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SHORT NOTE

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Neutron sensing techniques have attracted much attention to open possibilities in many fields of technologies. At accelerator facilities developing for medical and industrial applications, environmental neutrons must be monitored by highly sensitive detectors. The sensitivity of presently-existing detectors, however, is insufficient to provide reliable time-dependent neutron numbers at environments. A neutron tomographic system that is under rapid developments, needs a high sensitivity to achieve better imaging performances. For the reasons, it is desired to develop a highly sensitive neutron detector.

Gadolinium (Gd) is known to have an extremely large cross section for thermal neutron capture. A great deal of efforts have been made to apply Gd for thermal neutron detection, such as Gd-loaded liquid scintillators. Another attempt known widely was made by the use of natural Gd plates as neutron converters, where internal conversion electrons of about 30 to 250 keV, produced *via* neutron capture, were detected by additional sensors[(1)-(4)]. Since the range of those electrons is very short in Gd plates, the detection efficiency should be limited strongly. In recent years, a scintillator cerium-doped gadolinium orthosilicate, Gd_2SiO_5(Ce)-GSO(Ce), has been developed. Optical performances of GSO(Ce) scintillators were studied intensively and found to be excellent[(5)-(11)]: a high light output about 20% of that of NaI(Tl) crystal and a short scintillation decay time constant 50 - 60 ns which depend on the concentration of doped cerium. Since gadolinium is involved in the crystal as a constituent, the scintillator may have an advantage in detecting the conversion electrons with a high efficiency. Thus, GSO(Ce) should have the higher efficiency than detectors coupled to Gd plates. Furthermore, its timing response is much faster than that of a BF_3 counter, one of typical thermal neutron detectors, about 8 μs. The fast timing response is another advantage to allow high count rate measurements, for instance, a sub-criticality measurement in nuclear power reactors. Although GSO(Ce) scintillators have been expected as a candidate for highly sensitive neutron detectors[(12)(13)], there have been few measurements of the absolute efficiency. In this article, a simple detector system having a 4.3 cm cubic GSO(Ce) crystal was investigated in terms of the absolute efficiency for thermal neutron detection.

To estimate the neutron sensitivity of a detector, one should employ an assumption of a neutron source and a detector being point-like. Hence, one could use a relation;

$$Y = \frac{N_0 N_S}{4\pi r^2}, \tag{1}$$

where Y is the counting rate (cps), N_0 the neutron emission rate of the source (neutrons/4 π/sec), N_S the sensitivity to neutrons (counts·cm^2/neutrons), r the distance (cm) between the detector and the source. By the use of this relation and a standard neutron source, one can deduce the absolute neutron sensitivity. As is obvious from Eq.(1), the N_S is a unique measure of the sensitivity for the interested detector.

The neutron source used was Am-Be. The neutron emission rate of the source was calibrated with a commercial neutron rate meter (STUDSVIK-2202D). The N_S value of the rate meter was reported to be 0.45 (counts·cm^2/neutrons). As a result of the absolute measurement, a neutron emission rate $2.6(\pm 0.1)\times 10^4$ was obtained. The value is consistent with values 2.5×10^4 and 2.7×10^4 (neutrons/4π/sec) which have been estimated from the α-emission strength of ^{241}Am in the source. The difference can be ascribable to an ambiguity in a coefficient which gives a ratio of α-to-neutron conversion. Consequently, we decided to employ a number 2.6×10^4 (neutrons/4π/s).

Figure 1 is a sketch of the present detector system and the neutron source. Both of the detector and the source were put on a steel desk with a 1.2 m height to suppress an effect of neutrons scattered by a concrete floor. A crystal of GSO doped with 0.5 mol% Ce had a cubic shape with a 4.3 cm edge length, which was produced at Hitachi Chemical Co. Ltd. The GSO(Ce) crystal was covered by a teflon film and an aluminized mylar foil as a light reflector and a light shield. One of the faces of the crystal was viewed by a photomultiplier tube (PMT: HAMAMATSU-H1161). Both of the crystal and the PMT were surrounded by 5 cm thick paraffin plates to be a neutron moderator. A lead and a brass plate were placed between the detector and the ^{241}Am-Be neutron source to eliminate the background of γ-rays from the source and Pb X-rays. The effect

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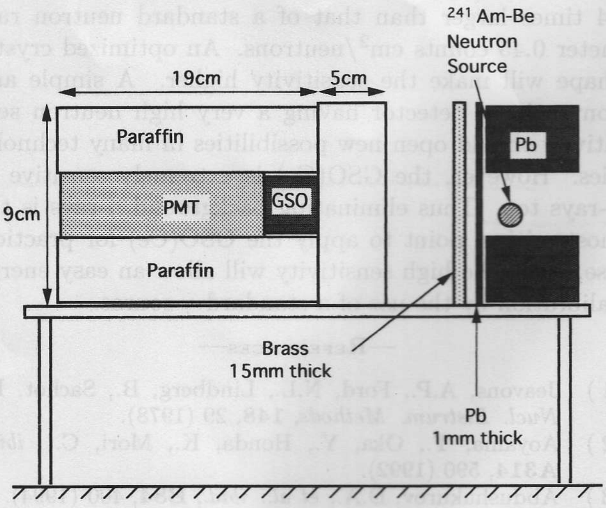

Fig. 1 Detector system consisting of a GSO(Ce), a photomultiplier tube and a paraffin moderator, and a neutron source Am-Be

of shielding plates was examined carefully, and a combination of a 1 mm thick Pb and a 15 mm thick brass plate was chosen. Pulse-height spectra were measured by an ADC system interfaced with a personal computer. Energy calibration was performed by using a standard γ source ^{137}Cs and a lead plate, *i.e.* 662 keV γ-rays, 75 keV Pb X-rays and 32 keV Ba X-rays. The energy resolution was 12% for the photoelectron-peak of 662 keV γ-rays.

A gross pulse height spectrum measured for thermal neutrons with the ^{241}Am-Be source is shown by a solid line in **Fig. 2**, together with a background spectrum by a dashed line. There are rather large number of background events because of no shield around the scintillator detector. **Figure 3** presents the response of the GSO(Ce) scintillator to thermal neutrons, where the background has been subtracted by an off-line analysis. In the figure are observed two sharp peaks below 100 keV and two broad peaks at higher energies. The structure of the response resembles that of Ref.(13) very well. The

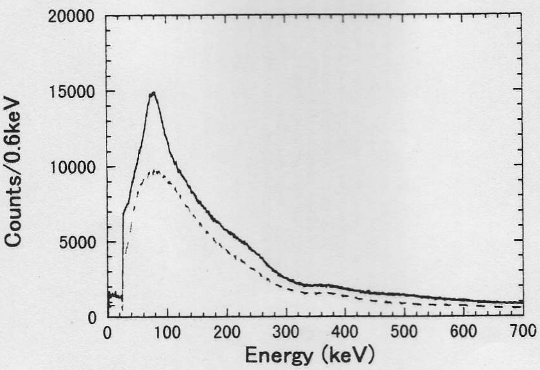

Fig. 2 Pulse height spectra measured with neutrons from Am-Be
Solid line: with the neutron source.
Broken line: without the neutron source.

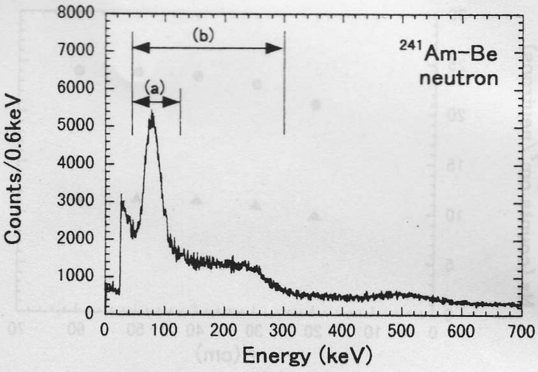

Fig. 3 Response of GSO(Ce) to neutrons from Am-Be. See text about regions (a) and (b)

energies of the second and the third peaks were determined to be 75 and 240 keV, respectively. These values are close to those of Ref.(13), 80 and 240 keV. Though the 35 keV peak was observed clearly in Ref.(13), there is a slight indication of the peak due to many events at lower energies, where a lower discriminator level was 20 keV. A cause of these events is not interpreted at present. The energy of the fourth peak is found to be 500 keV, which is higher than that of Ref.(13), *i.e.* 460 keV. This energy difference should be ascribed to the larger volume of the present scintillator crystal.

In neutron sensitivity measurements, neutron count rates were measured as a function of distance between the neutron source and the detector. To determine the sensitivity, a range of pulse height distribution must be chosen to discriminate neutron events from the background clearly. The range around the second peak from 45 to 120 keV is a good indication of neutrons, as is indicated by (a) in Fig. 3. The range (b), from 45 to 300 keV, including the second and the third peaks may be alternatively possible for the discrimination. The neutron numbers were obtained by analyzing spectrum data in the each pulse height region. The resulted neutron sensitivities of the detector are shown in **Fig. 4**, where dots present the results for region (a) and triangles for (b). A flat part of the curve will suggest that Eq.(1) is valid under the condition, hence the sensitivity results in 11 and 24 counts cm^2/neutrons for regions (a) and (b), respectively. Since the ratio of sensitivity (a) to (b) agrees nearly with a ratio of conversion electron intensities[14], the results can be convinced.

It is interesting to compare the present result with the sensitivity N_S of different types of detectors. The commercial rate meter (STUDSVIK-2202D) is a standard neutron detector, which consists of a BF_3 counter of 1.3 cm in diameter by 15 cm in length, and a moderator of polyethylene 21.5 cm in diameter by 23 cm in length. The volume of the moderator was similar to that of the present GSO(Ce), so and the both sensors of detectors were supplied with the similar number of thermal neutrons. The present result of 11 counts

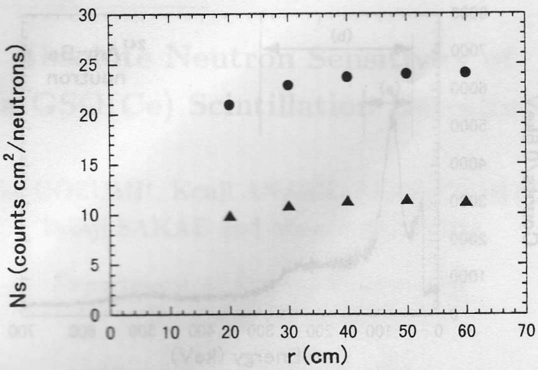

Fig. 4 Neutron sensitivity N_S as a function of distance r between the GSO(Ce) crystal center and the neutron source

Circles are results for region (a), and triangles for (b).

cm^2/neutrons for region (a) is approximately 24 times larger than that of the BF_3 rate meter 0.45 counts cm^2/neutrons. It must be noted that the sensitivity of a BF_3 counter depends on its gas volume, while that of the GSO(Ce) its surface area because of a very short penetrating range of neutrons about 11 μm. Therefore, the further discussion cannot be done on this result.

In conclusion, a detector system with a GSO(Ce) scintillator coupled to a photomultiplier tube was investigated in terms of an absolute sensitivity for thermal neutron detection. The 75 keV peak was found to be a good indication of thermal neutrons and give the sensitivity 11 counts cm^2/neutrons. This value is about 24 times larger than that of a standard neutron rate meter 0.45 counts cm^2/neutrons. An optimized crystal shape will make the sensitivity higher. A simple and conventional detector having a very high neutron sensitivity should open new possibilities in many technologies. However, the GSO(Ce) is extremely sensitive to γ-rays too. Thus eliminating background γ-rays is the most critical point to apply the GSO(Ce) for practical use, while the high sensitivity will allow an easy energy calibration by the use of a standard γ source.

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