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APPLICATION OF BGO FOR NEUTRON CAPTURE CROSS SECTION MEASUREMENTS

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Abstract: A total absorption gamma-ray detector has been made using twelve BGO scintillator bricks of 5 x 5 x 7.5 cm^3, with an incentive to study the possibility of BGO for neutron capture cross section measurements of higher precision.

In this report, a study of the detection efficiency of the BGO for thermal neutron capture is presented. The efficiency has been measured at a neutron time-of-flight spectrometer at KURRI electron linear accelerator. Cd, In, Au and Fe were employed for capture samples as they have different types of capture gamma rays. The efficiency have been found between 80 to 100 %.

A study has been made on a technique to estimate the efficiency for a sample of unknown cross section and cascade gamma-ray spectrum using the information of the pulse height spectrum obtained with the BGO. At present, the estimation is only partly succeeded. For a sample of high multiplicity cascade gamma-rays, the BGO is satisfactorily used for capture cross section measurements. Further studies are needed before the BGO is used for samples of low gamma-ray multiplicity.

(bithmuth germanium oxide scintillator, neutron capture cross section, total absorption detector)

Introduction

Two kinds of measurements are essential to determine a neutron capture cross section. One is the neutron flux of irradiation, and the other is the neutron capture rate in the sample. We made a Bismuth Germanium Oxide ($Bi_4Ge_3O_{12}$) detector to determine the flux and the capture rate, with an incentive to find a new-type detector which can be used in capture cross section measurements of higher precision. BGO crystal has a high specific weight(7.13 g/cm^2), therefore a total absorption detector of prompt capture gamma-rays is assembled with a small amount of volume. The present BGO detector assembly consists of twelve scintillator bricks of 5 x 5 x 7.5 cm^3 equipped with respective photo-multipliers. The scintillator bricks are assembled to have a 2.7-cm square through hole as shown in Fig.1. A capture sample is placed at the center of the hole.

The detector has an efficiency more than 70 % for a mono-chromatic gamma-ray of MeV emitted at the sample position. The detection efficiency of capture events is at least 70 % even if the cascade of prompt gamma-rays has low multiplicity. As the multiplicity becomes higher, the detection efficiency of capture events approaches to 100 %.

The present study is on the detection efficiency of the BGO detector for neutron capture events , whose reliable estimation is essential in a neutron capture cross section measurement of high precision. The first half of the study is to experimentally confirm the detection probabilities of thermal neutron capture events for Cd, In, Au and Fe which have different cascades of gamma-rays of variety. The second half is a trial to estimate the detection efficiencies from the pulse height spectra taken in the experiments.

Experiment

A thermal neutron beam provided at the time-of-flight spectrometer of the electron linear accelerator facility at Kyoto University Research Reactor Institute was used for the study in an energy region between 0.024 and 0.2 eV. The capture yields(the number of capture events for unit flux) of the neutron beam for foils of Cd, In, Au and Fe, have been measured by detecting the cascade of prompt gamma-rays by the BGO detector assembly. In the data processing the detection efficiencies of capture events for respective samples were temporarily assumed 100 %. The neutron flux impinging on the samples was determined with a Sm-sample and the BGO assembly. The Sm-sample is black for the neutron beam and the detection efficiency of capture events is 100 % as the gamma-ray multiplicity is high enough and the loss of counting is negligibly small.[1]

The capture yields can be calculated qouting capture cross section data from BNL-325 [2] and using the neutron energy spectrum measured with the Sm-sample and the BGO assembly. The detection efficiencies of capture events are given as the ratios of two kinds of capture yields above mentioned: the measured assuming the efficiency is 100 % and the calculated using the cross section values.

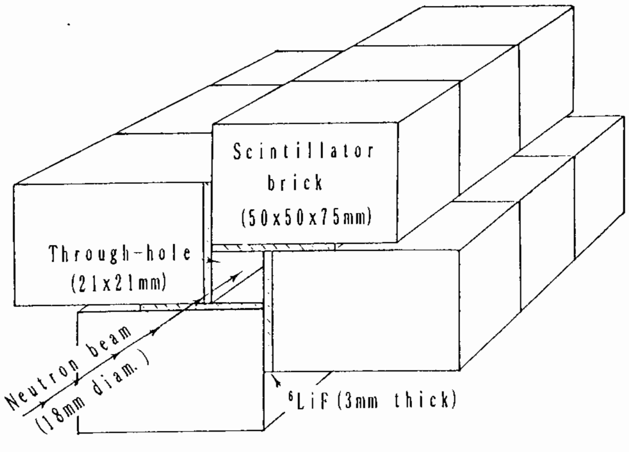

Fig.1 BGO scintillator assembly.

The electronic diagram for data acquisition system is shown in Fig.2. Linear pulse height signals from twelve BGO bricks are stored by summing twelve signals and sorting the signals according to the detection multiplicity. In this report, " detection multiplicity" means the number of BGO bricks responded to a capture event. "Gamma-ray multiplicity" is the number of gamma-rays emitted in a cascade following a neutron capture. A few examples of the pulse height spectra are shown in Fig.3.

The integrated area of the summed linear pulse height spectrum is proportional to the number of capture events. The capture event detection efficiencies are shown in Fig.4 for Cd, In ,Au and Fe by changing the discrimination level. The error bars in the Fig.4 are estimated from counting statistics only. Errors in atomic number density in the samples and those of capture cross section values are approximately 1 %. Multiple scattering effect of neutrons in capture samples was taken into account in data processing. The error caused by the effect roughly estimated 3% for Fe, and less than 1 % for the other samples.

Figure 4 shows that for capture gamma-rays of high multiplicity as in Cd and In, the integrated area of a summed pulse height spectrum is insensitive to the discrimination level and the detection efficiency of capture event is close to 100 %.

For low multiplicity gamma-rays, the discrimination level is still sensitive to the integrated area, and the detection efficiency is around 80 to 90 %.

An important procedure in the data processing when the BGO is used for an unknown capture cross section is to estimate the value of detection efficiency of capture events. The gamma-ray spectrum is usually not available in the processing. A trial of the estimation is presented in the following and the result is compared with the values given in Fig.4.

Estimation of the Detection Efficiency of Capture Events

Let us denote by A_i the probability that the number of gamma-rays following a neutron capture (i.e. gamma-ray multiplicity) is "i". They have the relation as follows:

$$A_1 + A_2 + A_3 + \ldots\ldots\ldots = 1.0 \,. \qquad (1)$$

If the detection efficiencies of individual gamma-rays have a similuar value E_s, the detection efficiency of captute events E_c is given by,

$$E_c = 1.0 - \{ A_1(1-E_s) + A_2(1-E_s)^2 + \ldots\}. \qquad (2)$$

Estimation of E_s

A result of a Monte Carlo calculation of the efficiency of the BGO for monoenergetic gamma-rays are shown in Fig.5. If a discrimination level of pulse height is employed near 400 keV, it is seen the value of E_s is 0.75.

Determination of A_i

Let us define P_{ij} and C_i as follows:

P_{ij} : The probability that the BGO assembly counts, as a full energy peak, a capture event of a gamma-ray multiplicity "i" and with a detector multiplicity "j",

C_i : Integrated count of the pulse height spectrm corresponging to full energy peak for a detector multiplicity "i".

Then, we have the following equations.

$$\begin{aligned} C_1 \quad & A_1P_{11} + A_2P_{21} + A_3P_{31} + \ldots\ldots \\ C_2 \quad & A_1P_{12} + A_2P_{22} + A_3P_{32} + \ldots\ldots \\ C_3 \quad & A_1P_{13} + A_2P_{23} + A_3P_{33} + \ldots\ldots \quad (3) \\ & \cdot \\ & \cdot \end{aligned}$$

If we employ an adequate set for P_{ij}, A_i s are determined by solving equations (1) and (3), and E_c is given by equation (2).

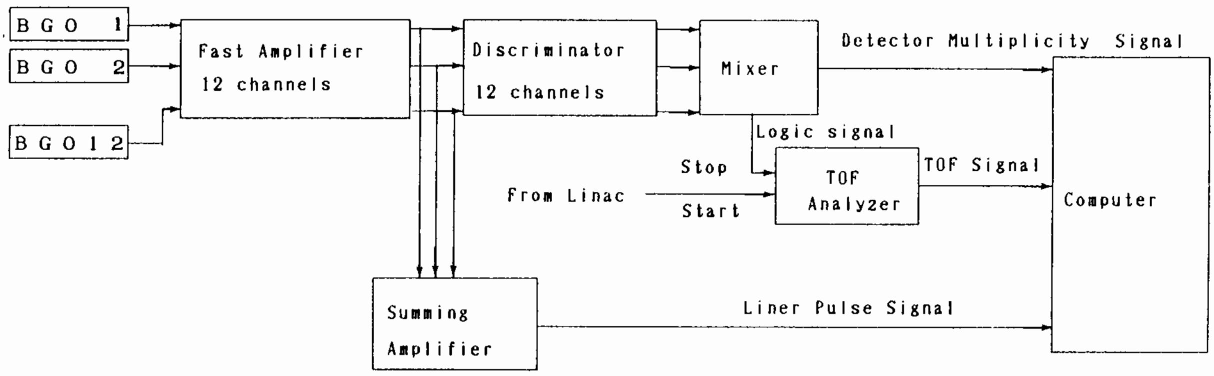

Fig.2 Electronic diagram of data aquisition system.

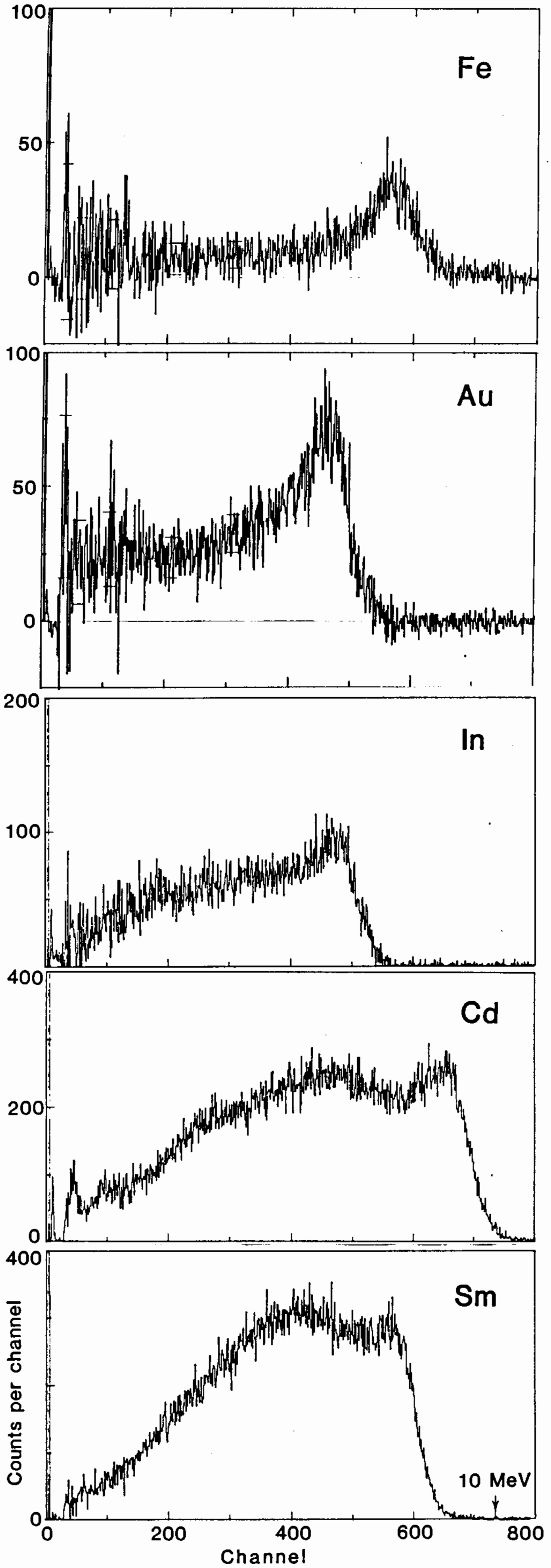

Fig.3 Pulse height spectra of BGO for thermal neutron capture.

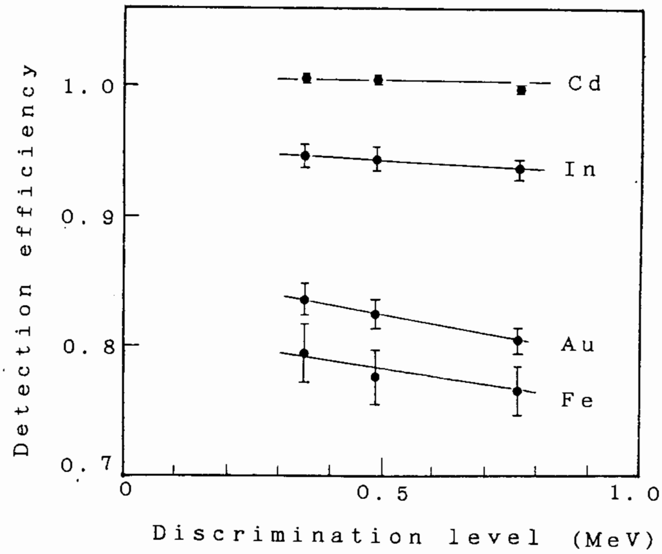

Fig.4 Detection efficiency of the BGO for thermal neutron capture.

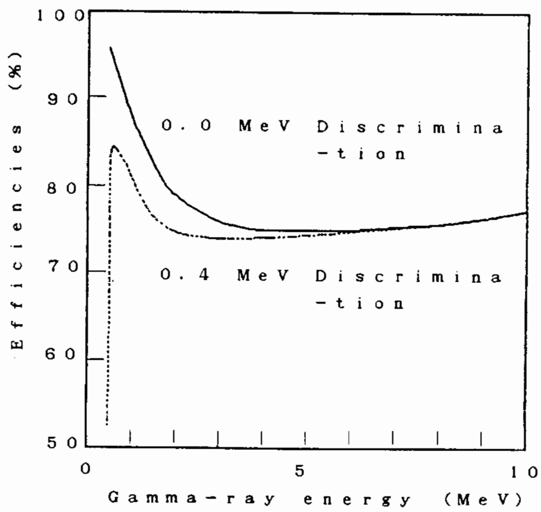

Fig.5 Calculated efficiencies for mono-energy gamma-rays.

Table 1 The results of E_C

The detection efficiency of thermal neutron capture events for Cd, In, Au and Fe obtained from the information in pulse height spectra.

	Cd	In	Au	Fe
A_1	0.005	0.03	0.12	0.26
A_2	0.10	0.27	0.43	0.46
E_C	0.99	0.98	0.93	0.89

To employ a set for P_{ij}, the following assumptions and approximations have been made.

1) P_{ij} is independent of gamma-ray energy,
2) P_{1j} is zero for i>2,
3) P_{11} + P_{12} = 0.60, which is obtained by a Monte Calro calculation, and P_{12}=1/3 P_{11}, which is a value obtained for 4.4 MeV gamma-rays,
4) Twelve scintillator bricks are symmetrically placed,
5) P_{ij}s are deduced using P_{11} and P_{12}.

The results obtained for E_c are shown in Table 1.

Summary

This study on the detection efficiency of neutron capture events is presently summarized as follows.

1)For a sample of high gamma-ray multiplicity, as is in the case of Cd, the detection efficiency is very close to 100 % with about 1% reliability. The BGO can be therefore used in capture cross section measurements in such a sample.

2)For a sample of low gamma-ray multiplicity, as is in the case of Fe, the detection efficiency is about 80 %. The 20 % loss of detection has been explained only partly. More study for the estimation of the loss is needed before the BGO is used for capture cross section measurements.

REFERENCES

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2. S.F.Mughabghab:" Neutron Cross Sections ", Academic Press, Inc., (1984).