# EFFICIENCY FOR CLOSE GEOMETRIES AND EXTENDED SOURCES OF A P-TYPE GERMANIUM DETECTOR WITH LOW-ENERGY SENSITIVITY

R.M. Keyser(1) and T.R. Twomey(1)

(1) ORTEC, 801 South Illinois Avenue, Oak Ridge, TN 37831 USA
(ron.keyser@ortec-online.com)

## Abstract

Typically, germanium detectors designed to have good sensitivity to low-energy photons and good efficiency at high energies are constructed from n-type crystals with a boron-implanted outer contact. These detectors usually exhibit inferior resolution and peak shape compared to ones made from p-type crystals. To overcome the resolution and peak-shape deficiencies, a new method of construction of a germanium detector element was developed. This has resulted in a gamma-ray detector with high sensitivity to photon energies from 14 keV to 2 MeV, while maintaining good resolution and peak shape over this energy range. Efficiency measurements, done according to the draft IEEE 325-2004 standard, show efficiencies typical of a GMX or n-type detector at low energies. The detectors are large diameter suitable for counting extended samples such as filter papers. The Gaussian peak shape and good resolution typical of a GEM or p-type are maintained for the high count rates and peak separation needed for activation analysis.

## Introduction

The first hyper-pure germanium (HPGe) radiation detectors were made as p-type diodes with a thick n-type contact on one surface of the germanium crystal and a thin p-type contact on the other surface. This is still the most common form of HPGE detector construction. In the normal construction of a true COAX or closed end COAX, the thicker contact is put on the outer cylindrical surface of p-type crystal material and the thinner contact is put on the inner surface of the cylinder, as shown in Fig. 1. The contacts are made in this way on p-type material to make the diode junction near the outer contact. Putting the junction near the outer contact gives the most uniform electric field inside the crystal and thus the best resolution.

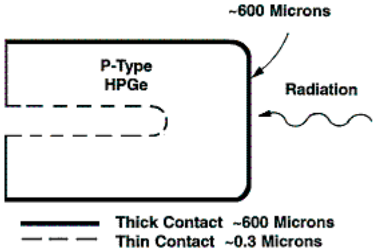

**Figure 1** Closed-End Coaxial HPGe Detector.

The outer contact is from 600 to 1000 microns thick. Generally, the contact thickness increases with detector size. The contact layer does not produce any signal for gamma rays which are absorbed in it; it is a “dead layer”. The inner contact is about 0.3 microns thick. The thick, outer contact completely absorbs low-energy photons, and these detectors have an efficiency which increasing gamma ray energy from zero until it reaches a maximum at about 120 keV. The endcap material also absorbs low-energy photons, further decreasing the low-energy efficiency.

If the germanium crystal material is n-type, then the contact material can be reversed, that is, the thin contact can be put on the outside and the thick contact on the inside, as shown in Fig. 2. This still maintains the junction near the outer contact. The low-energy efficiency is increased because of the reduced thickness of the dead layer. In most cases, the endcap material is also made of a material with high transmission at low energies, such as beryllium metal foil or carbon fiber foil. However, the resolution (FWHM) is not quite as good for the n-type detectors as for the p-type detectors at high energies.

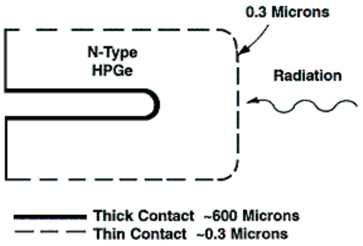

**Figure 2** Reverse Electrode Coaxial Detector.

Recently, a new thin n-type contact has been developed for the outer surface of p-type crystals. This results in an increase in the sensitivity to low-energy photons to almost that of the n-type detectors while maintaining the good resolution of the p-type detectors. The low-energy efficiency for these detectors is adequate for applications where the lowest energy of interest is above ~14 keV. For energies below this, the normal n-type detector is still needed. These new detectors also have the low atomic number endcap material, usually carbon fiber. Another advantage of the new p-type detectors is the availability of larger crystals for higher efficiency detectors at high energies with good resolution. These new detectors have been commercialized under the name ORTEC PROFILE series FX.

The methods described in IEEE draft standard 325-2004 were used for all the measurements described here.

## Methods

To compare the efficiency of the different types of detectors, one of each of the three types (GEM, GMX, FX) was selected such that they have similar physical diameters. Two other detectors were included in the comparison: an Act II[1] and an FX with a larger diameter, but similar length to the other FX and the ACT II.

The detectors were positioned, one at a time, in a low-background shield to minimize external counts. The shield is 15 cm of lead, lined with 8 mm of copper and 1 mm of tin. The sources used were all NIST-traceable, and included mixed nuclide and single nuclide sources. The mixed nuclide sources contain $^{241}$Am, $^{109}$Cd, $^{57}$Co, $^{139}$Ce, $^{203}$Hg, $^{113}$Sn, $^{137}$Cs, $^{60}$Co and $^{88}$Y. Single nuclide sources were used for $^{55}$Fe, $^{109}$Cd and $^{57}$Co. The 22 keV efficiency was measured using the combined X-ray peak (21.99 and 22.16) from $^{109}$Cd, with the intensity based on the yield ratio with 88 keV. The CTBTO sources are in the geometries specified by that agency for their samples and are 7 cm diameter by 5 mm and 15 mm thick. The matrix material is epoxy. The point sources are deposited on thin mylar, some have an evaporated aluminum coating on the mylar. The filter paper sources are paper filters in mylar film. The sources were held in position by low mass mounting to minimize scattering.

---

[1] ACT II is a 7 cm diameter by 27 mm deep LEGe detector from Canberra Industries Inc

The "on endcap" spectra were collected with the sources directly on the thin entrance window of the detector. The spectra were collected for sufficient live time to have 1% or less counting uncertainty in the smallest peak used. True coincidence or cascade summing was ignored in these measurements. The correction for random summing was also not applied.

The close geometry for some of the samples, and the high count rates caused some spectra to have distorted peak shapes, making the peak area determination different for these cases as shown in Fig. 3. In addition, the differences in resolution among the detectors made the determination of the low energy peak areas difficult for some detectors. Shown in Fig. 4 are the spectra at 88 keV for three detectors. The FWHM and FW02M for the FX are 0.74 and 1.91 keV; the GEM are 0.94 and 2.3 keV; and the GMX is 1.14 and 2.73 keV.  This indicates the need for the best resolution possible at low energies, when these are of interest in the spectrum.

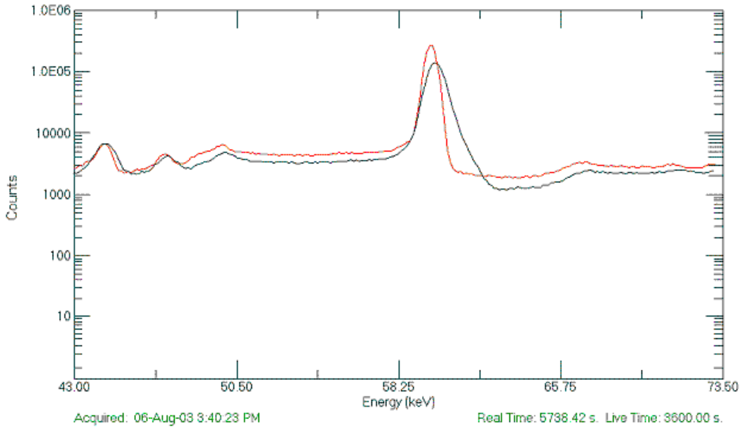

**Figure 3**  Different Peak Shapes for Different Detectors.

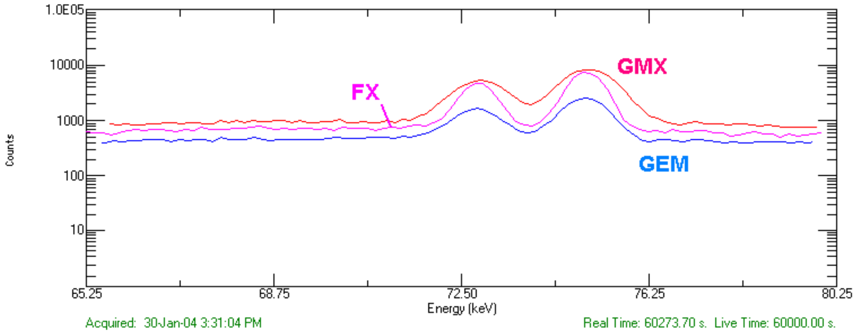

**Figure 4**  Different Resolutions at Low Energy for GMX, FX and GEM Detectors.

## Detectors

The detectors measured are shown in Table I. The top three detectors have similar diameters. The area of the front surface (diameter) is the major contributor to the low energy-efficiency. The ACT II detector has a diameter similar to the FX, but a larger diameter. The last FX detector has a similar length, but an even larger diameter.

The thick dead layer on sides of  the GEM and FX detectors will reduce the active diameter by about 1.2 mm. The GMX has a thin contact on the sides as well as the front.

Table I.  Detectors Measured

| Detector Number | Type | Diameter (mm) | Length (mm) |
|---|---|---|---|
| N21879A | GMX | 60.6 | 56.7 |
| P41358A | FX | 58.9 | 25.3 |
| P11697A | GEM | 60 | 83.9 |
| ACT II | BeGe | 70 | 27 |
| P41321A | FX | 85 | 30 |

## Results

*Disk Source 15 mm x 7 cm*

Figure 5 shows the absolute efficiency for the five detectors for the disk source on endcap. In Ref. 1, the efficiency of disk sources on endcap was shown to increase with increasing detector diameter until the detector is 130% of the source diameter. This is shown here, with the 85 mm detector having the highest efficiency. As expected the longer detectors have the highest efficiency at higher energies.

Figure 6 shows the low energy part of Fig. 5 expanded. Note that the GMX has the highest efficiency down to the lowest energy because it has the thinnest dead layer. The The GEM has the lowest efficiency due to the thick dead layer and the other three are similar and show the differences in diameter of the detectors.

*Disk Source 5mm x 70 mm*

Figure 7 shows the absolute efficiency for the 5 mm thick by 70 mm diameter disk source. Although not all detectors are shown, this shows the same relationships as the 15 mm disk source.

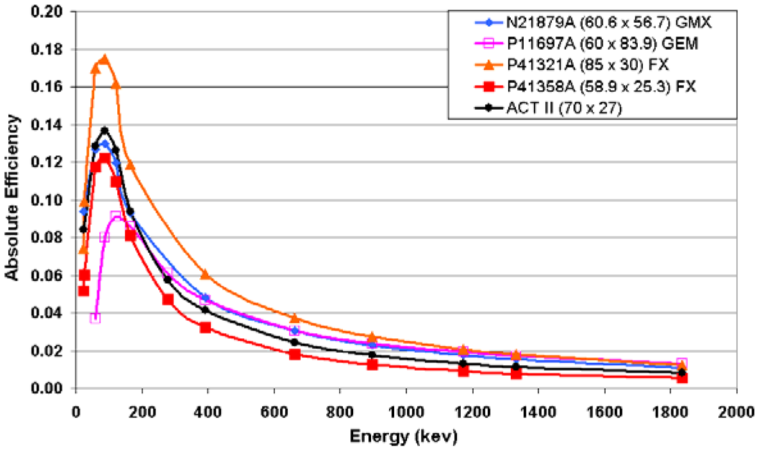

**Figure 5** Absolute Efficiency for 15 x 70 mm Mixed Nuclide Source on Endcap.

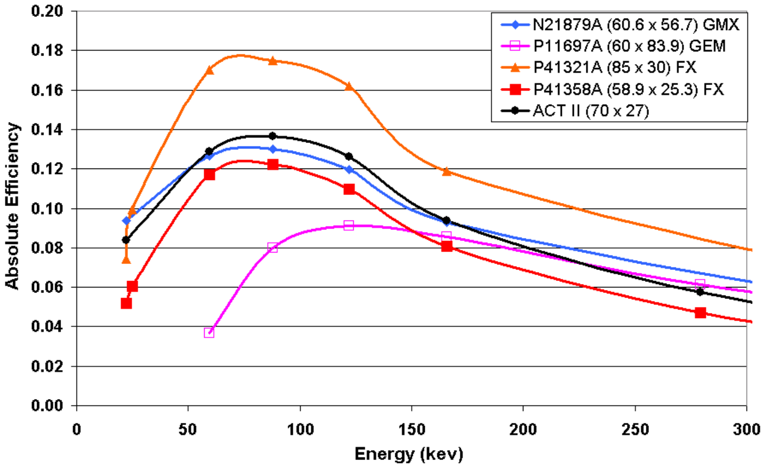

**Figure 6** Expanded Low-Energy part of Fig. 5.

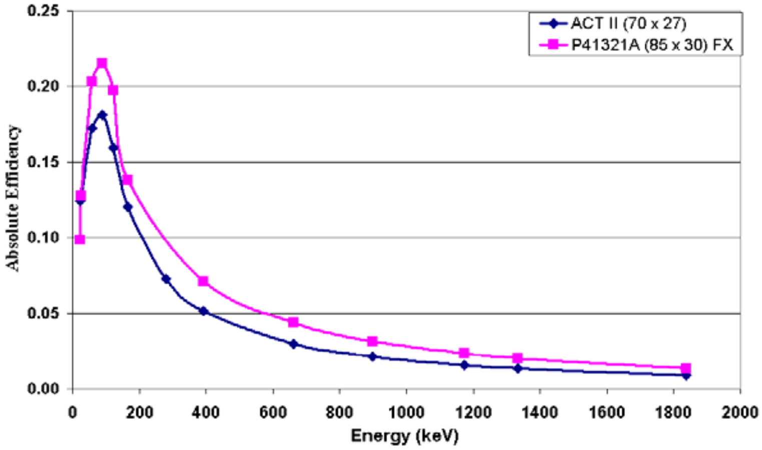

**Figure 7** Absolute Efficiency of the 5 mm x 70 mm disk source.

### *Filter Paper Source 50 mm Diameter*

Figure 8 shows the absolute efficiency for the thin filter paper source. Note that the differences among the different detectors is less than the differences for the 70 mm diameter source. All of these detectors have a larger diameter than the source, so the extra detector diameter is less effective.

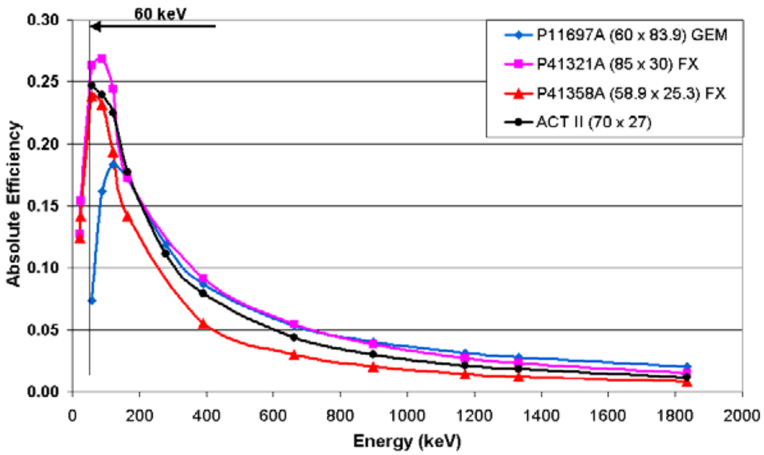

**Figure 8** Absolute Efficiency for 50 mm Filter Paper

### *Filter Paper Source 10 cm Diameter*

Figure 9 shows the absolute efficiency for the 10 cm diameter filter paper. Not all detectors are shown, but the GMX has high sensitivity to a lower energy than the other detectors shown and the larger diameter detector is significantly more efficient even though the diameter is smaller than the source diameter.

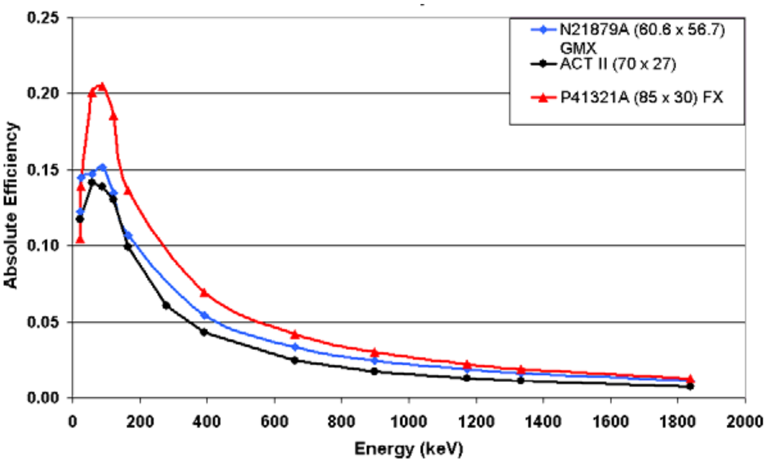

**Figure 9** Absolute Efficiency for 10 cm Filter Paper

### *Point Source on Endcap*

The point source efficiency on endcap is shown in Fig. 10. In this measurement, the detector diameter is less important to the efficiency than the dead layer and endcap attenuation. The GEM has the lowest efficiency at low energies and the GMX has the highest efficiency. The FX and ACT detectors are between these two.

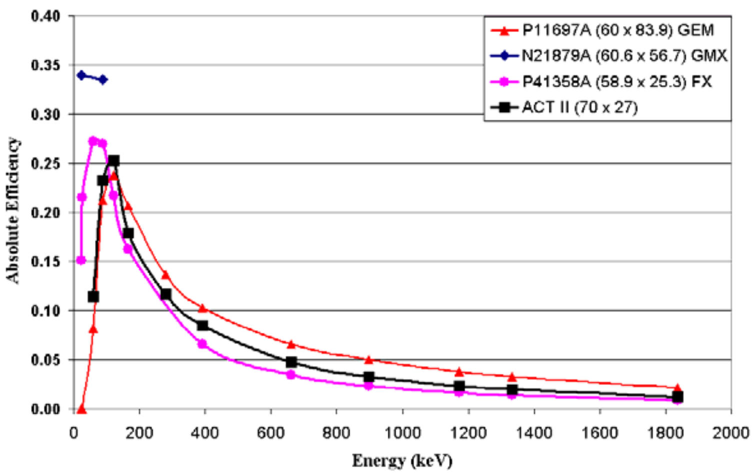

**Figure 10** Absolute Efficiency for Point Source on Endcap.

### *Point Source at 25 cm*

The point source efficiency at 25 cm distance is shown in Fig. 11. This measurement is shown for comparison with the traditional method of stating relative efficiency as the value for the 1.33 MeV line of $^{60}$Co at 25 cm on axis from the front face of the endcap. Note that at this energy, the efficiency of the large diameter, short length detector is about the same as the smaller diameter, long length detector. While the smaller FX and the ACT II have lower efficiency.

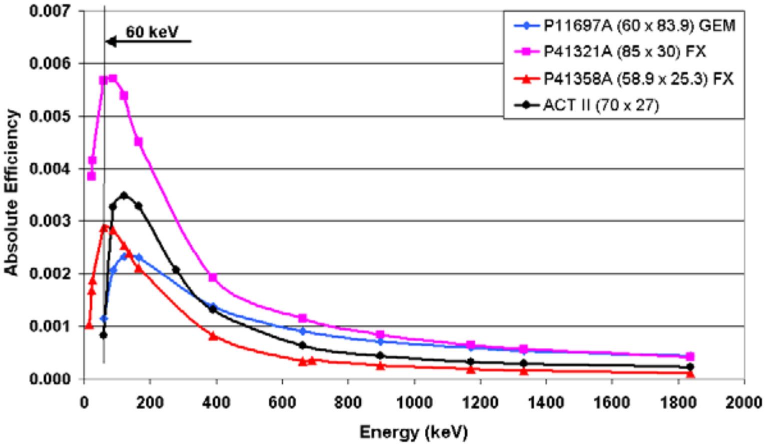

**Figure 11** Absolute efficiency for Point Source at 25 cm from endcap.

## Conclusions

The data show the new construction method can produce detectors with higher sensitivity or efficiency at lower energies than traditional p-type (GEM) detectors when installed in an endcap with a high transmission front window. The efficiency is not as high as a similarly sized GMX below about 14 keV. The resolution for the FX detector is better than either the GMX or the GEM. The increased efficiency from 14 to 100 keV and improved resolution are useful in many applications such as NAA and safeguards, where the ability to detect and separate low-energy gamma rays is important.

[1] 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