COMPARISON OF TWO LIQUID SCINTILLATORS USED FOR NEUTRON DETECTION

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In the detection of neutrons there is often an annoying presence of gamma rays. For energies up to ~ 100 MeV, a neutron detector can usually be protected from charged particles by deflection of the latter in a magnetic field or by an absorber that only modestly attenuates the flux of neutrons incident upon the detector. Gamma rays, however, are unaffected by a magnetic field and are almost as penetrating as neutrons.

In an organic scintillation detector exposed to neutrons and γ-rays, energy is deposited in the scintillator by protons and α-particles produced by the neutrons, and by electrons produced by the γ-rays. The heavy particles are slower and more highly ionizing than the electrons, which are mostly relativistic. The de-excitation light is emitted in approximately two time components, a fast component and a slow one. In some scintillators the fraction of light that appears in the slow component is greater for highly-ionizing radiation than for lightly-ionizing radiation [1], and therefore, for neutrons than for γ-rays. This effect is called pulse-shape discrimination (PSD). With suitable circuitry, e.g., [2], neutron/γ-ray (n/γ) discrimination can be performed and γ-rays can be rejected. In NE213 (or its equivalent, BC501A) the PSD effect seems to be the greatest, and these scintillators have been widely used for n/γ discrimination for more than three decades.

A more recently developed scintillator, BC519, reputedly has significant PSD capability, and for neutron energies below 25 MeV it has about 40% higher detection efficiency than NE213 due to its greater ratio of H atoms to C atoms. Our specific interest in the higher efficiency was for use in experiments on the dissociation of ^{6}He, ^{8}He and ^{11}Li into two neutrons plus the remainder core ^{4}He, ^{6}He and ^{9}Li. As it was necessary to detect both neutrons in these experiments, the gain in efficiency with BC519 would be a factor-of-two.

In our planned experiments both high efficiency and good PSD were important, the latter because we would be measuring not discrete peaks of neutrons but absolute values of continuum neutron spectra. Time-independent γ-rays could be removed from these spectra only by n/γ discrimination resulting from good PSD. Before choosing which scintillator to use, we made a quantitative comparison of the PSD of BC519 and NE213 (BC501A). We also compared the scintillation efficiencies of the two liquids. Both sets of measurements are described below.

Pulse Shape Discrimination

To evaluate the n/γ discrimination we encapsulated a sample of each liquid within its own cylindrical glass cell 5 cm in diameter, 7.6 cm long. Before sealing a cell, nitrogen was bubbled through the liquid to purge it of oxygen, an impurity that is known [3] to diminish the PSD capability of these scintillators. Each cell was glued to a Hamamatsu R329 phototube and covered with white reflectance paint. The neutrons and γ-rays came from a Pu-Be source, and the PSD signal was obtained with the method of Ref. 2. In that method a two-dimensional plot is made of either the early part (the first 30-40 ns) or the tail (all but the first 30-40 ns) of the pulse against the total integrated pulse. Because of the PSD effect the event points fall into two groups, one for neutron induced events (more light in the tail) and one for γ-ray induced events (less light in the tail). The reduced statistical fluctuation of big pulses makes the relative separation of the two groups improve with light output. It is of interest then to evaluate the n/γ discrimination as a function of light output. To see the n/γ discrimination for one value of light output, we use the data points within a narrow vertical slice of the two-dimensional plot with the slice centered at that value of light output to produce a PSD spectrum.

Examples of the result of this procedure are shown in Fig. 1 for light outputs of 1.0, 2.0 and 4.0 MeVee in the left, center and right columns, respectively. The top row is for NE213 (BC501A), the bottom row for BC519. To relate the integrated charge (proportional to channel number in Fig. 1) in the photomultiplier pulses to light outputs, we used the Compton edges of the γ-rays from sources of ^{60}Co (E_γ = 1.17 & 1.33 MeV), ^{228}Th (E_γ = 2.66 MeV) and Pu-Be (E_γ = 4.44 MeV).

The obvious and most important conclusion from Fig. 1 is that for n/γ discrimination NE213 (BC501A) is the better choice. When we first saw this we hopefully assumed that we had not sufficiently purged oxygen from the BC519 sample. When a few attempts at improvement through further bubbling of nitrogen made no change, we purchased a new bottle of BC519 and tested some of it, but there was again no change.

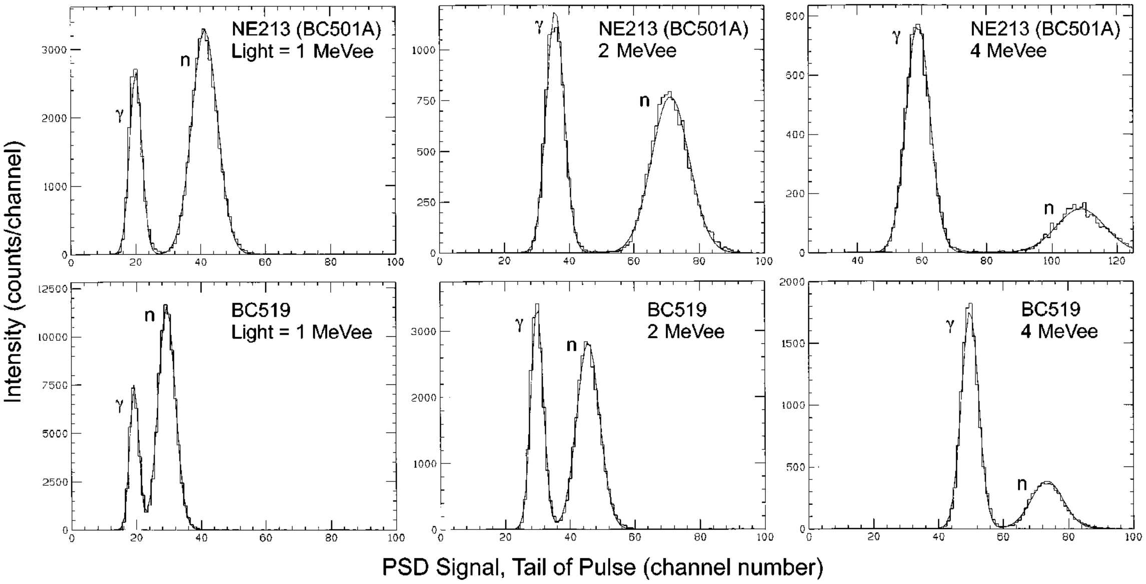

Figure 1. Comparison of neutron/gamma-ray discrimination in two liquid scintillators-- NE213 (BC501A) and BC519 for three values of light output--1, 2 and 4 MeVee.

The γ-ray peak always comes first because we used the tail rather than the early part of the pulse for the PSD signal. For each liquid, both the separation of the two peaks and the widths of the peaks increase with light output. The degree of the n/γ discrimination clearly improves with increasing light output, but to quantify the relative separation, we use a figure of merit (M) defined as the separation of the centroids of the two peaks divided by the sum of their FWHMs [4]. In the range of light output 1 – 4 MeVee, the figure of merit vs. light output is shown in Fig. 2. There is a steady increase of M with light output, and M is greater for NE213 (BC 501A) than for BC519 by almost 1.0.

Although the quality of the peak separation in Fig. 1 ranges from adequate (BC519, light output = 1.0 MeVee) to spectacular (NE213 (BC501A), light output = 4.0 MeVee), it should be noted that our geometry of a small cell (volume ~ 0.1 liter) directly coupled to the photomultiplier resulted in excellent light collection. In large systems there may be large losses of light and also time spreads of the arrival of the photons at the photomultiplier. Both effects broaden the peaks. In addition, if the intensity ratio of γ-rays to neutrons is much greater in the planned application [5] than what comes from the Pu-Be source we used for Fig. 1, the required M value will be increased. It should be noted that cosmic-ray muons are minimum ionizing and, therefore, give PSD signals in the γ-ray group. For these reasons, the detector we built [5], in which the volume of each element was ~ 10 liters and in which < 40% of the light reached a photocathode, used NE213 (BC501A).

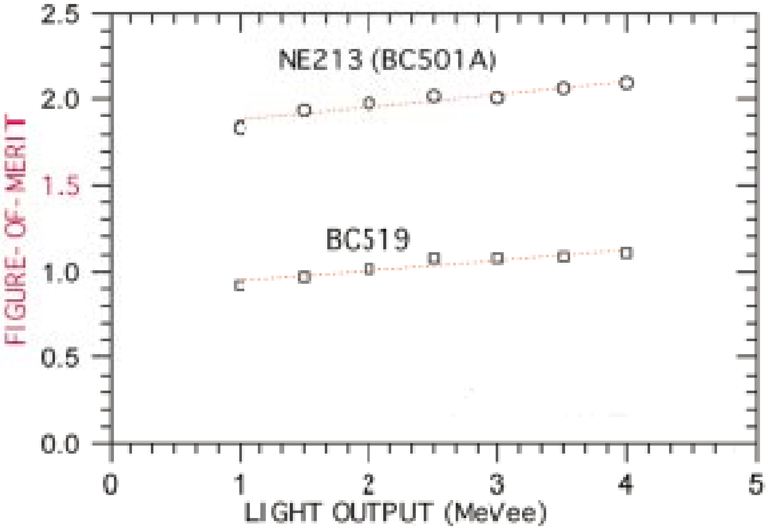

Figure 2. Comparison of figure of merit vs. light output for NE213 (BC501A) and BC519. The lines are meant only to guide the eye.

Scintillation Efficiency

There are two aspects to scintillation efficiency—conversion of deposited energy by minimum ionizing particles, such as electrons, and the conversion by slower particles, such as protons. For neutron detection, the latter aspect is the relevant one.

The light curve -- light output vs. particle energy -- is linear with energy down to ~ 0.1 MeV for electrons, but for slow particles the higher values of dE/dx produce a saturation effect that yields less light per MeV of energy loss. Birks' formula [6] gives a good parameterization of the light curve,— but for each particle (proton, α-particle etc.) and each scintillator the value of a parameter must be determined empirically. The light curve for NE213 (BC501A) has been measured for protons up to 15 MeV [7]. We made measurements in the same way on both NE213 (BC501A) and BC519.

We produced fast neutrons from the bombardment of an aluminum target with a beam of ^{18}O ions at an energy of 22 MeV/nucleon. Neutrons produced in the forward direction were incident on the cell described in Section 2. By calibration with the flight time of prompt γ-rays, we determined the time of flight (TOF) of each neutron. Gating the pulse-height spectrum in the scintillation detector with a narrow band of TOF gave us the proton recoil spectrum from neutrons of a given, known energy. The recoil spectrum is a continuum because the n-p collisions range from glancing, in which the proton receives almost zero energy, to head-on, in which the proton receives all of the neutron energy. These largest pulses are for the same energy as the neutrons in the TOF gate. We followed this procedure for protons in the range 2 – 11 MeV. The pulse heights and, therefore, the light outputs, were to within statistical accuracy of a few percent, the same for both liquids. According to Birks' formula, this would then be true for energies above 11 MeV also. Taking into account uncertainties in TOF gates, we conclude that the light outputs are the same to within 5%.

By calibration with Compton edges, the pulse heights were related to units of MeVee. Then they could be compared with the results of Ref. 7. The curve reported there could equally well fit our data.

Summary and Conclusions

We compared the liquid scintillators BC519 with NE213 (BC501A) as to their ability to distinguish neutrons from γ-rays and found that NE213 was the better of the two. However, for large light pulses, hence for neutrons with energies above ~ 50-100 MeV, either scintillator should give adequate n/γ discrimination. Within 5% the scintillation efficiency is the same for both liquids.

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