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The Performance of a Single-Crystal BGO Annulus as a Compton-Suppression Detector

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Abstract

We have tested a single-crystal bismuth-germanate annulus in conjunction with a high-purity germanium detector as a Compton-suppression spectrometer, and have measured gamma-ray energies of up to 6.13 MeV.

I. DETECTOR DESCRIPTION

We have tested a single-crystal BGO annulus (shown in Fig. 1) in conjunction with an Ortec high-purity germanium (HPGe) detector as a Compton-suppression spectrometer. Because the Compton cross section is forward peaked at higher energies, we have specified an annulus with most of the material in the forward scattering direction to maximize sensitivity at higher energies. A single phototube was chosen to enhance portability, although others have found that several phototubes improve the response[1]. The energy resolution measured with the annulus for 662-keV gamma rays from ^{137}Cs was about 40%.

Fig. 1. Harshaw single-crystal BGO annulus and phototube.

Figure 2 shows the counting circuit. Both sides of the veto circuit are identical and produce logical signals about 400 ns wide. A pre-amp is used with each detector, although it may not be necessary for the BGO. The final coincidence was made ~4 ms wide to accommodate the spectroscopy amplifier's

pulse width. Data were collected with a multichannel buffer and a computer readout. The time resolution of the veto circuit was about 60 ns.

II. DETECTOR PERFORMANCE

In previous work with a BGO-based Compton-suppression system, Hildingsson et al.[1] found that a very low BGO threshold was necessary to accommodate multiply-scattered gammas. Figure 3 shows some of the suppression ratios (that is, the gated spectrum divided by the ungated spectrum) from Hildingsson's work[1] and the BGO thresholds for each ratio. We can see that a BGO threshold of 15 keV was necessary for the best suppression results. The present annulus is housed in a 0.032-in.-thick aluminum skin. The minimum transmission energy for this much aluminum is around 30 keV. Figure 4 shows the effect of BGO threshold on the suppression for the present detector. The top curve corresponds to about zero threshold (no lower threshold had any effect), so we expect that this is the limit imposed by the aluminum skin.

Fig. 2. Counting circuit.

The very dense BGO should provide good shielding, which turns out to be the case. Although all other measurements were made with both detectors inside of a lead brick cave, we made two measurements outside of the cave for comparison; Fig. 5 shows these results. The lowest curve is an ungated spectrum

with the detector inside the BGO and the lead cave in place. The middle curve is an ungated spectrum taken with the HPGe detector still inside the annulus, but with all of the lead removed. Finally, the upper curve is the spectrum taken with the HPGe detector ungated and unshielded. We can see that the BGO does a credible job as a shield for these kinds of measurements. Recall that there is a rather large hole in the BGO to admit the primary detector, and in the second curve, this constitutes a hole in the shielding. Furthermore, since this detector is designed primarily for use at higher energies where the background is negligible, it would be desirable to dispense with the lead if the "hole" could be plugged. For example, a secondary detector could be placed behind the HPGe (inside the detector case) to act both as a shield and as a detector, since the annulus loses a lot of counts in this direction.

A common way to characterize gamma spectroscopy systems is by measuring the peak-to-Compton ratio, which is defined as the ratio of the number of counts in the highest channel of the 1.33-MeV peak to the average number of counts between 1.040 MeV and 1.096 MeV in the ^{60}Co spectrum. Figure 6 shows gated and ungated ^{60}Co spectra. Table I shows the associated peak-to-Compton ratios (an improvement of about 200 % for the gated results), as well as the ratio quoted by the detector manufacturer.

Table I
Peak-to-Compton ratio.

Ge quoted	Ge measured	Ge plus BGO
70	54	152

Fig. 3. Suppression ratio (ungated/gated) from Hildingsson et al. [1] shows the effect of threshold variation on gated spectra.

Fig. 4. Suppression ratios for our system.

Fig. 5. Shielding effects.

Figure 7 shows spectra from an encapsulated ^{241}Am and ^{13}C source, which produces a gamma-ray spectrum with a primary gamma ray at 6.13 MeV and several prominent gammas above and below this peak. There is significant improvement in the high-energy spectrum: many peaks that are not prominent enough to be seen above the noise in the ungated spectrum become visible when the Compton veto is used. For example, Fig. 8 shows an expansion for the gated and ungated spectra of the area around 7915 keV. In the gated spectrum, we can see a peak from gamma rays produced by neutron capture on Cu (neutrons are produced in the source); this peak is not distinguishable in the ungated spectrum. Other peaks in this area are obviously much clearer as well.

The veto circuit is also valuable for eliminating counts from first and second escape peaks in the primary detector. Table II shows the ratios of counts in the 6130-keV photo peak to counts in the first and second escape peaks for the gated and ungated spectra. The ratio for the first escape peak is improved by a factor of 3, and the ratio for the second escape is improved by a factor of 7; Fig. 9 shows this spectra expanded around these peaks. Because the annihilation photons should be produced isotropically in the primary detector, the cave entrance subtracts significantly from the escape-peak-suppression efficiency.

Table II
Escape peak suppression.

	Primary/First Escape	Primary/Second Escape
Ungated	1.16	2.18
Gated	2.97	14.4

Fig. 6. ^{60}Co spectra, gated and ungated.

Fig. 7. Spectra from the ^{241}Am and ^{13}C source, gated and ungated.

Fig. 8. $^{13}\text{C}/^{241}\text{Am}$ spectra, above 6130 keV.

Fig. 9. 6130-keV γ , primary and escape peaks.

In conclusion, the veto circuit significantly improves the quality of spectra for gamma rays in the few MeV range. The main problems are the large sizes of the detector cave entrance, which could be plugged with an extra BGO detector in the HPGe housing, and the thickness of the aluminum skin, which could be replaced with something thinner or more transparent.

III. REFERENCE

- [1] L. Hildingsson et al., "Transverse BGO Compton Suppression Shield," *Nuclear Instruments and Methods*, **A252** (1986), pp. 91-94.

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