

A New Thermal Neutron Detector for Protein Crystallography¹

G.J. Mahler, V. Radeka, N.A. Schaknowski, G.C. Smith, B. Yu and Z. Zojceski
Brookhaven National Laboratory, Upton, NY 11973-5000, USA

Abstract

A new position-sensitive detector is being developed for protein crystallography studies at a spallation source. Based on eight, independent, wire proportional chamber segments housed in a curved pressure vessel, the device covers a scattering angle of 120 degrees, and has a collecting area of 1.5m by 20cm. The position resolution will be about 1.3 mm FWHM, with a total counting rate in excess of one million per second. Timing resolution, essential for a spallation source application, is of order 1 μ s and provides neutron energy determination that is well suited for crystallography. Advanced features of this device include a digital centroid finding scheme, a seamless readout between segments, and a wire array design that minimizes anode modulation. Details of the mechanical design are given, together with digital centroid measurements that illustrate accurate, uniform response.

I. INTRODUCTION

Neutron scattering is an important technique for the determination of molecular and crystal structure of biological samples. It also permits studies of material characteristics not possible with X-rays. We are developing an advanced, large area detector, based on a gas proportional chamber, for a new protein crystallography beam-line at the LANSCE spallation source at Los Alamos Laboratory. Specifications include a position resolution of about 1.3 mm FWHM, a count rate capability in excess of one million per second, and timing resolution of about one microsecond.

II. DETECTOR DESCRIPTION

A. Pressure Vessel

The basis of the detection process is neutron absorption in ³He, which creates about 30,000 primary electrons, followed by low gain multiplication in a 2D wire proportional chamber. Protein crystallography benefits significantly from a large collecting area. Hence, eight segments of wire chambers will be used, each one independently read out to increase the total count rate capability. The segments are housed in a gas containment vessel, figure 1a, with a radius of curvature of about 70cm (the sample to detector distance), a length along the arc of 1.5m, and a height of 20cm. The pressure vessel material is 7075-T6 aluminum alloy, which has a yield strength of about 73000psi at 75°F. The more commonly used 6061-T6 aluminum alloy yields at about

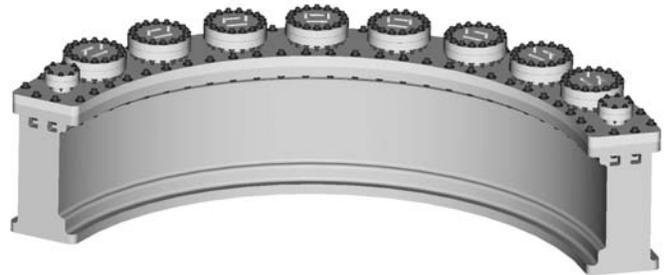


Figure 1a Pressure Vessel. The lower part will be fabricated from aluminum, the upper flange from stainless steel. In the sensitive area, the length of arc is 1.5m, the height is 20cm.

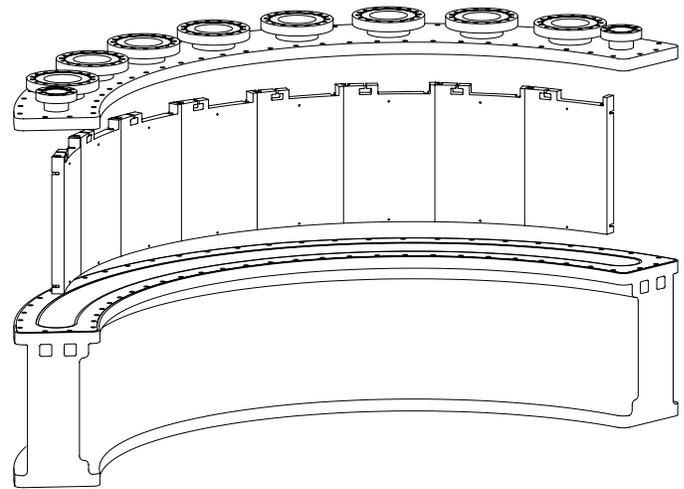


Figure 1b Upper flange is raised, showing eight aluminum back plates, each of which will hold one wire frame segment.

40000psi. Use of the high strength alloy permits the entrance window to be only 8mm thick, while maintaining a safety factor of 4 as required by ASME standards [1]. This keeps neutron scattering in the window to acceptably low levels. The eight wire chamber segments and feedthrough flanges, which carry power and signals, are directly mounted to the stainless steel top flange. The gas composition will be approximately 6 atm ³He and 2½ atm propane. This mixture achieves greater than 50% efficiency over the wavelength range of interest, about 1–6Å, and the stopping power of the propane enables a position resolution of about 1.3 mm FWHM to be achieved [2].

Figure 1b shows an exploded view of the detector, depicting the back support plates for each of the eight wire segments. These are fabricated to the correct curvature by a large milling head and electric discharge machining.

¹This work was supported by the U.S. Department of Energy under contract No. DE-AC02-98CH10886.

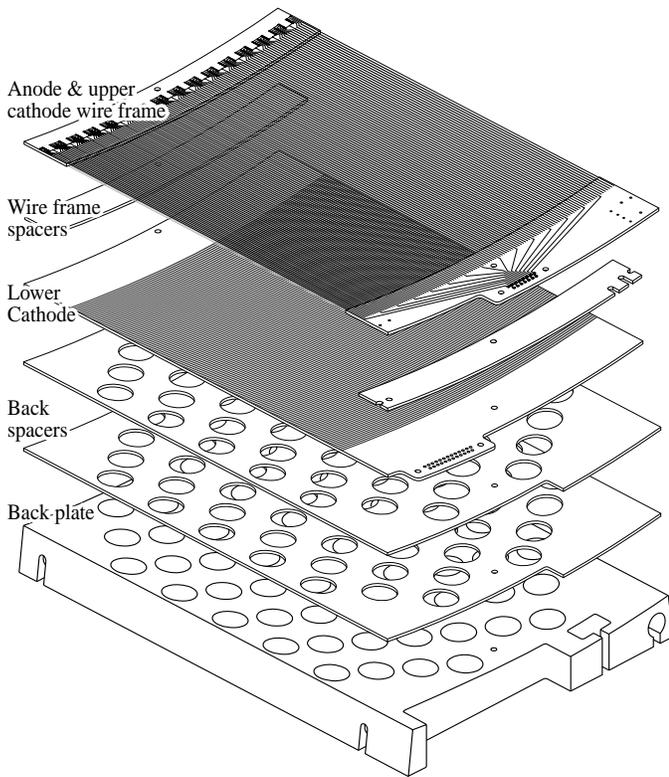


Figure 2a Component parts of one segment. At bottom is aluminum back plate (see fig. 1b), then two insulating spacers, then lower cathode and anode/cathode wire frame. A custom-built press laminates these frames to the correct radius of curvature.



Figure 2b Photograph of one completed segment. Notches in aluminum back plate allow accurate attachment of adjacent segments.

B. Wire Frame Segments

Each of the eight wire frames is similar to the standard 20cm by 20cm planar detector built in this laboratory for crystallography carried out at reactor installations [2], except for the appropriate curvature. An exploded view of the components of one segment is shown in figure 2a. The aluminum back plate forms the structural support. Two spacers, a cathode strip plane, wire frame spacers, and an anode/cathode wire frame are laminated in place. This is accomplished using a custom-built

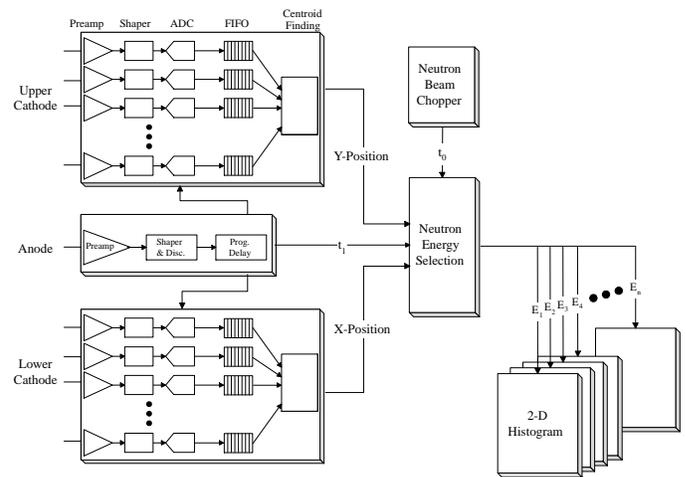


Figure 3 Electronic block diagram

press. Initially all of these fiberglass frames are flat, and they are pressed to conform to the curvature of the base plate. The spacer and wire frame material is Rogers 4000 laminate [3], which has a dielectric constant somewhat smaller than G10 (3.4 vs. 4.6 @ 1MHz) [3,4]. The role of the spacers is to reduce the capacitance between the lower cathode and the back plate. The holes in the spacers and the back plate further reduce the capacitance of the lower cathode and provide access to the resistor networks. A complete segment is shown in figure 2b.

C. Position Readout

Position readout of each segment is performed along both cathodes, with resistive charge division between a number of nodes, or fiducial points. This readout provides an extremely stable response, and low noise position information, thus allowing operation of each segment at low gas gain, greatly extending the life of the detector.

Figure 3 shows the basic electronics block diagram for one segment. As in ref. 5, the nodes of each cathode are read by charge sensitive preamplifiers, the signals from which are shaped by a time-variant filter, figure 4a (second-order gated base-line-restorer [6,7]). This circuit is realized as a small surface-mounted printed circuit board. The principal analog signals are presented in figure 4b. The signal gate, which controls switches SW_1 and SW_2 , is generated from the anode signal. A delay line of 250ns at the input of the shaper gives the time necessary to process the anode signal. In our existing 2D neutron detectors, shaper outputs are sequentially switched into a centroid finding filter [5]. Event position information will now be determined by a new centroid finding system that permits counting rates in each segment of several 100k per second, making use of the power of the most recent Digital Signal Processors (DSPs). The digital electronics will contain one ADC per channel followed by a FIFO memory. Centroid finding is carried out in a DSP (a recent digital system similar to that being developed in

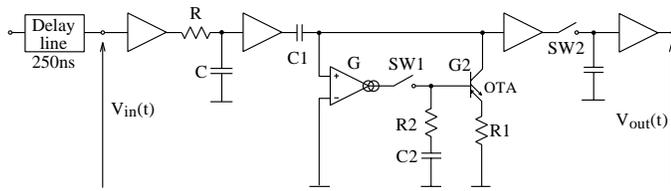


Figure 4a Schematic diagram of the shaper (second-order gated baseline restorer)

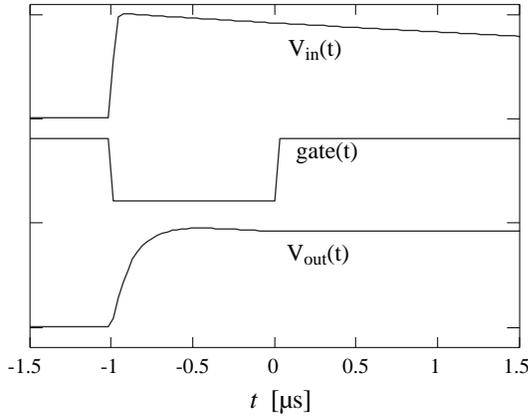


Figure 4b Principal analog signals

this project is described in ref. 8). The two digital position signals are then time stamped and fed to the corresponding level of a histogram. The time stamp is derived from the time difference between t_0 of the neutron chopper, the time at which the neutron pulse is created, and t_1 , the time the anode detects the neutron.

The digital electronics is presently under design, but a test of the digital algorithm has been carried out as follows. A large number of waveforms from the receiver unit of the existing centroid finding electronics has been collected on a digital oscilloscope (LeCroy 9360). One typical oscillogram is shown in figure 5. It contains 500 8-bit data-points. A PC program extracts preamplifier charge values by reading every 25th point through a GPIB interface.

The position in the detector is given by:

$$x = kw + w \frac{Q_{k+1} - Q_{k-1}}{Q_{k-1} + Q_k + Q_{k+1}}$$

where k is the position of the central channel, w is the strip pitch and Q_{k-1} , Q_k , Q_{k+1} are measured charges.

Figure 6a shows the X-axis uniform irradiation response (UIR) from one segment using the existing centroid finding electronics. Figure 6b shows the response from the same segment using the digital position evaluation. To obtain this result, as in ref. 8, it was necessary to add eight random, nonsignificant bits to the original ADC value in order to remove quantization effects of the 8-bit oscilloscope val-

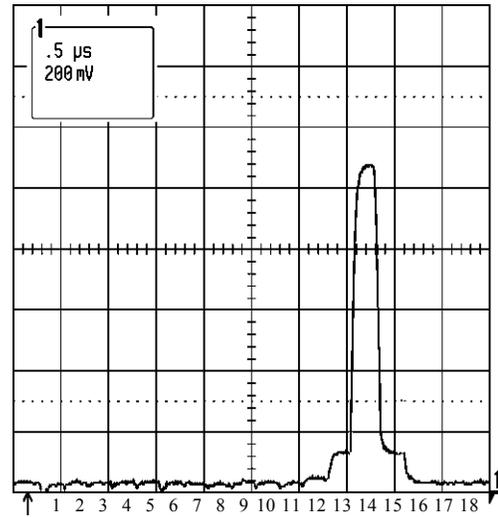


Figure 5 Output of receiver unit in centroid finding electronics [5]. This oscilloscope trace shows an event centered at node 14 in one axis. Charge from any event is spread over three nodes at most.

ues. Clearly, the new encoder yields a response almost identical to that using the centroid finding filter.

The anode and cathode wires in each segment are constructed with an arrangement that significantly reduces anode wire modulation in the position axis across the anode wires [9]. The modulation can be reduced by at least a factor two compared with normal wire arrangements, representing a major benefit for high resolution neutron studies. We also propose to implement a seamless position response across each segment boundary. In this method, the signals from the

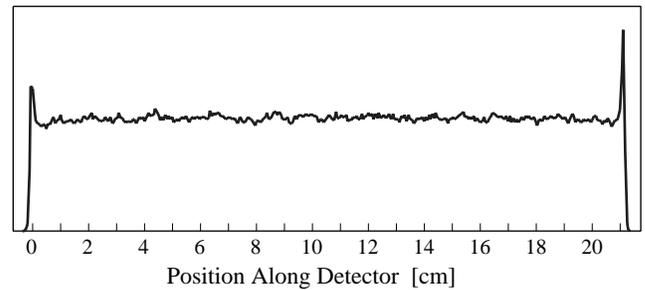


Figure 6a Uniform irradiation response from one detector segment using existing centroid finding electronics.

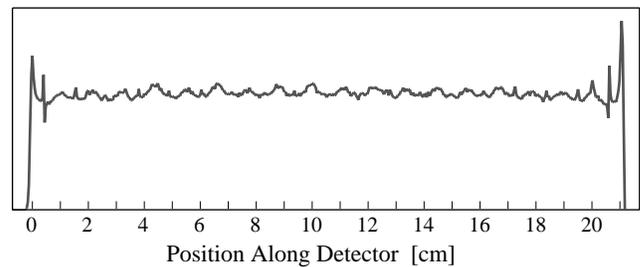


Figure 6b Uniform irradiation response from same detector segment, generated from analysis of many actual waveforms, as shown in fig.5. Algorithm used is described in section IIC.

boundary readout channels of two adjacent segments are fed in parallel to the analysis electronics of each segment. The centroid finding electronics of these two segments calculate the centroid of the event independently, yielding a result which is valid only for one segment.

III. DISCUSSION

The curved detector development described in this paper is part of a neutron protein crystallography station being constructed at LANSCE, Los Alamos National Laboratory. The mechanical design of the detector is complete, and the wire frame segments are in production. Construction of the readout electronics is underway.

We hope that this research work will become an asset to detector R&D programs focused on new spallation sources. For example, the European Spallation Source and the US Spallation Neutron Source are the next major planned facilities worldwide. Gas proportional detectors, which have the usual necessary characteristics of good efficiency, low gamma sensitivity, high rate capability, and good position resolution, also possesses timing resolution in the microsecond regime to permit determination of neutron energy, and the capability of

being constructed in small or large areas. These properties, summarized in Table 1 for detectors developed by our group, make this type of device well-suited for use at spallation sources.

IV. ACKNOWLEDGEMENTS

The authors are grateful to Benno Schoenborn (Los Alamos National Laboratory) for initiating the project and for subsequent encouragement and support.

V. REFERENCES

- [1] ASME Boiler and Pressure Vessel Code, American Soc. of Mech. Engineers, (1983) Sec. 8, Div. 2, Appendix 1 & Article M1.
- [2] V. Radeka, N.A. Schaknowski, G.C. Smith and B. Yu, "High Precision Thermal Neutron Detectors," in: *Neutrons in Biology*, ed. B.P. Schoenborn and R.B. Knott. Plenum Press, (1996) 57-67.
- [3] Manufactured by Rogers Corporation, 100 S. Roosevelt Av., Chandler, AZ 85226.
- [4] Clyde F. Coombs, Jr., ed., *Printed Circuits Handbook*, 4th edition, McGraw-Hill, (1996) p 8.28.
- [5] V. Radeka and R.A. Boie, "Centroid Finding Method for Position-Sensitive Detectors", *Nucl. Instr. & Meth.* 178 (1980) 543-554.
- [6] R.A. Boie and V. Radeka, "High Precision Position Readout for Large Area Neutron Detectors". *IEEE Trans. Nucl. Sci.* NS-27, No. 1, February (1980) 338-350.
- [7] J.C. Artiges, V. Hervier, A. Richard, P. Volkov, E. Wanlin and Z. Zojceski, "Compact CSC Acquisition System: VXI D-size Modules with a DSP Interface," *IEEE Trans. Nucl. Sci.* Vol 43, No. 3, (1996) 1784-1788.
- [8] P.J. Pietraski, Z. Zojceski, D.P. Siddons, G.C. Smith and B. Yu, "Digital Centroid-Finding Electronics for High-Rate Detectors", submitted to these proceedings.
- [9] G.C. Smith and B. Yu, "The Linearity Performance of a Two-dimensional, X-ray Proportional Chamber with 0.58mm Anode Wire Spacing. *IEEE Trans. Nucl. Sci.* NS-42 (1995) 541-547.

Table 1

Position Resolution (FWHM)	< 0.4 – 2 mm
Resolution Elements	128 × 128 – 4096 × 512
Size	5 × 5 cm ² – 150 × 20 cm ²
Wavelength Range	1 – 20 Å
Detection Efficiency	50 – 80%
Counting Rate (one module)	2 × 10 ⁵ sec ⁻¹ sustained
Integral Non-linearity	2 × 10 ⁻⁴ to 10 ⁻³
Absolute Position Accuracy	30 – 100 μm
Stability of Origin	< 50 μm
Stability of Efficiency	< 1%
Differential Non-linearity	± 3%
Dynamic Range	Single Neutron Counting
Timing Resolution (rms)	< 1 μs