Efficiency and Resolution of Germanium Detectors as a Function of Energy and Incident Geometry

Ronald M. Keyser, Senior Member IEEE and Walter K. Hensley

Abstract – The IEEE Germanium Test Standard (325-1996) is widely used for the specification of HPGe detectors, but only specifies detector performance in limited situations. Modeling programs such as MCNP are being used to predict the response of HPGe detectors in a wide variety of detector-source geometries. The accurate simulation of germanium detectors in response to incident gamma rays relies on knowledge of the performance of the detector in different detector-source geometries. The efficiency and resolution depend on the detector-source geometry. Other investigators [1,2] have shown that the peak shape and efficiency change with position of the incident gamma ray on the detector. The efficiency as a function of incident pencil beam gamma rays has been measured for several different types of detectors at different energies. Based on these measurements, the dead layer on the sides (cylindrical surface) of the detector was estimated and used in the MCNP program to calculate the efficiency in the same geometry. Using the detailed measurements, some agreement between experimental data and calculations was obtained.

I. INTRODUCTION

In previous work, Gehrke showed the change in peak area of a low-energy gamma ray (238 keV) for incident positions down the side of a detector. Metzger showed the change in peak area of a low-energy gamma ray (59 keV) for positions on the side of a detector. Such variability has possible implications for the accuracy the physical model of the detector used in the calculation of the peak shape and area determination. Of further significance is that the variation of the side and front responses is different for different detectors.

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R. Keyser is with ORTEC. He can be reached at ORTEC, 801 South Illinois Avenue, Oak Ridge, TN 37830, +865.483.2146, or RonKeyser@IEEE.org

W. Hensley is with Pacific Northwest National Laboratory. He can be reached at PNNL, Richland, WA 99352, or Walter.Hensley@PNL.GOV

To quantify the efficiency variation as a function of energy and incident point of incidence, measurements have been made on several coaxial detectors of various crystal types and sizes in different geometries. The full-energy peaks from 60 keV to 1.3 MeV were used. The detectors were placed in a low-background shield to reduce contributions from external sources. The detectors studied are given in Table 1 which are representative of the majority of detectors in use today.

Table 1. Detectors Studied

Detector Number	Diameter (mm)	Length (mm)
N21240A	60.5	60.4
N31626B	53.0	47.8
P41075A	84.5	100.5
P41182A	86.1	112.4
P41181A	81.5	53.7

The MCNP calculations are based on the P41075A detector. This detector was chosen because of its non-uniform behavior similar to that seen in the detector in [2].

The sources used for these measurements were ^{241}Am and ^{60}Co. The 59 keV gamma rays were collimated by a 3 cm thick lead collimator, with a 1 mm diameter hole. The ^{60}Co was used with a 8.2 cm thick tungsten collimator with a 2 mm diameter hole. These

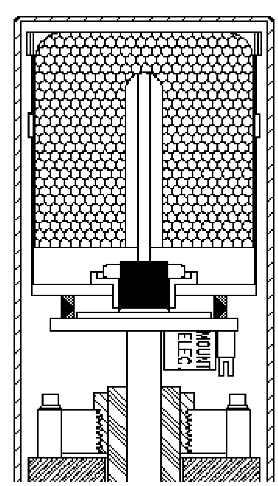

Figure 1. Detector Construction.

collimated sources were used to collect spectra for the incident beam on the front and sides of the detectors. The peak areas and widths were calculated using the methods given in IEEE 325-1996. Complete details of the collimators were presented earlier [3].

The general construction of a detector is shown in Fig. 1. Note the thick bands on the mounting cup. Only two are shown here, but there can be more.

The input detector description, collimator and source position for ^{241}Am are shown in Fig. 2. Not all of the details of the detector construction shown in Fig. 1 are included. The calculations were not extended below the crystal end and the internal details are not significant at these energies. The inputs for ^{60}Co are the same except the collimator.

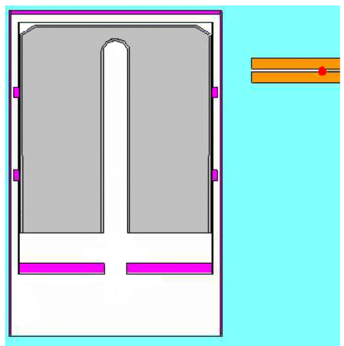

Figure 2. MCNP Detector and Source Input for ^{241}Am.

II. RESULTS AT 59 keV

The results of the ^{241}Am scan for P41075A and P41082A are shown in Fig. 3. Also shown is the result from (2) which were taken on a detector similar to P41075A in size. The Metzger results are normalized to

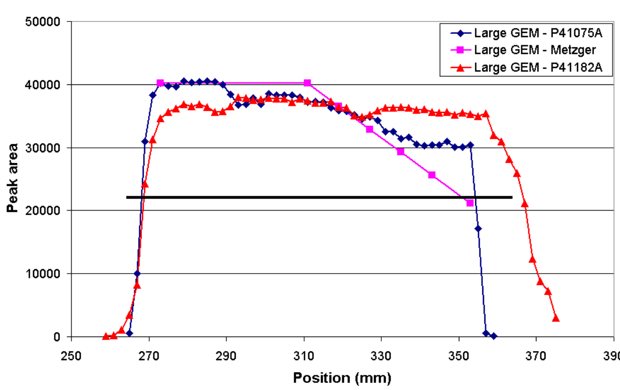

Figure 3. ^{241}Am Area for Three Detectors.

the efficiency of P41075A at the front of the crystal. The black bar is the physical length of the crystal. Note that P41075A and the detector measured by Metzger are similar, while P41082A does not show the drop in efficiency from the midpoint of the detector toward the bottom. Both P41075A and P41085A show the decrease in efficiency due to the bands.

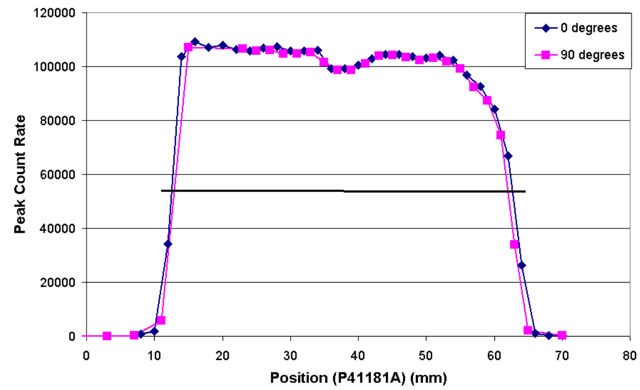

Figure 4. Scan at 59 keV on Short Detector.

The shorter detector, P41181A, is shown in Fig. 4. The data shows two scans at 90° apart on the endcap. The two are essentially identical. This result is similar to P41182A, which does not show a reduction in peak area toward the bottom of the crystal.

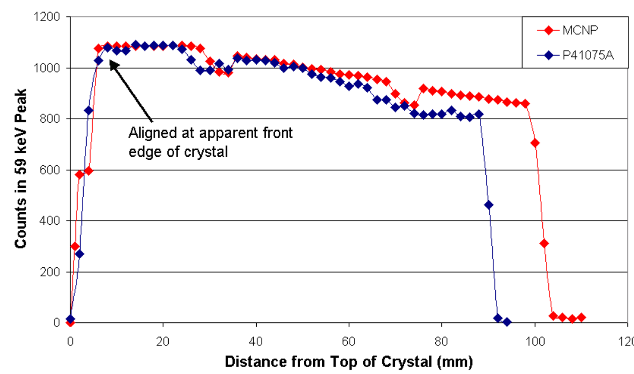

Figure 5. MCNP and P41075A Aligned at Front of Crystal.

Only the crystal used in P41075A was used in the MCNP calculation. Fig. 5 shows the results of the calculation compared to the experimental data. In this figure the two curves have been normalized so that the peak area at the apparent front of the crystal agree. The peak amplitude or efficiency has been normalized such that the average efficiency in the uniform region at 15 to 20 mm from the front of the crystal is the same in both cases. Note however, that the reduction in activity for the two regions with bands do not agree in the two curves.

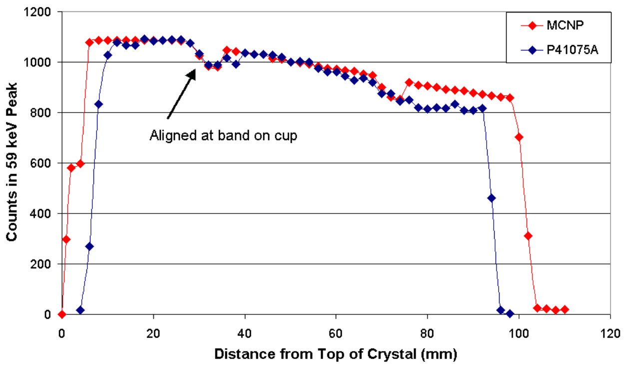

Figure 6. MCNP and P41075A Aligned at Bands.

Figure 6 shows the same data with the horizontal axis normalized so that the reduction in activity at the bands is at the same distance. The two bands agree in position along the length of the crystal.

There is an apparent disagreement in the efficiency for the total length of the detector. Except for this, there is reasonable agreement between the MCNP and experimental data for the relative efficiency of the detector. The calculation of absolute efficiency with MCNP and the experimental data was not attempted.

III. Results for 1173 and 1332 keV

The scan for ^{60}Co for P41082A is shown in Fig. 7. The two energies are shown plotted in both directions to show the uniformity of the peak area over the length of the crystal. The higher energies are less sensitive to the changes in the dead layer of the detector.

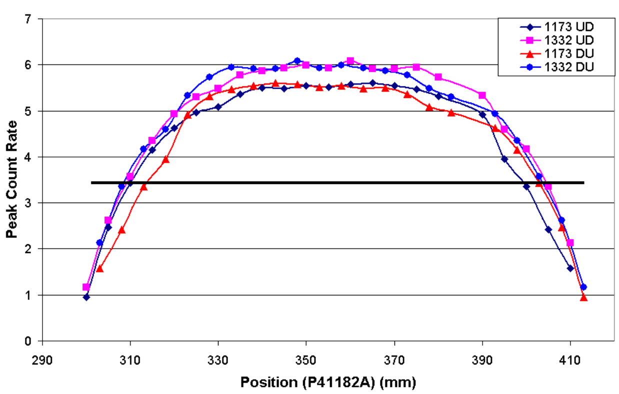

Figure 7. Side Scan for 1173 and 1332 keV.

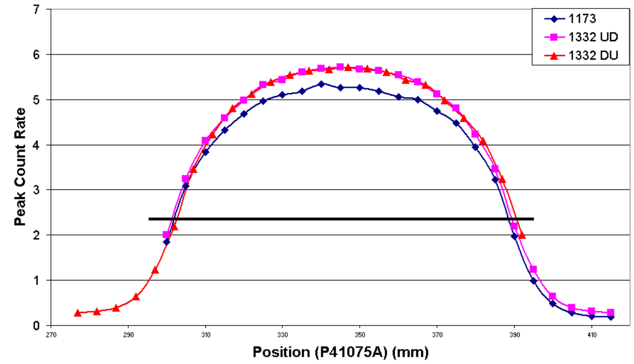

Figure 8. Side Scan for 1173 and 1332 keV.

Figure 8 shows the similar curve for P41075A. Again there is good uniformity along the length of the crystal.

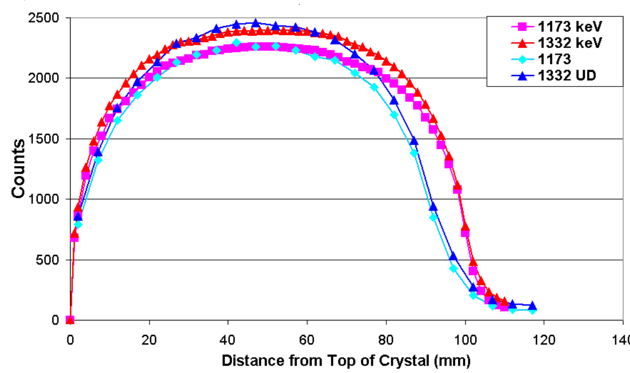

Figure 9. MCNP Result Compared to Measurement for 1173 and 1332 keV.

Figure 9 shows the MCNP calculation result compared to the experimental data. Both results show the same uniformity. The 1332 keV results are shown with higher efficiency than the 1173 keV results, which is contrary to the general reduction in efficiency with increasing energy. To account for this, it was necessary to allow MCNP to calculate the leakage through the tungsten collimator. Thus, it is believed that this result of the 1332 keV peak having higher peak areas than the 1172 keV peak is due to the higher penetration of the 1332 keV gamma ray through the tungsten.

Also, the apparent length of the crystal in terms of efficiency differs between the experimental and MCNP calculations. The difference is consistent between the two energies.

IV. Conclusion

The experimental data show that individual detectors can have different sensitivities along the length of the crystal. When the detailed measurements were used to define the detector for the MCNP calculations, the result for the peak sensitivities was shown to duplicate some of the individual detector differences. However, some important differences were not able to be duplicated. The detector construction and crystal details are necessary before accurate MCNP calculations can be made, but these are not sufficient to reproduce the detector response for all conditions.

V. References

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

[2] R. L. Metzger, private communication, see also: R. L. Metzger, K. A. Van Riper, and K. J. Kearfott, "Radionuclide Depth Distribution by Collimated Spectroscopy," 2002 ANS Topical Meeting, Santa Fe, NM.

[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.