CANBERRA

Compton Suppression ...Made Easy

APPLICATION NOTE AN-D-8901

INTRODUCTION

Photons interact with matter in one of three ways: 1) Photoelectric, in which the photon transfers all of its energy to an atomic electron; 2) Compton Scattering, in which the photon loses part of its energy to an atomic electron and is deflected from its original path; 3) Pair Production, in which photon energy leads to the creation of a positron-electron pair. The positron then annihilates with an electron, emitting 1.022 MeV of energy in the form of two 511 keV photons emitted in opposite directions (conservation of momentum).

The relative probability of these three processes in Ge can be seen in Figure 1.

Note that the pair production process does not occur below 1.022 MeV and that the Compton process is dominant in the range of 200 keV to several MeV. In a Ge detector, full energy peaks comprise photoelectric events and single or multiple Compton interactions, followed by photoelectric interaction of the scattered photon.

Nonetheless, the vast majority of Compton scattered photons escape the detector, leaving background counts in the spectrum. These background counts form a Compton continuum which is the dominant background in most systems. This complex background can be reduced by detection of the scattered photon in a guard detector

$$I = I_0 e^{-\mu d}$$

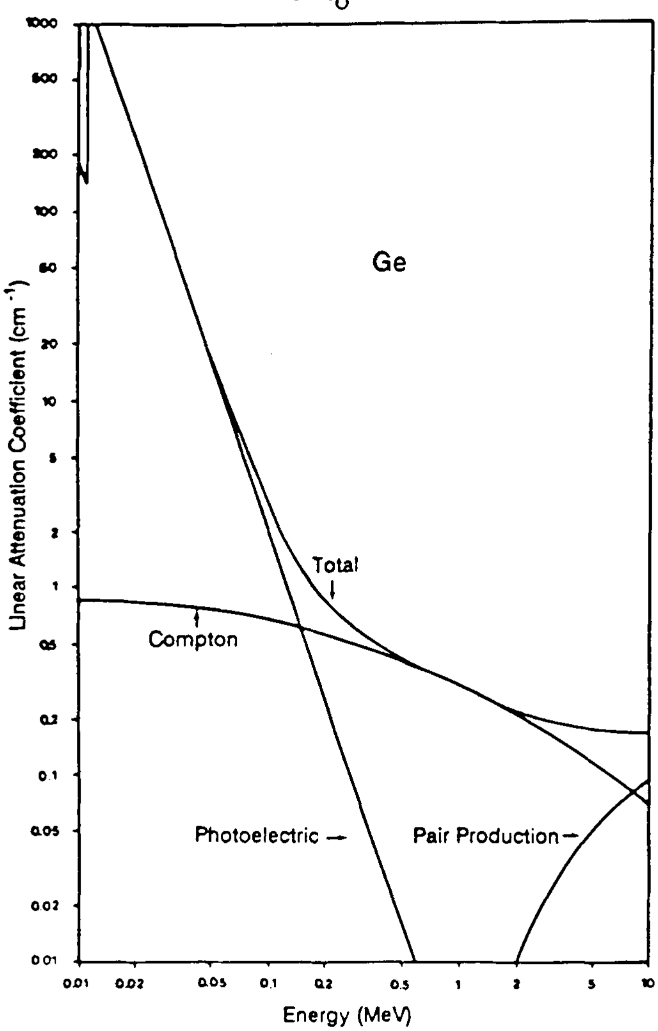
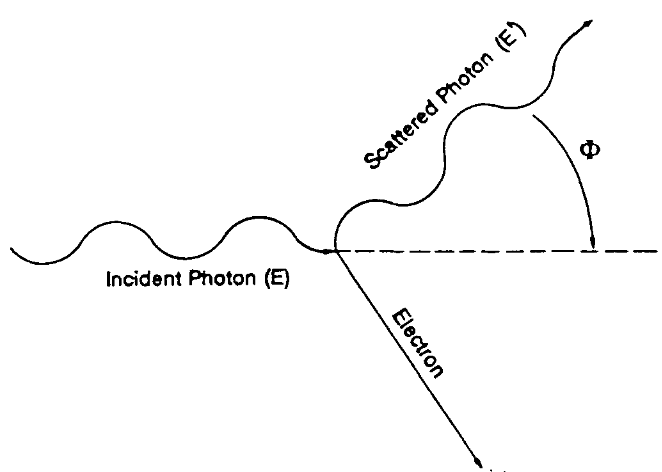


Figure 1. Linear Attenuation Coefficient of Germanium



$$E' = \frac{E}{1 + \frac{E}{0.511}(1 - \cos \Phi)}$$

Figure 2. Compton Scattering Diagram

and anti-coincidence gating of the Ge detector signal with the guard detector signal.

THE COMPTON SCATTERING PROCESS

A Compton scattered photon is depicted in Figure 2. The angle of scatter is shown as ϕ and the scattered photon energy (E') bears the stated relationship to the incident energy (E) and ϕ. A plot of this function with several different incident energies is shown in Figure 3.

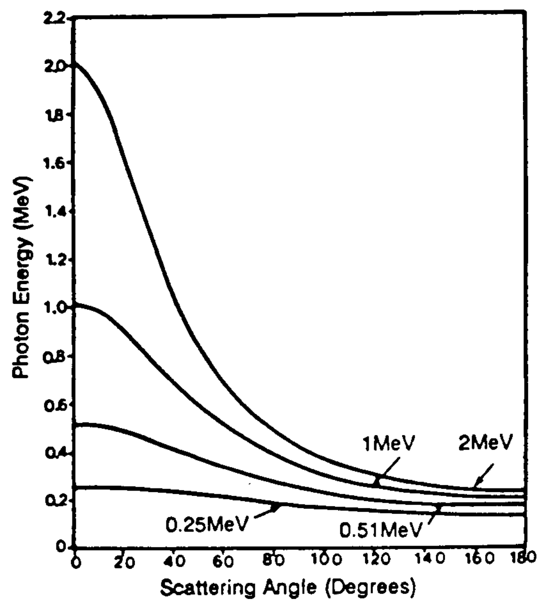


Figure 3. Compton Energy vs. Scattering Angle

A plot of the probability of scatter vs. angle (0 to 180°) for photons of various energies is given in Figure 4. From this it is seen that forward scatter increases with increasing energy.

THE GUARD DETECTOR

From the foregoing discussions, it is easy to understand the basic requirements of a guard detector. The suppression of Compton events can only be as good as the ability of the guard detector to detect the scattered photons. The effectiveness of the guard detector depends on its shape, size, and material of construction, all of which can vary greatly.

Figure 5 shows the relationship between the scattering angle and the resultant Compton continuum in a typical Ge detector spectrum. Failure to detect photons scattered in

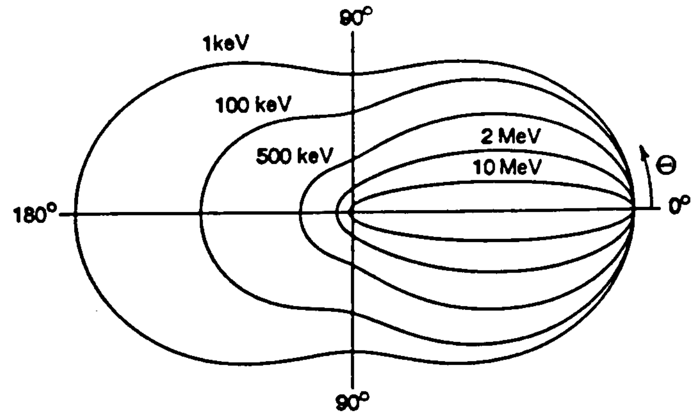


Figure 4. Polar Plot of Scattering Probabilities, 0° to 180°

a given direction will detrimentally influence the suppression ratio in a particular Compton region.

Note that γ_1' photons have lost little energy in the Ge detector and are traveling forward with high residual energy. γ_3' photons have lost most of their energy in the Ge detector and are scattered backwards. This dictates the need for high guard detector efficiency in the forward direction and much less in the backward direction, with intermediate efficiency in between.

Guard detector efficiency depends on the density (rather Z) and thickness of the material. NaI(Tl) and BGO (Bismuth Germanate) have both been widely used in Compton Suppression Spectrometers. The greater density of BGO (7.13 vs. 3.67 g/cc) leads to a linear attenuation coefficient at 500 keV of 0.944/cm vs. 0.343/cm for NaI(Tl). Thus much smaller guard detectors can be employed to achieve the same suppression as NaI. This is the reason for the popularity of BGO suppressors in detector arrays for nuclear physics experiments where detectors need to be closely spaced.

Typical configurations of Ge and guard detectors are shown in Figure 6. Configurations suitable for sample counting are shown with (•) depicting sample location. Others show gamma ray entry path ($\gamma\rightarrow$). Some show both.

1. Annular Guard – The traditional and most common design. Relatively large escape angles.
2. Well Guard – Good for sample counting if a system is provided for easy and safe movement of detectors for sample entry.
3. Annular Guard/Plug – Addition of plug above the sample will greatly reduce the Compton edges.

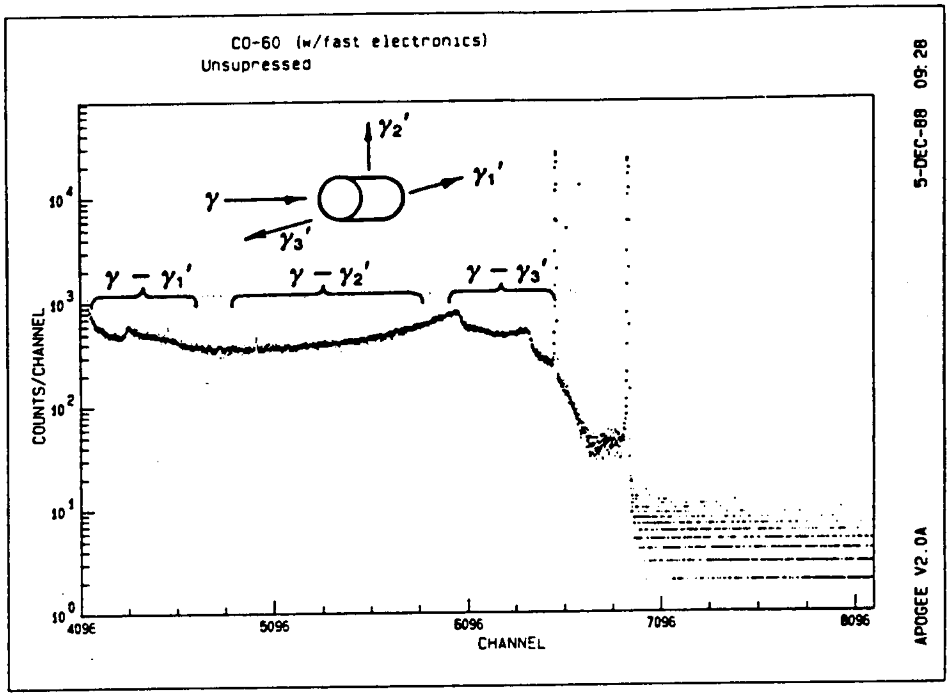


Figure 5. Scattering Angles vs. Compton Continuum

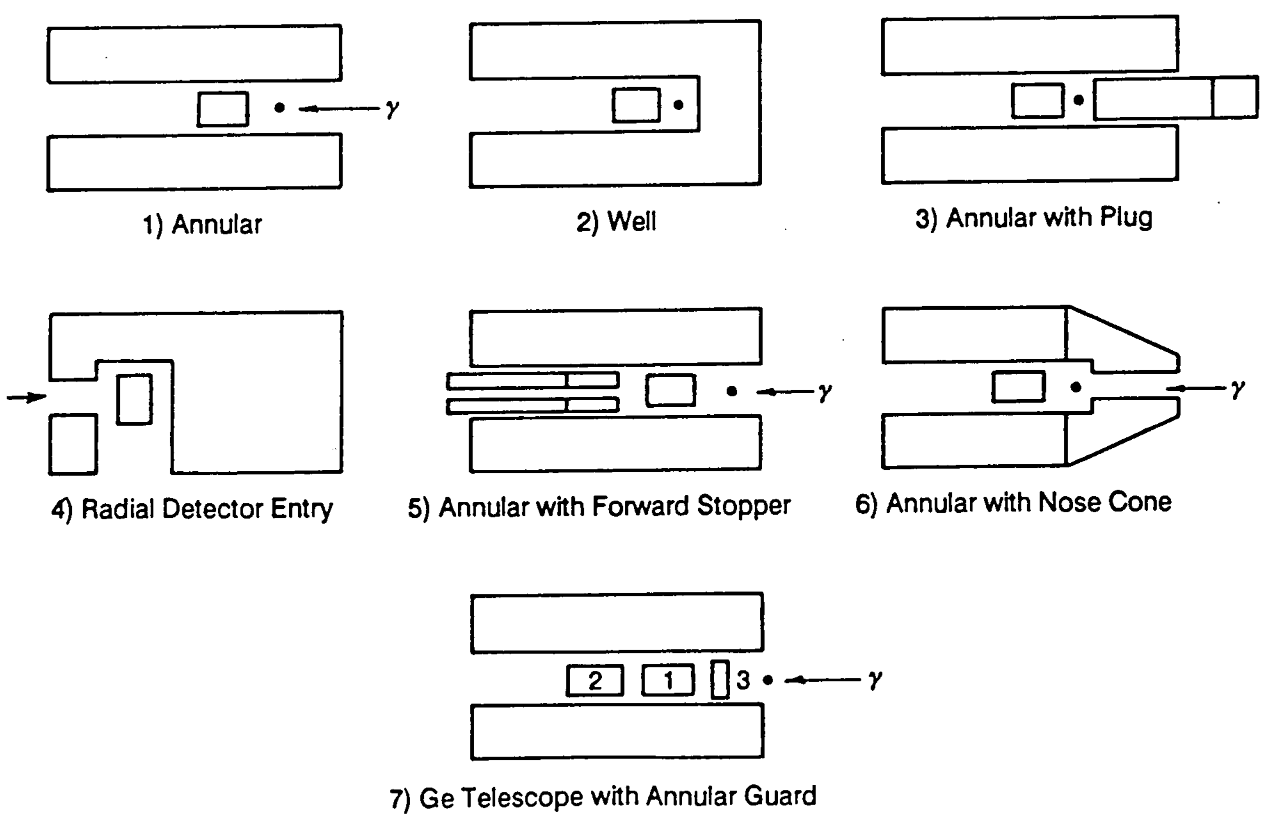


Figure 6. Various Ge/Guard Combinations

4. Radial Detector Entry – A thick guard region in the direction of forward scatter reduces low energy background. Undesirable side entry on Ge.

   Annular/Forward Stopper – Small semi-cylindrical detectors help efficiency for forward scatter.

6. Annular with Nose Cone – A reduced diameter nose cone provides efficiency for backscatter. This section is often NaI optically coupled to BGO annulus.

7. Ge Telescope – Two- or three-element telescopes provide a Ge guard for forward scatter (2) and backscatter (3). Canberra has produced a variety of these systems.

THE Ge DETECTOR

Modern large volume Ge detectors exhibit higher P/C ratios without suppression than their earlier, smaller predecessors. Ge detectors also generally have less dead material (no P-core) than Ge(Li) detectors and the dead Ge on the outside surface can be insignificant, as in the case of REGe (Reverse Electrode) detectors. All these factors lead to greater P/C ratios overall in Compton Suppression Spectrometers, although the suppression ratio may actually be diminished by the fact that there is less Compton scatter to begin with in the large volume, high performance detector.

The effect of dead layer is similar to the effect of the detector holder, the end cap and the guard detector liner. All these intervening layers of material can stop the scattered photon before it reaches the active guard material. For this reason, these materials should be thin and of low density. Aluminum is usually the material of choice, although magnesium and plastics can be used in some applications. The internal dimensions of the guard detector should be sized to the requirements of the Ge detector element with minimal space between the two detectors in order to reduce the escape angle.

Typical dimensions for 20% P-type coaxial detectors and N-type Reverse Electrode Coaxial detectors are shown in Figure 7.

ELECTRONICS CONFIGURATION

Compton Suppression Spectrometers do not require fast timing and fast coincidence electronics in order to provide good suppression. Coincidence resolving times of 0.5 to 1.0 μs are more than adequate considering Ge detectors operate typically with amplifier time constants of 2-4 μs with resultant pulse widths (and dead times) of 8-20 μs. Nevertheless, some predictable and consistent coincidence (anti-coincidence) electronics setup is required to ensure good performance. Often experiments require fast timing and good timing resolution for other reasons and in such cases the timing electronics is available for use in Compton suppression.

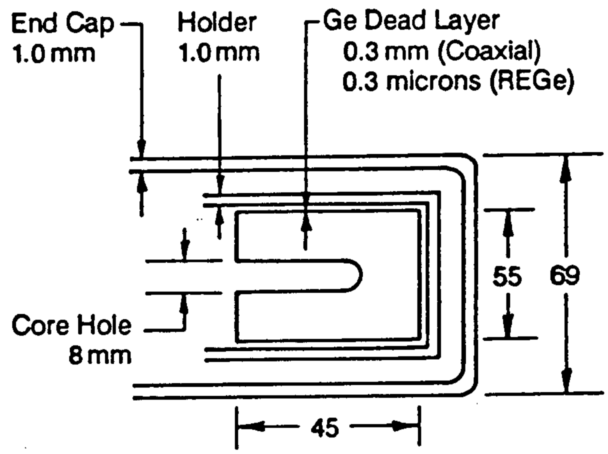


Figure 7. Typical Compton Suppression Detector Dimensions

Three different electronics setups have been used in evaluating the performance of both BGO and NaI(Tl) suppressed Ge detector systems. These systems vary greatly in sophistication and cost, as can be seen in the block diagrams that are shown in Figures 8, 9 and 10

The system depicted in Figure 8 uses timing filter amplifiers and constant fraction discriminators which are necessary for the ultimate in timing resolution. Setup and adjustment of the electronics for the best timing performance requires a good deal of skill and experience.

The system depicted in Figure 9 has been used in many Canberra supplied Compton Suppression Spectrometers. Timing performance of the Model 2037A Timing SCAs operating in Crossover mode is more than adequate for Compton Suppression but poor in comparison to that of Figure 8. The cost and complexity is somewhat less.

The system shown in Figure 10 is Compton Suppression made easy. Using the Model 2020 Amplifier with its exclusive ICR (Incoming Count Rate) fast discriminator circuit for coincidence, results in a system of elegant simplicity with virtually no requirements for special setup procedures or adjustments. The ICR circuit is easily adjusted by the pileup rejector discriminator, there are no delays between the Ge and guard detectors to compensate for, and the coincidence resolving time is in the same 0.5 to 1.0 μs range that is optimum for the more sophisticated systems.

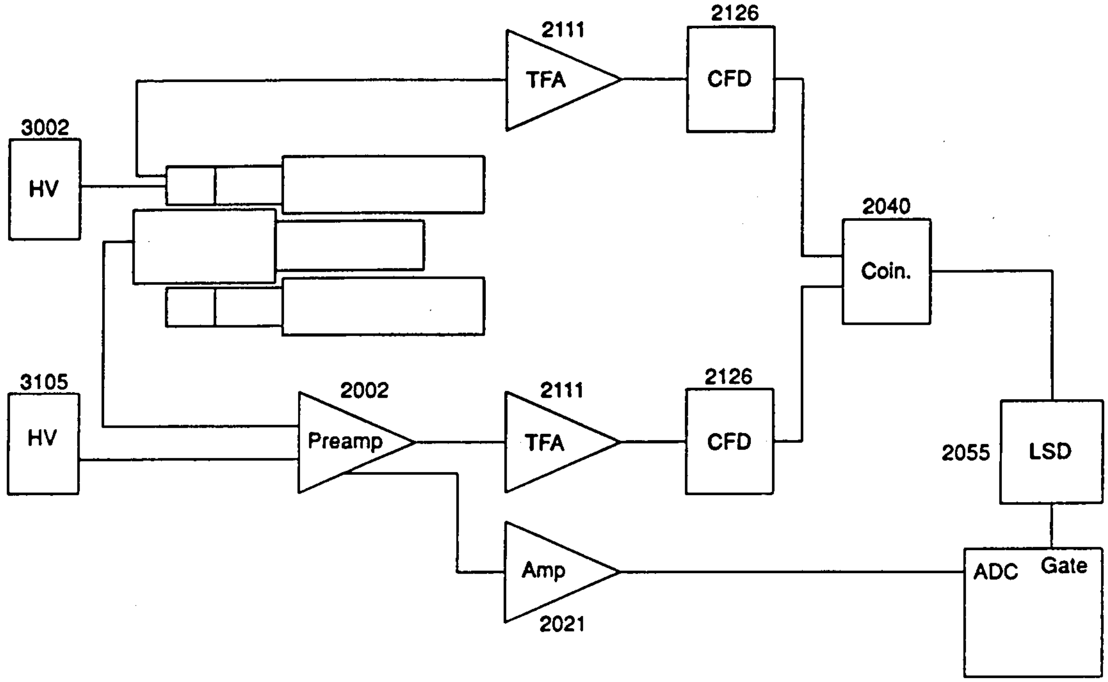


Figure 8. Compton Spectrometer with Fast Timing

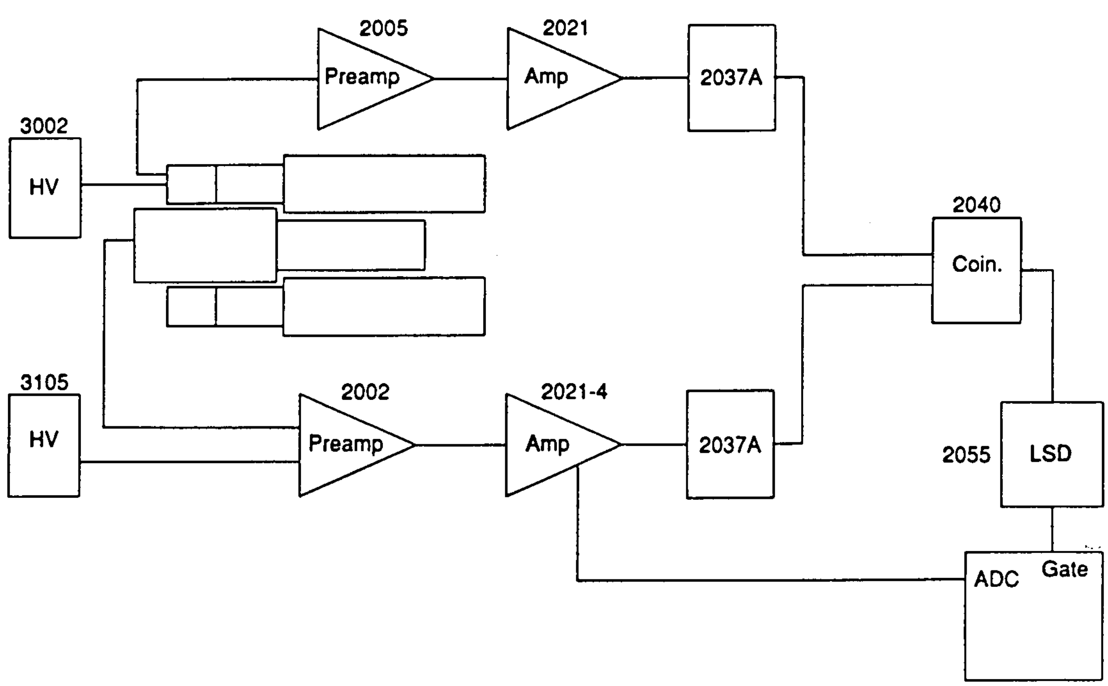


Figure 9. Compton Spectrometer with Standard Timing

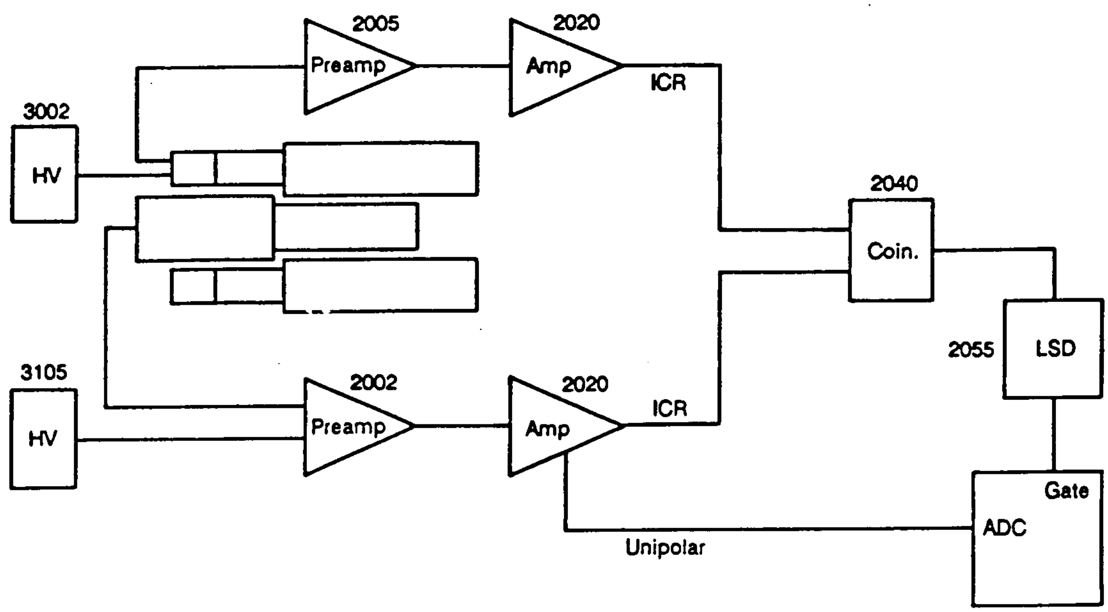


Figure 10. Compton Suppression with Easy Timing

SYSTEM PERFORMANCE

Two systems were evaluated with each type of electronics setup and the same Ge detector. The systems differed only in that one involved a BGO guard detector and the other a NaI(Tl) guard. The guard detector configurations are given in Figure 11. Dimensions refer to the detector element, not to the enclosure.

The Ge detector used in these tests was a Canberra Model GR1820 Reverse Electrode Coaxial Detector mounted in an endcap measuring 70mm ϕ by 152 mm long. The crystal

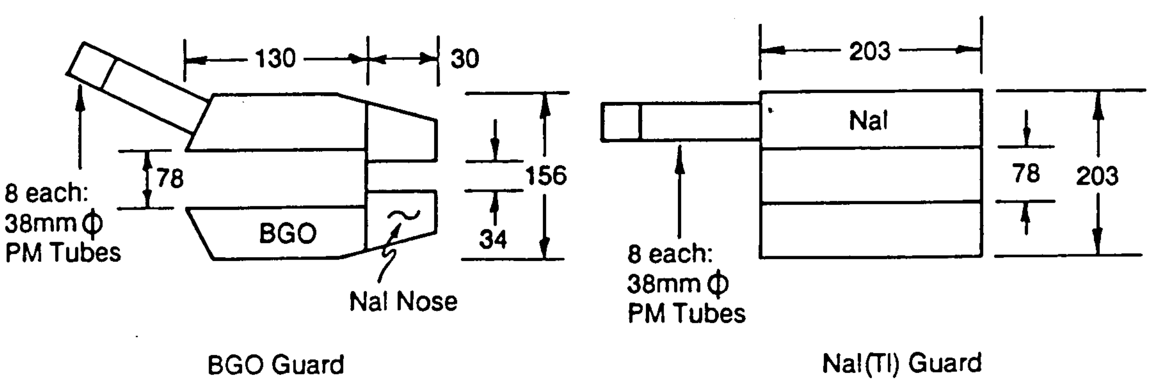


Figure 11. Guard Detector Configurations (Dimensions in mm)

dimensions were 50 mm ϕ by 39 mm long. Measured performance of the detector was as follows:

Relative Efficiency:	18.8%
Resolution:	0.86 keV (FWHM) at 1.22 MeV
	1.93 keV (FWHM) at 1.33 MeV
Peak/Compton:	45.1

The Ge detector protruded into the guard detector approximately 130 mm in each case. The guard detectors were both designed with inside diameters sufficiently large for Ge detectors having nearly twice the efficiency of the one used. Better results could have been obtained with guards having smaller inside diameters but the size of the Ge detector would be limited in this case. Representative spectra from the two systems are shown in Figure 12. The ^{60}Co source was located outside the guard detector and collimated to prevent direct interaction with the guard. This data was taken with the Easy Timing Electronics option.

The suppression factor (P/C without suppression divided by P/C with suppression) is a function of the fraction of scattered photons that are detected in coincidence with the primary photon interaction in the Ge detector. If 0.X of the scattered photons result in successful vetoes of the primary signal, then the overall Compton background will be reduced by

$$\frac{1}{1 - 0.X}$$

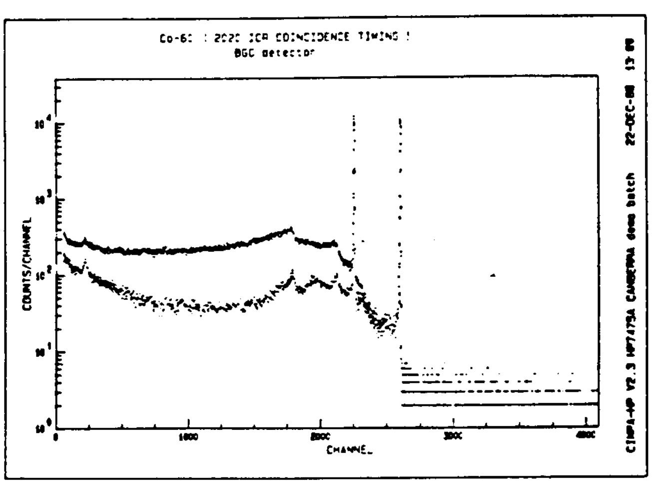
This means, for example, that 80% of the scattered photons must be detected in order to achieve an overall suppression of 5. Of course the suppression ratio will va along the continuum, depending on where the guarc more or less efficient. To compare performance of variou systems we are using overall peak to total ratios as a figure of merit rather than suppression factors which are energy dependent.

Qualitatively, the two systems appear to give results that are quite similar. A quantative measure of overall system performance is given by peak to total ratios in which we compare peak counts (both ^{60}Co peaks) to the total number of counts in the entire spectrum. Summarized results from all experimental configurations are given in Tables 1 and 2.

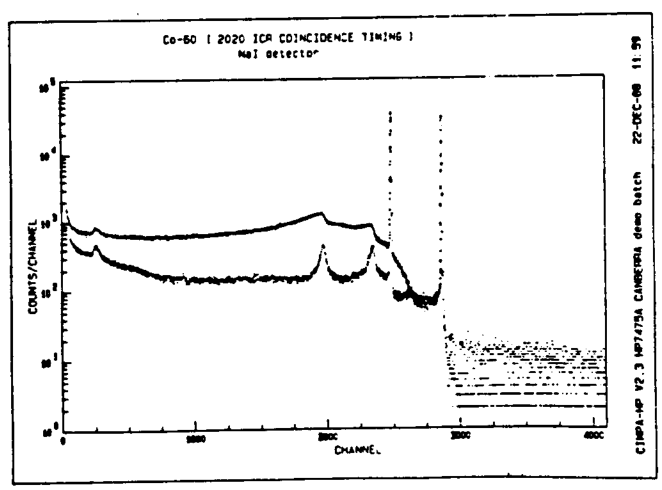
Table 1 shows peak to total ratios and overall suppression ratios for three different electronics set-ups.

Table 1

	Electronics		
	Standard	Fast	Easy
With Suppression	0.446	0.392	0.45[illegible]
Without Suppression	0.188	0.189	0.18[illegible]
Suppression Ratio	2.37	2.07	2.45



BGO Guard



NaI(Tl) Guard

Figure 12. ^{60}Co Spectra From the Detectors of Figure 11

Table 2 shows peak to total ratios and overall suppression ratios for BGO and NaI guards using Easy Timing ...tronics. (the peak to total ratios without suppression ...er, possibly because of increased scatter through the ...stricted window in the case of the BGO detector or because of collimation differences.)

Table 2		
	Guard	
	NaI(Tl)	BGO
With Suppression	0.453	0.438
Without Suppression	0.185	0.171
Suppression Ratio	2.45	2.56

CONCLUSIONS

Electronics Setup

The simple, low cost approach, called Easy Timing, which is made possible by the Canberra Model 2020 amplifier with ICR discriminator circuit, gives excellent results in Com...n suppression compared to far more sophisticated ap...oaches. Coincidence resolving times of less than 0.7 μs appear to reduce suppression with this system while less than 0.6 μs begins to affect the more complex systems.

Guard Detector

For moderate incident energies, where scattered photons are of relatively low energy, the NaI guard performs well in comparison with a much more expensive BGO guard. This is subject to vast change with high incident energy or where it is desirable to use the guard detector to determine total energy.

ACKNOWLEDGEMENTS

The NaI(Tl) and BGO guard detectors were supplied by Bicron, Inc., the latter on a hastily arranged loan basis. Steve Hancharyk, from Canberra's Customer Engineering Department, took reams of data on the various systems in the short time available for testing.

REFERENCES

This application note is far from a rigorous treatment of the subject of Compton Suppression. For those desiring more information, refer to the following sources:

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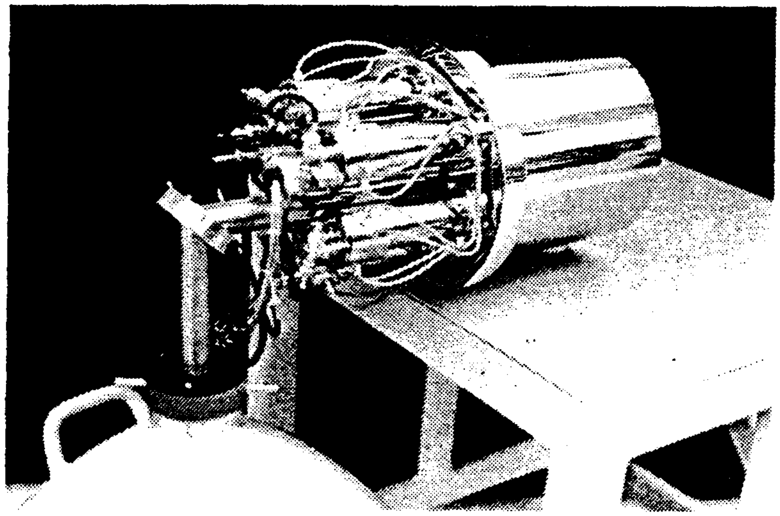

Figure 13 Compton Suppression Spectrometer
With NaI(Tl) Guard

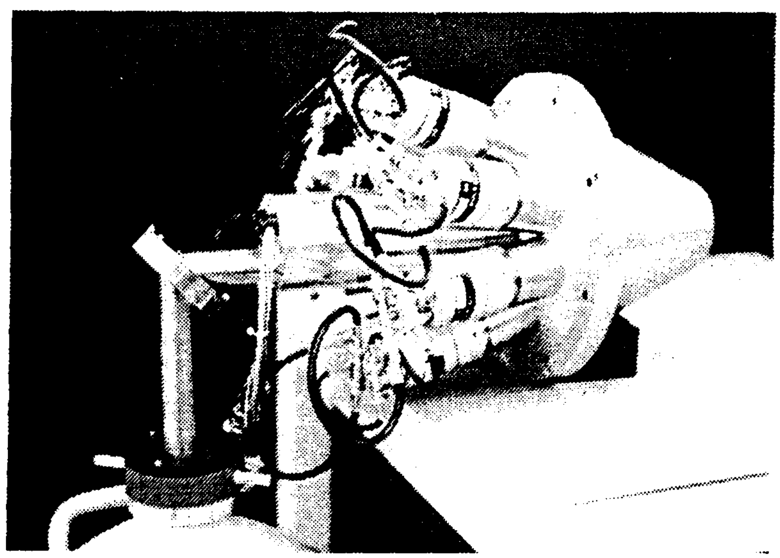

Figure 14 Compton Suppression Spectrometer
With BGO Guard