

# Information about Photon Detectors



## A5. Categories of Photon Detectors

EG&G ORTEC has the right photon detector for a wide range of x- and gamma-ray energies. See Fig. 13 for the energy ranges of the detectors discussed in this section.

### A5.1. GEM and GAMMA-X Coaxial Detectors

GEM and GAMMA-X (GMX) coaxial detectors are characterized by the following specifications:

| Specifications                               | Coaxial Detector Type |
|--|-----------------------|
| • Relative Efficiency at 1.33 MeV            | GEM and GMX           |
| • Energy Resolution at:                      |                       |
| 1.33 MeV                                     | GEM and GMX           |
| 122 keV                                      | GEM                   |
| 5.9 keV                                      | GMX                   |
| • Peak-to-Compton Ratio at 1.33 MeV          | GEM and GMX           |
| • Peak Shape at 1.33 MeV                     | GEM and GMX           |
| FW.1M/FWHM                                   |                       |
| FW.02M/FWHM                                  |                       |
| • <sup>109</sup> Cd 22-keV/88-keV Peak Ratio | GMX                   |

### Efficiency as a Function of Energy

As shown in Fig. 15 (Refs. 3–5), the absolute efficiency of HPGe coaxial detectors varies with energy. The ratio of the number of counts in the full-energy photopeak to the total number of gamma rays emitted from a source is known as the absolute full-energy photopeak efficiency. This includes the effect of the solid angle subtended by the detector, and thus the source-to-detector distance. This absolute detection efficiency is a function of energy. For a gamma-ray or x-ray to be detected, the photon must transfer part or all of its energy by one of three interaction modes: photoelectric effect, Compton scattering, or pair production. For a count to occur within a nuclide's full-energy photopeak, all of the photon's energy must be deposited in the detector's active volume, either as a single photoelectric interaction or as a multiple

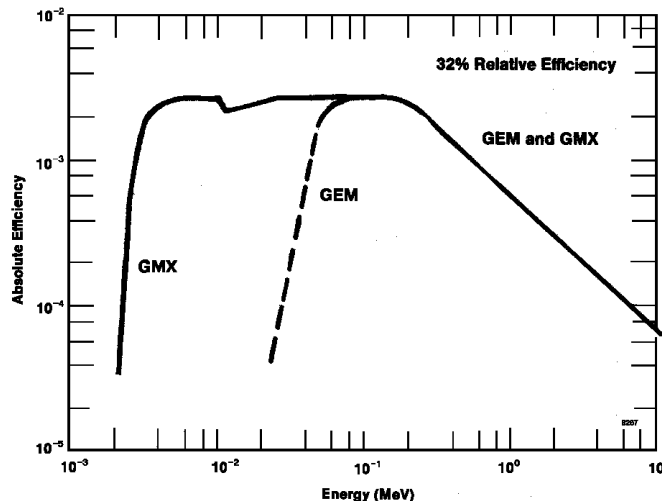


Fig. 15. Absolute Efficiency vs. Energy for 32% GEM and GAMMA-X HPGe Coaxial Detectors.

event. At 1.33 MeV, ~80% of the full-energy counts start with a Compton interaction.

At gamma-ray and x-ray energies up to ~40 keV, the relationship of efficiency to energy is dominated by the attenuation of these photons by materials outside the detector and by any dead layers on the detector periphery. For this reason, the GEM (p-type) and GAMMA-X (n-type) detectors have different responses.

In GAMMA-X detectors, the 0.3- $\mu$ m boron ion-implanted contact and thin beryllium front window allow photons of energy down to 3 keV to enter the active volume of the detector. Except for the anomaly at the 11-keV germanium absorption edge, virtually all photons up to 200 keV are detected. Above that energy, the efficiency falls off with the total absorption cross section of Ge, which is dominated by the fall-off in the photoelectric cross section.

Due to the 700- $\mu$ m-thick Li-diffused outer contact of the GEM detector, it experiences a fall-off of efficiency below ~100 keV, with almost all photons below 40 keV being absorbed in the outer dead layer. At higher energies the relationship between efficiency and energy is dominated by the average path length in the active volume of the detector. The efficiency decreases with increasing energy because the probability that the photon will interact within the detector also decreases with energy. Because it is primarily the detector volume (and somewhat the detector dimensions) that determines this average path length, both GEM and GAMMA-X detectors have the same efficiency at high energies (Refs. 3, 4, and 5).

A useful presentation is in Figure 16 (after Vano\*), which demonstrates there is little relationship between the relative efficiency at 1.33 MeV and the relative efficiency at other energies. See Section B.1.3 for further discussion.

\*Nucl. Instrum. Methods, 23 (1975) 573–4.

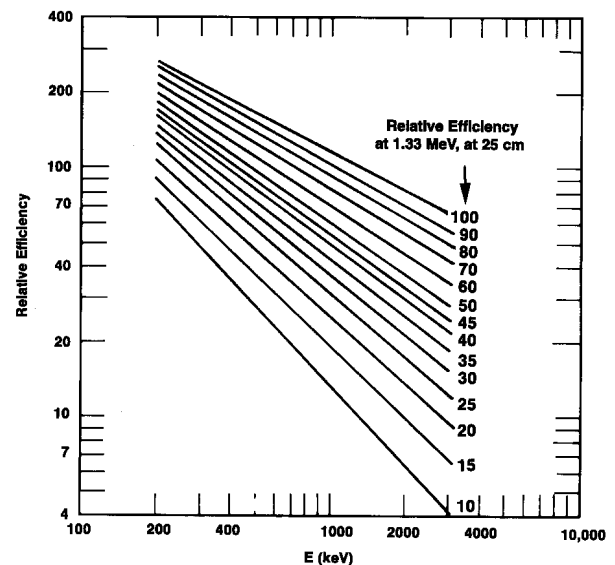


Fig. 16. Relative Efficiency as a Function of Energy for Detectors with Relative Efficiency from 10% to 100% at 1.33 MeV.

# Information about Photon Detectors



## Attenuation Effects

An example of attenuation effects in external materials is shown in the table below of the **percentage of photons transmitted through 1 mm of aluminum**, a material commonly used in detector endcaps. The relationship describing this attenuation is:

$$N = N_0 e^{-\mu x}$$

where N is the number of remaining photons in the beam of original intensity  $N_0$  after traversing distance x, and  $\mu$  is the absorption coefficient for aluminum.

Table 3. Percentage of Photons Transmitted, as a Function of Energy, through 1 mm of Aluminum.

| Energy (keV) | % Transmitted       |
|--------------|---------------------|
| 3            | $2 \times 10^{-32}$ |
| 5            | $1 \times 10^{-6}$  |
| 10           | 7                   |
| 20           | 50                  |
| 30           | 90                  |
| 50           | 96                  |
| 80           | 98                  |
| 100          | 98.3                |
| 400          | 99.1                |
| 1000         | 99.4                |

Another example is the percentage of photons transmitted through 0.7 mm of germanium, which is the typical thickness of the outer contact of a GEM (p-type) detector.

A practical example of the effects of detector dead layers on low-energy spectra is shown in Fig. 17.

Table 4. Percentage of Photons Transmitted, as a Function of Energy, through 0.7 mm of Germanium.

| Energy (keV) | % Transmitted |
|--------------|---------------|
| 20           | 0             |
| 30           | 0.2           |
| 40           | 7             |
| 50           | 24            |
| 60           | 42            |
| 80           | 67            |
| 100          | 79            |

## Relative Efficiency (at 1.33 MeV)

For historical reasons, the relative detection efficiency of coaxial germanium detectors is defined at 1.33 MeV relative to that of a standard 3-in.-diameter, 3-in.-long NaI(Tl) scintillator. The measurement is performed by the method that is described in the IEEE Standard Test Procedures for Germanium Detectors for Ionizing Radiation (ANSI/IEEE 325-1996) and in the equivalent IEC standard. A National Institute of Standards  $^{60}\text{Co}$  source with known intensity is positioned 25 cm from the endcap face, and a fixed-time count is taken for the 1.33-MeV peak. The absolute efficiency is the ratio of the number of counts in the photopeak divided by the number of gamma rays emitted from the source during the same period of time. This absolute efficiency is then divided by  $1.2 \times 10^{-3}$ , which is the absolute efficiency at 1.33 MeV of a standard 3-in. by 3-in. NaI(Tl) crystal 25 cm from the source. The ratio of these measurements is the basis for the efficiency specification of the germanium detector.

## The Efficiency Advantage

Many EG&G ORTEC coaxial germanium detectors have a measured relative efficiency substantially higher than the warranted value.

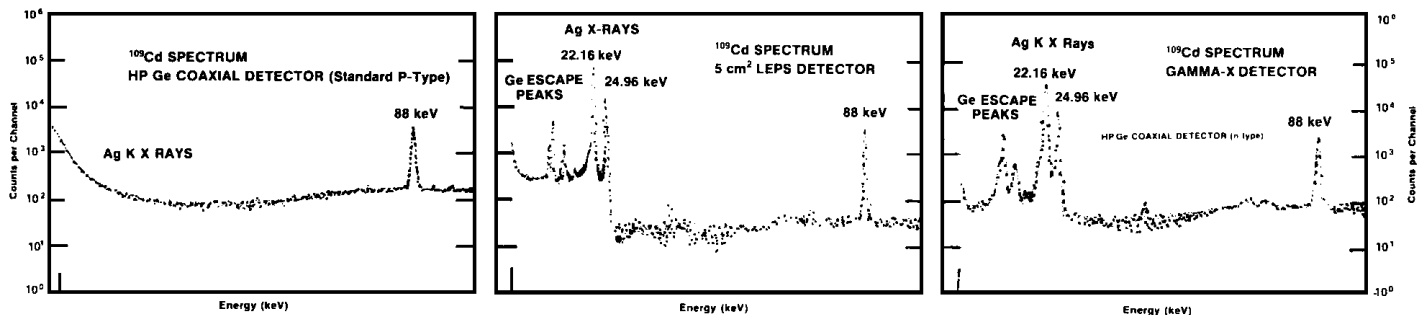


Fig. 17.  $^{109}\text{Cd}$  Spectrum Observed with: (a) a 10% Relative Efficiency GEM Detector; (b) a 5-cm<sup>2</sup> Active Area, 10-mm Active Depth HPGe LEPS Detector; (c) a 10% Relative Efficiency GAMMA-X Detector.

# Information about Photon Detectors



## Relationship of Relative Efficiency to Active Volume

As the volume of a coaxial detector increases, so does its relative efficiency (measured at 1.33 MeV). However, there is not a simple relationship between volume and efficiency. The efficiency increases faster with detector radius than with detector length. An approximate (**not** dimensionally correct) relationship is:

$$\text{Relative Eff (\%)} = \frac{\text{Volume (cc)}}{4.3}$$

Since the density of germanium is 5.33 g/cc, ~23 g of Ge in the finished detector is required for each “percent” of efficiency.

A more recent empirical formula relating volume to efficiency is the following (courtesy of Dr. T.L. Khoo of Argonne National Lab):

$$\text{Relative Eff (\%)} = KD L ,$$

where D = active crystal diameter, L = crystal length, K = 2.4321, = 2.8155, and = 0.7785. (Diameter and length in decimeters.)

## Energy Resolution

The energy resolution is a measure of the detector’s ability to distinguish closely-spaced lines in the spectrum. The method used to measure the energy resolution is also described in ANSI/IEEE 325–1996.

## Energy Resolution as a Function of Energy

For the energy range **up to 1.5 MeV**, the following approximate (and **not** dimensionally correct) expression is useful for predicting the resolution of a Ge detector:

$$R = (N^2 + 2E)^{1/2}$$

where R is the energy resolution (FWHM) at the energy of interest, N is the noise line width, and E is the energy of interest, with all quantities expressed in eV (**not** in keV).

For the range from 1.5 MeV to 10 MeV (as shown in Ref. 4), the expected resolution (FWHM) is *approximately* 0.08% to 0.1% of the energy of the line of interest. At the higher energies the measured resolution can be worse than this due to even minor trapping. The actual measured values depend on the quality of the Ge crystal used to manufacture the detector element, the depth of the hole in the center of the crystal, extent of shaping of the crystal’s front “corners,” and other manufacturing details. All Ge detectors are not created equal!

### The Energy Resolution Advantage

Most EG&G ORTEC detectors have measured energy resolution substantially better than the warranted resolution.

## Energy Resolution as a Function of Temperature

Most HPGe detectors begin to show increasing leakage current and electronic noise at temperatures above ~110 K. Due to the different cooling capabilities of various cryostats, HPGe detectors normally operate at temperatures in the range from 85 to 100 K. A stable operating temperature is essential. Because E, the average energy necessary to create an electron hole-pair, varies with temperature at a rate of  $2.53 \times 10^{-4}$  per degree K (Ref. 6), temperature variations during a measurement result in a peak shift that degrades the energy resolution. Temperatures below 40 K may result in deterioration in energy resolution due to trapping effects.

There are several references<sup>7,8</sup> useful for those planning to use germanium detectors at temperatures higher or lower than the customary temperature. Because the FET that is in the first stage of the preamplifier is inside the cryostat and yet must be held at ~115 K, the use of germanium detectors at unusual operating temperatures may result in increased first-stage preamplifier noise.

Si(Li) detectors do not operate well at temperatures below 77 K.<sup>10</sup>

## Operation in Magnetic Fields

If it is necessary to operate a germanium detector in a high magnetic field (~ several hundred millitesla) there is danger that even with a good vacuum a Penning discharge may cause surface leakage current, which will make the detector inoperable.

EG&G ORTEC can, on request, prevent such an occurrence by providing a modified detector mount which includes an insulator between the endcap wall and the detector outer contact sitting at high voltage.

## Peak-to-Compton Ratio

The peak-to-Compton ratio, also measured in accordance with ANSI/IEEE 325–1996, is the key indicator of a detector’s ability to distinguish low-energy peaks in the presence of high-energy sources. **The peak-to-Compton ratio is one of the most important and yet most often overlooked — sometimes even unspecified — measures of detector performance.** The Compton plateau results from Compton interactions in the detector in which the resulting photon, reduced in energy, escapes from the sensitive volume of the detector. The peak-to-Compton ratio is obtained by dividing the height of the 1.33-MeV peak by the average Compton plateau between 1.040 and 1.096 MeV. Again, the typical measured peak-to-Compton ratio for EG&G ORTEC detectors is substantially better than the warranted specifications. For a given value of the relative efficiency, **higher peak-to-Compton values are achieved with better values of energy resolution.** [Note: For two HPGe detector elements **having the same diameter and length**, the product of resolution (at 1.33 MeV) times the peak-to-Compton ratio is a constant; therefore, if one detector has 10% better resolution, it will have a 10% higher peak-to-Compton ratio.]

# Information about Photon Detectors

## Peak Shape

In cases where two peaks have nearly identical energies (and the smaller peak is on the low-energy side of the larger peak), near-perfect Gaussian peak shape is essential to quantify the smaller peak's net area. As demands for reduced MDAs become more pervasive, excellent peak shape is increasingly important. Even when the most sophisticated software is employed to deconvolute interferences, the precision of the result and the MDA is limited by the extent of the interference of the peaks with each other.

The ratios FW.1M/FWHM (FW.1M = Full Width at One-Tenth Maximum) and FW.02M/FWHM (FW.02M = Full Width at One-Fiftieth Maximum) are excellent means of describing this shape. The theoretical Gaussian peak has a FW.1M/FWHM ratio of 1.83 and an FW.02M/FWHM ratio of 2.38. *Most EG&G ORTEC detectors have peak shapes close to these theoretical numbers.*

### The Peak Shape Advantage

**Only EG&G ORTEC** warrants the **FW.02M/FWHM** ratio for all coaxial detectors.

## 22-keV Peak/88-keV Peak

This specification quantifies the thinness of the entrance window in GAMMA-X detectors. The natural ratio of gamma rays from the 22-keV and 88-keV lines of a <sup>109</sup>Cd source is ~21:1. A GAMMA-X detector typically displays a ratio >20:1. For comparison, the ratio for a GEM (p-type) detector is ~1:100.

## Timing with HPGe Coaxial Detectors

The timing performance of a coaxial detector defines its ability to distinguish between two events closely spaced in time.

Timing performance depends greatly on proper electronic setup. Table 5 shows some typical timing results measured with EG&G ORTEC detectors. The timing performance of a 61% GAMMA-X detector (with a Model 583 Constant-Fraction

Discriminator threshold set at 50 keV and the energy range selected with a Model 551 Timing Single-Channel Analyzer) is as follows:

|                           |                |
|---------------------------|----------------|
| At E > 100 keV            | FWHM = 5.5 ns  |
| At E = 1.33 MeV (±50 keV) | FWHM = 3.7 ns  |
|                           | FW.1M = 8.9 ns |

Results obtained with large GAMMA-X detectors are shown in Table 6.

**Table 6. Timing Data Obtained on Three High Efficiency GAMMA-X Detectors Included in the EUROGAM Array**  
(P. Nolan, *et al.*, Internal Daresbury Report – July 1991).

| Detector | Efficiency (%) | E (keV) | FWHM (nsec) |
|----------|----------------|---------|-------------|
| A        | 69.2           | 50–1332 | 5.8         |
|          |                | 1332    | 4.3         |
|          |                | 779     | 6.8         |
|          |                | 344     | 9.0         |
|          |                | 122     | 19.0        |
| B        | 80.2           | 50–1332 | 9.2         |
|          |                | 1332    | 6.7         |
|          |                | 779     | 8.7         |
|          |                | 344     | 13.3        |
|          |                | 122     | 18.1        |
| C        | 70.2           | 50–1332 | 7.2         |
|          |                | 1332    | 4.7         |
|          |                | 779     | 6.0         |
|          |                | 344     | 10.6        |
|          |                | 122     | 22.2        |

### The Timing Advantage

EG&G ORTEC's coaxial detectors are the standard of excellence for timing spectroscopy.

**Table 5. Typical Timing Results Measured with EG&G ORTEC's Coaxial Detectors.**

| Detector System | Detector Type | Efficiency (%) | Optimum Delay (ns) | Measure | Timing Resolution (ns)                   |      |      |      |  |      |      |      |      |  |
|-----------------|---------------|----------------|--------------------|---------|--|------|------|------|--|------|------|------|------|--|
|                 |               |                |                    |         | Mean Energy (keV) Using <sup>22</sup> Na |      |      |      | Mean Energy (keV) Using <sup>60</sup> Co |      |      |      |      |  |
|                 |               |                |                    |         | 150                                      | 250  | 350  | 511  | 511                                      | 750  | 950  | 1170 | 1330 |  |
| 1               | HPGe-P        | 11.0           | 24                 | FWHM    | 9.2                                      | 6.7  | 5.8  | 4.0  | 3.9                                      | 3.0  | 2.6  | 2.0  | 1.7  |  |
|                 |               |                |                    | FW.1M   | –  | 45.3 | 22.2 | 9.9  | 10.2                                     | 8.4  | 7.5  | 5.6  | 5.1  |  |
| 2               | HPGe-N        | 19.8           | 23                 | FWHM    | 12.5                                     | 8.6  | 7.0  | 4.5  | 4.9                                      | 3.7  | 3.1  | 2.2  | 2.0  |  |
|                 |               |                |                    | FW.1M   | 84.0                                     | 33.0 | 18.1 | 10.2 | 11.8                                     | 8.6  | 7.7  | 5.5  | 4.9  |  |
| 3               | HPGe-P        | 28.0           | 34                 | FWHM    | 11.3                                     | 8.8  | 7.7  | 5.6  | 6.2                                      | 5.7  | 4.0  | 3.6  | 3.4  |  |
|                 |               |                |                    | FW.1M   | –  | 55.8 | 27.1 | 12.8 | 13.4                                     | 12.3 | 11.8 | 9.8  | 9.0  |  |

# Information about Photon Detectors



## A5.2. HPGe (IGLET, IGLET-X, GLP) and Si(Li) Planar, and LO-AX Coaxial Low-Energy Photon Spectrometers

While the traditional high-resolution choice for very low photon energies (<1 keV) has been the planar Si(Li) detector (SLP Series), IGLET and IGLET-X detectors are now preferred for most applications. For each of these planar detectors the following information is provided: active diameter, active depth, and resolution at 5.9 keV measured with optimal time constants. For GLP and LO-AX detectors an additional specification (energy resolution at 122 keV) is provided. For IGLET and IGLET-X detectors a high count rate specification 5.9 keV resolution at 100 kcps at a 0.5  $\mu$ s time constant, is given.

### Intrinsic Efficiency

Intrinsic (full-energy) efficiency is the probability that a photon of a given energy, impinging on the front of the detector will be completely absorbed by the detector element. Although the intrinsic efficiency is not a standard specification for SLP, GLP, IGLET, and IGLET-X detectors, it is a parameter of interest for GLP detectors from 3 to 100 keV, for IGLET detectors from 3 to 50 keV and down to very low energies for SLP and IGLET-X detectors. The low energy portion of the intrinsic efficiency curves for SLP and IGLET-X detectors is dominated by the beryllium window thickness. The curves in Fig. 18 show the intrinsic efficiency for SLP detectors; those in Fig. 19 show intrinsic efficiency values for GLP detectors, and Fig. 20 the intrinsic efficiency for IGLET-X detectors in which the beryllium window thickness dominates the low energy efficiency.

Typically, SLP series detectors are "black" (total absorption) for energies up to 20 keV, while GLP series detectors are "black" for energies up to 120 keV.

### Maximizing IGLET-X Efficiency for Ultra-Low-Energy X Rays

IGLET-X detectors are capable of detecting photons of energy <0.5 keV. Arranging that such photons actually impinge on the detector front contact is difficult. Polymer windows are a less than perfect solution, due to their fragility and failure to be light tight. Loss of such low energy photons due to interactions with air is an additional problem. A better solution is a windowless detector with a gate valve which can be opened when the detector is placed in a vacuum common to the source of the x rays. Windowless detectors are supplied with a beryllium window that allows a general test of the detector performance upon arrival.

At energies below 3 keV the Intrinsic Full Energy Efficiency of SLP and IGLET-X detectors is greatly reduced by x-ray absorption in the endcap window. Figure 20 displays the results obtained with Be windows of different thickness.

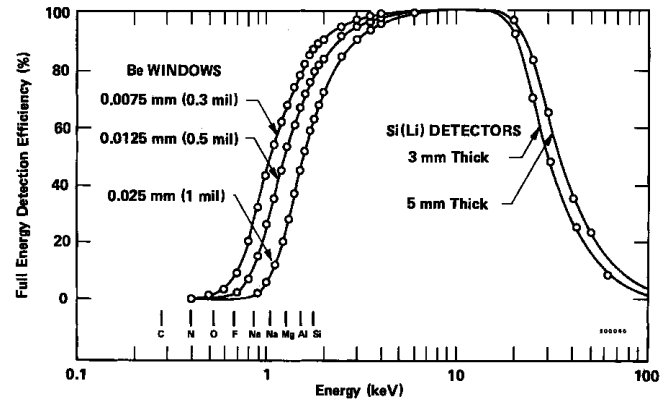


Fig. 18. Intrinsic Full-Energy Detection Efficiency for SLP Detectors as a Function of Be Window Thickness and Detector Thickness.

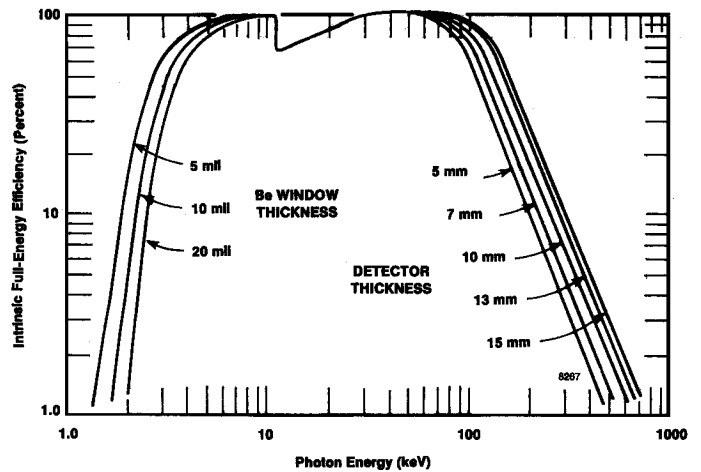


Fig. 19. Intrinsic Full-Energy Efficiency vs. Energy for GLP Detectors as a Function of Be Window Thickness and Detector Thickness.

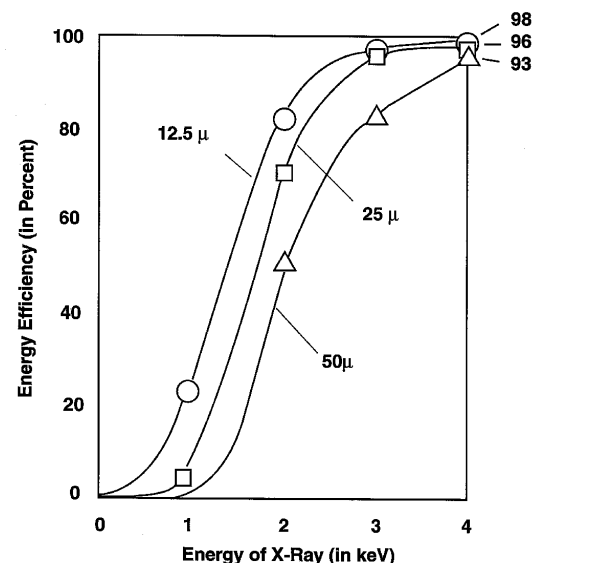


Fig. 20. IGLET-X Intrinsic Full Energy Efficiency in % vs. X-Ray Energy.

# Information about Photon Detectors



## Timing at Low Energies with Planar Germanium Detectors

For timing measurements at energies below 150 keV planar HPGe (GLP series) detectors are the best choice. Table 7 shows results obtained with GLP detectors of 10 cm<sup>2</sup>. Note: LO-AX, IGLET, or similar quasi-planar detectors are unsuitable for such measurements.

Table 7. Timing at Low Energies with 10 cm<sup>2</sup> Active Area Planar Detectors\*.

| Source            | Energy (keV) | Time Resolution(ns) |
|-------------------|--------------|---------------------|
| <sup>22</sup> Na  | 20 ±10       | 20 ±2               |
|                   | 100 ±10      | 8.5 ±1              |
|                   | 511 ±5       | 4.5 ±0.2            |
| <sup>133</sup> Ba | 31 ±3        | 19 ±2               |
|                   | 81 ±3        | Isomer              |
|                   | 85 ±5        | 11 ±1               |
|                   | 356 ±5       | 6.0 ±0.5            |
| <sup>152</sup> Eu | 41 ±3        | 15 ±1               |
|                   | 122 ±5       | Isomer              |
|                   | 125 ±5       | 6.5 ±0.5            |
|                   | 344 ±5       | 5.0 ±0.2            |
|                   | 779 ±5       | 3.8 ±0.3            |

\*Data courtesy of Dr. Kim Lister, Argonne National Laboratory.

## A5.3. Well Detectors (GWL Series)

Well detector design maximizes efficiency for small samples. The Well detector is actually a p-type HPGe coaxial detector mounted with a large central hole facing the front of the endcap.

Historically, Well detectors have been characterized by the following parameters:

- Active volume (cc)
- Diameter (mm) of endcap well
- Depth (mm) of endcap well
- Energy resolution at 1.33 MeV (keV FWHM)
- Energy resolution at 122 keV (keV FWHM)

### The EG&G ORTEC Well Detector Advantage

The "blind well" approach pioneered by EG&G ORTEC puts active germanium immediately under the sample, and thus increases the detector efficiency, particularly for low-energy lines.

## Efficiency of Well Detectors

Data on efficiency of Well detectors can be found in the literature (Ref. 10). Figure 21 shows a typical efficiency curve for point sources placed at the bottom of the Well.

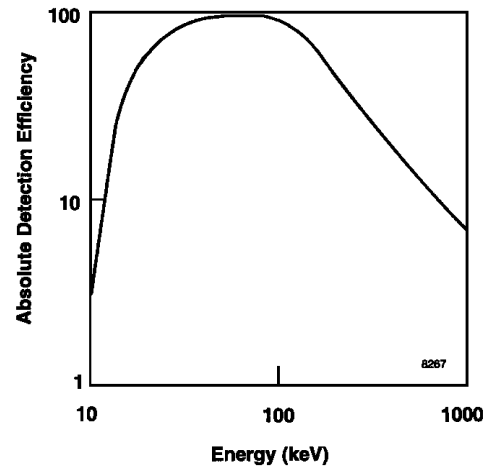


Fig. 21. Absolute Detection Efficiency vs. Photon Energy for a Typical EG&G ORTEC Well Detector.

## A5.4. Detector Microphonics

After 30 years of germanium detector production the phenomenon of microphonics is still not well understood. A back-of-the-envelope calculation leads to the false conclusion that no germanium detector will ever operate. For example, consider a metal part, such as the cup that holds the detector, which has a small, but non-zero capacitance with respect to the FET gate. Assume that sound waves, such as from a voice, induce a variation of merely 0.5 femtofarads in the value of this capacitance; the result would be a signal equivalent to 10 keV!

Although there is no IEEE standard on the measurement of the extent of microphonics, considerable work has been done in this field:

- 1) Special design: EG&G ORTEC has always been at the forefront in this field, for example production of a rugged detector designed for the U.S. Navy (Ref. 11). EG&G ORTEC has also provided arrays of germanium detectors for helicopter aerial surveillance.
- 2) Proper electronic setup: As the microphonics spectrum is primarily in the few kcps range, a high pass filter (shorter amplifier time constants and baseline restorer "on") will often improve detector performance.
- 3) Vibration decoupling: Users typically obtain improvement by using soft foam rubber around and under the detector.