The Shape of the Full-Energy Gamma Ray Peak in Germanium Detectors for Different Energies and Incident Geometries

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Abstract

The accurate analysis of gamma-ray spectra from germanium detectors requires that the peak shape of the full-energy gamma-ray peak be used in the determination of the peak area, especially in the difficult deconvolution regions needed in isotopic ratio programs such as MGA and PC/FRAM. Modeling programs such as MCNP also use the peak shape to predict the response of HPGe detectors. The resolution and peak shape are defined in the IEEE 325-1996 standard by the Full Width at Half Maximum (FWHM), Full Width at Tenth Maximum (FW.1M) and Full Width at Fiftieth Maximum (FW.02M) values. However, IEEE 325 only specifies the measurements at one geometry and two energies. Nearly all measurements are made in a different geometry and at other energies. Other investigators[1] have shown that the peak FW.1M and FW.02M change with position of the incident gamma ray on the front of the detector. To quantify the resolution and peak shape as a function of energy and point of incidence, measurements have been made on several coaxial detectors of different sizes in various source-detector geometries. The full-energy peaks from 60 keV to 2.6 MeV were used. The sources used were an ^{241}Am source, ^{60}Co and a natural thorium oxide sample. The ^{241}Am 59 keV gamma rays were collimated by a 2 cm thick, 1 mm diameter bore lead collimator. For one series, the ^{60}Co 1332 keV gamma rays were uncollimated and taken at 25 cm for comparison with manufacturer's specifications. The ^{60}Co and ^{208}Tl were collimated with a 10 cm thick, 2 mm diameter bore tungsten collimator. These collimated sources were used to collect spectra for the incident beam on the front and sides of the detectors. The detectors were placed in a low-background shield to reduce any contribution from external sources. None of the detectors tested was a low-background type. Data are presented to show that the peak shape changes with incident beam position and full peak energy.

Introduction

In a previous paper[2], it was shown that the normal specifications for a germanium gamma-ray detector are not sufficient to determine the appropriateness of the detector for a specific application. Gehrke demonstrated this, but also gave measurement results showing that even more details of the detector are needed. Specifically, these details are needed when the performance of the detector is to be predicted by modeling programs. To study this peak-shape variation further, several detectors were scanned in a fashion similar to the previous work. Both n-type (GMX) and p-type (GEM) detectors were used. For the p-type detectors, only large detectors were used as it was expected that these would have the largest variation. In this paper, the results of measurements similar to those of Gehrke, but on different types of detectors, are shown. The measurements are scans of the detectors using small-diameter, well-collimated beams of different energy gamma rays. These scans show the peak shape as a function of incident position.

The detectors described here ranged from 45 mm to 86 mm diameter and 50 to 110 mm length.

Experimental Setup

The sources used were ^{241}Am, ^{60}Co and natural thorium oxide. The ^{241}Am and ^{60}Co are point sources and the thorium oxide is bulk powder. The ^{241}Am source was collimated to a 1 mm diameter beam by a 3 cm long by 17 mm diameter lead collimator. The ^{60}Co source was collimated to a 2 mm diameter beam by a tungsten collimator. The thorium oxide source is a cylinder 8 mm diameter by 53 mm long. It was placed in the same collimator as the ^{60}Co. All of the measurements were taken with the detector in a lead shield. In addition, ^{60}Co data were collected without a collimator. Complete details of the collimators were presented earlier[3].

The measurements were made on the top or front of the detector in East-West and North-South modes and on the side of the detector in Up-Down mode as shown in Fig. 1.

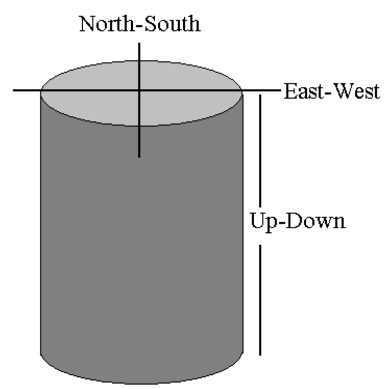

Figure 1 Scan Definitions on Detector

The spectra were collected with a DSPEC Plus, with 12 µs rise time, 1 µs flattop and a cusp of 1. The deadtime was always less than 10%. The number of channels was 16k, giving at least 6 channels in the FWHM of the narrowest 59 keV peak.

The peak areas and widths were calculated using the methods described in IEEE 325-1996 and IEC 61976-2000. The position numbers are arbitrary scale readings and are related to the detector position by the count rate data.

Unshielded ^{60}Co

The IEEE 325 specifies the FWHM of the 1332 keV peak of ^{60}Co be measured by placing the ^{60}Co point source at 25 cm from the face of the endcap and centered on the long axis of the detector. When the source is positioned closer to the detector the resolution will increase as shown in Figs. 2, 3, 4 and 5. These figures show the FWHM, FW.1M and FW.04M increase when the source is within 5 cm of the front face. The crystal is typically 4 to 10 mm from the inside of the endcap. The GMX detectors show more of an increase than the GEM detectors. The FW.1M and FW.04M show a larger percentage increase than the FWHM. In addition to the on-axis data, one data point was taken on endcap at approximately the edge of the crystal. The increase in peak width is attributed to the gamma rays being incident at high angles when the source is close.

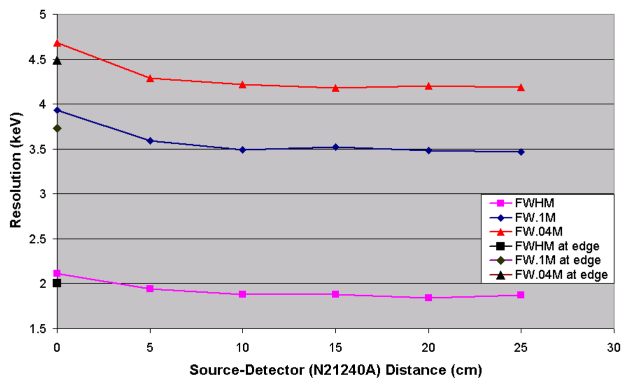

Figure 2 Resolution as a Function of Distance for GMX (N21240A).

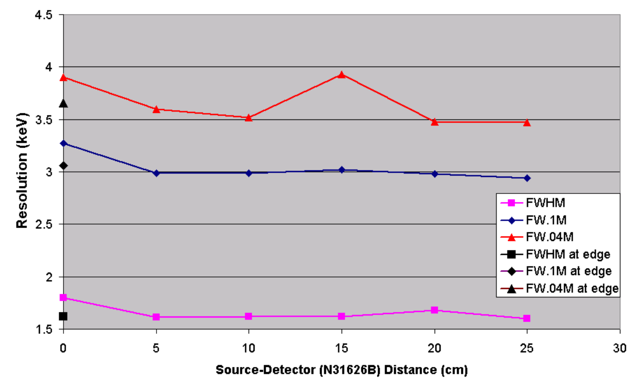

Figure 3 Resolution as a Function of Distance for GMX (N31626B).

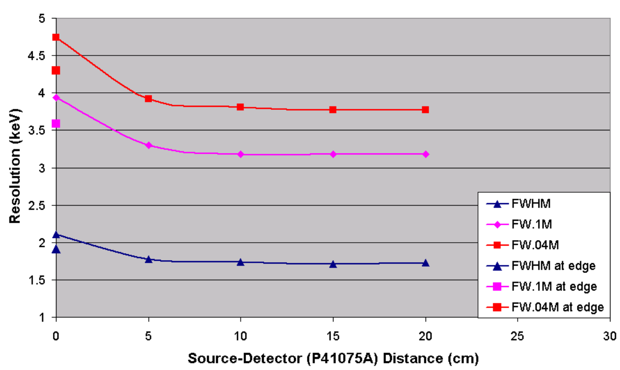

Figure 4 Resolution as a Function of Distance for GEM (P41075A).

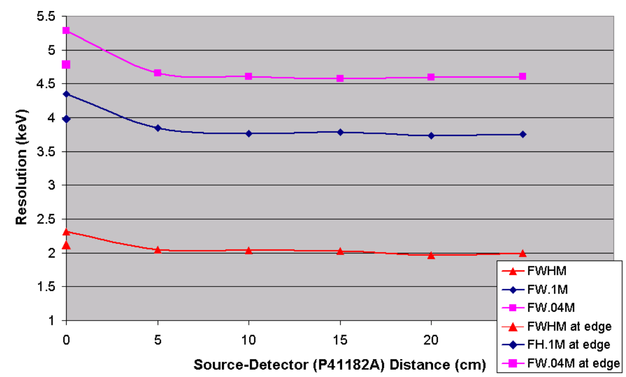

Figure 5 Resolution as a Function of Distance for GEM (P41182A).

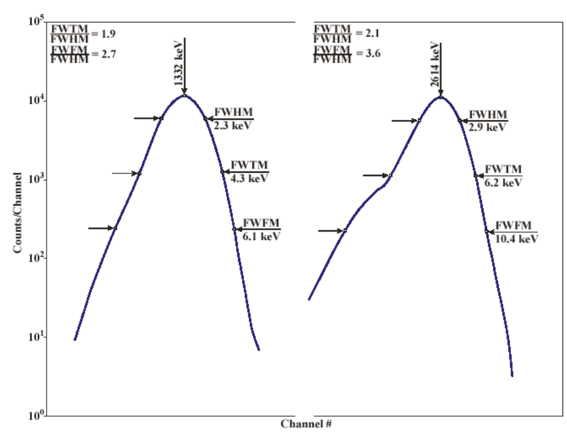

Figure 6 Peak Shape on and off Center. Adapted from Gehrke.

Collimated Thorium Source

In preparation for use in his modeling program, Gehrke measured one large GEM detector. Both sensitivity and peak shape were measured. The peak shape for the 2.6 MeV peak for a large p-type detector is shown in Fig. 6. Note the difference in the shape of the bottom of the peak between the position at the radial midpoint (midway between the outer edge and center) and the center of the crystal. A similar measurement on a different detector is shown in Fig. 7. This shows the FWHM, FW.1M and FW.04M at three positions on the crystal front. The size of the crystal is shown by the box. This confirms the earlier measurements of a detector of similar size. The resolution down the side of the crystal is shown in Fig. 8. Note there is no change with position. The smaller GMX detectors do not show the same dependance.

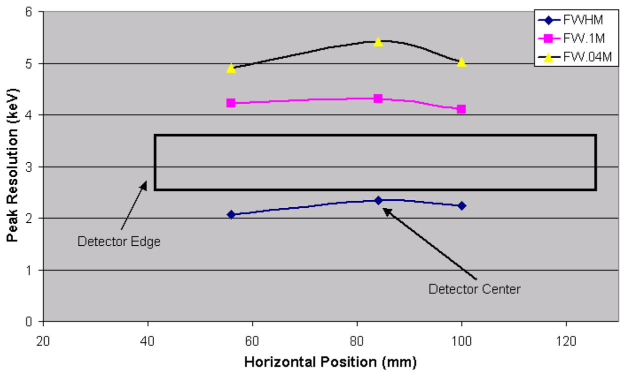

Figure 7 Resolution at 2.6 MeV on the Front of Detector P40175A.

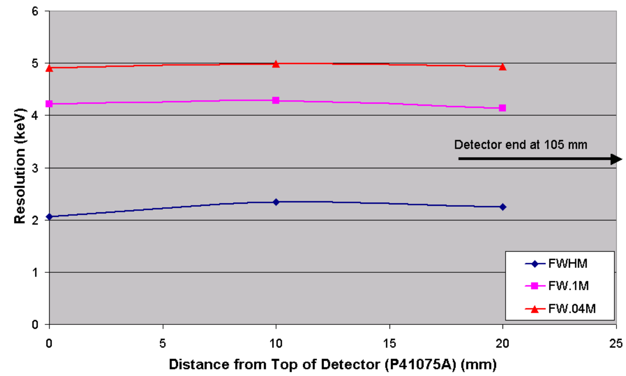

Figure 8 Resolution at 2.6 MeV Down the Side of the Detector P40175A.

Collimated ^{241}Am

The ^{241}Am scan on the front of a GMX (N31626B) with dimensions of 60 mm diameter and 60 mm length is shown in Fig. 9. The crystal diameter is shown by the black bar. Additional detectors are shown in Figs. 10, 11 and 12. Note the uniformity of the peak shape over the front, with the exception of the increase for a region in Fig. 10 and the general broadening near the edges of the crystal.

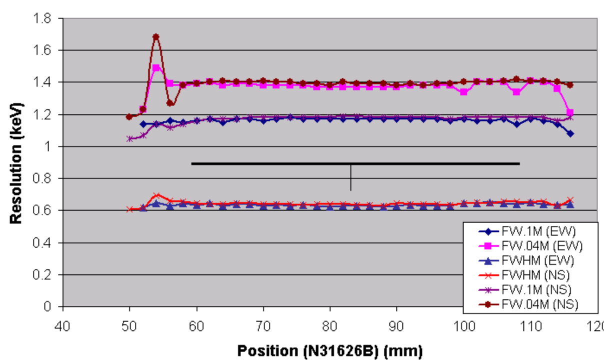

Figure 9 Resolution at 59 keV Across Front of GMX (N31626B).

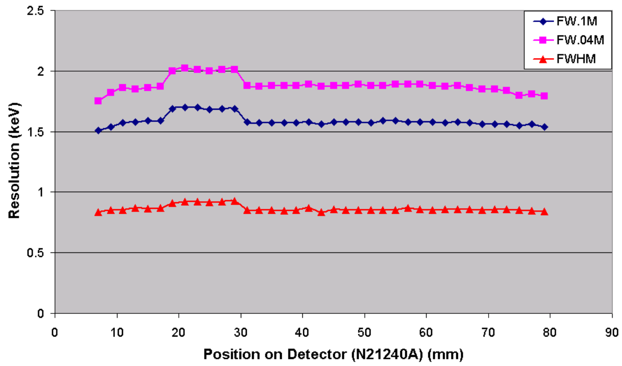

Figure 10 Resolution at 59 keV Across Front of GMX (N21240A).

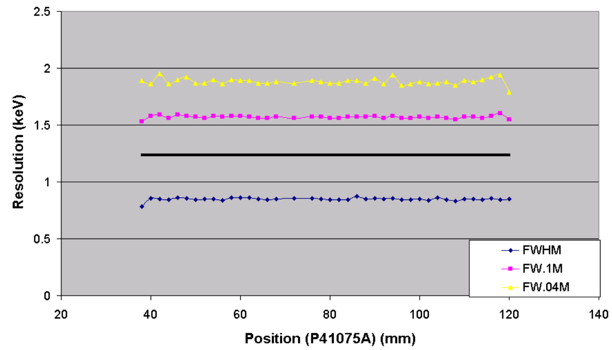

Figure 11 Resolution at 59 keV Across the Front of GEM (P41075A).

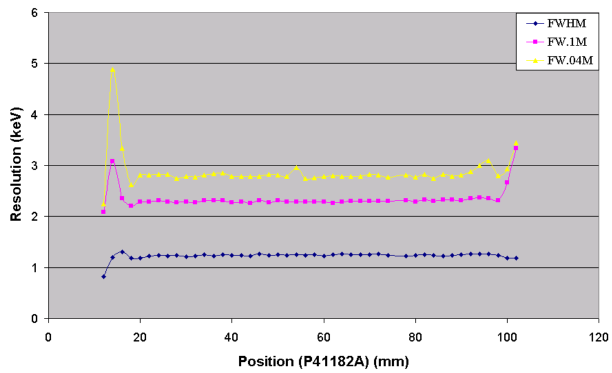

Figure 12 Resolution at 59 keV Across the Front of GEM (P41182A).

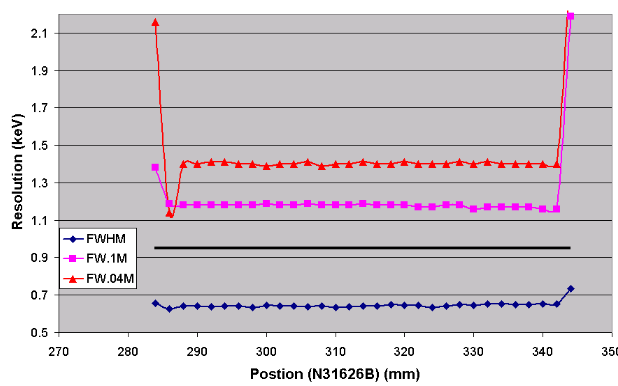

Figure 13 Resolution at 59 keV on the Side of GMX (N31626B).

The peak FWHM for the scans down the length of the crystal are shown Figs. 13, 14, 15 and 16. Both the EW and NS positions are shown for N31626B. These are again uniform. With the exception of Fig. 10, it is expected that the detectors would exhibit this behavior because the low-energy gamma rays interact near the surface.

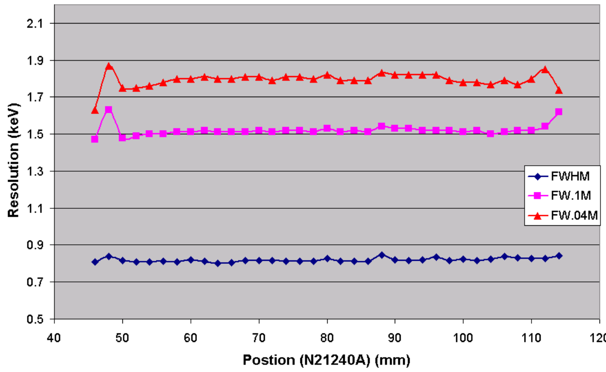

Figure 14 Resolution at 59 keV the Side of GMX (N20140A).

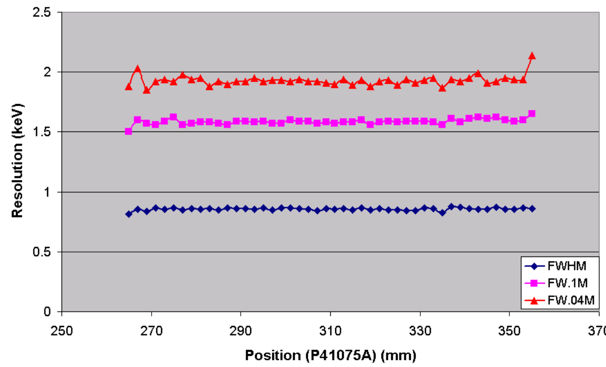

Figure 15 Resolution at 59 keV on the side of GEM (P40175A).

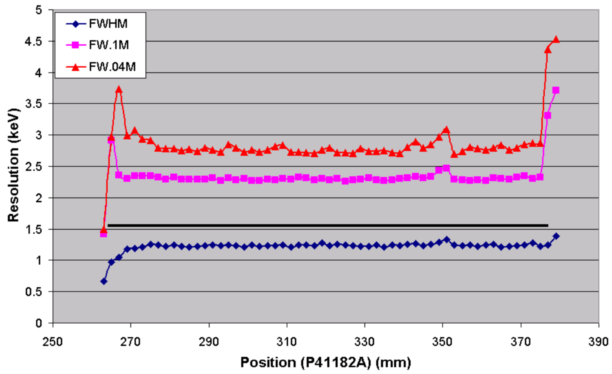

Figure 16 Resolution at 59 keV on the Side of GEM (P41182A).

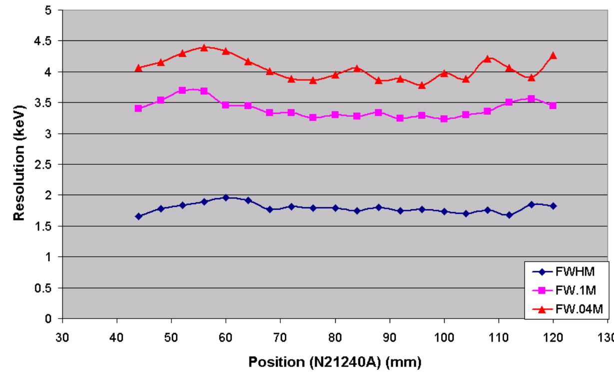

Figure 17 Resolution at 1332 keV Across Front of GMX (N21240A).

Collimated ^{60}Co

The 60Co scans across the front for the same detectors are shown in Figs. 17, 18, 19 and 20. The 1173 and 1332 keV peaks show similar results. The GMX detectors do not show the increase in width at the center of the crystal, but the increase is seen in the GEM detectors. This is consistent with the thorium results above. Note that this is a general increase in peak width, but is more pronounced at the base of the peak.

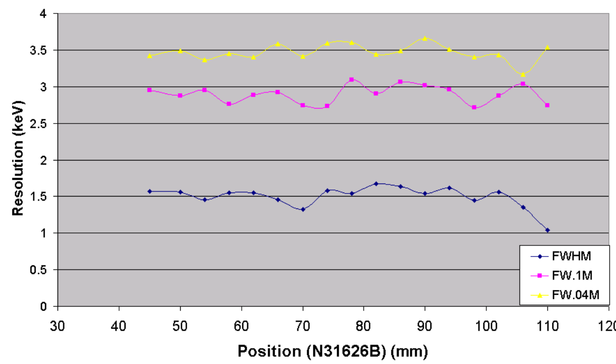

Figure 18 Resolution at 1332 keV Across Front of GMX (N31626B).

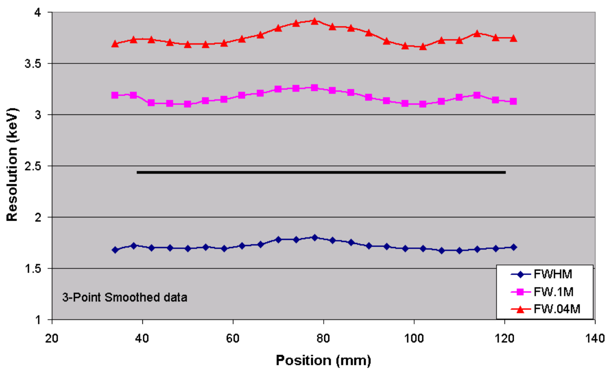

Figure 19 Resolution at 1332 keV Across Front of GEM (P41075A).

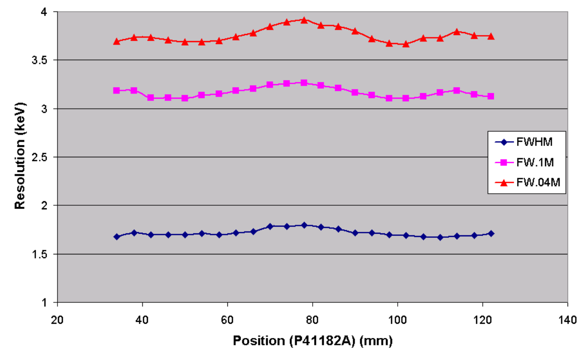

Figure 20 Resolution at 1332 keV Across Front of GEM (P41182A).

The scan on the side for GEM detectors is shown in Figs. 21 and 22. Note the shape is very nearly constant over the length except at the bottom of the crystal for Fig. 21 , but begins to significantly increase about 75% of the distance from the top in Fig. 22.

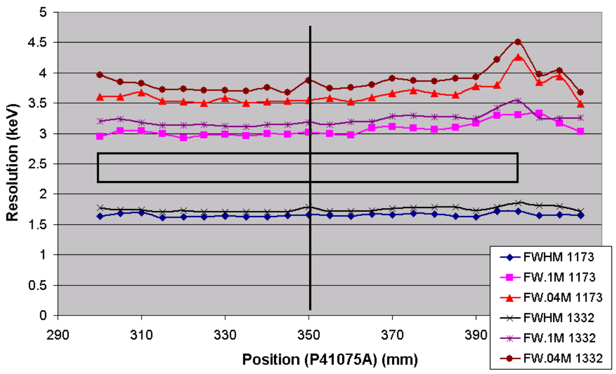

Figure 21 Resolution at 1332 on Side of GEM (P41075A).

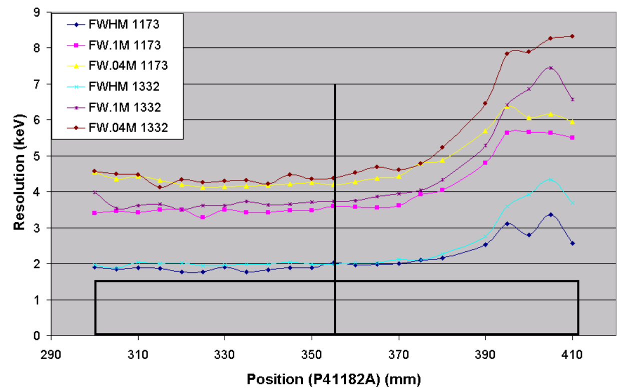

Figure 22 Resolution at 1332 on Side of GEM (P41182A).

Conclusion

The measurements on these several detectors support, in general, the measurements made previously, indicating that the peak shape can not always be considered to be a uniform for different positions of the crystal. Thus, any model of a detector performance will, of necessity, require a very precise characterization of the detector and detailed knowledge of the crystal and the source for the model to be accurate.

1. R. J. Gehrke, R. P. Keegan, and P. J. Taylor, "Specifications for Today's Coaxial HPGe Detectors," 2001 ANS Annual Meeting, Milwaukee, WI

2. R. M. Keyser, T. R. Twomey and P. Sangsingkeow, "Advances in HPGe Detectors For Real-World Applications," Journal of Radioanalytical and Nuclear Chemistry, Vol. 244, No. 3 (2000) 641-647.

3. R. M. Keyser, "Resolution and Sensitivity as a Function of Energy and Incident Geometry for Germanium Detectors", 2002 IRRMA Meeting, June 2002, Bologna, Italy