A COMPACT COMPTON SUPPRESSION SPECTROMETER USING BISMUTH GERMANATE SCINTILLATOR

MONA MOHSEN
Department of Physics, Faculty of Science, (Girls College), K.A.U., Jeddah, Saudi Arabia

ABSTRACT

Geometrical and random sampling methods of calculation have been used to estimate the dimensions of a compton suppression spectrometer using bismuth germanate (BGO) scintillator. Similar calculations have been also done using sodium iodide. It has been found that the dimensions of the BGO shield can be decreased to nearly half those of NaI (TI).

INTRODUCTION

In γ-ray spectroscopy dealing with reactions or decay, the complexity of the spectra and the low yield of many transitions is difficult to analyze without increasing the peak-to-background ratio. One of the ways to enhance weak transitions with energies up to 4 MeV is in the suppression of compton continuum.

Camp (Camp, 1969) designed a symmetrical Ge(Li)-NaI(Tl) compton suppression spectrometer, which consists of a cylindrical scintillator shield with a coaxial hollow core for a central detector at one side and the incoming γ-ray beam at the opposite side. Such set up suffered from the presence of collinear holes which lead to a low suppression of double escape peaks as well as compton scattering in the low and high energy parts of the spectrum.

This disadvantage could be avoided in an asymmetrical geometry, where the central detector is oriented at right angle to the direction of the incoming radiation. Using this geometry, Ge-NaI (Tl) compton suppression spectrometers have been successfully constructed and their performance has been studied in radioactive decay (Konijn, 1973), gamma–gamma coincidence (Aarts, 1989) and in experiments dealing with in beam gamma–ray spectroscopy at the external beam of synchrocyclotron (Beetz, 1977). However, it will be of value especially for multiparameter measurements to reduce the size of such spectrometer without affecting its function and this could be achieved by replacing NaI (Tl) by bismuth germanate (Bi_{4}Ge_{3}O_{12} known as BGO), which has recently proved to be a more efficient scintillator (Mohsen, 1982). Due to its high atomic number and high density (7.13 g/cm³), the stopping power and the photopeak efficiency of this scintillator shield could be increased. Moreover its full energy peak efficiency at 1.33 MeV has been measured by EVANS (EVANS, 1980) and found to be greater than that of NaI (Tl) by a factor of 4.5. These properties make BGO advantageous for construction of compact compton suppression spectrometers.
The aim of the present work is to present a comparative study for an asymmetrical compton suppression spectrometer using Ge-BGO as well as Ge-Nal (I). For this purpose a geometrical and a random sampling methods have been applied to calculate the dimensions of each spectrometer as a function of its relative absorption.

**PRINCIPLE**

A compton suppression spectrometer consists of a central Ge-detector surrounded by a scintillation shield (BGO or NaI). Gamma rays from a source outside are collimated before striking the Ge-detector positioned at right angle to the direction of the beam. Compton scattered gamma rays from that detector can then interact with the surrounding scintillating material. If the resulting signal is above the noise level, then it can be used to reject the recording of any coincident signal in the Ge-detector. Accordingly, full energy events should only in principle remain in the spectrum of the Ge-detector. However, the compton continuum is not completely eliminated since backscattered gamma rays can escape the scintillation crystal through the entrance hole of the incident beam. Such gamma rays lose most of its energy in the Ge-detector and its contribution appears at the compton edge of the spectrum.

**GEOMETRICAL METHOD OF CALCULATION**

In order to estimate the dimensions of a compton suppression spectrometer geometrically, gamma events in the germanium due to single compton collisions are assumed. The continuum spectrum without shielding could be represented as:

\[
\frac{d\sigma}{dE} = \left( \frac{d\sigma}{d\theta} \right) \left( \frac{d\theta}{dE} \right)
\]

where \(\sigma\) is the cross section for compton collision, \(E\) is the kinetic energy of the recoil electron in the Ge-detector and \(\theta\) is the angle of the scattered gamma relative to the incident gamma. The quantity \(\frac{d\sigma}{d\theta}\) is the cross section for photons scattered between two cones at \(\theta\) and \(\theta + d\theta\). The quantity \(\frac{d\theta}{dE}\) is obtained from

\[
E = h \gamma_0 \left[ 1 - \left| x \right| \right] \left[ 1 - \cos \theta \right]^{-\frac{1}{2}}
\]

where \(h \gamma_0\) is the energy of incident gamma ray and \(x = \frac{h \gamma_0}{mc^2}\).

To determine the expected effect of the anticoincidence shield in suppressing the continuum, the absorption of the scintillator around the Ge-detector is investigated according to the scattering angle \(\theta\). The fractional absorption \(A/A_0\) of the scattered gammas in the appropriate path length \(x(\theta)\) of the scintillator is calculated from

\[
A/A_0 = 1 - e^{-\mu \times (\theta)}
\]

where \(\mu\) is the total linear absorption coefficient of the scintillator for the gamma energy \((h \gamma_0 - E)\) at angle \(\theta\).
RANDOM SAMPLING OF PATH LENGTH

The trajectory of a gamma ray $\times (\theta)$ has been simulated (Peterman, 1972) by the equation

$$x = -\frac{1}{\mu} \ln \xi$$  \hspace{1cm} (4)

where $\xi$ is a random number uniformly distributed on the interval from 0 to 1. The random numbers used for the calculation have been generated by the multiplicative method (Peterman, 1972)

$$\xi_{i+1} = \xi_i (2^{16} + 3) \mod (2^{31} - 1)$$  \hspace{1cm} (5)

with $\xi_0 = 987 \; 654 \; 31$

RESULTS AND DISCUSSION

The investigated spectrometer as shown in Fig. 1a consists of a Ge-detector of dimensions $\phi \; 5 \; \text{cm} \times \; 5 \; \text{cm}$ located assymetrically in a cylindrical scintillation material (BGO or NaI) of diameter $d \; \text{cm}$ and length $l \; \text{cm}$. The Ge-detector is placed perpendicularly to the direction of the gamma ray incident through a hole diameter of $1 \; \text{cm}$ at a distance $1 \; \text{cm}$ from the detector.

Assuming the compton scattering to occur at the center of the Ge-detector, the absorption ranges $\times (\theta)$ in NaI and BGO shieldings have been calculated (eq. 3) for different percentage values of A/Ao and using incident energies ranging from 600-1500 keV. Fig. 1b shows a representation for the contours of the ranges in both BGO and NaI for 1 MeV $\gamma$-ray energy and assuming a 90% fractional absorption A/Ao. For the same energy region i.e. 600-1500 keV, geometrical and random calculations have been carried out to estimate the dimensions of the BGO and NaI shields as functions of A/Ao as presented in fig. 2. A good agreement between both methods of calculations can be seen for the lengths and diameters of the shields as well as its thickness in front of the Ge-detector as shown in sections a, b, c of that figure respectively. Accordingly, one can adopt for such calculations the geometrical method for its simplicity. Moreover from the comparison between BGO and NaI (11) curves, it can be concluded that for a fractional absorption of 90% a decrease can be reached in the dimensions of BGO compton suppression spectrometer to nearly half those of NaI. It is of interest to apply this result in predicting the shape of a spectrum after suppression with BGO. On basis of $^{60}$Co spectrum measured by Aarts et al. (Aarts, 1980) before and after suppression with a NaI crystal of $\phi \; 30 \; \text{cm} \times \; 35 \; \text{cm}$ as shown in fig. 3, one can achieve a similar suppression when using BGO scintillator of $\phi \; 14 \; \text{cm} \times \; 16 \; \text{cm}$.
Fig. 1 (a) Schematic cross-sectional drawing of the Compton-suppression spectrometer through a plane perpendicular to the axis of Ge-detector.

(b) The 90% absorption range contour of Compton scattered γ-rays for $h\gamma_0 = 1\text{MeV}$ in NaI (TI) and BGO.
Fig. 2. Geometrical and random calculations for the dimensions of BGO and NaI shields as functions of the fractional absorption \( A/A_0 \) for an energy of 600 keV.
Fig. 3  Spectrum of $^{60}$Co as measured by Aarts et al. 1980, down to an energy of 600 keV with NaI - suppressor of $\Phi$ 30 cm $\times$ 35 cm which can be similar to that of BGO suppressor of $\Phi$ 14 cm $\times$ 16 cm.

ACKNOWLEDGEMENT

The author wishes to thank Prof. Dr. F. El-Bedewi, King Abdulaziz University and Dr. T. L. Khoo, Argonne National Laboratory in Illinois, U.S.A. for their interest and stimulating discussions.

REFERENCES

Mohsen, M., 1982, to be published.
مطياف مداج لاستفادة كومتون باستخدام مادة جرامات البزموت الوضيعة

د. م.ب. محسن
قسم الطبيعة (قسم الطالبات) كلية العلوم - جامعة الملك عبد العزيز بجدة

ملخص البحث:

تمكن باستخدام كل من الطريقة الهندسية والعشوائية تقدير أبعاد مطياف حامد لاستفادة كومتون مادته الوضيعة اما جرامات البزموت أو أيوديد الصوديوم. وبناءً على مكانيّة خفض أبعاد المطياف المستقبلي على جرامات البزموت إلى حوالي نصف قيمتها في حالة استبدالها بأيوديد الصوديوم.

123