Optical Readout for Imaging Neutron Scintillation Detectors

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Abstract

The Spallation Neutron Source (SNS) under construction at the Oak Ridge National Laboratory (ORNL) will be the most important new neutron scattering facility in the United States. Neutron scattering instruments for the SNS will require large area detectors with fast response (< 1 microsecond), high efficiency over a wide range of neutron energies (0.1 to 10 eV), and low gamma ray sensitivity. We are currently developing area neutron detectors based on a combination of a $^{6}LiF/ZnS(Ag)$ scintillator screen coupled to a wavelength-shifting fiber optic readout array. A 25 x 25 cm prototype detector is currently under development. Initial tests at the Intense Pulsed Neutron Source at the Argonne National Laboratory have demonstrated good imaging properties coupled with very low gamma ray sensitivity. The response time of this detector is approximately 1 microsecond. Details of the design and test results of the detector will be presented.

Position Sensitive Detector

A prototype 25 x 25-cm position sensitive detector has been designed and constructed. The detector uses a scintillator screen fabricated from a mixture of $^{6}LiF/ZnS(Ag)$ powders held in an epoxy matrix A photograph of the detector and fiber optics readout array is shown in Figure 1. The neutron scintillator screen, fiber optics readout and photomultiplier tubes are mounted in an aluminum light-tight enclosure. Neutrons enter the detector through a 0.125-inch thick cover plate. An array of wavelength-shifting fibers is clamped on the screen opposite the cover plate in a 2-dimensional array with 48 fibers in each direction. One end of every fiber is mapped onto an individual cathode of a Philips

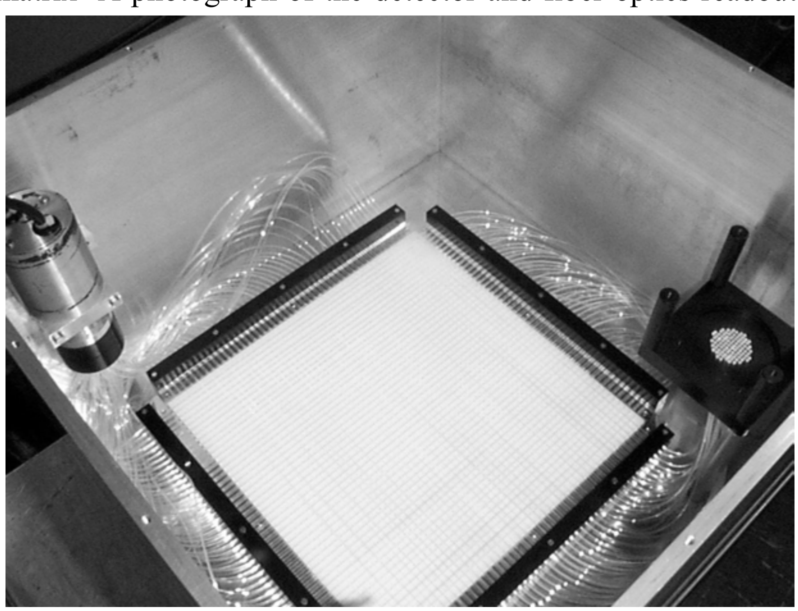
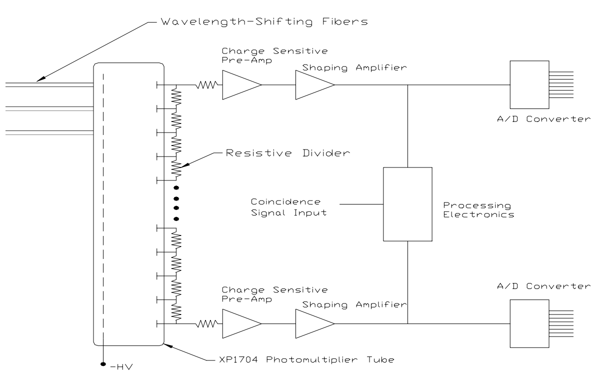


Figure 1Scintillator Screen and Fiber Readout Array

XP1704 multi-anode photomultiplier tube. This tube contains 96 individual anodes in a single vacuum envelope. The other ends of the fibers are attached to a single anode Hamamatsu R1924 tube, which provides a coincidence pulse for each detection event. A simplified diagram of the detector electronics is shown in Figure 2. The 96 anodes of the multi-anode photomultiplier tube are connected to two resistive divider networks, one for each axis of the detector. The resistive dividers allow the pulse current from each detection event to be divided between the charge-sensitive pre-amplifiers attached to the ends of the divider strings. This combination of amplifiers produces Gaussian-shaped pulses whose height is proportional to the current coming from each end of the resistive divider strings. The digitized data is recorded by a computer that calculates and stores the x and y coordinates of each event. After the computer records an event, the triggering circuit is re-armed for another event. Because the computer is in the timing loop, the count rate limit for the detector is currently approximately 50 kHz. Future improvements to the electronics will include a hardware position determining circuit so that the count rate will be limited only by the 1-microsec timing of the pulse shaping amplifiers.

Testing on HFIR

Initial testing of the detector involved the measurement of a continuous beam of neutrons scattered from a piece of single crystal germanium placed in a 0.056 eV neutron beam from the High Flux Isotope Reactor (HFIR) reactor at ORNL. A plot of the scattered neutron image from the germanium crystal is shown in Figure 3. The neutron beam generated by the crystal is approximately 20-mm in diameter and is matched by the spot size in the image. The limiting factor of the spot size resolution is the noise and dynamic range of the front-end electronics and 8-bit A/D converters.



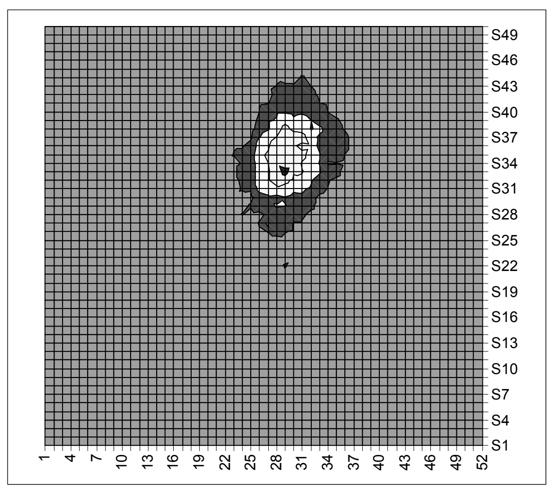


Figure 2 Electronic Readout for the Crossed Fiber Detector	Figure 3 Scattered neutron image from germanium crystal

Testing on IPNS

Following initial testing on a fixed energy neutron beam on HFIR, the detector was transported to the Argonne National Laboratory for testing on the Intense Pulsed Neutron Source. The detector was located on the QUIP beamline on IPNS. A graphite target was used as the scattering target. A schematic diagram on the set-up is shown in Figure 4.

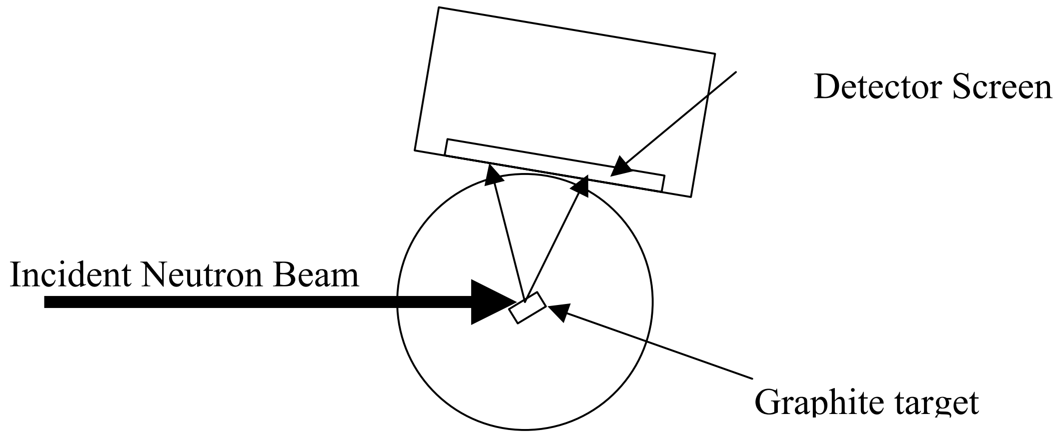


Figure 4 Neutron scattering geometry on IPNS

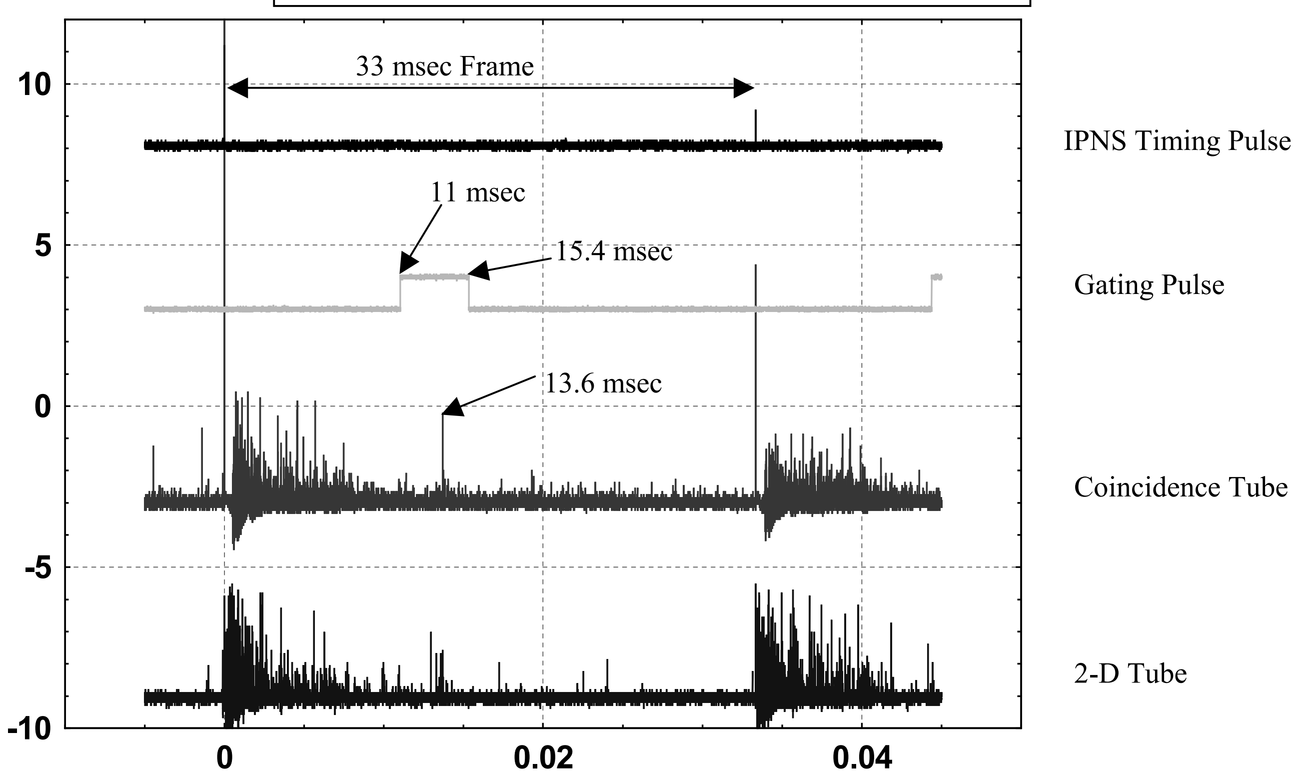


Figure 5 Timing sequence on IPNS

The Intense Pulsed Neutron Source (IPNS) at Argonne National Laboratory produces 30 neutron pulses per second. A timing signal coincident with the neutron pulse is produced to allow energy selection of scattered neutrons by a simple time of flight calculation. The top trace in Figure 5 represents two consecutive timing pulses spaced 33 milliseconds apart designating one timing frame. The second trace represents a gating pulse generated by our detector electronics to count neutrons arriving at the detector from 11 to 15.4 milliseconds after the spallation pulse. This timing window corresponds to neutrons with a wavelength of 3.956 to 5.54 Å representing a velocity of 714-1000 m/sec. The graphite scattering target was oriented to deflect neutrons with a velocity of 808 m/sec onto the detector screen. This peak is visible at a time of 13.6 msec on the third trace, which is a display of the raw signal from the coincidence tube. The lower trace in Figure 5 is the raw signal from one end of the resistor current divider chain of the 2-D photomultiplier tube. A cluster of neutron events is visible near the same 13.6 msec peak as observed on the coincidence tube. A two dimensional image of this data is shown in Figure 6. A black rectangle has been drawn over the image that is the exact size of the graphite target. The image falsely appears symmetric about the horizontal axis because the data points were folded and averaged about a horizontal axis passing through the center of the image to improve statistics for the contour plot.

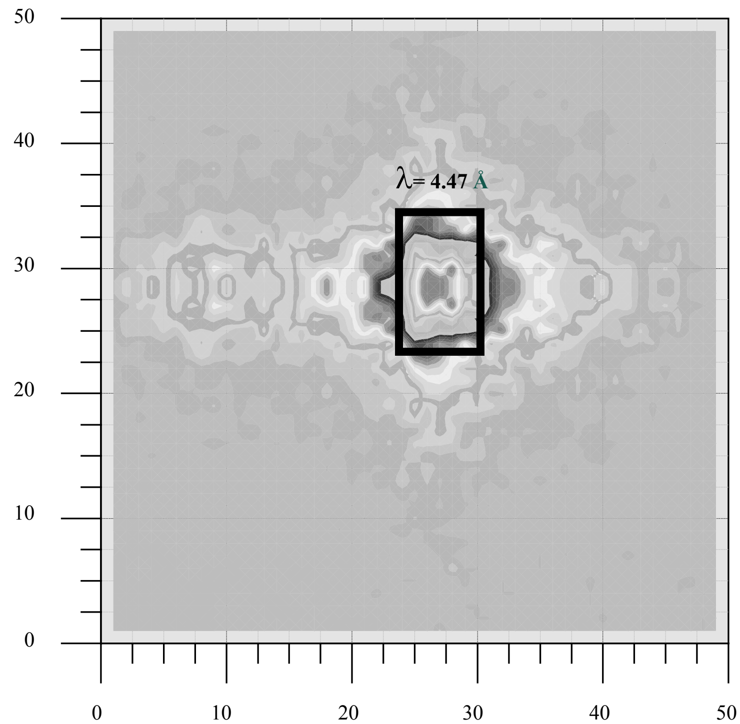


Figure 6 Scattered neutron image of carbon target

Software and hardware problems precluded data files containing over 10,000 events per run. During these data runs, we had insufficient shielding around the detector and the high background level prevented longer data collecting periods. This first test on a spallation source indicated that the following improvements are be needed before this type of detector can be used for physics data acquisition:

1. Improved Shielding--B_4C enclosure around detector
2. Increased Dynamic range--Front end amplifiers have a limited voltage range--Parallel A/D Converters--Simultaneous low and high voltage capture
3. Software--Increase array sizes for better statistics

4. Examine need for coincidence tube–The current architecture appears to be overly restrictive and the data appears to be under-sampled by the 3-way coincidence requirement, reducing the efficiency of this detector.

Future Directions

In addition to the improvements mentioned above we continue to investigate other technologies to improve the capabilities of area neutron detectors. One specific area of interest is scintillator performance. Our current design uses a combination of a ^{6}LiF/ZnS(Ag) powders in an epoxy binder to form the scintillator screen. The decay time of the ZnS(Ag) scintillator is on the order of 1 microsec limiting operation to a maximum count rate of a few hundred KHz at best. Also the screen is translucent resulting in attenuation of the emitted light. Currently we are investigating ZnS(Ag) nanocrystals to replace the powdered version of the scintillator in a clear matrix. This material is under development at ORNL under a DOE SBIR grant to Neutron Sciences, LLC located in Knoxville, TN. The nanocrystals were fabricated under the leadership of Dr. Sheng Dai in the Chemical Sciences Division at ORNL. A 337 nm, 1 nanosec pulsed N_2 laser has been used to investigate the spectral emission and decay time of the nanocrystals. Figure 7 shows the emission spectrum of three different samples excited by the laser. The emission wavelengthsfor the 6.5 nm, 4.5 nm and 1-2 nm samples peak at

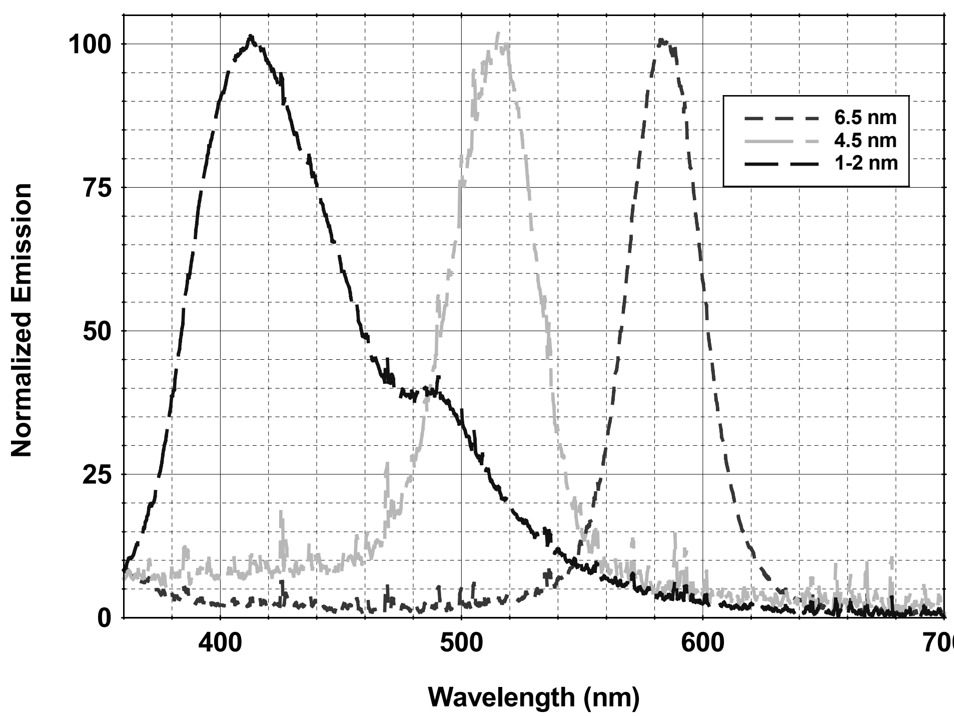


Figure 7 The normalized emission for three nanocrystal particle sizes can be controlled by selecting the appropriate physical particle diameter.

585 nm, 515 nm and 415 nm, respectively. As is shown in Figure 8, all three samples exhibited a decay time of less than 30 nsec. Although fluorescence by UV laser excitation does not necessarily indicate how the scintillator will function with charged

particle excitation, the promise of a fast decay time combined with high light output makes this material very interesting for further investigations. Since the emission characteristics can be tailored with the particle size during fabrication, the spectrum may be optimized to match other detector parameters such as photomultiplier sensitivity or wavelength-shifting fiber response.

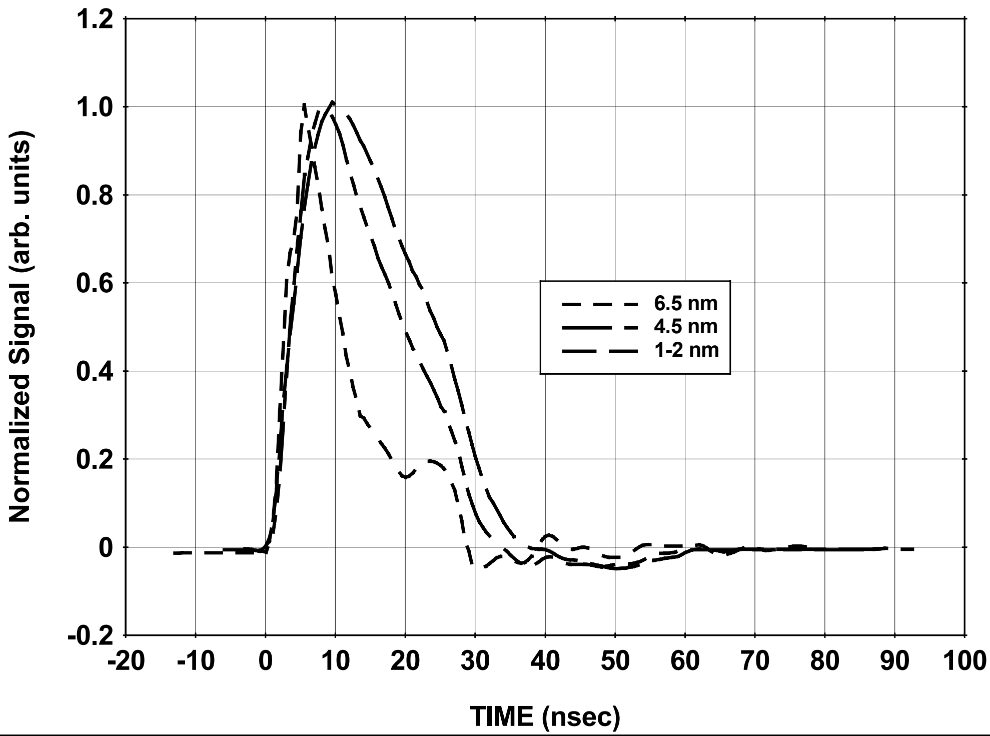


Figure 8 All three nanocrystal samples exhibit a decay time of less than 30 nsec.

Summary

A fiber optic read-out array technique has been developed for area neutron detectors. Tests on a continuous neutron beam from the High Flux Isotope Reactor at the Oak Ridge National Laboratory and a pulsed neutron beam from the Intense Pulsed Neutron Source at the Argonne National Laboratory indicate the feasibility of the concept. Improvements are underway to correct deficiencies identified as a result of these tests and optimize the detector for operation in high-speed, area neutron detectors for applications in neutron scattering.

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