Standoff Performance of HPGe Detectors in Identification of Gamma-Ray Radiation Sources

Ronald M. Keyser, Timothy R. Twomey, Sam Hitch

ORTEC
801 South Illinois Avenue
Oak Ridge, TN, 37831 USA
Email: ron.keyser@ametek.com, tim.twomey@ametek.com, sam.hitch@ametek.com

Abstract:

The detection and identification of radiation sources at distances in the range of 15 meters or more is becoming increasingly important for illicit materials interdiction and the location of lost or orphan sources. In most locations, there is a considerable gamma-ray flux from natural background (NORM) and cosmic-induced nuclides. This gamma-ray flux varies with time, weather conditions, location, and changes in the materials at a location such as a portal. All of these contribute to changes in the detector total count rate unrelated to the nuclides of interest and can mask considerable quantities of material. The high resolution of HPGe enables the nuclide-specific peak and background counts to be extracted from the spectrum of the suspect object or area without relying on background spectrum subtraction techniques using background spectra necessarily collected at either different places or times. Data were collected with and without collimators. The collimators reduce the detector field of view and improve the signal-to-noise ratio thereby reducing the minimum identifiable activity (MIA). A straightforward summing technique allows the data from multiple detectors to be aggregated to improve the signal. Data have been collected for ^{137}*Cs at distances up to 80 meters and used to predict the performance at 100 m. The MIA has been calculated for given false positive and false negative rates for systems with up to 8 HPGe detectors.*

Keywords: Standoff, HPGe, illicit trafficking, detection limit

1. Introduction

Long distance or standoff measurements are increasingly important for illicit materials interdiction and the location of lost or orphan sources as the operations move from portal monitoring to searching. The search for radiation sources can take place where the distance between the detectors and the sources is in the range of 15 meters or more. In addition, it is necessary to identify the nuclides producing the gamma-ray flux as well as detect the increase in gamma rays. In most locations, there is a considerable gamma-ray flux from natural background (NORM) and cosmic-induced nuclides which can mask the material of interest. This gamma-ray flux varies with time, weather conditions, location, and changes in the materials at a location such as a portal as well as normal variation during a search over a wide area [1]. All of these contribute to changes in the detector total count rate unrelated to the nuclides of interest and can hide considerable quantities of material. The good resolution of High Purity Germanium Detectors (HPGe) enables the nuclide-specific peak and background counts to be extracted from the spectrum of the suspect object or area with sufficiently low uncertainty to make nuclide identifications on fewer total peak counts than low resolution detectors. [2] Because of the constantly changing background, this is best done without relying on spectrum subtraction techniques using background spectra necessarily collected at either different places or times. The HPGe data were collected with and without collimators on the detectors. The collimators reduce the detector field of view and improve the signal-to-noise ratio thereby reducing the Minimum Identifiable Activity (MIA). A straightforward summing technique allows the peak and background data from multiple detectors to be aggregated to improve the signal. The combination is not done on a channel-by-channel basis. Data have been collected for ^{137}Cs at distances up to 80 meters and used to predict the performance at 100 m. The MIA has been calculated for given false positive and false negative rates for systems with up to 8 HPGe detectors.

2. Equipment and Setup

HPGe Detectors
The HPGe detectors used were ORTEC IDMs, as shown in Fig. 1. Each IDM is a fully integrated gamma spectrometry subsystem consisting of an 85 mm diameter x 30 mm deep, p-type HPGe crystal, Stirling cooler, DSP MCA, high voltage supply, shielding against gamma rays from behind the front surface, and high speed USB communication. A complete description is given in [3]. The large diameter detector is optimized for energies in the 100 to 400 keV range, which is important for detection of SNM.

Eight IDMs were used for this measurement. The relative efficiency according to the IEEE 325 method ranged from 50 to 55%.

Figure 1 The Interchangeable Detector Module

Mounting
The eight IDMs were mounted in 2 m high cabinets with 4 IDMs in each cabinet. The IDMs were uniformly spaced in the vertical direction. The cabinets were positioned side-by-side as shown in Fig. 2.

At the distances measured, the precise relative positions of the IDMs do not impact the resulting data. The data were collected in a typical factory-type building with a concrete floor, gypsum internal walls, and steel supported roof. The data were collected in list mode. List mode enables the data to be combined in many different ways after collection, such as different integration times.

The background flux is incident from all directions. The ^{137}Cs flux was incident from the front only.

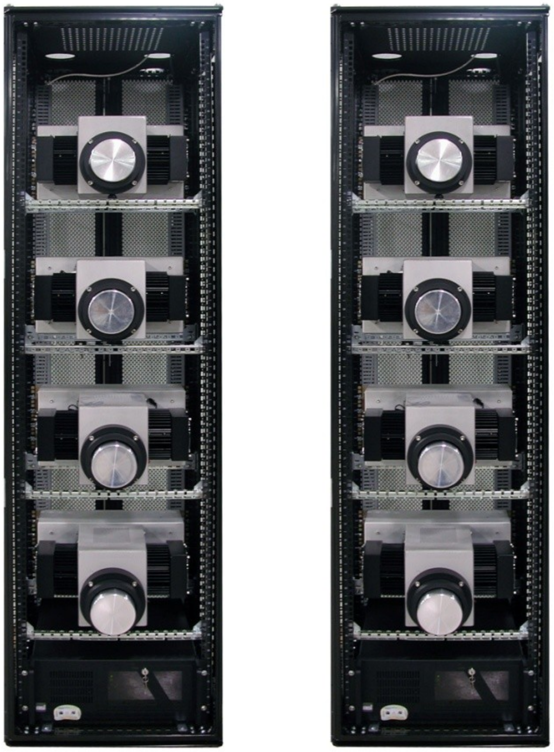

Figure 2 Eight IDMs in two cabinets

Shielding
The IDM includes some steel shielding (the black ring around the detector endcap in Fig. 2). Data were collected in this configuration. It is also possible to add additional shielding on the sides of the detectors to reduce the background contribution from the sides and to reduce the field of view. Cylindrical shielding can be placed on the endcap in front of the black shield to reduce the contributions from below (nearby ground) and above (buildings or sky shine).

The steel shielding extends from just behind the detector crystal for a distance of 10 cm. It is 12 mm thick for 4 cm and 25 mm thick for the remaining length. The additional shielding was 5 cm of lead for the vertical side shield and 12 mm of lead for the cylindrical shield. The side shield extends from the steel shield outer diameter to 13 cm in front of the detector endcap. The cylinder shield extends from the steel shield inner diameter to 4.5 cm in front of the detector endcap. This is shown in Fig. 3.

Peak Quality Factor

The identification of the nuclide is based on the presence in the spectrum of the intense gamma rays from that nuclide. The peak is present in the spectrum if a measured parameter is above a threshold. The peak parameter or peak quality (Q) is defined as the net peak area divided by the uncertainty in the net peak value [4]. The threshold is based on the desired false positive rate and false negative rate. There is a threshold specified for each gamma ray in the analysis table. The gamma rays in the table are given in [5, 6, and 7].

The Q can be calculated for the 8-IDM combination data in a similar manner, thus giving the Q for a detector of 8 times the efficiency of a single IDM.

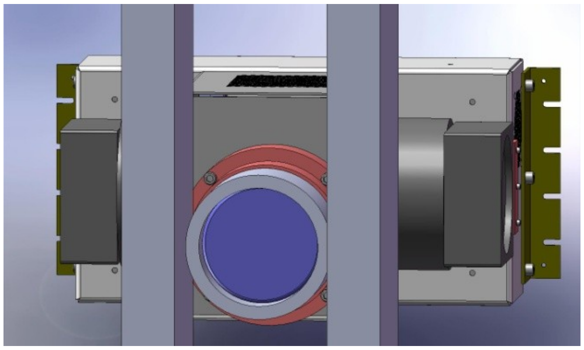

Figure 3 IDM with side and cylindrical shielding

Source

The source was a ^{137}Cs point source of 0.46 mCi at the time of measurement. It was positioned at 1 m from the floor on a ring stand with little material near the source. The source was positioned in front of the IDMs at 10 m intervals. The length of the room limited the maximum distance to 80 m.

3. Field of View

The Field of View (FOV) is the area in front of the detectors where a source of gamma rays (NORM or other source) could contribute to the spectrum. It can be expressed in angle or length at a distance (between the emitter and detector). The effective FOV is the area in front of a detector where a source could contribute significantly to the spectrum. The effective FOV can be much smaller than the actual FOV because the source contribution is limited by the reduction in flux due to distance ($1/r^2$) and absorption by the air. Background activity outside the effective FOV should be blocked from the spectrum by collimation.

Figure 4 shows the relative contribution to the spectrum of a source at positions along a line that is 50 m from the source at its closest position. The contribution to the spectrum is normalized to the contribution when the source is at the minimum distance. In a measurement where the source is moving relative to the detector, either searching or portal monitor, there is little relative contribution to the spectrum for large horizontal distances. If the source is moving, the contribution to the spectrum in a 120º FOV is about 60% of the contribution of a source stationary at the minimum distance, ignoring air attenuation.

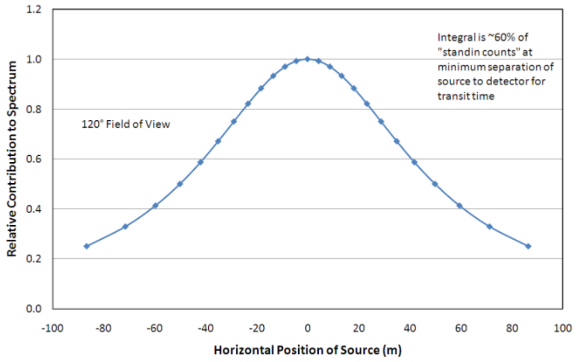

Figure 4 Contribution to the Spectrum for a Source at 50 m

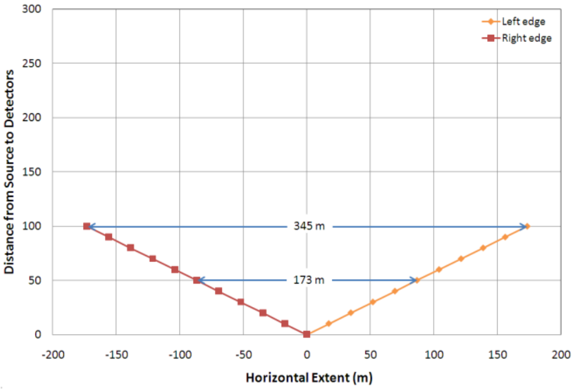

Figure 5 Width of 120º FOV at various distances

Figure 5 shows that the source could contribute to the spectrum over a length of 173 m when the FOV is 120º (as defined by the collimation) the minimum source-to-detector distance is 50 m.

Comparing Figs. 4 and 5, it can be seen that the background contribution could be reduced without a reduction in the source contribution with shielding. Thus, the signal-to-noise ratio could be improved by reducing the FOV with collimation.

4. Background

Figure 6 shows the background from one IDM with only the integral steel shield in place. The total count rate is about 100 cps. The largest peak is ^{40}K with a count rate of 1.06 cps. There are few counts above 2 MeV. The distribution with energy is typical of background spectra. Most of the counts are in the region below 250 keV and are scattered gamma rays. This energy region is important for SNM detection.

The spectrum for the same detector with the addition of the 5 cm lead side shields is shown in Fig. 7. The total count rate (0 – 3 MeV) is about 50 cps and the ^{40}K count rate is 0.45 cps. This reduction in background by a factor of about 2 will result in a reduction of the MIA by about 1.4. Note that the region below 250 keV is reduced, indicating that this region does not contain many counts from Compton scattering inside the detector.

The above spectra are typical, but the background varies significantly with time. Figure 8 shows the background for the peak region at 661 keV with no ^{137}Cs present and the side shields installed. The average background is 41.6 counts with the minimum at 19 and the maximum at 67. At 10 kph, the source will be in the FOV for about 62 s at the minimum separation distance of 50 m. In the following results, the peak analysis is done using the background under the peak in the actual spectrum rather than using a stored background.

5. Results

The spectrum of ^{137}Cs, positioned at 20 m for the sum of 8 IDMs and a data collection of 20 s is shown in Fig. 9. This is without the side shields. The peak analysis does not use this summed spectrum, but rather sums the peak results from each IDM. This method reduces the need for precise channel alignment and preserves the resolution of each detector in the result.

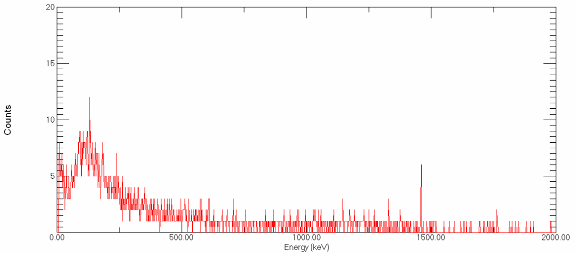

Figure 6 Background with no Extra Shielding (60 s)

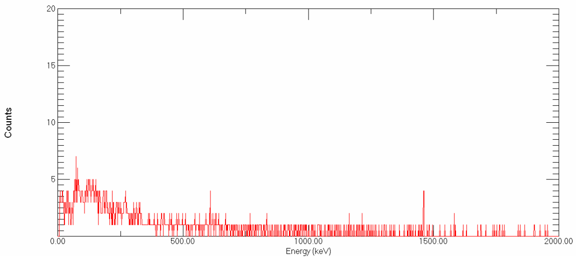

Figure 7 Background with Vertical Side Shielding (60 s)

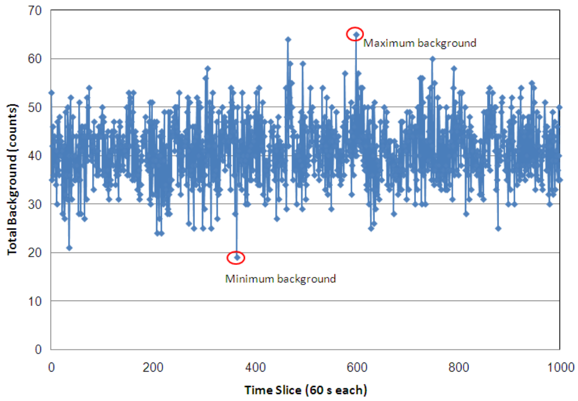

Figure 8 Background Variation with Time in the 661 keV peak region in 8 IDMs

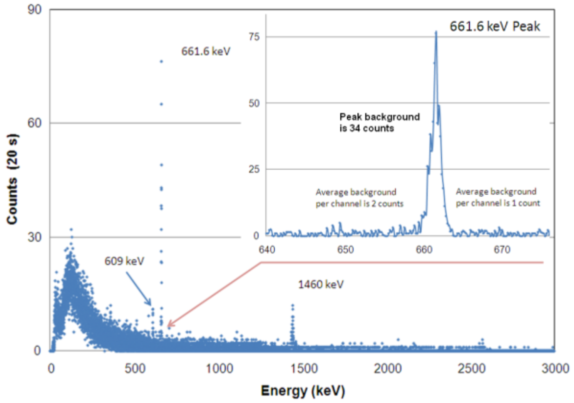

Figure 9 Spectrum of ^{137}Cs at 20 m for 8 IDMs Collected for 20 s without side shields

Figure 10 shows the same spectrum for the 50 m source position. Note that the net peak area is impacted by both the distance and the absorption by air.

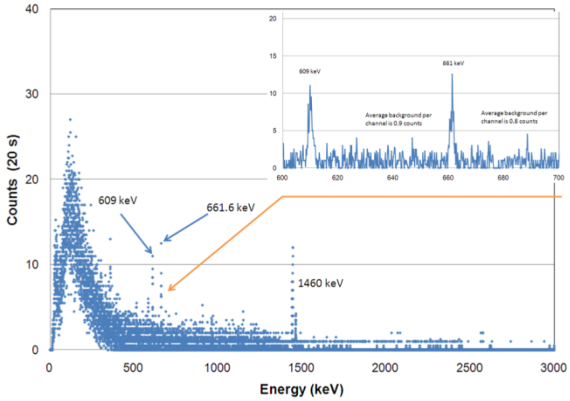

Figure 10 Spectrum of ^{137}Cs at 50 m for 8 IDMs Collected for 20 s without side shields

Figure 11 shows the measured count rate of ^{137}Cs at distances of 10 to 80 m. For comparison, the background peak areas at 609, 1461, and 2614 keV are shown. The $1/r^2$ is also shown. Note that for distances above 30 m, the ^{137}Cs peak rate is below the background peak count rate without side shields. Figure 10 shows the 609 and 661 keV peaks clearly separated. For low and medium resolution detectors, these peaks will merge into one peak. In addition, the variation in the background (see Fig. 8) by a factor of 3 over time means that good resolution is the only way to detect low activities.

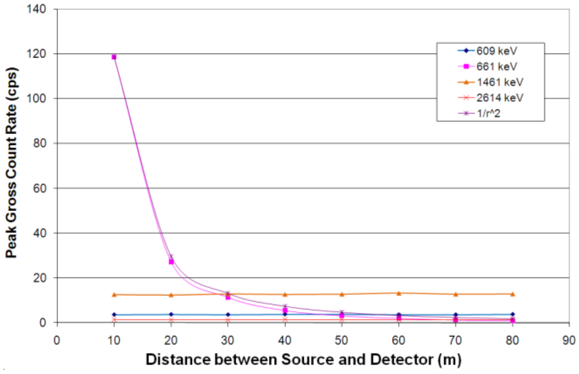

Figure 11 Count rate for 137Cs using 8 IDMs vs Distance

The MIA is related to the Q for the peak or peaks of the nuclide in question. The relationship is the peak area: Q must be above the threshold for the peak to be present, and the MIA is the activity that would produce that peak area. Figure 12 shows the Q for different distances with and without the side shielding. The Q is improved by about 18% with the shields at a source distance of 80 m. Previous work showed that for most cases, a threshold of 5 for Q will meet the 1:10000 FP and the 1:1000 FN rates. At 100 m distance, the extrapolated Q value is 5.1, indicating that an 8 IDM system with shielding would be able to detect 1 mCi of ^{137}Cs in 60 s.

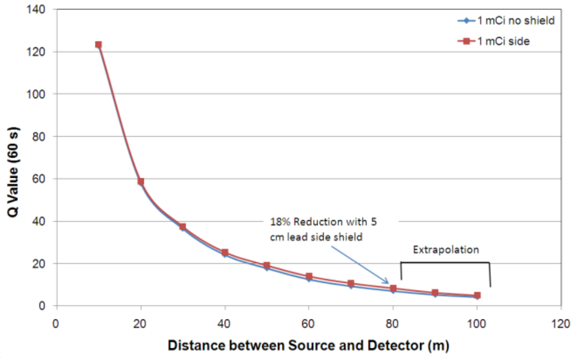

Figure 12 Q Based on 8 IDMs for Different Shielding

This same data can be used to estimate the time for an eight IDM system with shielding to detect 1 mCi at various distances as shown in Fig. 13, when the threshold is 5.

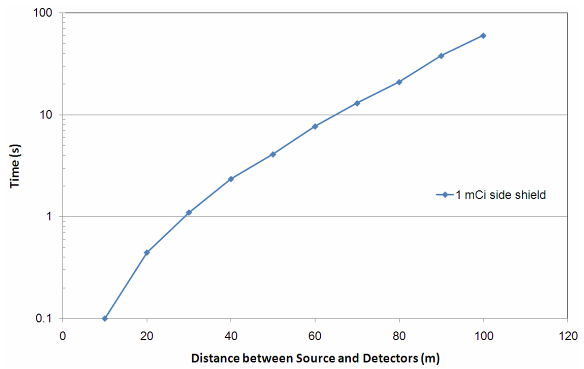

Figure 13 Time to Detect by Distance for 8 IDMs

6. Conclusion

These measurements with an 8 IDM system with the internal steel shield and 5 cm of lead shield show that a 1mCi ^{137}Cs source can be detected with conservative FP and FN rates at a distance of 100 m in about 60 s. In special circumstances, for example, when additional information suggests the presence of SNM in a certain location, the search operation may be willing to accept a higher FP rate (by lowering the Q threshold) to improve sensitivity. Lowering the Q threshold will substantially reduce the ^{137}Cs identification time. This result depends on the background in the spectrum at 661 keV from both the natural background and any other sources that may be present. With suitable collimation to reduce the background, this time is still within the expected time a source would be in the FOV for a search system moving at 10 kph.

7. References

[1] Ronald M. Keyser and Timothy R. Twomey, "False Positive Probability as a Function of Background for Short Data Collection Times in a Germanium Detector Portal Monitor," Proceedings of the 2008 INNM Annual Meeting, July, 2008

[2] Ronald M. Keyser and Timothy R. Twomey, "Detector Resolution Required for Accurate Identification in Common Gamma-Ray Masking Situations," Proceedings of the MARC VIII Conference, April, 2009

[3] Ronald M. Keyser, Timothy R. Twomey, and Sam Hitch, "Characteristics of an Integrated Germanium Detector Based Gamma-Ray Spectrometer for Monitoring Systems," Proceedings of the 2007 ESARDA Annual Meeting, May, 2008

[4] Keyser, R.M., Sergent, F. Twomey T.R and Upp, D.L., "Minimum Detectable Activity Estimates for a Germanium-Detector Based Spectroscopic Portal Monitor," Proceedings of the 2006 INMM Annual Meeting, July, 2006

[5] "Technical and Functional Specifications for Border Monitoring Equipment", IAEA Nuclear Security Series No. 1, IAEA, Vienna, 2006, and "Detection of Radioactive Materials at Borders," IAEA-TECDOC-1312, IAEA, Vienna, 2002

[6] N42.34, American National Standard, "Performance Criteria for Hand-held Instruments for the Detection and Identification of Radionuclides," The Institute of Electrical and Electronics Engineers, New York, January, 2004

[7] IEC 62484 "Radiation protection instrumentation – Spectroscopy portal monitors used for the detection and identification of illicit trafficking of radioactive material", International Electrotechnical Commission, Geneva