Performance of Light-Weight, Battery-Operated, High Purity Germanium Detectors for Field Use

Ronald Keyser, Timothy Twomey, Daniel Upp
ORTEC
801 South Illinois Avenue
Oak Ridge, TN USA 37831

Abstract
The detection and identification of chemical and nuclear materials for safeguards and interdiction purposes often depend on the analysis of the complex gamma ray spectra from the material, either directly or induced by neutron interrogation. The gamma-ray detector should have sufficient stopping power for the high energy gamma rays and sufficient resolution to separate the individual gamma rays in the analysis. To be of practical use for portable applications, the detector element must be of a size adequate to collect sufficient data in reasonable measurement times. Only HPGe detectors can combine adequate size and stopping power with high resolution, but they must be cryogenically cooled to operate. Many electro-mechanically cooled detectors have been developed to overcome this limitation for use in fixed installations. These coolers have typically required significant electrical power and many are heavy. Commonly, such coolers may not be moved while operating or even relocated without extensive time to recover from the movement. The mechanical actions of the coolers can cause degradation of the resolution. Several recent advances have been made in refrigerator technology to overcome the power, transportation and vibration problems. This has enabled several different low-power coolers to be developed for HPGe detectors. In this work, we investigate the absolute efficiency and resolution over a wide energy range for a HPGe detector designed for use in field identification of illicit materials. Results will be presented for efficiency from 60 keV to above 1.5 MeV in several common geometries, as well as resolution over the same energy range and incident geometries.

Introduction
Germanium detectors (HPGe) have been the choice for high-resolution, gamma-ray spectroscopy for many years because of their high resolution and efficiency or stopping power especially at energies above 2 MeV. The interdiction of nuclear materials during illegal transportation requires both the detection of the radiation and the identification of the radionuclides in order to distinguish among the various categories of nuclides. Interdiction regimes, based upon available technologies, were developed rapidly after the tragic events of 9-11.

In general, a low resolution or “no-resolution” portal monitor based on an inorganic or organic scintillator provides initial detection, followed by a search and identify phase. A major problem with these systems is that of “innocent alarms” or false positives, where, for example, a naturally radioactive substance triggers a portal monitor. An equally severe problem is the false negative problem whereby nuclear material can be masked or hidden in an otherwise innocent shipment.

Ultimately a nuclide identification must be made. For logistical reasons, such as to preserve traffic flows, it is necessary to make a positive identification in as short a time as possible. It is therefore highly desirable to have a hand held system with excellent resistance to both false positives and false negatives.

In the ITRAP[1] study two years ago, it was concluded that none of the available hand-held identifiers was adequate for this purpose. NaI based identifiers had good efficiency but inadequate resolution. Room temperature semiconductors such as CZT, have adequate resolution, but low efficiency. HPGe, apart from the need for cryogenic cooling, is the ideal candidate for this application.

A hand-held instrument must be small and light enough to be easily carried and positioned near the vehicle or container to be checked. The system may sit unused for extended periods of time, but must be available quickly when a suspected container is detected.

While a portable HPGe detector is the choice for resolution and efficiency, it must be cooled to 100 °K to operate properly. For many years, this was done with liquid nitrogen[2]. Liquid nitrogen however, has disadvantages for a system that is in a remote location and operated by non-scientists. In principle, these disadvantages can be overcome by the use of mechanical coolers.

Early mechanical coolers were very heavy and consumed significant power (~4 kW). More recently low-power, lighter-weight, portable models have been developed[3,4,5], but not yet widely used, especially in portable applications. The newest devices are extremely low power and are now light enough in weight to be used as handheld units even when integrated with the batteries, signal-processing electronics, computer and display, to make a complete system.

A potential disadvantage is the vibration of mechanical coolers; vibration causes microphonic noise on the detector output signal, which usually increases the peak resolution. Careful mechanical design can help reduce the noise, and active methods have been developed to compensate or remove the remaining noise contribution to the output signal[2,6].

The Prototype Instrument

A small ORTEC HPGe detector cooled by a high reliability Stirling cooler (SAX101) from Hymatic Engineering was constructed. The cooler is capable of approximately 1 W of heat lift at 100° K, and draws less than 25 watts when operating. The crystal size chosen was a GEM (P-type) 50mm diameter by 30mm deep coaxial crystal. This size was chosen because it is easily cooled by the SAX101 even in high ambient conditions and has single nuclide sensitivity comparable to the NaI detectors in common use for hand held identifiers. An active digital noise reduction filter (LFR) was implemented in a DSPEC jr digital gamma-ray spectrometer. The prototype detector and cooler are shown in Fig. 1.

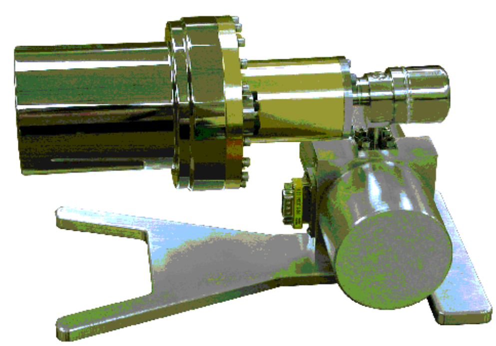

Figure 1 Prototype Detector and Cooler

Testing

Several reports and standards have been written to define the tests and performance necessary for an instrument used for detection of nuclear material[7,8] at border crossings and for other security needs. Two important parameters to be tested in ANSI 42.34 are the efficiency and the ability to differentiate between gamma rays of similar energy.

The efficiency of HPGe detectors has been measured according to IEEE 325-1996 for many years. However this definition does not adequately describe the absolute efficiency in the screening applications, which are the intended use of this system. To show the efficiency performance of the detector, the efficiency is measured over a wide range of energies and incident angles.

The ability to separate close gamma-ray peaks is indicated by the resolution of the detector. The IEEE 325 standard is used to define the resolution, but the point source geometry specified in the standard has been replaced with a geometry closer to the expected situation.

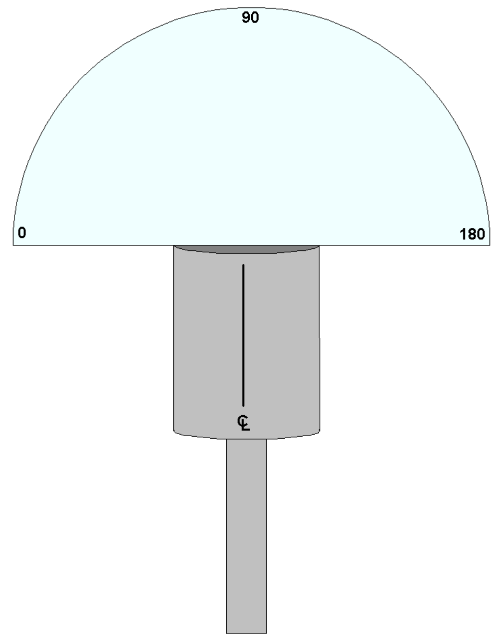

Figure 2 Vertical Plane Configuration

Experimental Setup

The detector efficiency was measured using a NIST-traceable, mixed-nuclide, point-source standard with energies from 59 to 1836 keV. The source was positioned at a distance of 25 cm from the center of the flat circular surface of the endcap, at different positions in two orthogonal planes. The first plane (vertical) was on the cylindrical axis of the detector, such that the 90° position was on axis of the detector. The second plane (horizontal) was orthogonal to the first, in the plane of the endcap flat surface, centered on the center of the surface, and with the sources at a distance of 25 cm. In both planes, the source was positioned at 10-degree increments beginning at 0° and continuing to 180°. The 0° and 180° positions are thus the same for both planes. Spectra were taken at each position such that the peak area uncertainty was generally less than 5%. Plane 1 is shown in Fig. 2. Plane 2 is not shown.

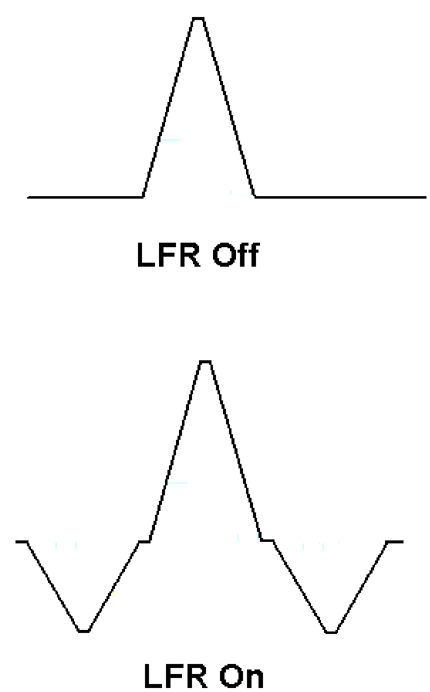

Figure 3 Filter Function with LFR On and Off

The resolution was measured using a similar NIST-traceable point source. The source was positioned at 10 cm from the center of the endcap. Spectra were collected on the modified DSPEC jr for different shaping time constants. Both the filter rise time and the flattop width were varied. The shaping time specified in the IEEE 325 standard is 6 microsecs. Shorter time constants are used here in order to replicate the performance of the system as it is likely to be used in the field.. The DSPEC jr was modified to include the LFR filter in place of the normal trapezoidal filter. The LFR filtering is designed to remove the low frequency component of the signal. The vibration from the cooler is typically low frequency. Data were collected with the LFR on and off. The LFR filter output waveform is shown in Fig. 3.

Angular Response Results

The efficiency vs energy for the on-axis case at 25 cm is shown in Fig. 4. It shows the typical energy dependance for a GEM (P-type) HPGe detector. Other angles are similar.

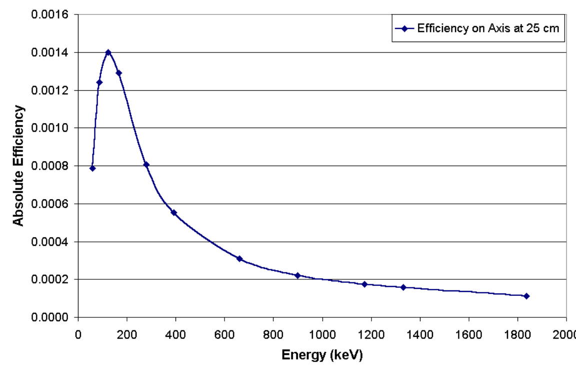

Figure 4 Efficiency vs Energy for On-Axis Point Source

The efficiency vs angle response for all energies for Plane 1 is shown in Fig. 5. The data in Fig. 4 were taken at 90° . For energies above about 300 keV, there is little change in the efficiency as a function of angle. For 59 keV, there is a decrease from the efficiency at 90° to the efficiency at 0° and 180°, which are in the plane of the endcap. This decrease is due to the increased thicknesses of material in the sides of the detector construction. N42.34 specifies that there must be no change in nuclide identification for a source placed anywhere within a cone whose apex is on the detector endcap center with angle of 45°. Within the 45° window, the efficiency varies less than 15% above 200 keV and about 30% for the worst case of 59 keV. It is not expected that this small reduction will affect the nuclide identification.

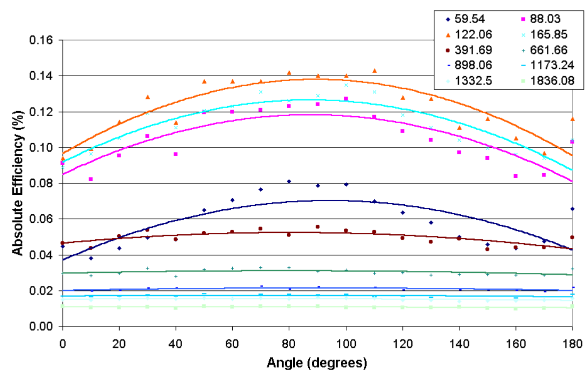

Figure 5 Efficiency vs Angle for Vertical Plane

The efficiency vs angle response for all energies in plane 2 is shown in Fig. 6. These data do not show any angular dependance, indicating that the detector is cylindrically symmetric, in both sensitive and insensitive material distribution.

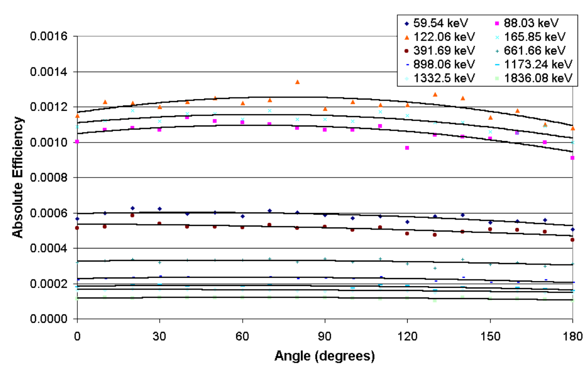

Figure 6 Efficiency vs Angle for Endcap Plane

Energy Resolution Results

The resolution with the LFR on and off, at energies from 59 to 1836 keV for a flattop setting of 0.8 microseconds as a function of rise-time are shown in Figs. 7 and 8. The results for other flattop settings of 0.6 and 1.0 are similar. The best resolution for the various flattop values occurs at different rise-time values for LFR on and off. The best results for each combination of LFR and flattop are shown in Fig. 9. The resolution is approximately 1.2 keV at 60 keV and 2.0 keV at 1.3 MeV with LFR on. These are obtained for all of the flattop settings, but at different risetimes.

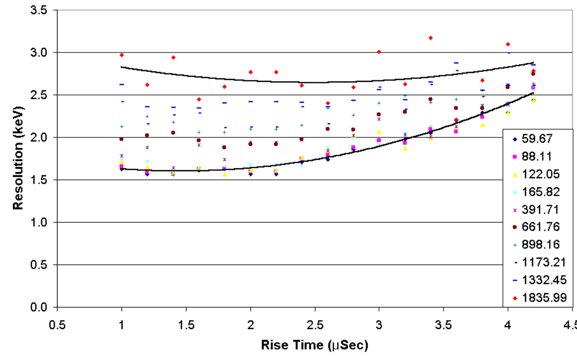

Figure 7 Resolution vs Risetime for Energies from 60 to 1800 keV with LFR Off

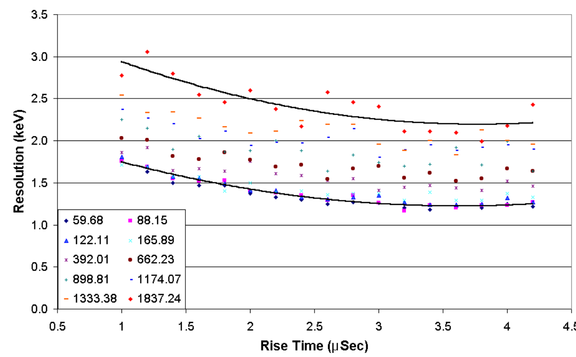

Figure 8 Resolution vs Risetime for Energies from 60 to 1800 keV with LFR On

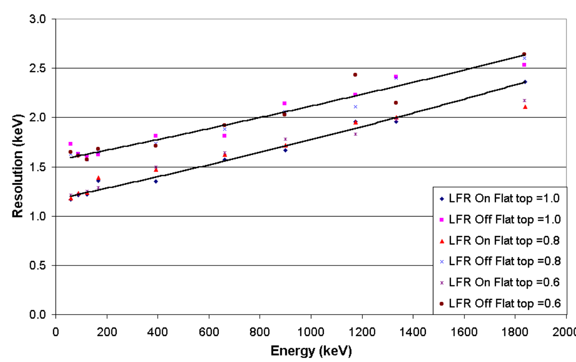

Figure 9 Resolution vs Energy for LFR On and Off and Different Flattop-Risetimes

Conclusions

A prototype HPGe detector, cooled by a portable high reliability Stirling cryocooler has been built and tested.

The efficiency and resolution results show that a low-power, hand-held HPGe detector system is feasible and is capable of meeting the requirements of a nuclide identifier intended for use in Homeland Security and border control of nuclear materials.

The efficiency results show that the detector has acceptably good sensitivity over a wide range of incident angles and energies. Resolution performance is good, even at short rise times which can be important in the intended applications, where wide ranging count rates may be anticipated. Further work will concentrate on improving detector performance.

Acknowledgment

The authors would like to acknowledge the on-going assistance from members of the Stirling Products Group at Hymatic Engineering Ltd, Reddich, England.

Refernceces

1. ITRAP, "Illicit Trafficking Radiation Detection Assessment Program", Final report, ARC Seibersdorf. February, 2001

2. T.J. Paulus, D. D'Adamo, T.R. Twomey, S.E. Wagner, "A portable, High-Rate HPGe Spectrometer Useful for Safeguards Applications", 15th Annual ESARDA Meeting, Rome, Italy

1993, Proceedings Page 621

3. A. Lavietes, G. Mauger, E. Anderson, “Electromechanically-Cooled Germanium Radiation Detector System”, UCRL-JC-129695, 1998.

4. J. A. Becker, C. P. Cork, L. Fabris, N. W. Madden, “Portable, Low-Power, mechanically-Cooled Ge Spectrometer”, Symposium on Radiation Measurements and Applications, Ann Arbor, May 2002

5. Masaki Katagiri, Atsushi Birumachi, Kaoru Sakasai, Kouji Takahashi, “Portable Gamma-ray Monitor Composed of a Compact Electrically Cooled Ge Detector and a Mini-MCA system”, 2002 IEEE Nuclear Science Symposium Conference Record, November 2002

6. D. L. Upp, R. M. Keyser, T. R. Twomey, “New Cooling Methods for HPGe Detectors and Associated Electronics”, MARC VI proceedings, April 2003

7. American National Standards Institute, “Performance Criteria for Hand-held Instruments for the Detection and Identification of Radionuclides”, ANSI N42.34 Draft, March, 2003

8. International Atomic Energy Agency, “Detection of Radioactive Materials at Borders”, IAEA-TECDOC-1312, September 2002