AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 mm

1 2 3 4 5

Inches

1 of 1

Conf-940524--8

PNL-SA-24259

THIN GSO SCINTILLATOR FOR NEUTRON DETECTION

P. L. Reeder

May 1994

Presented at the
1994 Symposium on Radiation Measurements
and Applications
May 16-19, 1994
AnnArbor, Michigan

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

PNL-SA-24259

Thin GSO Scintillator for Neutron Detection

P. L. Reeder

Pacific Northwest Laboratory*
Richland, WA 99352, USA

Abstract

The new scintillator cerium-doped gadolinium orthosilicate (GSO = Gd_2SiO_5:Ce) has a light output that is about 20% that of NaI(Tl). The enormous cross section of Gd for capture of thermal neutrons makes GSO a candidate for novel types of neutron detectors. The characteristic radiations from neutron capture in Gd can be stopped in about 75 μm of GSO. Data obtained from a GSO detector that was about 0.6-mm thick demonstrated that thermal neutrons could easily be detected and that higher energy gamma rays caused minimal interference.

*Operated for the US Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

1. Introduction

A new scintillator cerium-doped gadolinium orthosilicate (GSO - Gd_2SiO_5:Ce) has a light output that is about 20% that of NaI(Tl) [1]. Although originally developed as a possible replacement for BGO in Positron Emission Tomography applications, the enormous cross section of Gd for capture of thermal neutrons (49,000 b) makes GSO a candidate for novel types of neutron detectors. Thick GSO detectors are not needed for neutron detection as the penetration of a thermal neutron is only about 11 μm from the surface of the GSO.

About 80% of the neutron captures in Gd occur in ^{157}Gd and 18% of the neutron captures occur in ^{155}Gd. The binding energies of the neutron in the capture products ^{156}Gd and ^{158}Gd are 8.5 and 7.9 MeV, respectively. This excitation energy is released by a cascade of high-energy gamma rays. However, most of the cascades pass through a series of low-lying states where internal conversion can occur. Thus, neutron capture by Gd produces gamma rays, x-rays, and conversion electrons.

The low-lying states of ^{156}Gd and ^{158}Gd are shown in Fig. 1. The level structure is quite similar for these two isotopes. In GSO the resolution is not adequate to distinguish one isotope from the other. The final transitions in the de-excitation of ^{158}Gd and ^{156}Gd are low energy and occur in a nuclide with rather high Z (Z=64). Thus, internal conversion competes with gamma emission. The energies of K shell conversion electrons for each of the transitions are shown in Fig. 1 along with estimated conversion coefficients (α_K). Thus, the $2^+ \rightarrow 0^+$ transition undergoes internal conversion 70% of the time, and the $4^+ \rightarrow 2^+$ transition is converted about 17% of the time. Internal conversion of the 80 keV $2^+ \rightarrow 0^+$ transition generates a 29 keV conversion electron and a 44 keV Gd K x-ray. In GSO, the conversion electron has a range of only 2 μm, so in most cases, the conversion electron does not escape the crystal. The 44 keV x-ray has a range of about 75 μm and so escapes the crystal completely in 50% of the decays because all capture events are near the surface. Thus, half of the time this energy adds to the conversion electron energy, thus creating a peak at about 80 keV, and half of the time only the conversion electron is detected thus giving a

peak at about 35 keV. Both the 35- and 80-keV peaks should be good indicators of a neutron capture event.

We have previously shown that thermal neutron capture in 1-cm^3 cubes of GSO did indeed produce the distinctive peaks at about 35 and 80 keV [2]. The present work extends the previous work by showing the response of a thinner GSO detector to thermal neutrons and a ^{137}Cs gamma source.

Thin GSO detectors for neutrons might find use in applications where an all solid state sensor is required due to vibration or other environmental problems. The light output of GSO is sufficient that the 80-keV peak should be above the noise levels in present day avalanche photodiode (APD) detectors. The combined thickness of the GSO scintillator and APD could be less than 3 mm. This would provide a simple, small, rugged neutron sensor. In addition, a segmented APD or multianode photomultiplier tube could be used with a thin GSO detector for imaging slow neutrons.

Experiments

A 1-cm^3 cube of GSO doped with 2 mol% Ce was sliced at PNL to give a slab 0.95 cm by 0.71 cm by 0.06 cm. The cutting process introduced numerous cracks in the crystal, so the tests reported below were not on an optimum sample. The sample was mounted with optical grease on a 1-cm photocathode-diameter photomultiplier tube (Hammamatsu R2557-02). Alternatively, a 1-cm^3 cube of GSO doped with 0.5 mol% Ce was mounted on the same photomultiplier tube (PMT). The PMT with either of the two GSO crystals was placed in a polyethylene and lead shield shown schematically in Fig. 2. Pulse-height spectra were measured using a CAMAC-based data acquisition system interfaced to a Macintosh computer.

From our previous work, the 0.5 mol% Ce crystal was known to produce about 16% more light than the 2.0 mol% Ce crystal [2]. However, the voltage on the PMT had to be reduced for the thin crystal relative to the high voltage for the thick crystal to match the pulse amplitudes for the Ba X-ray from a ^{137}Cs source. The cause of this higher light output from the thin sample is unknown at this time. The response of the thin crystal to the ^{137}Cs source is compared to the response of the thick crystal in Fig. 3. Both spectra have been corrected for the background

pulse-height spectrum. The ^{137}Cs 662-keV photopeak and the 32-keV peak from the Ba X-ray were used to calibrate the energy scale for all the experiments reported here. The 662 keV photopeak from ^{137}Cs is dramatically reduced in the pulse-height spectrum for the thin GSO detector compared to the thick GSO detector.

A PuBe source was placed behind the 10.16-cm-thick lead brick in the location shown in Fig. 2. The lead eliminated gamma rays from the PuBe source. The 2.3-mm-thick copper sheet shielded the detector from any lead X-rays. The polyethylene served as the moderator to reduce the neutron energies to thermal energies. The pulse-height spectrum from the neutron irradiation of the thin GSO crystal is compared to the spectrum from the thick GSO crystal in Fig. 4. We note that the characteristic peaks at 35 and 80 keV corresponding to neutron capture events are present in both spectra. Both spectra have been corrected for their respective backgrounds. The energies reported here are a few keV higher than those reported in Ref. [2] due to an improved energy calibration.

The thick GSO crystal shows broad peaks at about 240 and 460 keV corresponding to gamma transitions from the second and third excited states of ^{156}Gd and ^{158}Gd. These peaks are greatly reduced in the spectrum for the thin GSO crystal. These data clearly show that the thin GSO crystal maintains its distinctive neutron capture peaks while greatly minimizing its sensitivity to higher-energy gamma rays relative to the thick GSO crystal.

The background count rate decreased by a factor of 10 between the thick and thin crystals, whereas the net neutron count rate decreased by a factor of about 4. The reduction in neutron count rate was proportional to the relative surface areas of the two samples (area thick/area thin = 3.9). The volume ratio of the two GSO samples was 25, which is another indication that neutron detection by GSO is a surface phenomenon rather than a volume phenomenon.

Conclusions

The GSO detector has been demonstrated to have a high efficiency for capturing thermal neutrons and producing a distinctive signature in its pulse-height spectrum. To be useful as a neutron detector, it is important that any sensor material have no or minimal sensitivity to other types of radiation. In bulk form, GSO has a significant gamma sensitivity because of its high effective nuclear charge Z. This work has shown that thin slabs of GSO retain the ability to detect thermal neutrons and have minimal gamma sensitivity.

From the data in Ref. [2], we estimated that the 80-keV neutron capture peak in GSO corresponds to about 800 photons. If avalanche photodiodes can be made with noise levels less than about 100 photons, the 80-keV peak should be easily observed above the noise. The combination of a thin GSO scintillator and an APD photodetector should provide a simple and compact neutron sensor.

Besides the standard configuration of a thin crystal mounted on a PMT, one can imagine many novel neutron-detector assemblies based on this scintillating crystal. It should be straight forward to construct an imaging neutron sensor based on a thin crystal mounted on a position sensitive photomultiplier tube, for example.

Another advantage of the GSO neutron detector is its fast-timing characteristics. The fluorescence decay time of GSO is about 50 ns, which is typical of Ce-doped scintillators. This allows GSO to be used in fast-timing coincidence arrangements with other types of detectors. The timing characteristics are much better than the typical gas proportional counter tube, but are not as fast as those for liquid scintillators. However, a GSO detector could be much more rugged and compact than a liquid scintillator.

Acknowledgments

We thank C. L. Melcher of Schlumberger-Doll Research and M. J. Weber of Lawrence Livermore National Laboratory for stimulating discussions

concerning GSO. This work was performed under the auspices of the US. Department of Energy.

References

[1] H. Suzuki, T. A. Tombrello, C. L. Melcher, and J. S. Schweitzer, Nucl. Instr. and Meth. A 320 (1992) 263 (and references therein).

[2] P. L. Reeder, "Neutron Detection Using GSO Scintillator", Nucl. Inst. Meth. Phys. Res. A 340 (1994) 371.

Figure Captions

Fig. 1. Low-lying level structure of ^{156}Gd and ^{158}Gd. In addition to energies of individual transitions, energies of coincidence sum peaks are given. Internal conversion coefficients are estimated from the energies and transition types. Energies of conversion electrons are given in parentheses next to the gamma transition energies.

Fig. 2. Source and shielding arrangement for pulse height measurements.

Fig. 3. Pulse-height spectra for ^{137}Cs in GSO scintillator. Upper curve - thick GSO. Lower curve - thin GSO.

Fig. 4. Pulse-height spectra for neutrons in GSO scintillator. Upper curve - thick GSO. Lower curve - thin GSO.

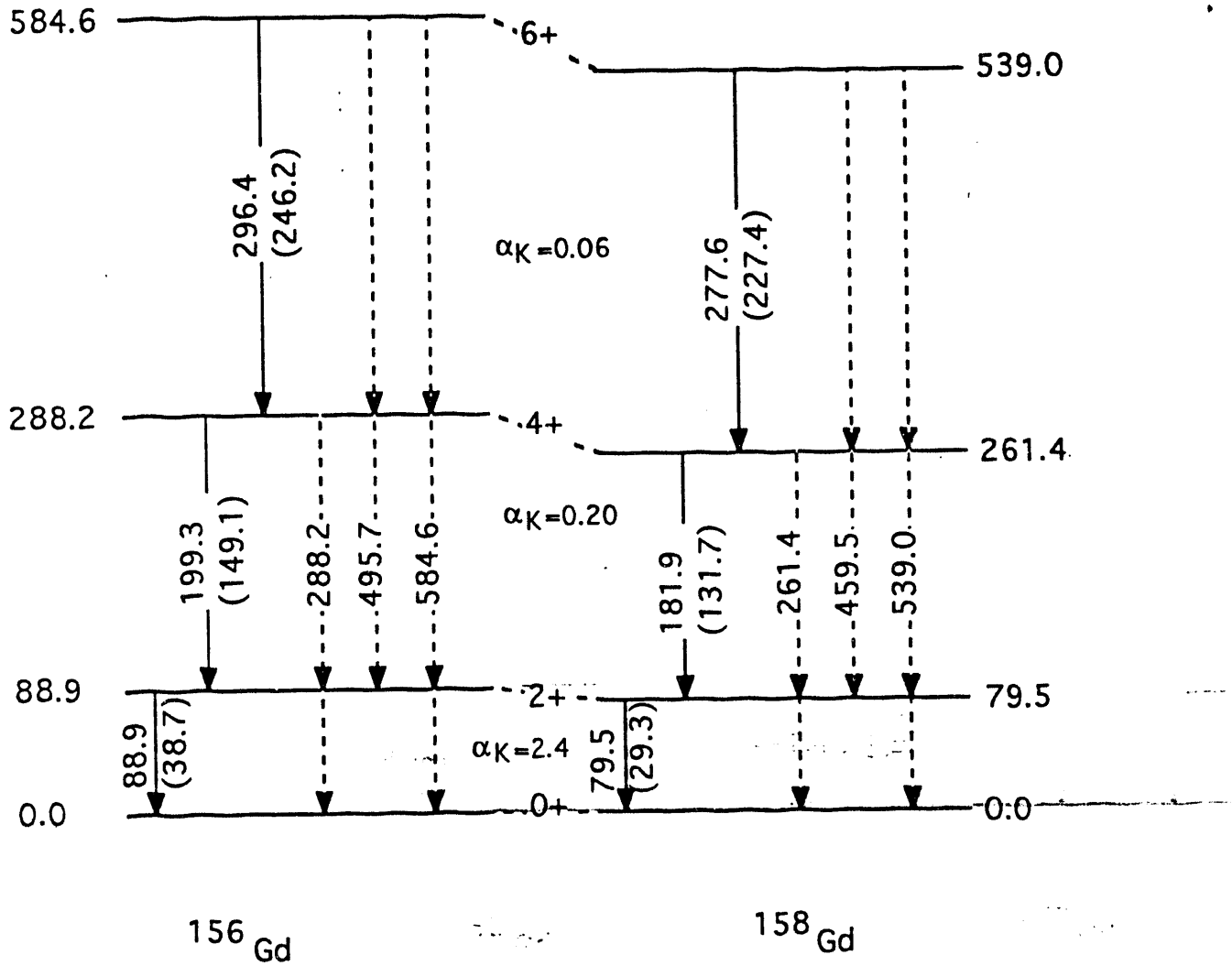

Fig. 1. Low-lying level structure of ^{156}Gd and ^{158}Gd. In addition to energies of individual transitions, energies of coincidence sum peaks are given. Internal conversion coefficients are estimated from the energies and transition types. Energies of conversion electrons are given in parentheses next to the gamma transition energies.

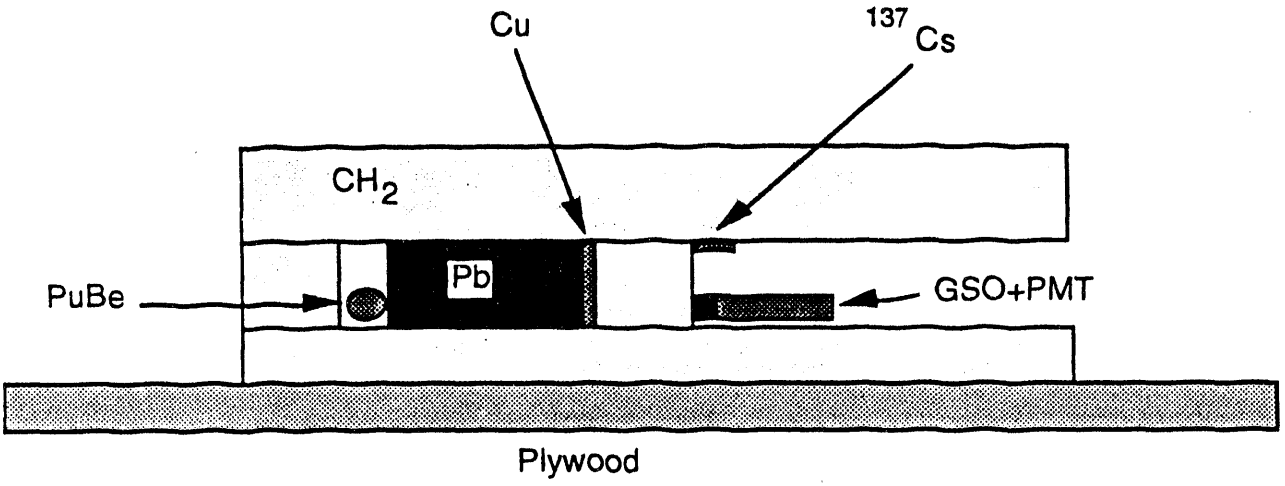

Fig. 2. Source and shielding arrangement for pulse height measurements.

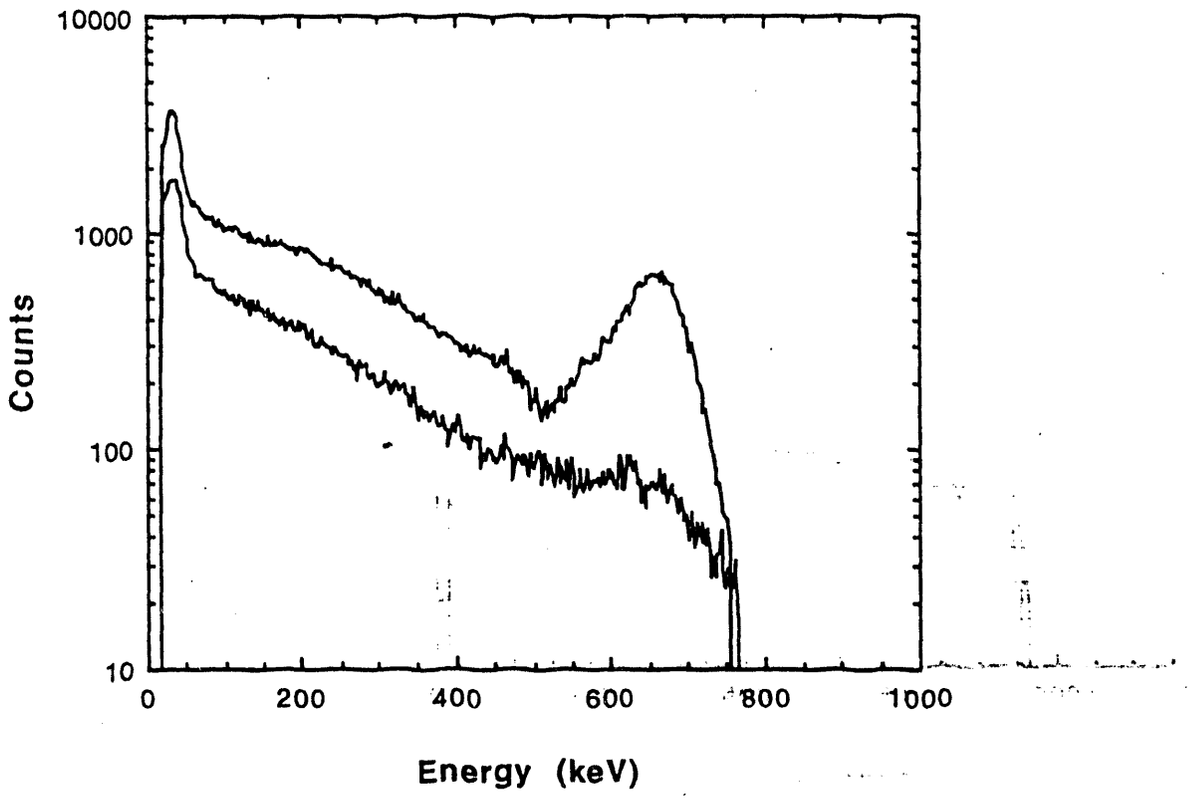

Fig. 3. Pulse height spectra for ^{137}Cs in GSO scintillator. Upper curve - thick GSO. Lower curve - thin GSO.

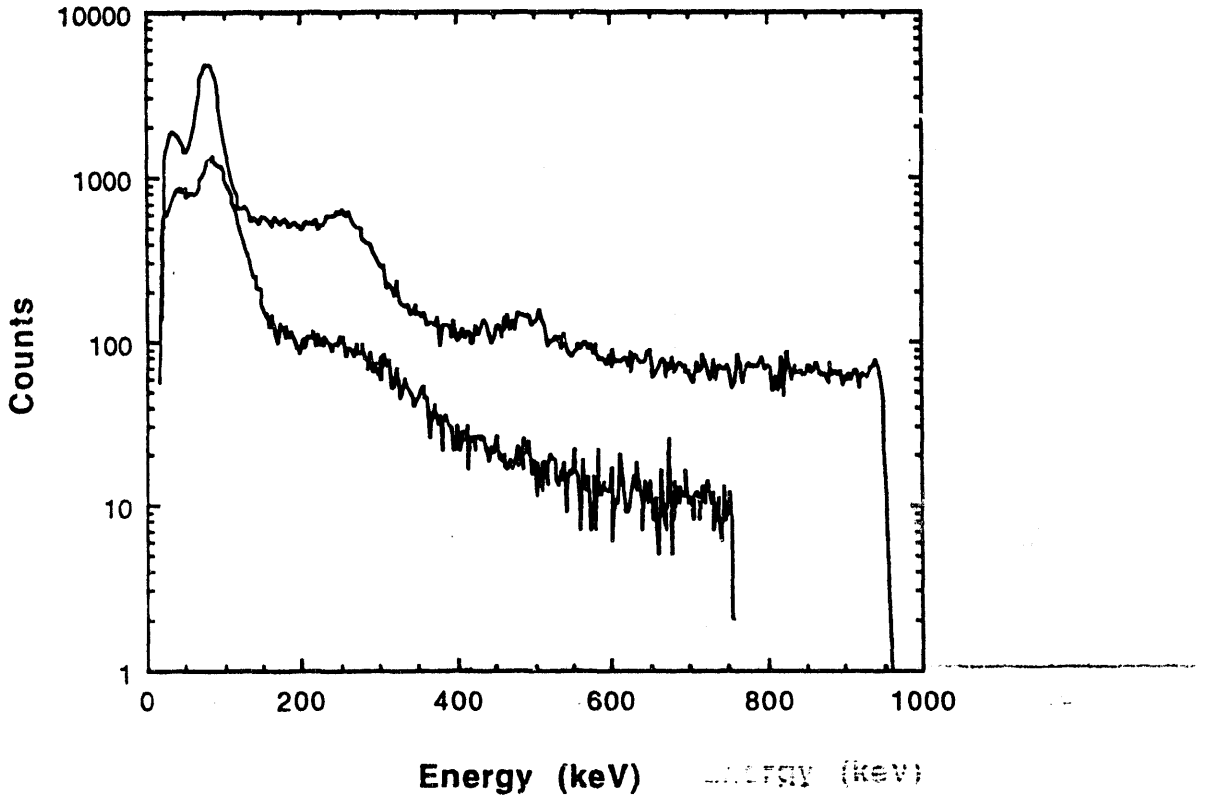

Fig. 4. Pulse height spectra for neutrons in GSO scintillator. Upper curve = thick GSO. Lower curve = thin GSO.

DATE
FILMED
8/10/94

END