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Capture-gated neutron spectrometry

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Abstract

The applications of a new inorganic scintillator, lithium gadolinium borate, to neutron dosimetry and spectroscopy, are described. A dosimeter using this material registers, in separate energy bins, thermal, epithermal and MeV neutrons. A spectrometer for MeV neutrons has a calculated energy resolution of 10% FWHM. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Neutron detector; Spectrometry; Organic scintillator

1. Introduction

A new neutron-sensitive inorganic scintillator is utilized for neutron detection in capture-gated spectrometers. The new material, lithium gadolinium borate [1], is much more efficient at capturing low-energy neutrons and converting the resulting energy into light, than previous scintillators (see Table 1). Varying the isotopic composition of the capturing nuclei in fabricating this scintillator yields great versatility for various applications. An unusually low index of refraction permits small crystals of lithium gadolinium borate to be incorporated into transparent plastic scintillator matrices in various configurations that provide detailed neutron energy information.

2. Dosimetry

When used in dosimetric applications, this spectrometer is capable of distinguishing between thermal, epithermal and MeV neutrons and of providing the dose rate to high accuracy. For this application, borate crystals with an isotopic composition of $^{6}Li_6Gd(^{11}BO_3)_3:Ce$ are incorporated in approximately 100 cm^3 of plastic scintillator, at a concentration of 10% by weight. The dosimeter is sensitive to incident thermal neutrons through capture in Gd and to incident epithermal neutrons through capture in ^{6}Li. Gadolinium capture yields approximately 8 MeV of gamma energy, which produces a large, fast signal in the plastic scintillator matrix (5 ns decay time). Capture of an epithermal neutron in ^{6}Li produces a monoenergetic slow signal (270 ns decay) that is easily distinguished from the Gd-capture signals. An incident MeV neutron interacts first with the plastic scintillator (multiple neutron, proton elastic collisions) and subsequently by capture at low energy in ^{6}Li [2–4]. This dual signal from a single

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Table 1
Scintillator characteristics

Chemical formula: $Li_6Gd\ (BO_3)_3:Ce$
Light output relative to GS20 glass scintillator: 6.0
^{6}Li-capture signal in Burle S83006 PMT: 6200 photo-electrons
Scintillation decay time: 270 ns fast component; 2 μs slow component
Ce emission spectrum: 370–470 nm
Macroscopic cross section at 0.025 eV: GS20 glass 16 cm^{-1}, ^{6}Li borate 31 cm^{-1}, ^{10}B borate 63 cm^{-1}
Index of refraction: 1.66
Li atomic density: 3.3×10^{22} atoms cm^{-3}
Electron energy equivalent for ^{6}Li capture peak: 2.2 MeV
Electron energy equivalent for ^{10}B capture peak: 0.46 MeV

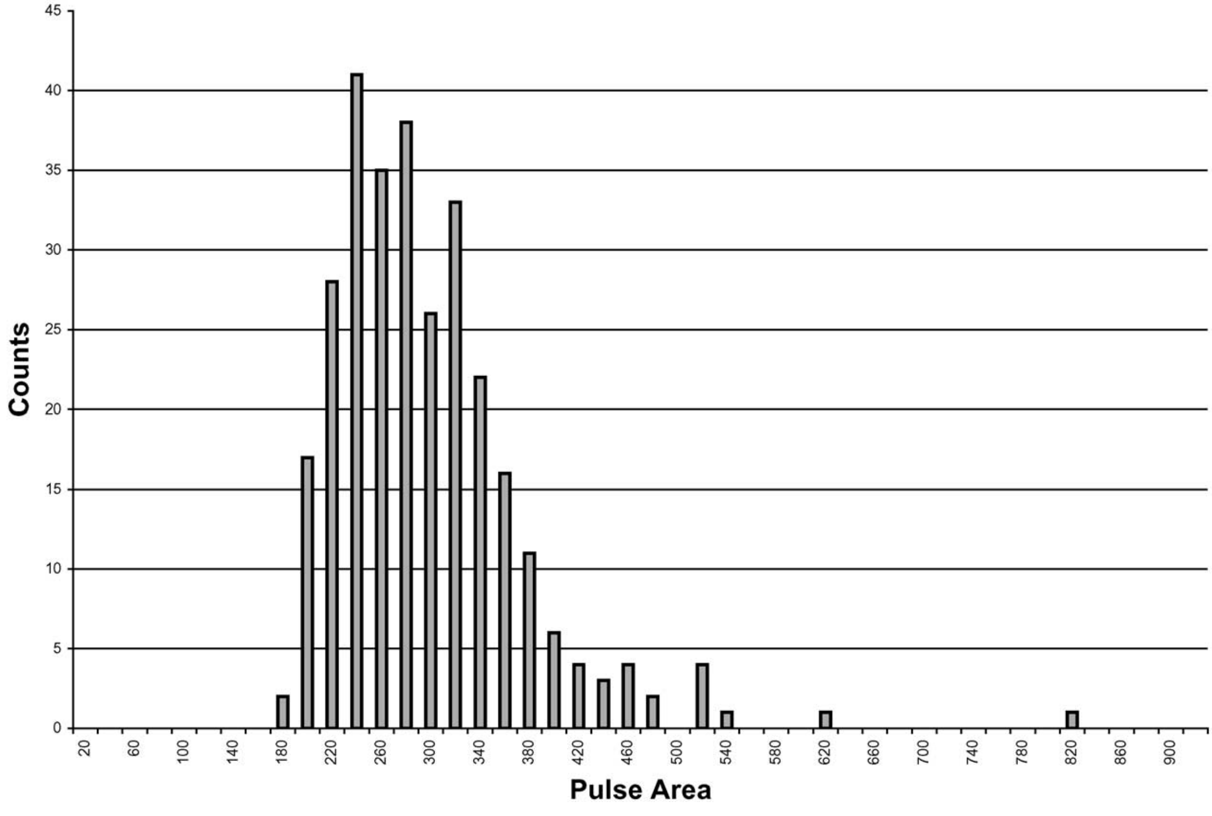

Fig. 1. Pulse-area spectrum of 75 cm^3 dosimeter for 4-MeV incident neutrons.

incident neutron discriminates against simple gamma background events and yields the neutron energy by summing the multiple signals from the proton collisions (see Fig. 1). A total of 12 energy bins are employed (thermal, epithermal, and 10 high-energy bins) to provide the detailed spectral information required for high-precision dosimetry, making it possible to closely match the current ICRP recommendation. The complex signal analysis for this dosimeter is accomplished by waveform digitization in a small, lightweight, printed circuit board. The pulse area (signal size) and pulse shape are recorded for each detected particle and sorted into the appropriate classification for processing into the overall dose rate. The plastic scintillator is also utilized as the detector material for gamma dosimetry, as is currently done with some commercially available gamma dosimeters. In this case, a small, fast, plastic scintillator signal is recorded, as described above, and converted to gamma dose.

3. Spectroscopy

This capture-gated spectrometer can also be adapted to a low-efficiency, high-resolution version. For a thin layer of material, multiple neutron scattering followed by capture is unlikely. So, for capture to occur, the neutron must lose almost all of its kinetic energy in *one* collision. For normal incidence, these scattered, low-energy neutrons will remain in the plane of the detector and out-scatter or capture with high probability. If capture occurs, the incident neutron has transferred almost all of its kinetic energy to a single proton, so the observed proton spectrum reflects the incident neutron spectrum. The optimum capturing material for this detector is ^{10}B due to its high capture cross section and the $1/v$ dependence of the cross section upon neutron velocity, therefore, an isotopic composition of $^{7}Li_6Gd(^{10}BO_3)_3:Ce$ is used. Table 2 lists the Monte-Carlo calculated efficiency of a 1-cm-thick by 10-cm-diameter disk of Li Gd borate powder in plastic scintillator. Fig. 2 displays the measured time interval between the single proton-recoil pulse and the following ^{6}Li-capture pulse for a 1-cm-thick by 5-cm-diameter borate/plastic disc. A bare ^{252}Cf source

Table 2
Spectrometer efficiency for normally incident neutrons

E_n (MeV)	Monte-Carlo calculated efficiency[a] ($\times 10^{-4}$)
1.0	10.0
2.0	4.8
4.0	1.7
6.0	1.4

[a] 10% $^{7}Li_6Gd(^{10}BO_3)_3$, by weight, in plastic scintillator.

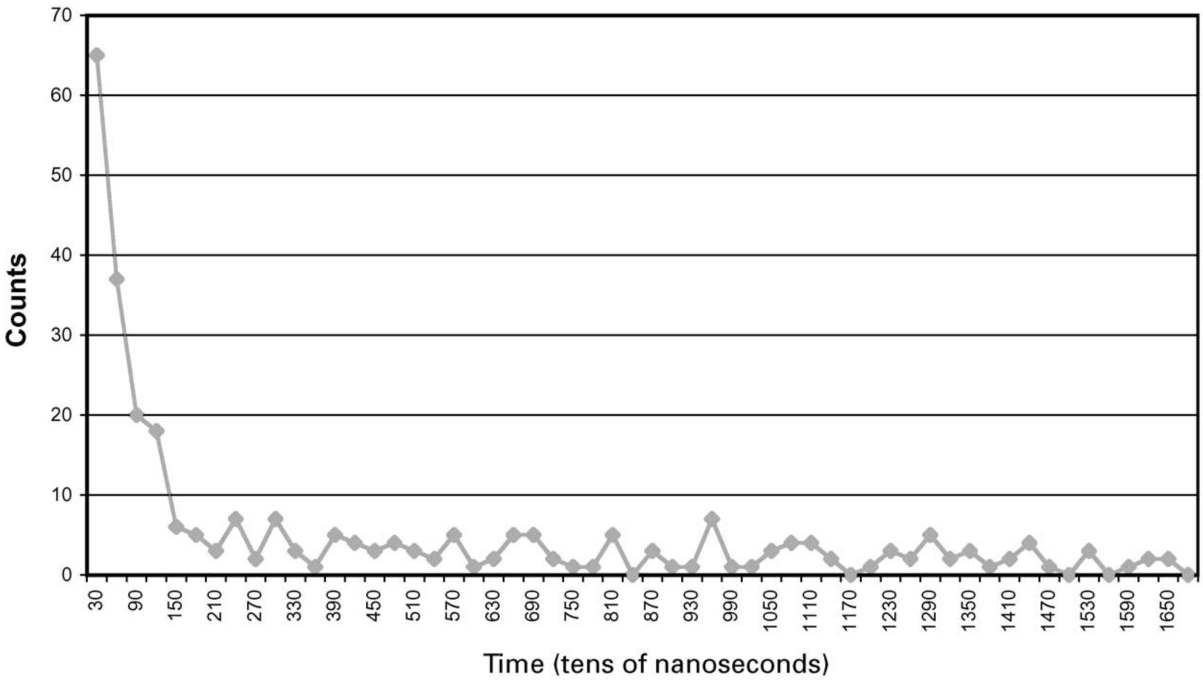

Fig. 2. Time-interval spectrum for 1-cm-thick spectrometer.

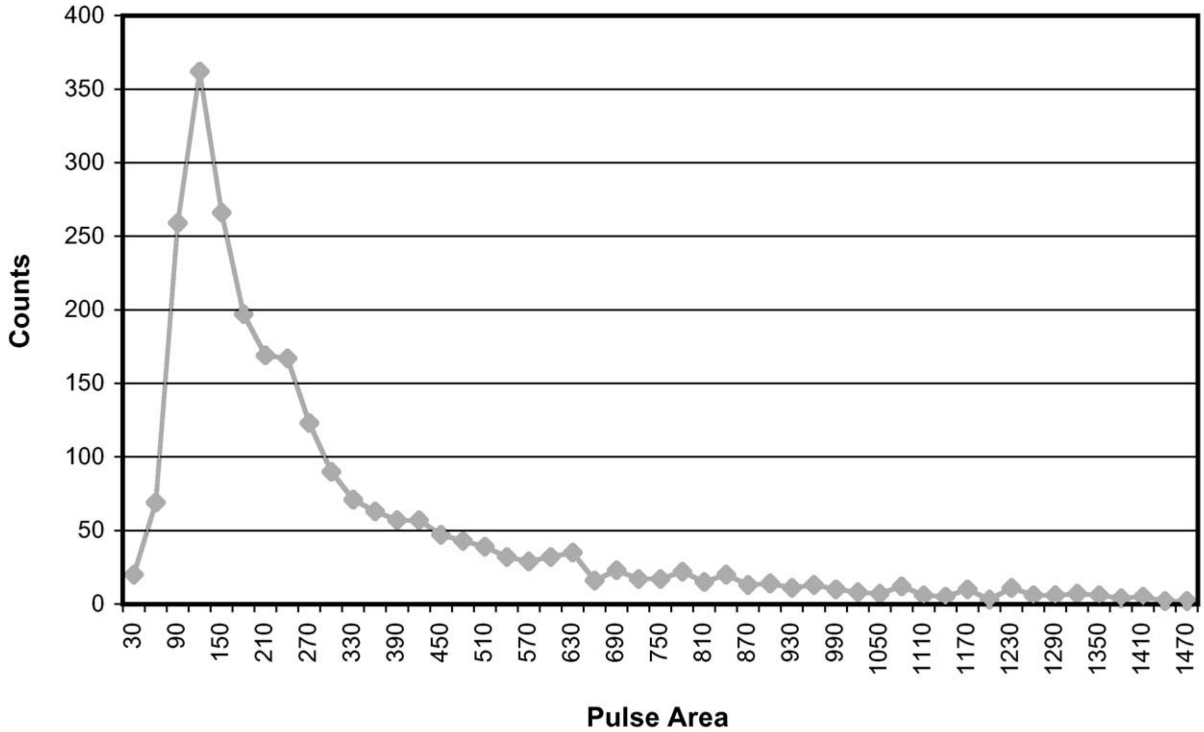

Fig. 3. Pulse-area spectrum for bare ^{252}Cf source, uncorrected for detector efficiency vs. energy.

provided the neutrons. These data were obtained with a spectrometer composed of $^{6}Li_6Gd(^{11}BO_3)_3$ crystals, instead of the more efficient $^{7}Li_6Gd(^{10}BO_3)_3$.

Fig. 3 shows the pulse area spectrum from a bare ^{252}Cf source, observed by the spectrometer. Only events in the first 1.5 μs of Fig. 2 are included.

Efforts are underway to measure the energy resolution of the spectrometer with monoenergetic neutrons in the MeV region.

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References

[1] J. Mascetti, C. Fouassier, P. Hagenmuller, J. Solid State Chem. 50 (1983) 204.
[2] J.B. Czirr, G.L. Jensen, Nucl. Instr. and Meth. A284 (1989) 365.
[3] G.L. Jensen, J.C. Wang, J. Bart Czirr, Nucl. Instr. and Meth. A 333 (1993) 474.
[4] J. Bart Czirr, G.L. Jensen, Nucl. Instr. and Meth. A 349 (1994) 532.