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Abstract

A proposed design for an optically-based, one-dimension scintillation detector to replace the gas-filled position-sensitive proportional counter currently used for a wide-angle neutron detector (WAND) at the High-Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory (ORNL) is presented. The scintillator, consisting of a mixture of ^6LiF and ZnS(Ag) powders in an epoxy binder, is coupled to an array of wavelength shifting optical fibers which provide position resolution. The wide-angle neutron detector is designed to cover a 120 degree arc with a 75 cm radius of curvature. The final detector design provides for 600 optical fibers coupled to the scintillator screen with an angular resolution of 0.2 degrees. Each individual pixel of the detector will be capable of operating at count rates exceeding 1 MHz. Results are presented from the measurement of neutron conversion efficiencies for several screen compositions, gamma-ray sensitivity, and spatial resolution of a 16 element one-dimensional array prototype.

Proposed WAND Detector Design

An optically-based, one-dimension scintillation detector capable of operating at count rates exceeding 1 MHz per pixel has been proposed to replace a gas-filled position-sensitive proportional counter commonly used as a WAND at ORNL. The scintillator screen consists of a mixture of ^6LiF and ZnS(Ag) powders in an epoxy binder and is coupled to an array of wavelength shifting optical fibers to provide position resolution. The wide-angle detector is being designed to cover a 120 degree arc with a 75 cm radius of curvature. Each of the 600 individual fibers bonded to the scintillator screen constitute a single pixel of

the detector and occupies 0.2 degrees of arc. The height of each pixel is 80 mm. The blue scintillator light (420 nm) from alpha interactions in the ZnS(Ag) powder penetrates the wavelength-shifting fiber (WSF) and is absorbed by the doping in the fiber. The energy is re-emitted in the green (480 nm) and is efficiently coupled to modes within the fiber core. Clear optical fibers are heat bonded to the WSF to efficiently transport the pulses to the photomultiplier tubes. The scintillator screen of the detector is organized into 10 sectors, each containing 64 elements connected to a single multi-anode photomultiplier tube (i.e., Philips 1722A).

Experimental Measurements

Three experiments were performed to determine the viability of the concept for the detector design: (1) a measurement of the neutron detection efficiency of several screen samples on a 56.9 meV neutron beam on the HB-1B beam line at HFIR, (2) a position resolution measurement of a 16-element prototype array on a 14 meV neutron beam on the HB-3A beam port at HFIR, and (3) a gamma-ray rejection measurement of the samples using a ^{137}Cs gamma emitter and ^{90}Sr bremsstrahlung source to simulate the measured gamma background of HFIR.

1. Neutron Efficiency Measurement

Five samples were prepared by adding variable amounts of the ^6LiF and ZnS(Ag) mixture with Eccobond #27 clear epoxy in a 2.54 cm diameter mold. The mass ratio of ^6LiF :ZnS(Ag) was held to 1:3 based on work by McElhaney.¹ The samples are made by mixing the powders with uncured epoxy and pouring the mix into a glass mold. The powder then settles to the bottom of the mold before the binder cures. The resulting samples are of different thicknesses because of the varying quantity of ^6LiF and ZnS(Ag) powders. A test fixture consisting of two Hamamatsu R1924 photomultiplier tubes connected to opposite ends of a 20 mm wide x 6.35 mm thick x 102 mm long lucite light

guide has been constructed. The light guide is wrapped with a single layer of white teflon tape to improve the optical reflectivity of the guide walls. A later modification of the test fixture replaced the lucite light guide with an array of closely packed 2 x 2 mm square WSF with substantial improvement in efficiency. The ends of the WSF were placed in direct contact with the photomultiplier tubes. The samples are held in mechanical contact with the light guide by a spring clamped by the aluminum cover. The assembly is constructed in an aluminum housing with "o"-ring light seals. The neutron beam is in normal incidence on the sample through a 1.6 mm thick aluminum light tight cover. The two photomultiplier tubes are operated in the coincidence mode to eliminate tube noise and direct interaction with background gamma rays. The test fixture is not surrounded by shielding to eliminate stray neutrons or gamma rays. The output pulses from the photomultiplier tubes are amplified by a charge sensitive pre-amp with a charge gain of 1 volt/pC and filtered by an amplifier with a shaping time constant of 300 nanosec. The shaped pulses are fed into two ORTEC Model 550 NIM single-channel analyzers(SCA) followed by an ORTEC Model 418A NIM Coincidence Unit. A graphite Bragg crystal is used to reflect a neutron beam with an energy of 56.91 meV into the test fixture. A ^3He counter (assumed to be 90% efficient) located a few centimeters from the Bragg crystal provides a reference neutron count rate for the efficiency measurement. The LZ14 sample containing a mass density of ^6LiF of 40 mg/cm² demonstrated the highest efficiency of 56.28% with the lucite light guide and over 95 % using the WSF array for light transport. The data from all five samples is summarized in Table I. Although samples LZ15, LZ16, and LZ17 all contain more ^6Li than LZ14, scattering and self-absorption of the scintillation light reduced the pulse height distribution to a level below the threshold of the SCA.

Table I--Conversion Efficiency for Scintillator Samples

Sample	^6LiF (mg/cm ²)	ZnS(Ag) (mg/cm ²)	Conversion Efficiency Lucite Lightguide (%)	Conversion Efficiency WSF (%)
LZ13	20	60	35.7	Not tested
LZ14	40	120	56.3	>95
LZ15	60	180	17.7	Not tested
LZ16	80	240	13.5	Not tested
LZ17	100	300	11.7	Not tested

2. Position Resolution of the 16-Channel Prototype Array

A 16-channel prototype one-dimension neutron detector has been tested. The scintillator screen is 1 mm thick x 32 mm wide and 76 mm long and contains 14 mg/cm² of ^6LiF and 42 mg/cm² of ZnS(Ag) powder in a binder of Eccobond #27 epoxy. Sixteen WSF elements (Bicron BCF-91), heat bonded to 50 cm long 1-mm diameter clear fibers on both ends, are placed in mechanical contact with the scintillator screen. The one millimeter diameter WSF are separated by a one millimeter diameter aluminum wire to yield a net pitch of 2 mm. One end of the clear fiber from each WSF is placed in mechanical contact with the face of a Hamamatsu type R2487 cross-wire anode photomultiplier tube.. Only one axis of the cross-wire photomultiplier is used for this experiment. Each of the wire anodes is connected to a charge-sensitive pre-amp with conversion gain of 1volt/pC followed by a shaper amplifier with a voltage gain of 225 and a shaping time constant of 300 nanosec. The output of each shaper amplifier is connected to a quad discriminator/ECL line driver integrated circuit. All 16 discriminators are connected to a common discriminator voltage reference, typically set at 0.5 volts. The other end of the clear fibers from all 16 channels are placed in contact with the face of a single Hamamatsu R1924 to provide a coincidence signal. The output of the discriminators are connected to a digital logic board that collects and stores only those counts from the cross-wire tube which are in coincidence with pulses

from the R1924. The data from the logic board is transferred to a PC-compatible computer by a DMA interface on the board. The prototype screen/fiber array, the two photomultiplier tubes and the analog electronics including the discriminators are located in a light tight enclosure. Neutrons enter the enclosure through a 0.32 cm thick aluminum cover. A 2-mm wide B_4C slit is located 30 centimeters in front of the detector array to limit the width of the neutron beam incident on the screen. The prototype assembly is illuminated by 14 meV neutrons reflected from a Bragg crystal beamsplitter on the HB-3A beam port at HFIR. This prototype detector response has a FWHM of 5.4 mm. A low level count extends to the channels well away from the peak. This feature is due to illumination of fibers by light undergoing multiple reflections in the scintillator screen and prompted the aluminum dividers suggested in the section on the proposed design for the WAND detector. This channel crosstalk makes an absolute neutron conversion efficiency measurement impossible with this setup. Cross-talk between the individual pixels of the screen will be prevented by 0.039 mm thick aluminum foil embedded in the screen separating each pixel and secured by the epoxy binder during construction of the actual detector. The aluminum dividers will reduce the screen neutron conversion efficiency by less than one per cent. The background count rate for the 16-channel assembly is approximately 1-2 counts/sec/channel and is believed to be due to stray neutrons from other experiments in the area. This point is discussed in the next section.

3. Gamma-Ray Rejection

In order to assess the gamma ray rejection of the scintillator, a NaI(Tl) crystal (2.54 cm x 2.54 cm x 2.54 cm) mated to an R1924 photomultiplier tube is mounted immediately behind the sample holder described above. The $^{137}\text{Cesium}$ gamma source and the $^{90}\text{Strontium}$ bremsstrahlung source are mounted directly against the aluminum cover for these measurements. The gammas from the cesium source and the bremsstrahlung radiation from

the strontium source pass through the scintillator sample before impinging on the NaI(Tl) crystal. The gamma ray response varies from 1/600,000 to 1/1,200,000 depending of the range of pulse height channels used for the calculation. The detected event rate with the ^{90}Sr source is 0.0075/sec. The background measured at HFIR is 1-2/sec. From the gamma measurements presented in this section, a count rate of only 0.00075/sec can be attributed to gamma rays. This result indicates that the 1-2/sec background measurements observed at HFIR are due to stray neutrons and not gamma rays. Although the gamma response appears relatively low, improvements of perhaps one or two orders of magnitude may be possible. Two groups have reported that the pulse decay time of ZnS(Ag) to gamma rays and alpha particles differ by a factor of approximately 7 (10 nanosec decay for gammas to a 70 nanosec decay for alphas)^{2,3}. Experiments are underway to investigate the decay response to gamma ray and alpha particles so that we may exploit the difference to enhance the gamma rejection of the ZnS(Ag) scintillator.

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