

Characteristics of an Integrated Gamma-Ray Spectrometer Using Germanium Detectors in Fixed and Mobile Measurement Systems

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

To address the need for high resolution detection systems to be used in portal monitors and mobile search systems, 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 can be used in a wide variety of applications, including use in stationary or mobile systems for the detection 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 resolution removes peak overlaps and helps to overcome the problems of masking with common nuclides. In a situation where either the spectrometer or the material is moving, the Field of View (FOV) determines the time the material contributes to the spectrum. The absolute efficiency and background determine the minimum detectable or identifiable quantity for the material in the FOV. To characterize the expected performance in a general system, the absolute efficiency was measured for several units over the energy range of 80 keV to 1.8 MeV. The horizontal FOV is limited by collimators and was measured for several distances corresponding to the ANSI N42.38 test criteria. The vertical FOV (no collimation), important to determine the detector spacing, was also measured. The background was measured in a typical pedestrian portal situation. The measurements presented show this unit can be applied to a wide variety of monitoring situations.

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

INTRODUCTION

As a consequence of increasing efforts to prevent the illicit trafficking of nuclear materials, particularly across national borders, there is a growing requirement for monitors of all types capable of detection of radioactive materials. The precise form of the monitoring system depends on the Concept of Operations or "CONOPS" at the crossing or facility. Consequently, because of the increased level of monitoring, it is of growing importance that these monitors be resistant to all forms of incorrect result: false negatives, false positives and false alarms ("no signal" alarms) are all highly undesirable.

The requirement to avoid false positives and negatives implies that the system must provide highly reliable nuclide identification. The majority of gamma-ray emissions from Special Nuclear Materials (SNM) are in the 100 to 600 keV range, implying that the detection efficiency in this energy range will depend mainly on the surface area of the detector. In germanium detectors, for example, a depth of 46 mm absorbs 90% of all 400 keV gamma rays

incident on the face of the detector. Thus, surface area is more important than depth. (For example, see [1])

Large area, high purity germanium (HPGe) detectors meet all of these needs, but have historically had one major limitation, namely the requirement that they be cooled to cryogenic (LN₂) temperatures.

Recent developments in high reliability cryocoolers have resulted in the increased use of mechanical cooling for HPGe. Certain types of Stirling-cycle mechanical coolers typically have a design life on the order of 50,000 hrs, or more, of continuous operation, thereby greatly reducing the need for service intervention. Advances in spectroscopic signal processing using Digital Signal Processing (DSP) techniques have improved the spectrum quality both in terms of resolution improvements and stability with respect to temperature change and other causes of long term change in the position of the gamma-ray peaks. DSP technology allows pulse-by-pulse corrections to be applied to the data stream to eliminate deleterious effects such as degradation of the resolution by periodic noise. [2]

A completely integrated, autonomous spectrometer has been constructed, comprising a large surface area HPGe detector, mechanical cooling, and DSP electronics. It may be used as a “building block” component for the simplified construction of portal monitors for pedestrians, packages, vehicles, cargo containers, and rail freight cars as well as of vehicle and airborne mobile search systems. The modular spectrometer is referred to as the “Interchangeable Detector Module” (IDM).

The data shown below are for a pedestrian portal as defined in ANSI N42.38-2006 [3]. The pedestrian portal was selected because the small size is easier to test. The results show that a portal with relatively few large area HPGe detectors can meet the requirements of ANSI N42.38.

EQUIPMENT

The IDM consists of an 85 mm x 30 mm HPGe Detector, Stirling cooler, DSP MCA, high voltage supply, shielding against gamma rays from behind the front surface, and high speed USB communication. The instrument can be mounted in a standard electronics enclosure (rack mount), as shown in Fig.1. It uses standard, low-current mains power.

The large diameter detector gives good low-energy efficiency. Standardized detector crystal dimensions mean that all IDMs will perform similarly so that efficiency recalibration is not necessary if an IDM is replaced in a system.

The uniform construction also allows computer modeling to be used to predict system performance. This means that customized solutions may be designed which will match the required CONOPS of a particular facility, for example, in terms of traffic flows and analysis speeds versus system cost.



Figure 1 Complete IDM

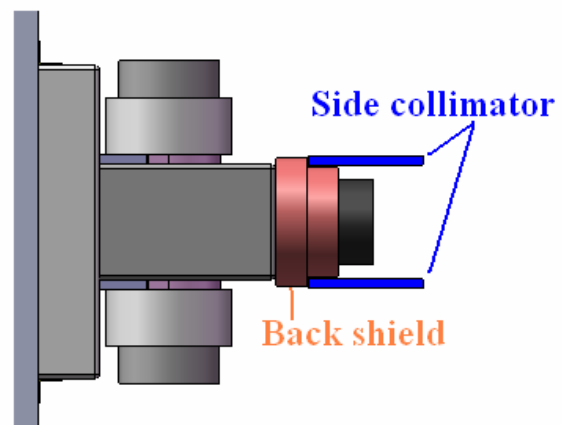
The high cooling capacity, highly reliable, Stirling cooler will operate in the environmental conditions stipulated by ANSI N42.38-2006 without the need of external heaters or air conditioning units. The hardened cryostat is designed for long operational life and can be temperature cycled at any time, even from partial warm-up, eliminating the problems associated with loss of electrical power. If the power is turned off, it will automatically restart when the power is turned on.

The DSP MCA has 16k channels and can operate in histogram mode (standard PHA mode) or streaming list mode. Streaming list mode has no loss of data between spectrum captures and allows for off-line data manipulation to improve the detection ability. Raw or processed data can be sent to the controlling computer over the high speed USB connection. The IDM can operate and collect data without a PC, but the normal operating mode would use a PC for data display.

The field-of-view measurements were made using the commercial ORTEC GammaVision software, and Region-of-Interest analysis of the peaks from ^{133}Ba , ^{57}Co , and ^{60}Co . The detection and identification was done using a method similar to that used in the ORTEC Detective Handheld Identifier. This method has been shown to perform well in the short data collection time expected in the portal monitoring application.

Experimental conditions

For the standard efficiency measurements, the IDMs were positioned on a table with the mixed gamma point source (gamma-ray energies from 59 keV to 1.8 MeV) at 25 cm from the front face of the endcap and centered on the endcap. While the portal monitor application is an identification application and does not typically produce activities, measuring the efficiency in this way (IEEE 325-2006) allows comparison with other HPGe detectors. The energy resolution (FWHM) was measured using the same spectra.



The Field-of-View (FOV) measurements were done with the IDMs supported on adjustable supports with steel collimators to reduce the field of view. The steel collimators were positioned as shown in Fig. 2. To cover the occupancy zone of the two-sided pedestrian portal, 4 IDMs (2 on each side) were positioned at vertical positions of 50 cm and 160 cm. The front faces of the detector endcap are 1 meter apart. The total assembly (without collimators on the right side) is shown in Fig. 3. The sources were moved using an automated positioner. The reproducibility of the position is about 1 mm. The FOV was measured using ^{133}Ba , ^{57}Co and ^{60}Co .

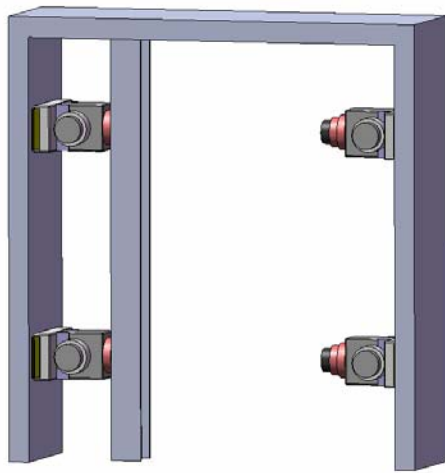


Figure 3 Pedestrian Portal Configuration

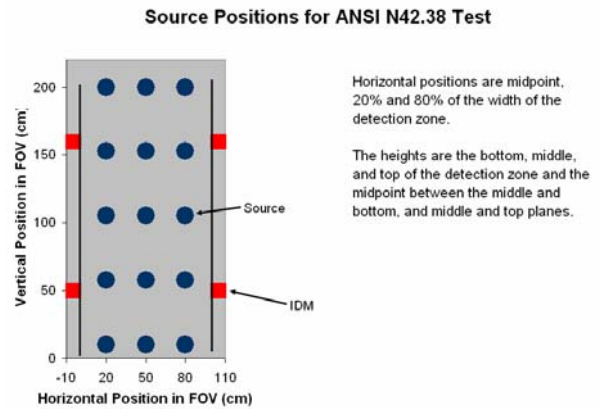


Figure 4 Source Positions in Detection Zone

The uniformity of the response in the detection zone was measured by moving the sources at 15 positions through the detection zone as shown in Fig. 4.

RESULTS

Efficiency

A total of 8 IDMs were measured. The absolute efficiency for all IDMs is shown in Fig. 5. This shows the typical dependence on energy of p-type HPGe detectors and that the IDMs have efficiencies within 5% for energies above 100 keV. The efficiency at 59 keV depends on the crystal dead layer thickness which varies from detector to detector, giving this point a standard deviation of 15%. The standard deviation at 1332 keV is 1.7%. The average efficiency is shown in Fig. 6. The relative efficiency of the average detector is about 55%.

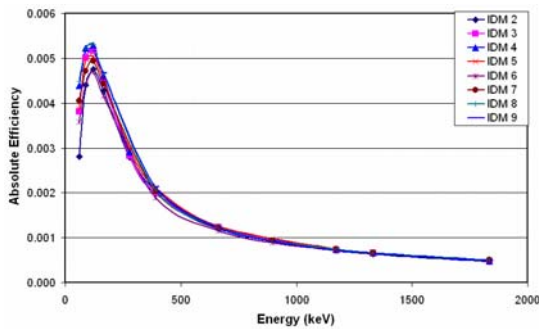


Figure 5 Efficiency for Point Source at 25 cm for Several IDMs

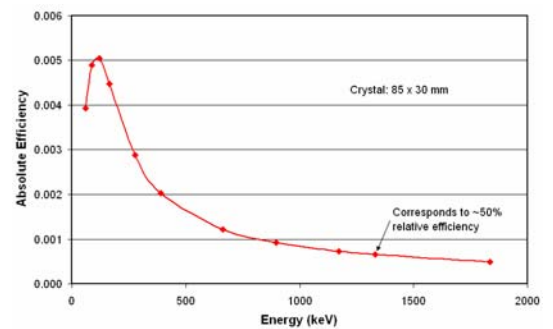


Figure 6 Average Efficiency for IDMs

RESOLUTION

The resolution (FWHM) for all 8 IDMs is shown in Fig. 7. With one exception, the results are clustered together showing the detectors are similar enough to be treated equally by any analysis software. There is no explanation for the performance of IDM 5, that is, IDM 5 appears to be the same as the others in other aspects. The average resolution is shown in Fig. 8.

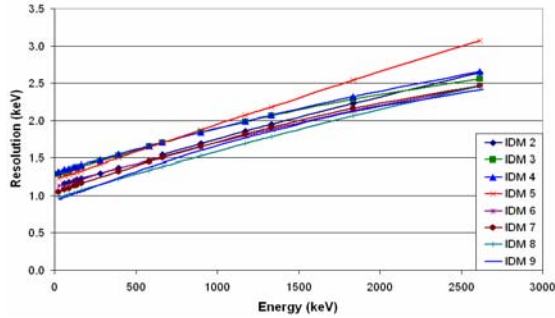


Figure 7 Resolution of all 8 IDMs

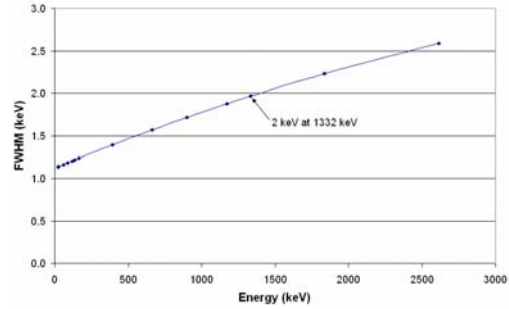


Figure 8 Average Resolution of IDM

Response along the vertical direction

The IDMs are uncollimated in the vertical direction. For the pedestrian portal, the detection zone is from 10 cm to 2 m above the floor. The response should be as uniform as possible for activity anywhere in this zone. Based on measurements of the detector response, the distance between the detectors was determined to have the best uniformity when the detectors were separated by 1.1 m. Figure 9 shows the relative response, at 383 keV, for 2 IDMs individually and the expected composite result.

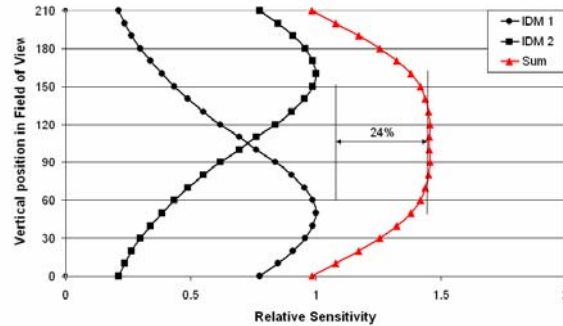


Figure 9 Calculated Vertical Response for 2 IDMs

The source was moved vertically in a plane 1 m from the front face of the detector. The composite or sum represents the response of the two IDMs which are added to improve the detection ability.

Horizontal Field of View

The horizontal field of view (FOV) as shown in Fig. 10 is reduced by collimators (Fig. 2). The FOV is reduced to minimize the contribution from other pedestrians and the natural background. The collimator in this measurement was 12.5 mm steel plates positioned 19.7 cm apart with the detector endcap recessed 9 cm. The source was 1 m from the endcap. The width of 0.8 meters is the nominal horizontal length of the detection zone when using the ANSI N42.38 specification of a 1 second collection time and the pedestrian moving at 1.2 m/s. Data collected when the pedestrian was in

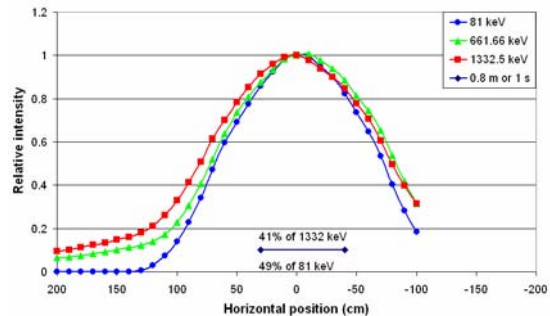


Figure 10 Horizontal Field of View

this zone would represent about 49% at low energy and 41% at high energy of the possible data collected over a length of 4 meters. This is because the steel collimator is more effective at low energies. This indicates that more collimation could be used to reduce background and unwanted counts from the next person without reducing the data from the subject in the detection zone. The ability to collect data in the list mode (that is, a continuous time-stamped data log) enables the software to dynamically determine the time when the source is centered in the portal and select the time window for the best sensitivity.

Response in the Detection Zone

The test positions for the source are in the 20%, middle and 80% of the horizontal distance of the detection zone and at five vertical positions: bottom, 25% of height, middle, 75% of height, and top of the detection zone as required by the ANSI standard and shown in Fig. 4. For the pedestrian portal, this corresponds to a horizontal distance between the source and endcap of 20, 50, and 80 cm and vertical distances from the floor of 10, 57.5, 105, 152.5 and 200 cm. The response at 383 keV for 2 IDMs is shown in Fig. 11, with the source at 0.5 m. The response at 1.3 MeV for the sum of 4 IDMs is shown in Fig. 12 for these positions.

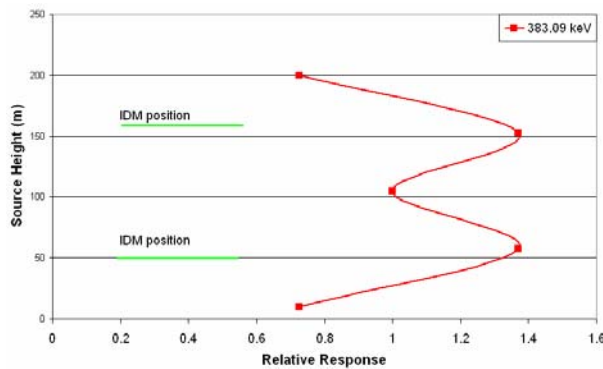


Figure 11 Measured Vertical Response for 2 IDMs

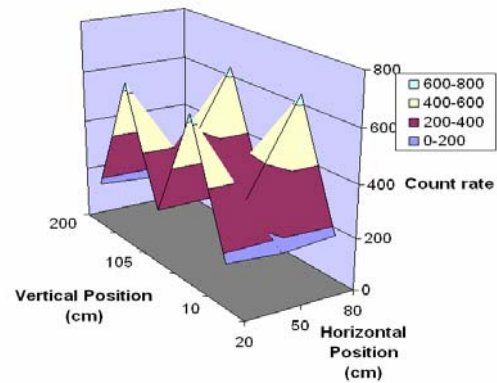


Figure 12 Response for 4 IDMs in Detection Zone at 1.3 MeV

Most of the detection zone has a response from 200 to 300 (count rate). The use of 4 IDMs smoothes out the response. Figure 13 shows the horizontal response for 1 IDM when the source goes through the detection zone at the point nearest the IDM. Figure 14 shows the horizontal response for the same IDM at the highest point in the detection zone.

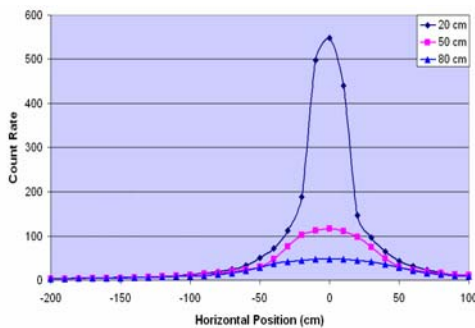


Figure 13 Horizontal Response at 1.3 MeV at Closest Position

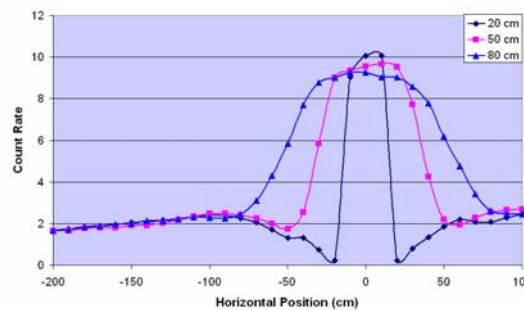


Figure 14 Horizontal Response at 1.3 MeV at Farthest Position

One measure of the minimum identifiable activity is the spectrum contents in the expected count time. The count time is fixed at 1 s in N42.38. Figure 15 shows the 1 second (real time) spectrum with the source stationary at the midpoint for the sum of 4 IDMs. Figure 16 shows the summed spectrum over a 1-second time window for 4 IDMs with the source moving through the portal. Both of these spectra were taken with 2.5 MBq ^{133}Ba , 110 kBq ^{57}Co and 728 kBq ^{60}Co sources.

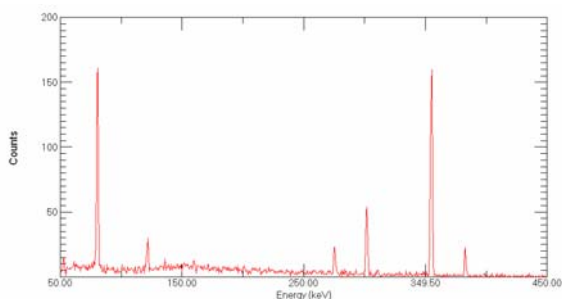


Figure 15 Response for 1 s at Center of Detection Zone

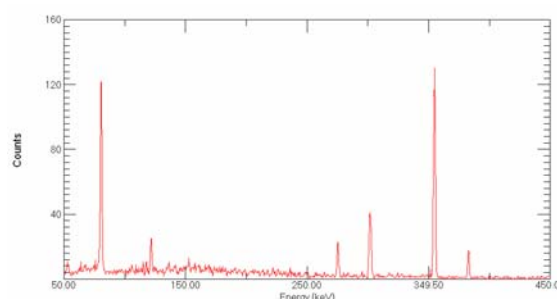


Figure 16 Response for 1 s pass through

The stationary spectrum has about 20% more total counts than the moving spectrum. In Fig. 16, the peak quality factor (Q) [4] for 122 keV peak is about 7.1. The Q threshold for the required false positive rate depends on the local background, but is generally set to 5. This gives the Minimum Identifiable Activity (MIA) of ^{57}Co based on the 122 keV peak as less than 110 kBq for the collection time of 1 s moving at 1.2 m/s, which is lower than the detection activity of 185 kBq and the identification activity of 555 kBq given in N42.38.

CONCLUSIONS

The configuration of a pedestrian portal with 4 IDMs, each with a HPGe of 85 x 30 mm, has been tested for uniformity of response and sensitivity (efficiency). The detector placement was shown to have good uniformity in the detection zone as defined in ANSI N42.38. In addition, the number and size of detectors have the necessary sensitivity to meet the detection requirements of the standard. Further work will concentrate on determining the false positive rate and determine the minimum identifiable activity for more nuclides.

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