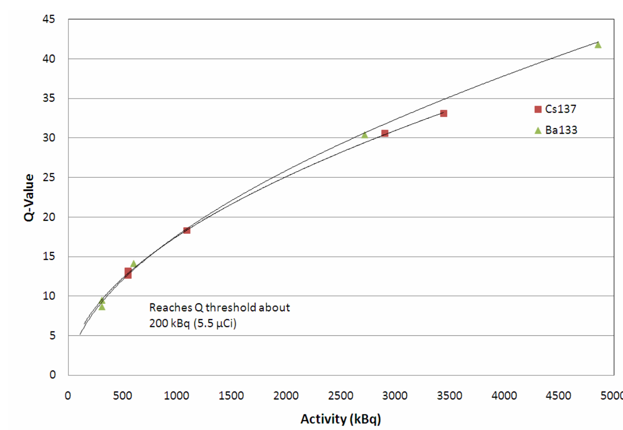

Figure 10. MIA based on Q for ^{133}Ba and ^{137}Cs

CONCLUSION

The portal or package monitor consisting of 8 IDMs with a detection zone of 2 meters high by 4 meters wide has a FOV that gives an average data collection time for data from a point source traveling at 0.28 m/s of about 6 s. This data collection time is sufficient for the identification of 200 kBq of ^{133}Ba at various positions in the detection zone. The identification limit depends on the background activity level, but not on the position in the detection zone, demonstrating good uniformity of sensitivity throughout the detection zone. The analysis method selects the best quality data from the total data set based on 250 ms time windows. This allows the detection of sources in different positions in the object to be detected and identified independently of each other.

REFERENCES

1. *American National Standard Performance Criteria for Spectroscopy- Based Portal Monitors Used for Homeland Security,* IEEE, 3 Park Avenue, New York, NY 10016-5997, USA January 2007

2. International Atomic Energy Agency, "Technical and Functional Specifications For Border Monitoring Equipment Reference Manual," IAEA Nuclear Security Series no 1. 2006, ISBN 92–0–100206–8

3. R. M. Keyser, T. R. Twomey, and S. Hitch, Performance of an Integrated Germanium-Detector Based Gamma-Ray Spectrometer for Monitoring Systems, ESARDA Annual Meeting 2007

4. B.D. Geelhood, J.H. Ely, R.R. Hansen, R.T. Kouzes, J.E. Schweppe, and R.A. Warner, Overview of Portal Monitoring at Border Crossings, IEEE NSS MIC 2003

5. R. M. Keyser, F. Sergent, T. R. Twomey, and D. L. Upp, Minimum Detectable Activity Estimates for a Germanium-Detector Based Spectroscopic Portal Monitor, INMM 47th Annual Meeting 2006