Current Progress on Scintillation and Semiconductor Area Detector Development at ORNL

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Workshop on Neutron Detectors for Spallation Sources
Brookhaven National Laboratory
September 24-26, 1998

Outline

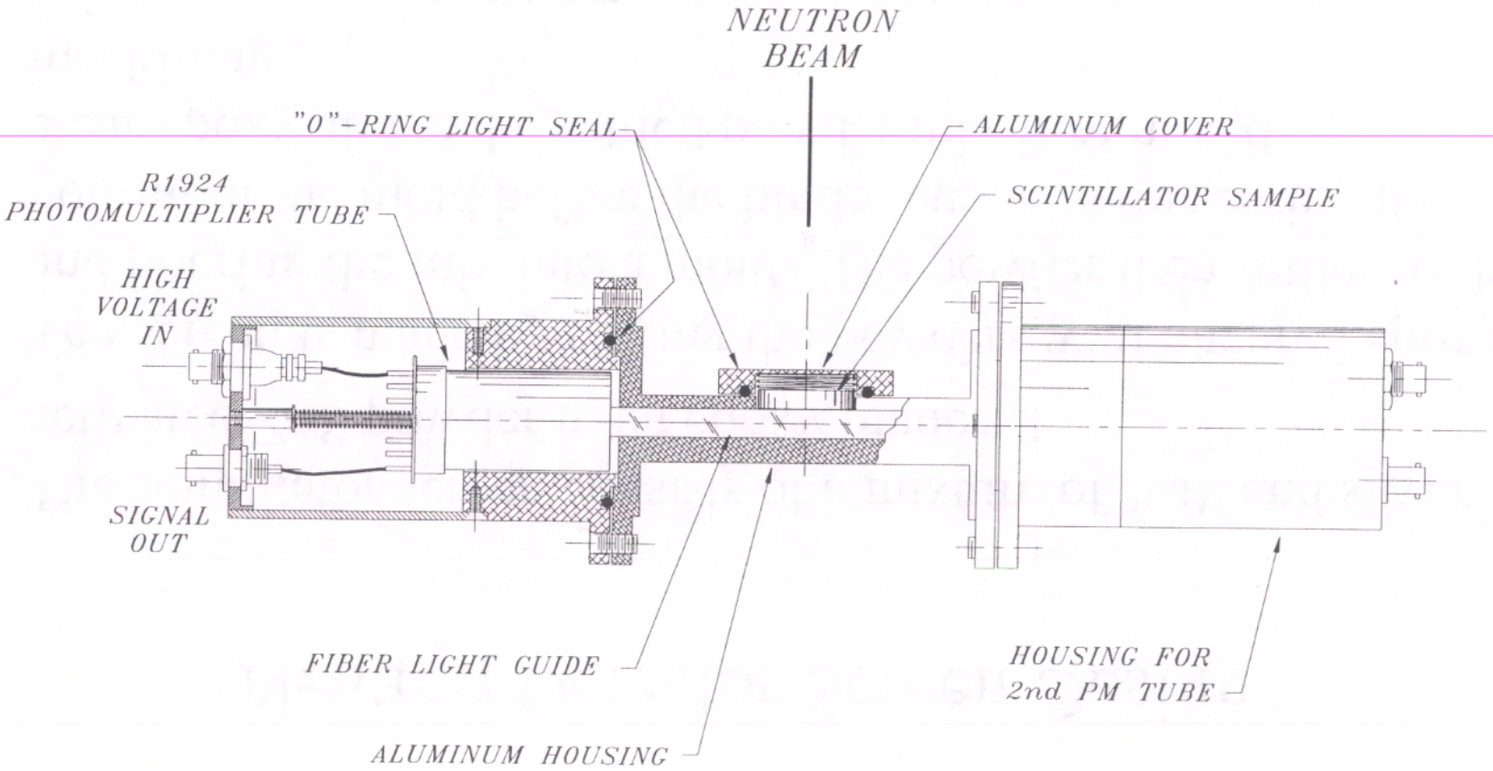
- ^{6}LiF / ZnS(Ag) scintillator screens
- Original free space detector concept
- Wavelength-shifting optical fibers
- 1-D fiber based detectors
- 2-D crossed-fiber based detector
- "High-Efficiency, High-Speed, Position Sensitive, Energy Resolving Neutron Detector"

- More information about the last two topics will be presented in the poster session.

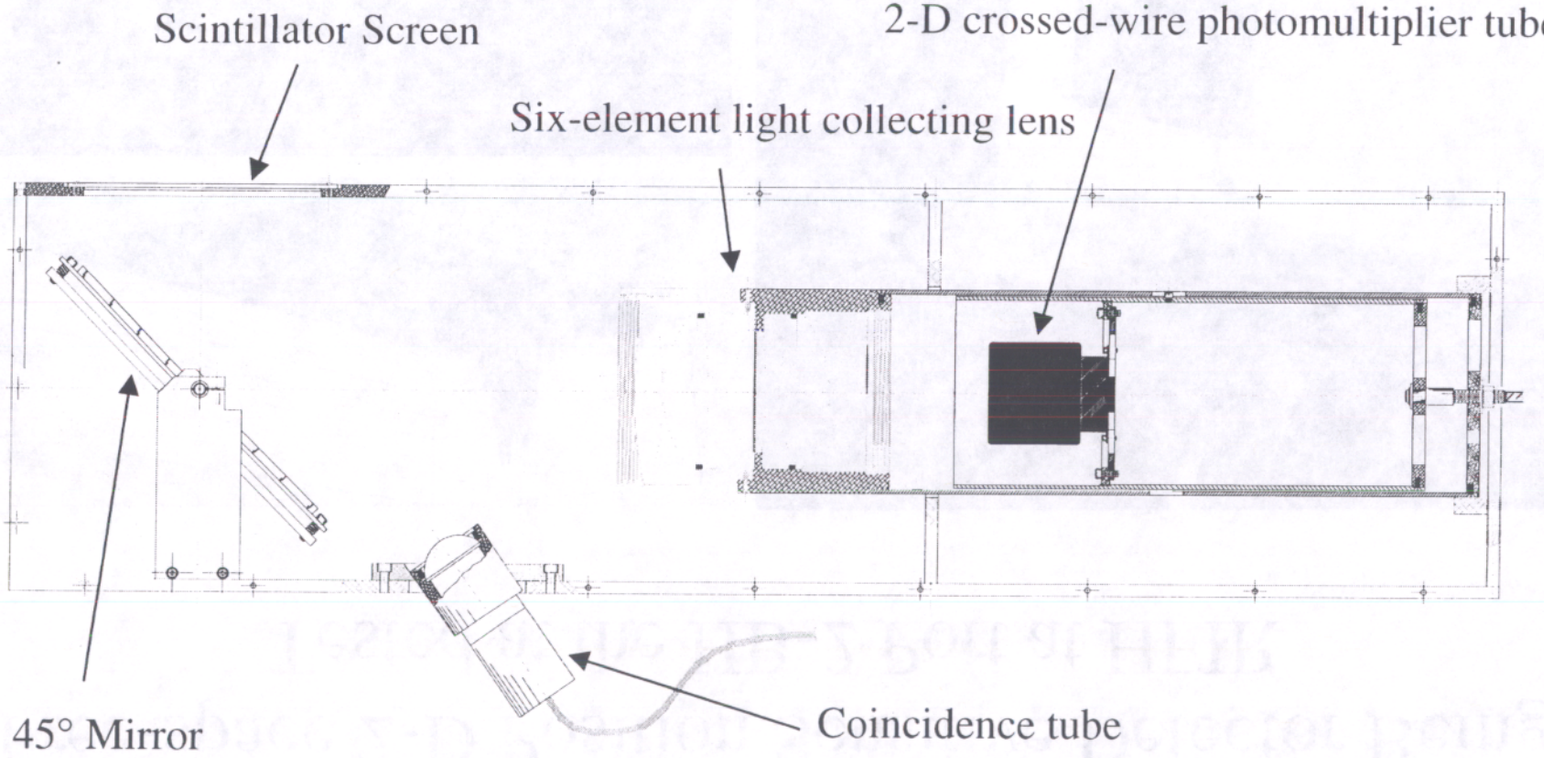
Neutron Detector Screen Design

- The scintillator screen consists of a mixture of ^{6}LiF and silver-activated ZnS powder in an epoxy binder.
- The screen is made by mixing the powders with uncured epoxy and pouring the mix into a mold. The powder then settles to the bottom of the mold before the binder cures. After curing the clear epoxy above the settled powder mix is removed by machining.
- The mass ratio of ^{6}LiF:ZnS(Ag) was held to 1:3 based on work by McElhaney.
- A mixture containing 40 mg/cm^2 of ^{6}LiF and 120 mg/cm^2 of ZnS(Ag) has a measured neutron conversion efficiency of over 90%.

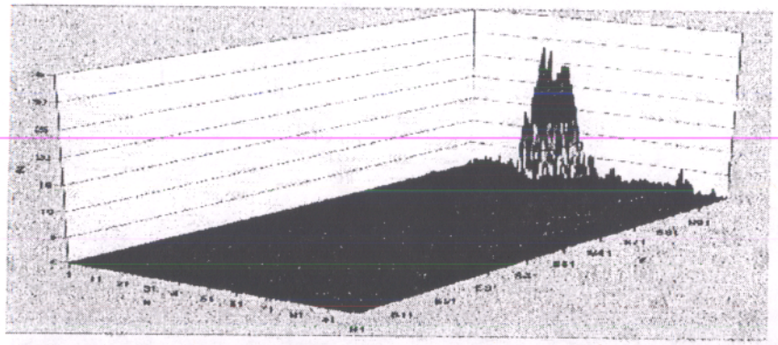
Test Fixture to Measure Characteristics of Scintillator Samples

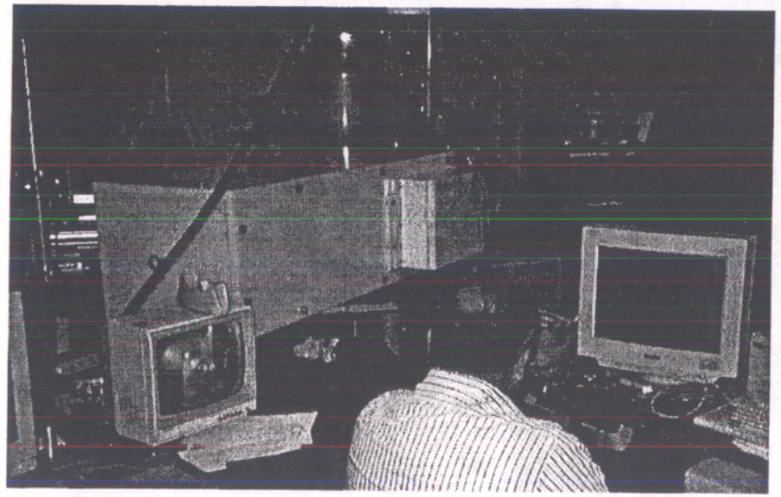


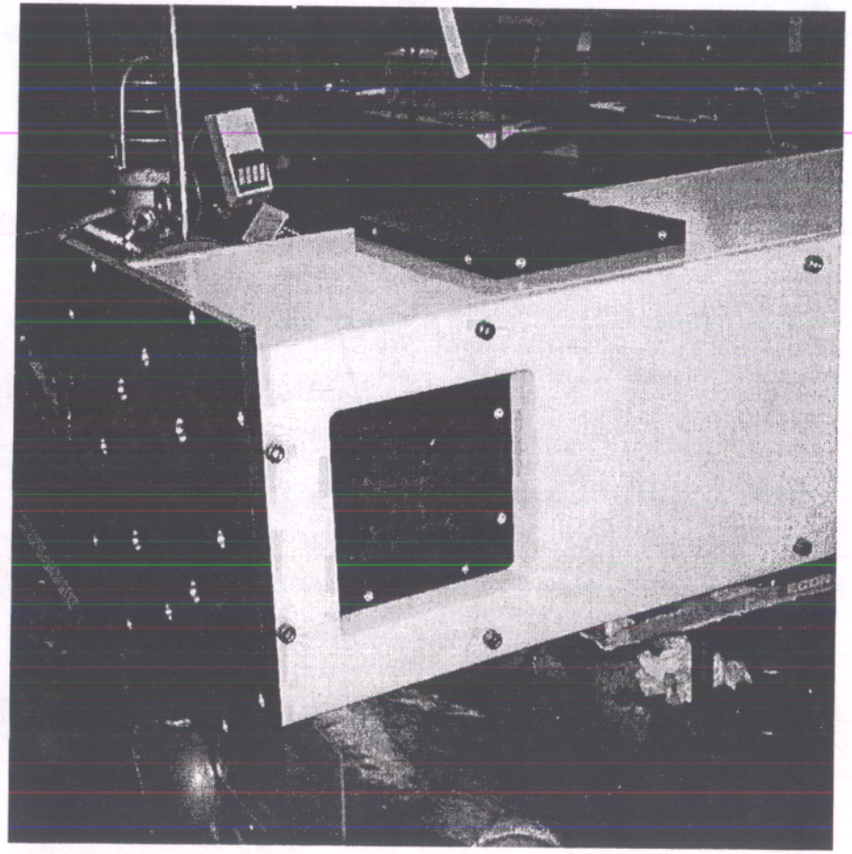
Free-space 2-D Position Sensitive Detector



Free-space 2-D Position Sensitive Detector Being Tested at the HB-2 Port at HFIR

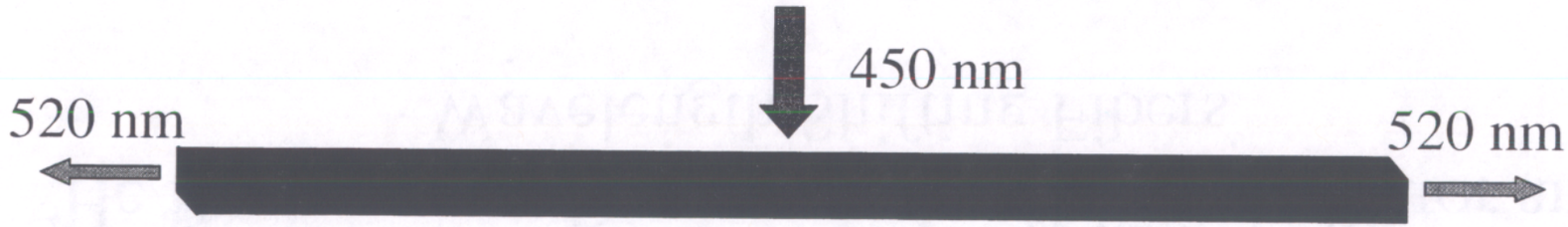




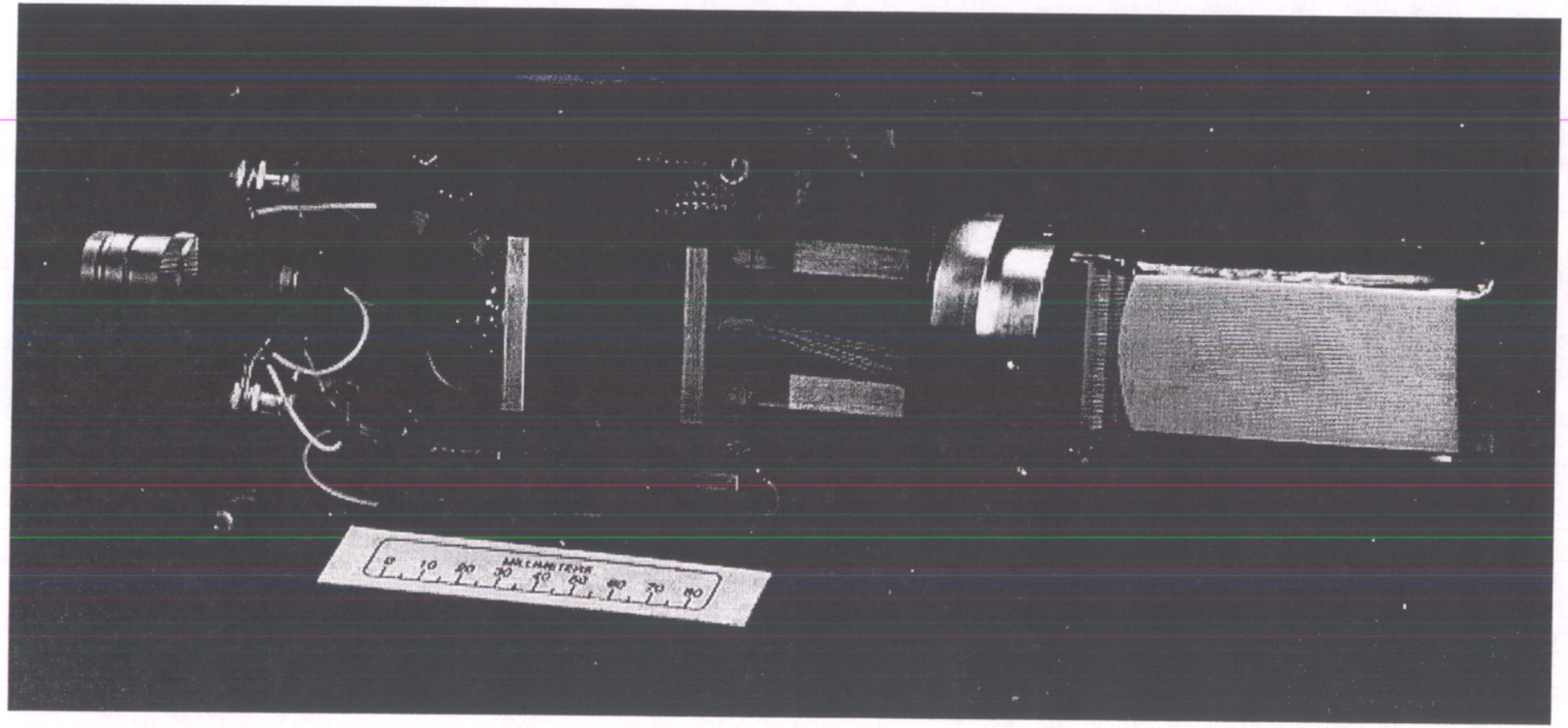


Wavelength Shifting Optical Fibers

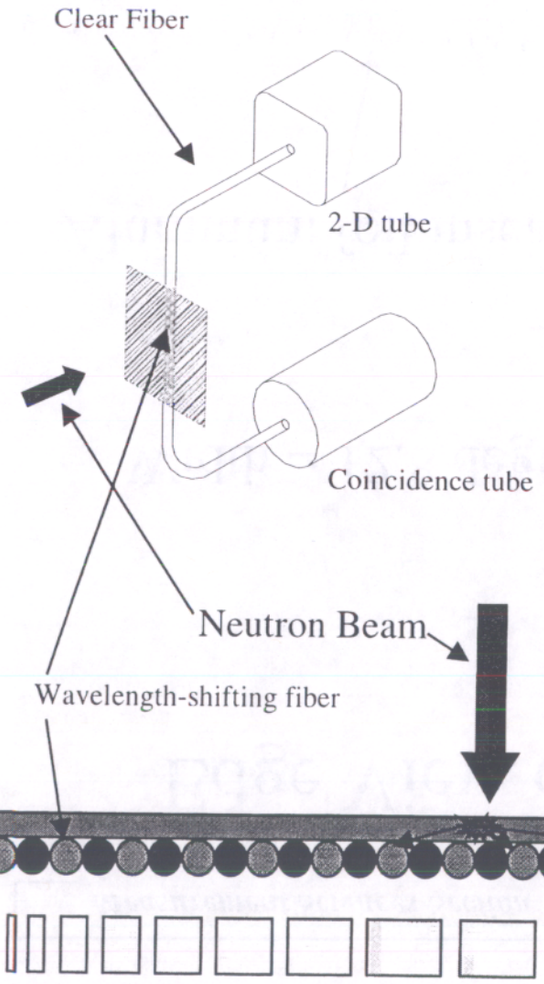
- The ^{6}LiF:ZnS(Ag) screen scintillates at a wavelength of approximately 450 nm.
- The 450 nm photons are absorbed in wavelength-shifting optical fibers where they are converted to 520 nm photons that are emitted in modes that propagate out the ends of the fibers.

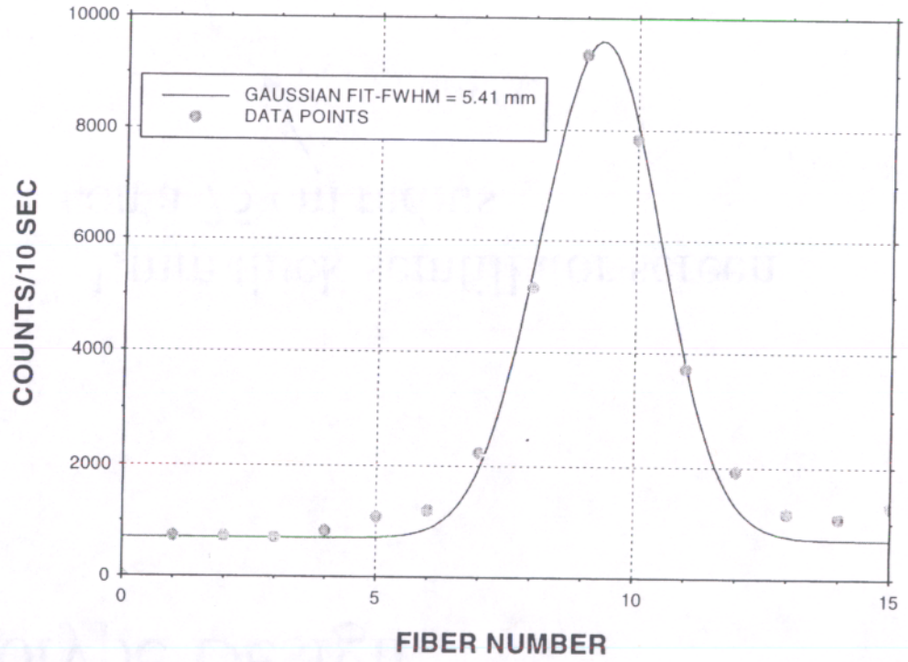


^{3}He Replacement Detector Using ^{6}LiF Scintillator and Wavelength Shifting Fibers



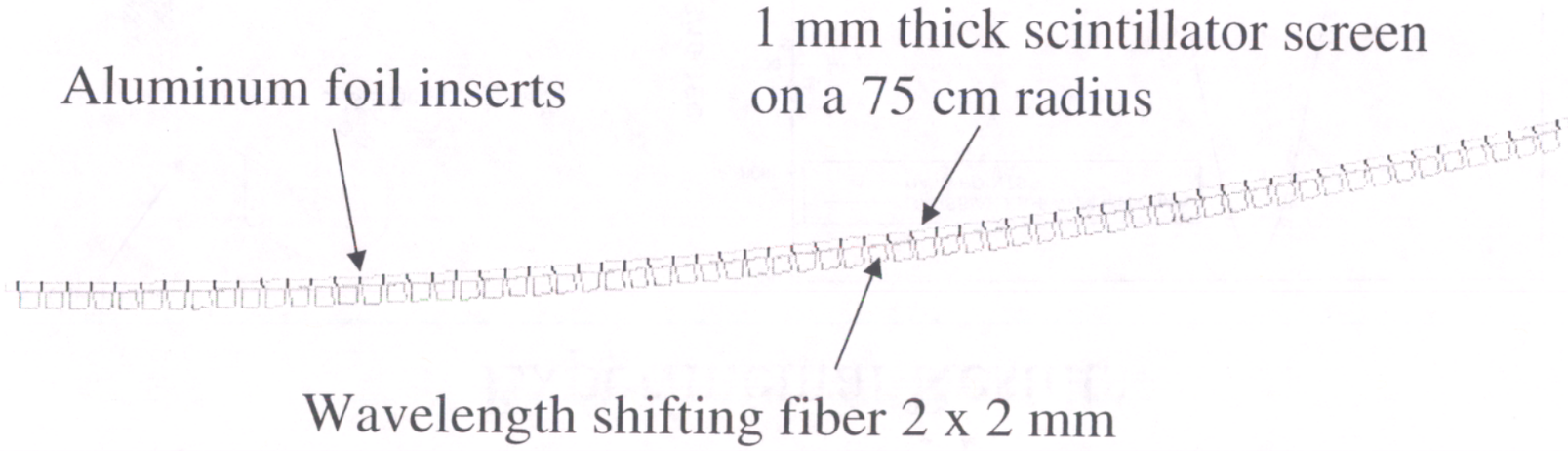
16-element WAND Prototype Schematic and Experimental Results





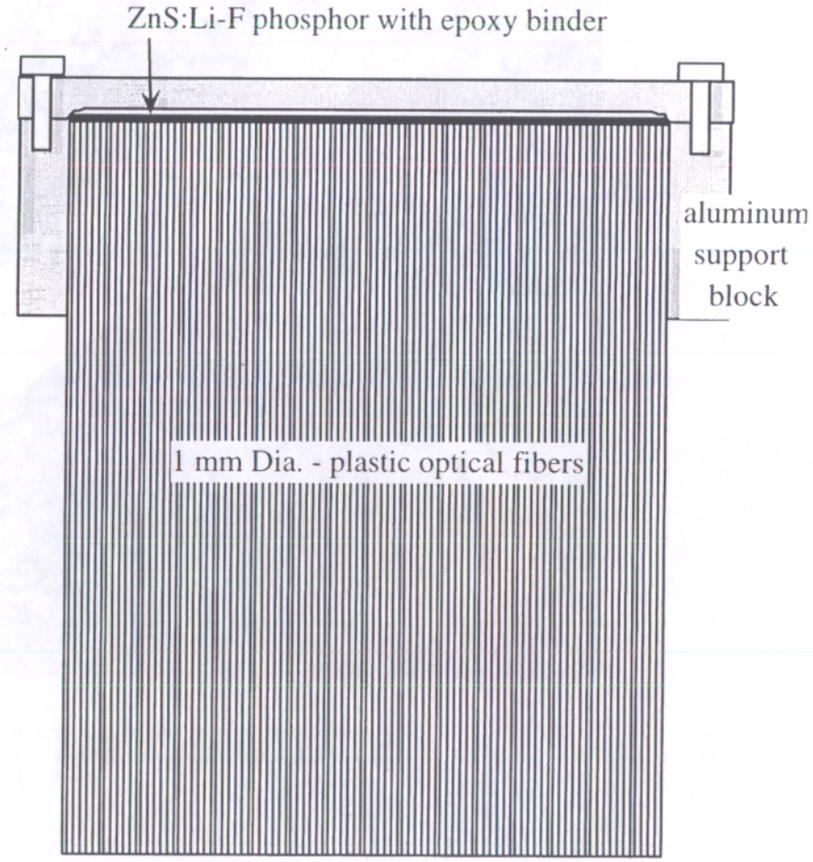
Edge View of 64-element WAND Section Prototype Design

Width = 12.8 degrees

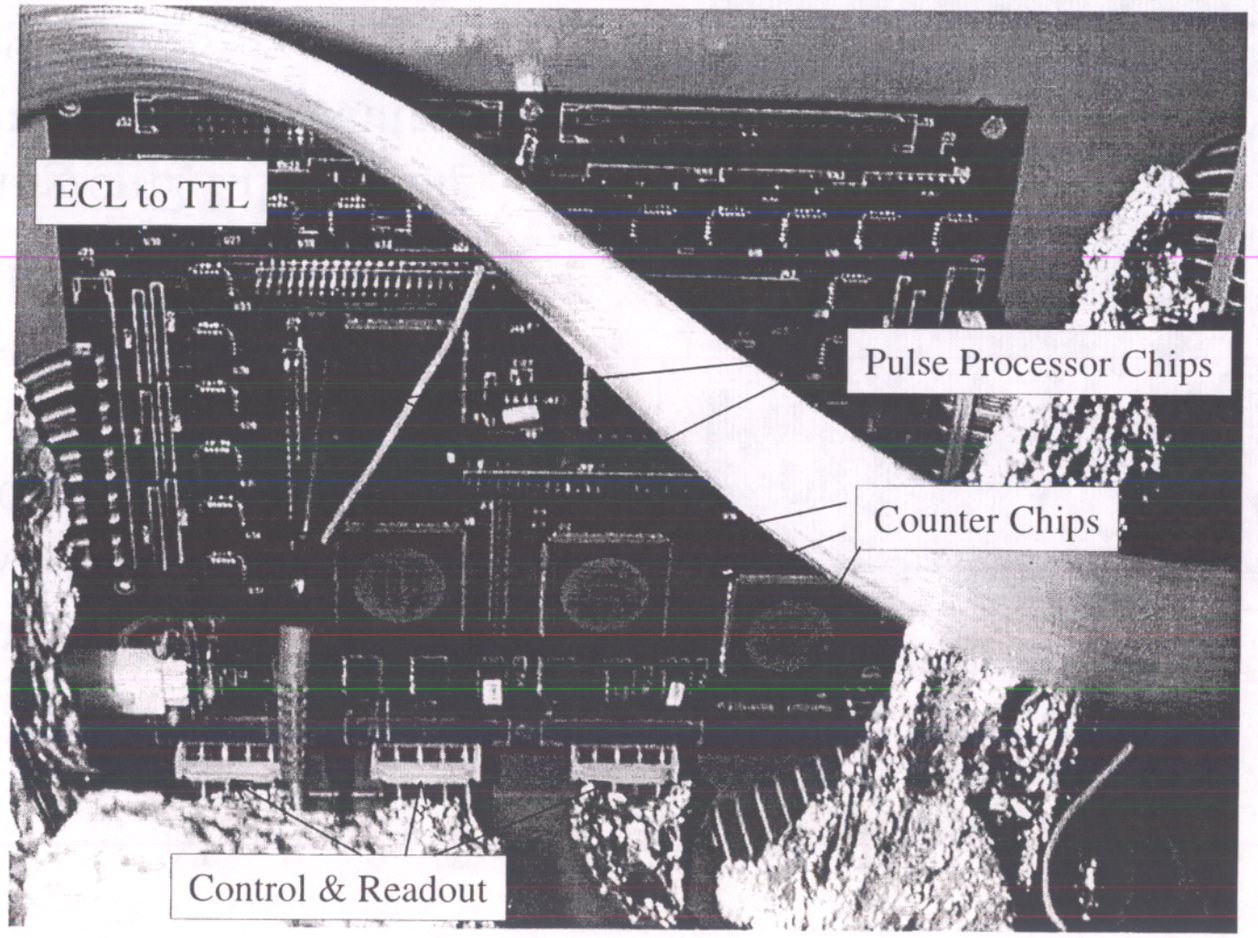


Neutron Tomography Detector

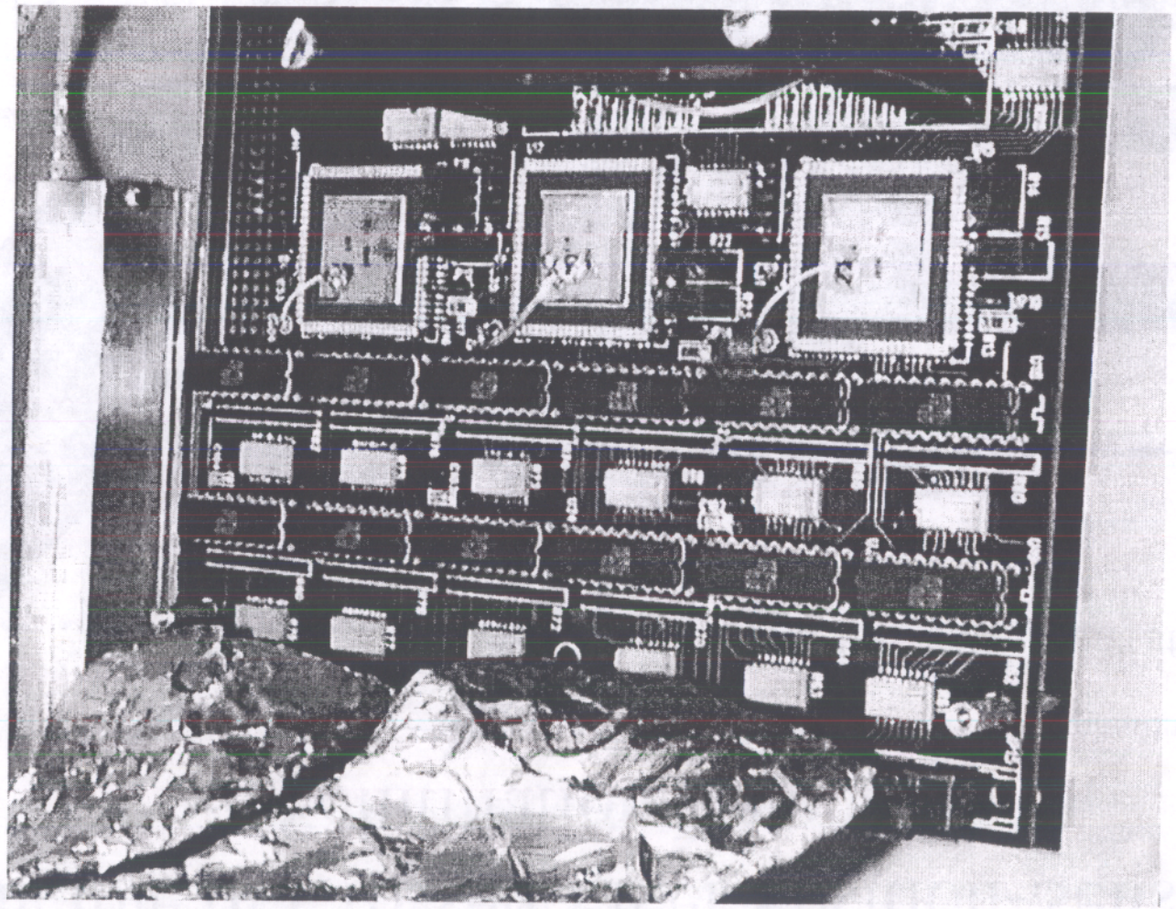
- Epoxy mixed so that powders settle to fiber tips before setting
- Epoxy polished to minimal thickness to minimize neutron interaction
- 40 mg/cm2 LiF loading results in ~90% neutron efficiency
- Count rate limit ~10^6/second per channel



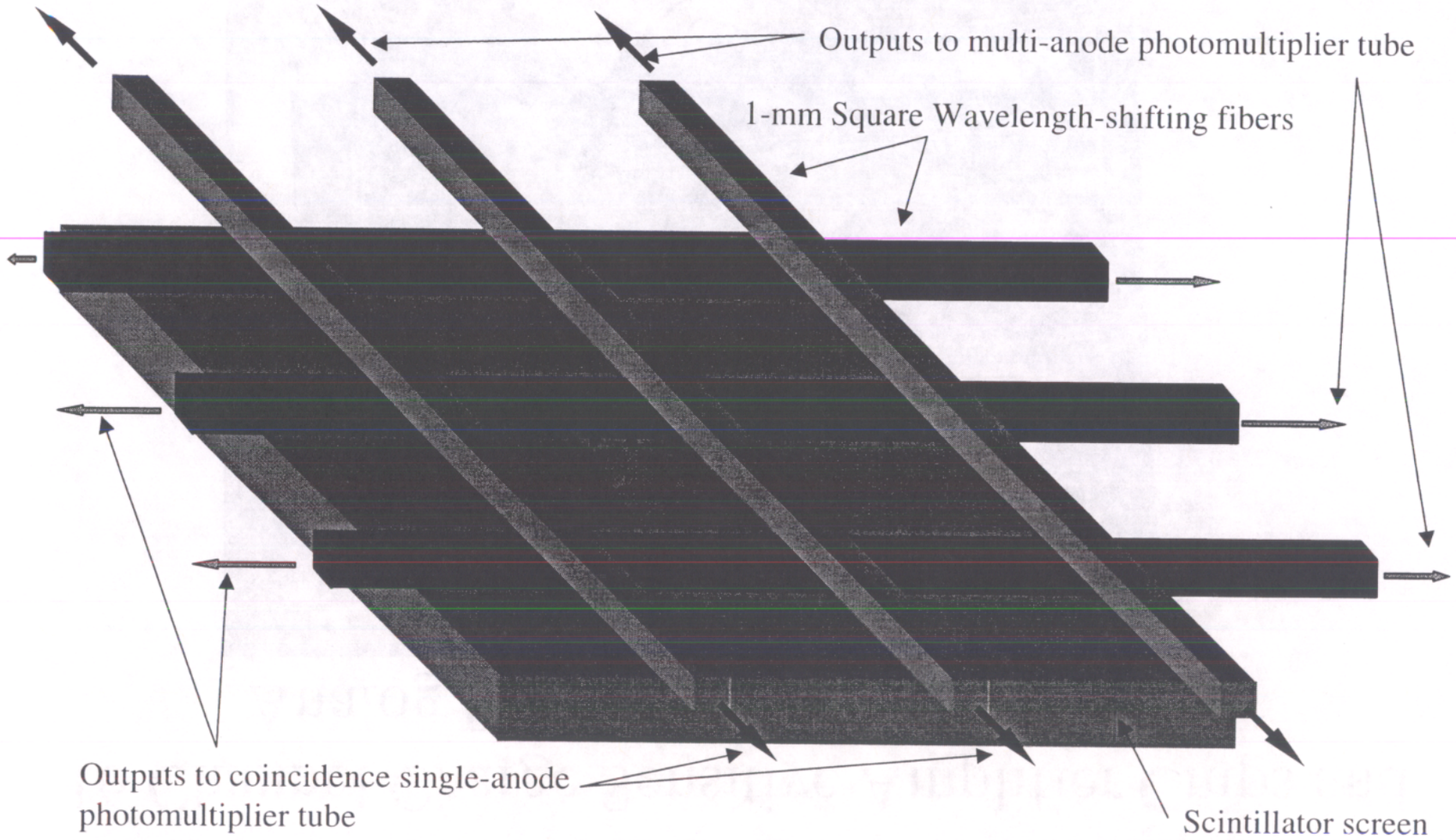
Digital Board Electronics



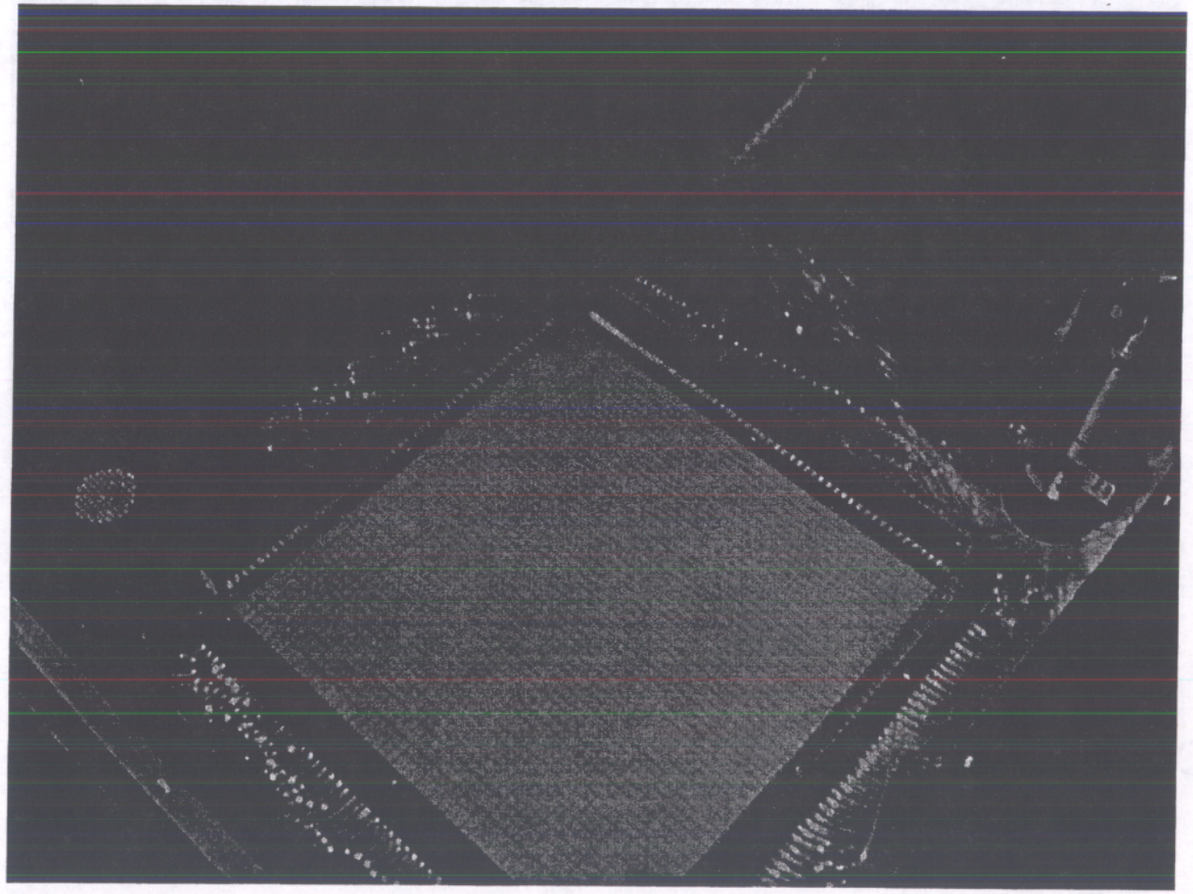
16 Channel Charge Sensitive Amplifier Chips and Analog Pulse Height Analysis Chips



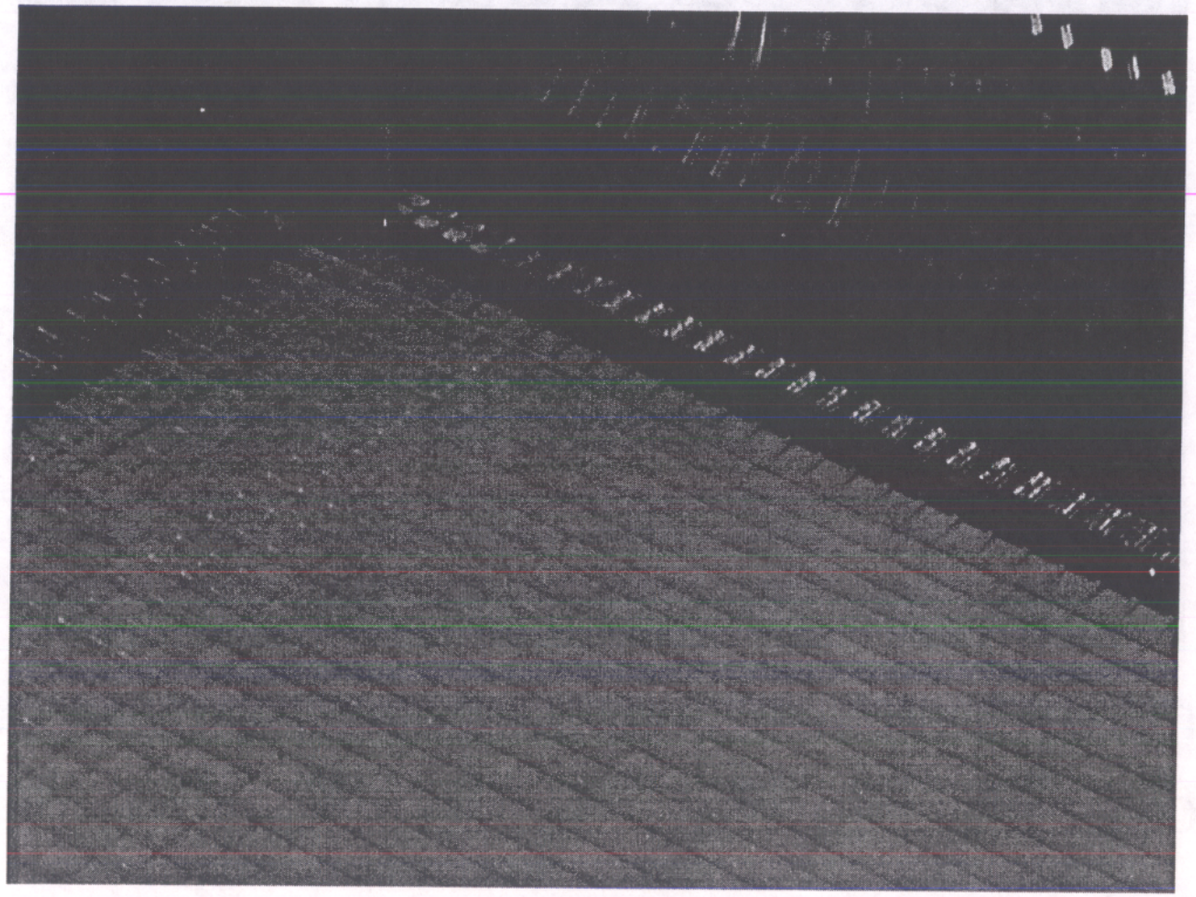
Principle of Crossed-Fiber Position-Sensitive Scintillation Detector



Wavelength-shifting Fiber Coupling of Scintillator Screen to Photomultiplier Tubes



Close-up View of Fibers on Scintillator Screen



96 Element Phototube

- Phillips Photonics model XP1704
- 9 foil dynode electron multiplier layers
  - Regularly perforated metal sheets
- Last dynode is segmented into array of 2.54 mm square elements
- Essentially 96 individual PMTs in one glass envelope

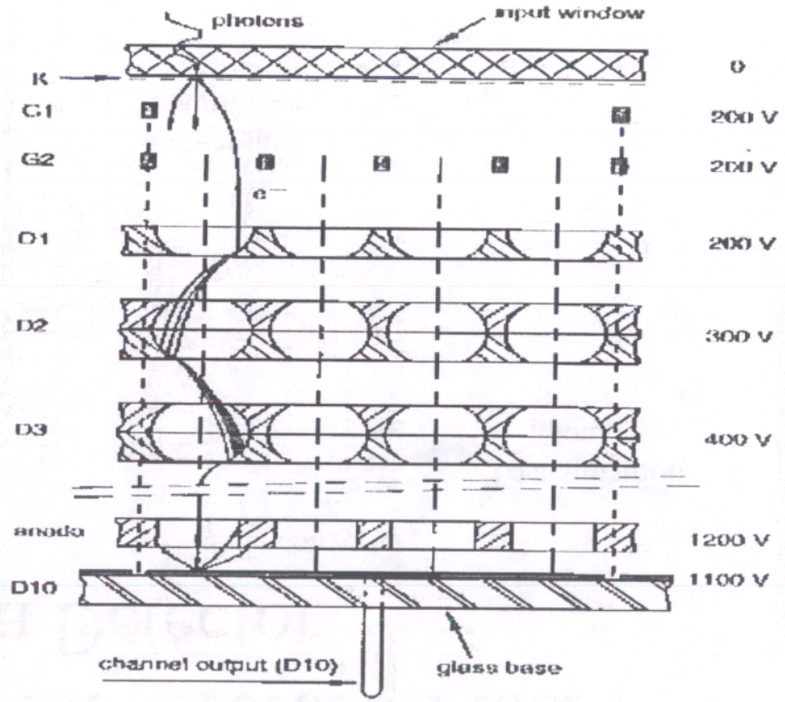
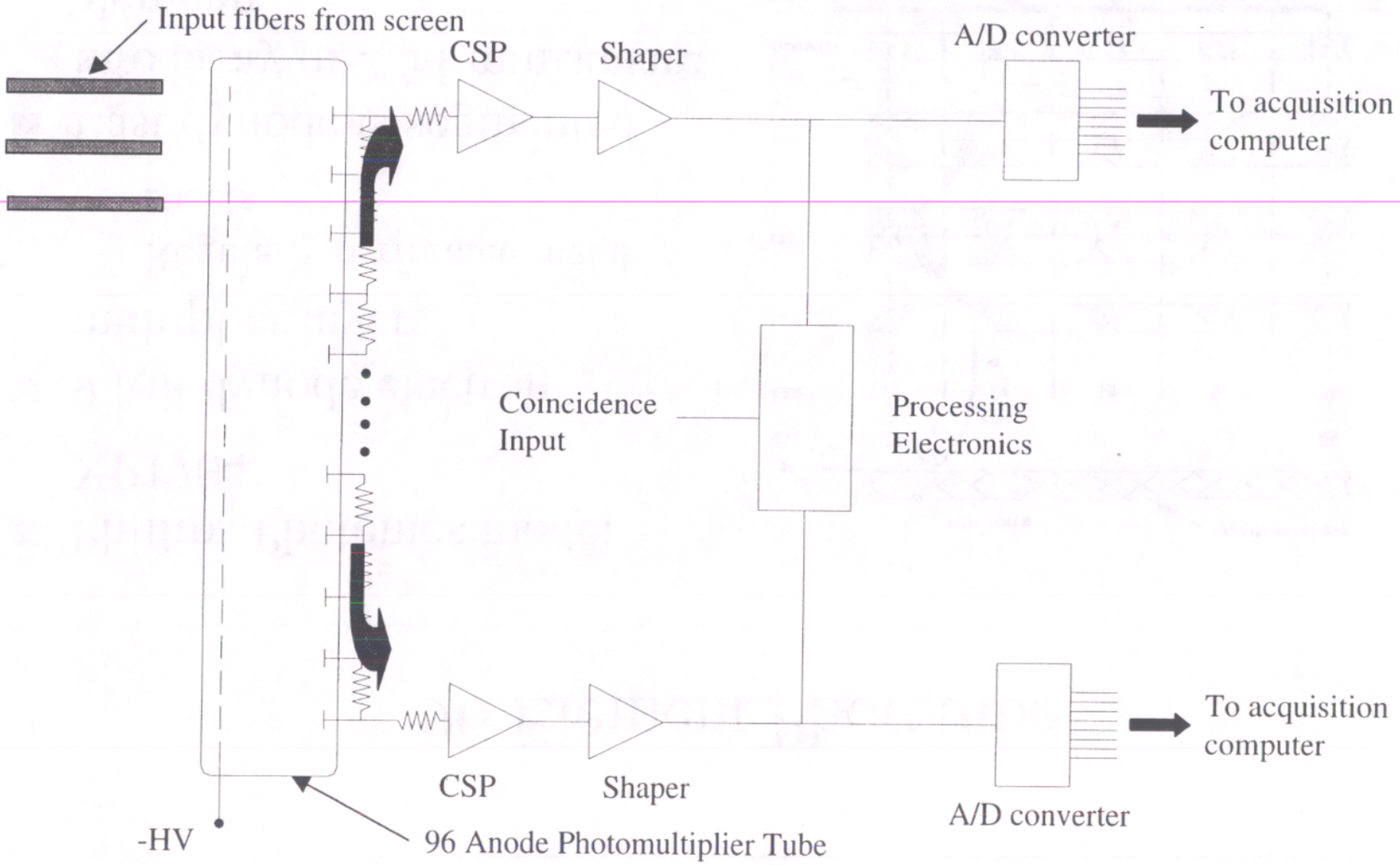
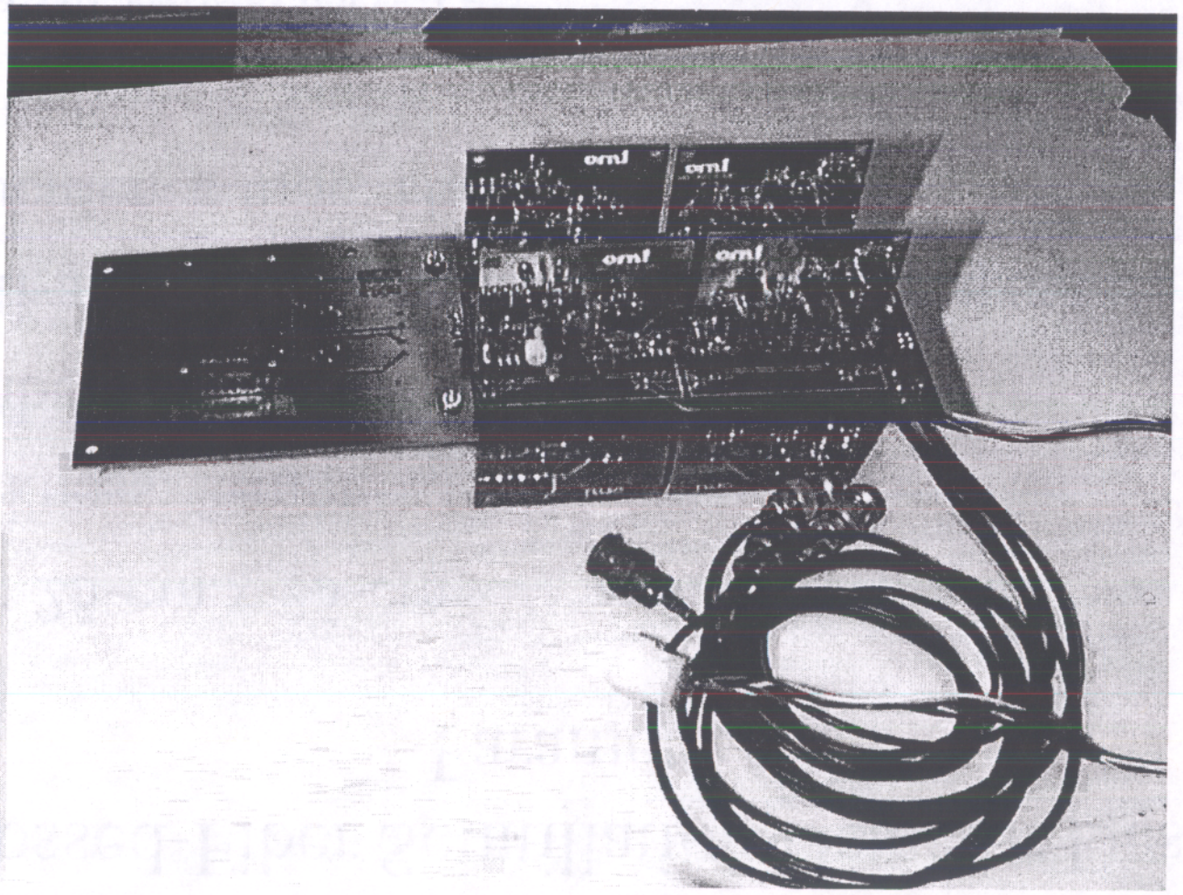


Fig.2 Cross section through one detection channel. G1 and G2 are high-transparency grids; D1 to D10 dynodes, the latter segmented.

Electronics Scheme for Crossed-Fiber Scintillation Detector



Charge-Sensitive Pre-Amp and Shaping Amplifier for Crossed-Fiber Detector



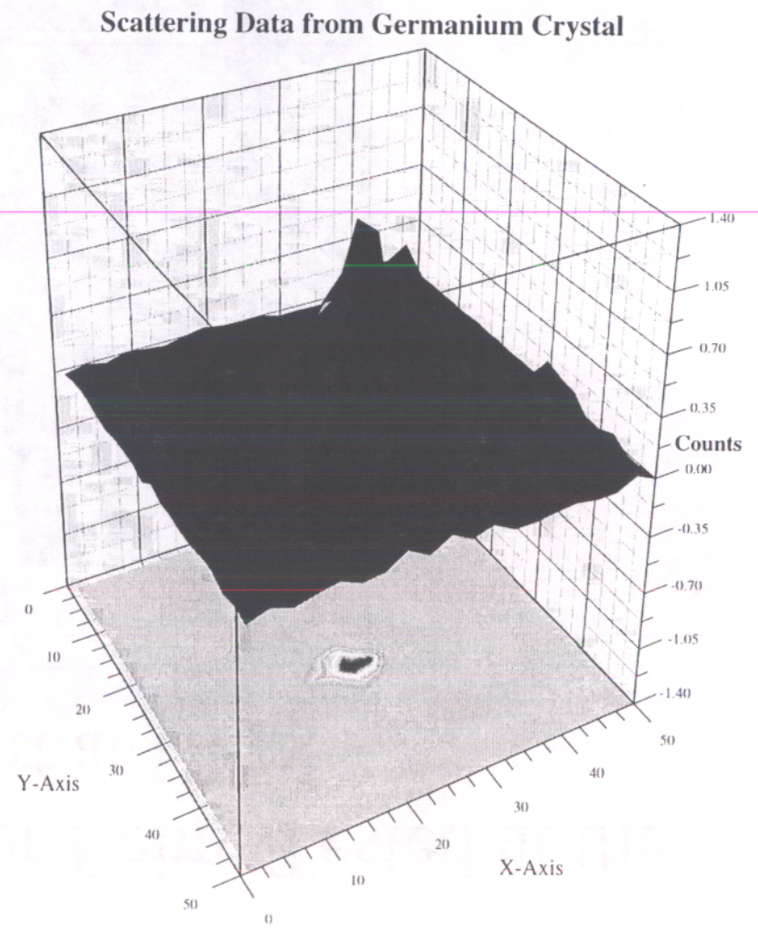
Crossed-Fiber Scintillation Detector Design Parameters

- Size: 25-cm x 25-cm
- Thickness: 2-mm
- Number of fibers: 48 for each axis
- Multi-anode photomultiplier tube: Phillips XP1704
- Coincidence tube: Hamamastu 1924
- Resolution: < 5-mm
- Shaping time: 300 nsec
- Count rate capability: ~ 1 MHz
- Time-of-Flight Resolution: 1 μsec

Crossed-fiber Detector Being Tested at the HB-1B Port at HFIR

First Measurement of Neutron Scattering Using the Crossed-fiber Detector

- Normalized scattering from 1-cm high germanium crystal
- En ~ 0.056 eV
- Detector 50-cm from crystal

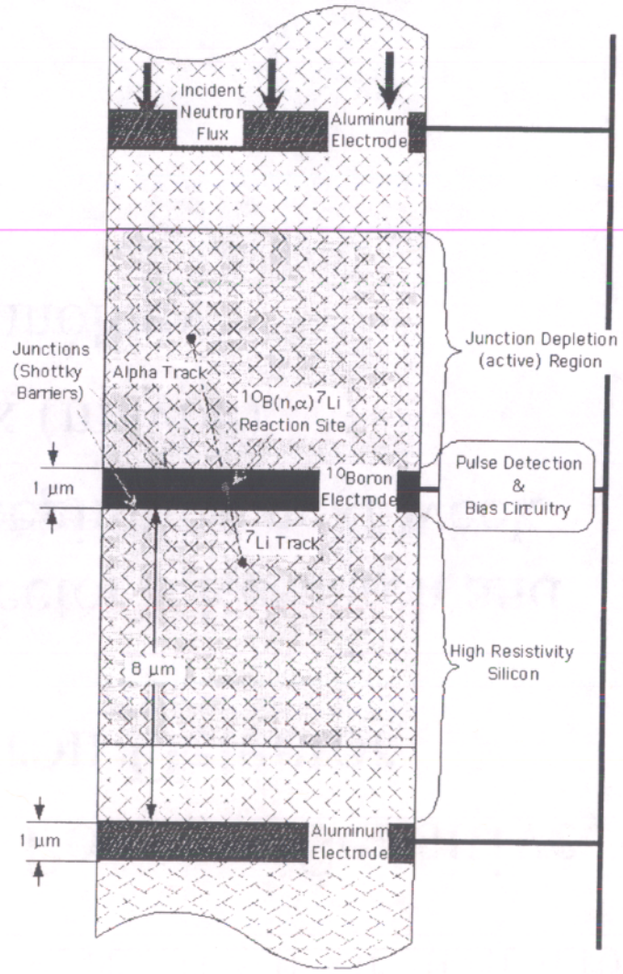


High-Efficiency, High-Speed, Position Sensitive, Energy Resolving Neutron Detector

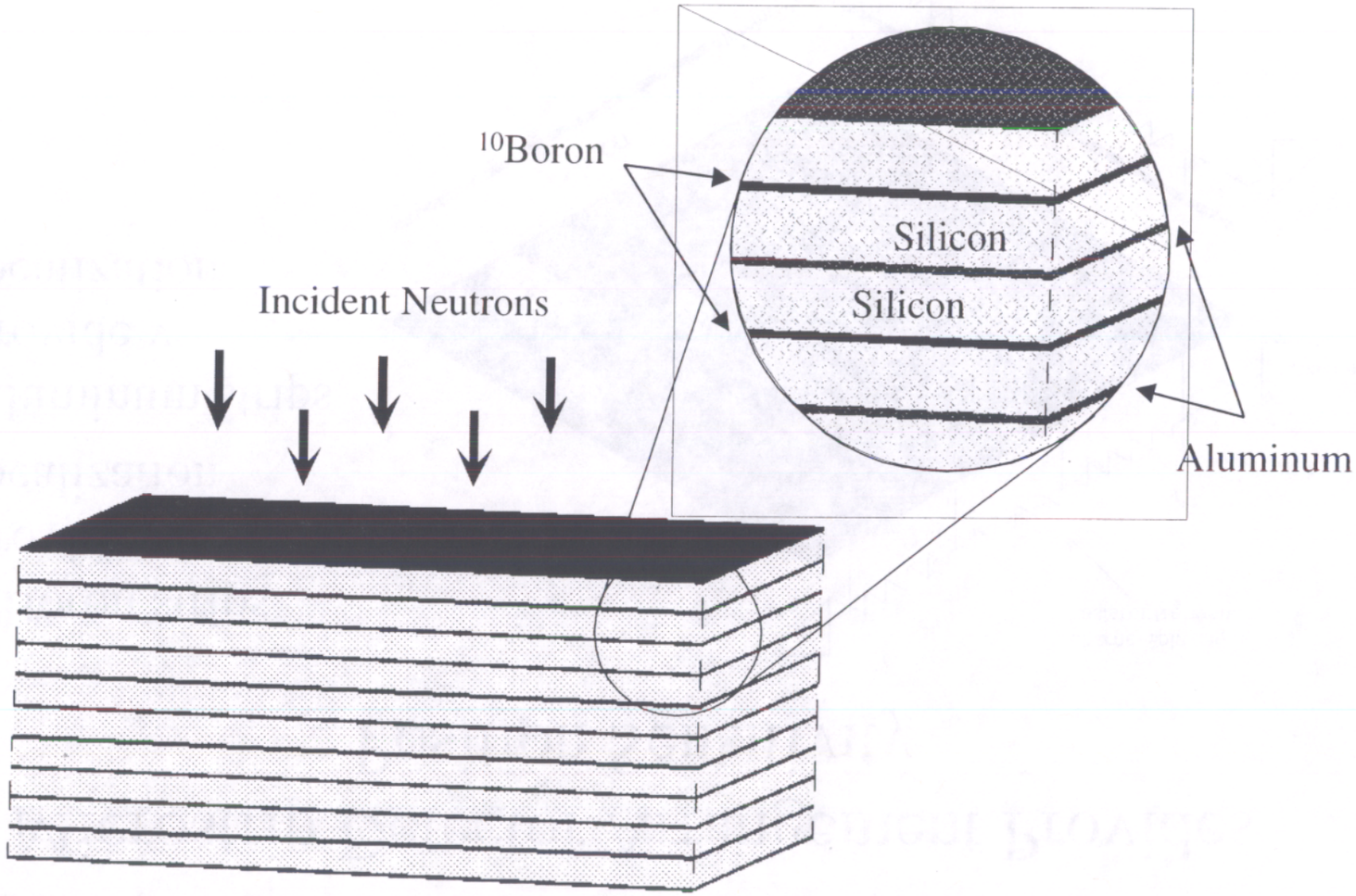
- Awarded ORNL Laboratory Director's Research and Development (LDRD) funding beginning next week
- Patent application filed this week (maybe)
- Based on ^{10}B semiconductor technology

Single Layer of Detector Structure

- Neutrons incident vertically
- Interact in ^{10}Boron
- Causing high energy charged particles
  - Alpha & ^{7}Lithium
- Exciting electrons in silicon into conduction band
- Charge collection at Electrodes

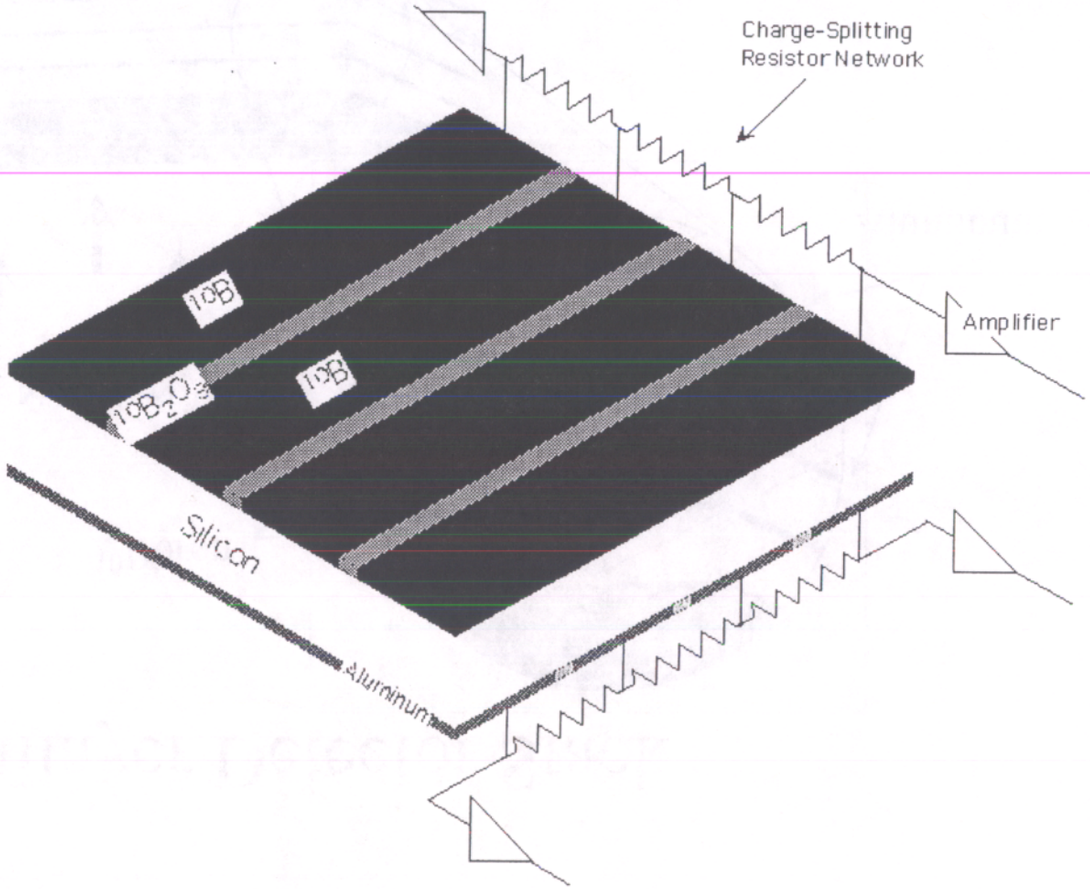


Multilayer Detector Stack



Microstrip Detector Arrangement Provides Position Sensitivity

- ^{10}Boron strips provide x localization
- Aluminum strips provide y localization



Detector Features High Efficiency, High Speed, and Position Sensitivity

- Multilayer structure provides for neutron efficiency of ~90%
  - ~85 μm ^{10}B layer required for a 90% interaction probability of 0.1 eV neutrons
  - Alpha particles have ~5.7 μm range in silicon & 3.6 μm range in boron
- Short range charge collection —> fast devices (10^9/sec)
- Position sensitivity: double-sided microstrip detector arrangement

Neutron Energy Spectrum Obtained Through Exponential Stripping

- ^{10}Boron has a large inverse velocity dependent low-energy neutron interaction cross-section
- Neutrons have an exponential attenuation with ^{10}B penetration
- Higher energy neutrons interact preferentially deeper into the structure
- All other detector materials have small neutron interaction cross-sections

Summary

- The combination of our ^{6}LiF / ZnS(Ag) scintillator screens with wavelength-shifting optical fibers shows great potential for:
  - high count rate (> 10^{6} Hz)
  - high resolution timing (< 1μS)
  - high neutron sensitivity (> 90%)
  - low gamma sensitivity (>10^{6} rejection)
  - good spatial resolution (~ 1mm)
  - low cost for large detection areas
- Prototype detectors have been constructed
- Testing and optimization at HFIR is underway
- Semiconductor detector development is just now beginning