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ANL-LASL Workshop on Advanced Neutron Detection Systems

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ANL-LASL Workshop on Advanced Neutron Detection Systems

Compiled by

T. A. Kitchens

ANL-LASL WORKSHOP ON ADVANCED NEUTRON DETECTION SYSTEMS

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ABSTRACT

A two-day workshop on advanced neutron detectors and associated electronics was held in Los Alamos on April 5-6, 1979, as a part of the Argonne National Laboratory-Los Alamos Scientific Laboratory Coordination on neutron scattering instrumentation. This report contains an account of the information presented and conclusions drawn at the workshop.

SUMMARY ON THE WORKSHOP ON
ADVANCED NEUTRON DETECTION SYSTEMS

In response to the request by the ANL/LASL Coordination Committee on Spallation Neutron Instrumentation, a workshop on Advanced Neutron Detection Systems was held at the LASL National Security and Resources Study Center on April 5-6, 1979. Attention was directed toward detectors for neutrons with energies below a few tens of eV. The agenda of the meeting and the list of participants is attached. The major topics considered at the workshop are listed below and brief summaries and recommendations for each topic follow.

1. Gas-Filled Detectors and Associated Encoding Electronics (summarized by P. Seeger)

2. Scintillation Detectors and Associated Encoding Techniques (summarized by J. Carpenter)

3. Data Acquisition Electronics (summarized by R. Hendricks), and

4. Advanced Neutron Detection Techniques (summarized by R. Fluharty)

A few highlights are:

In the first topic, Gas-Filled Detectors, it was concluded that this technique, with some improvements listed in the summary, will suffice for spallation neutron detection in the short term (less than 3 years). Position-sensitive gas proportional detectors have been developing in the U.S. for the last decade at BNL and ORNL. Unfortunately Veljko Radeka, who had initially planned to attend the workshop and give us the benefit of the Brookhaven experience, was unable to attend.

Michael Strauss discussed the pros and cons of scintillation neutron detectors in relation to gas-filled detectors. In principle, scintillation detectors·look especially useful. Jack Carpenter discussed the recent tests made at Argonne on the scintillation detectors produced by Harold Wroe of the Spallation Neutron Source (SNS) project at Rutherford Laboratory. The major shortcoming is the difficulty of obtaining and the lack of uniformity of the glass-based scintillation materials. The present plans at the SNS are to use this technique extensively by 1984.

The data acquisition systems discussed by D. Machen, R. Hendricks, R. Nelson and D. McMillan all use fast (less than 250 nsec cycle time) microprogrammed processors. It was concluded that the problems likely to be encountered at spallation neutron sources will be much the same as at synchrotron radiation sources and in many particle physics experiments. It should, therefore, be extremely beneficial to coordinate efforts in this area at the DOE laboratories.

Many novel neutron detection techniques were discussed by R. Fluharty and the other workshop participants. These techniques all need development. It was observed that there is no continuously-supported neutron detector development in the U.S. Since it has taken ten years or so to bring gas-filled area multidetectors to their present state, it is imperative that we start now to investigate the scintillation detection and other techniques for low-energy ($E \lesssim 10$ eV) neutrons.

AGENDA FOR THE
ANL-LASL WORKSHOP ON
ADVANCED NEUTRON DETECTION SYSTEMS

April 5, 1979 LASL National Security and Resources Study Center

9:20 Welcome and Agenda Discussion
9:30 Systems Using 2-D Gas-Filled Detectors
M. Kopp, ORNL (Fundamental)
R. Hendricks, ORNL
9:55 Systems Using 1-D Gas-Filled Detectors
R. Berliner, University of Missouri
10:10 The LASL Multiple Detector System
P. Seeger, LASL
10:20 Discussion of Gas Detector Systems: BNL and ILL
10:50 Coffee Break
11:00 Position-Sensitive Detection Systems Using Scintillators
J. Carpenter and M. Strauss, Argonne National Laboratory
11:20 Discussion of Existing Neutron Detection Systems
12:00 Fast Data Encoding, Transmission and Fast Preprocessor Electronics
D. Machen and D. Brown, Los Alamos
12:15 Discussion on Data Acquisition Systems
12:30 Lunch (South Mesa Cafeteria)
2:00 General discussion of Conventional Detector Systems
3:30 Continued discussion of Data Acquisition Systems
4:00 Resonance Detector Systems
Rex Fluharty, LASL
4:15 Discussion of Resonance and Other Novel Neutron Detection Schemes
a. For Neutrons of Epithermal Energies (0.3-1.0 eV)
b. For Neutrons of Higher Energies (1-10 eV)
5:00 Social Hour (Red Room)
7:00 Dinner (Philomena's)
9:00 Evening Session (Preliminary work on Workshop Summary)

April 6, 1979 LASL National Security and Resources Study Center

9:10 Continued Discussion on Advanced Detection Systems
9:45 Draft Summary of Workshop
11:00 Adjournment

A tour of the Los Alamos Pulsed Neutron Source, the WNR, was arranged in the afternoon for those interested.

Non-LASL Attendees

Fred Glesius
Reuter Stokes

Joe Skarupa
Reuter Stokes

Arthur Lucas
Harshaw Chemical Co.

Ronald Nutt
Technology for Energy Corp.

C. Cassapakis
Science Applications, Inc.

V. Verbinski
Science Applications, Inc.

R. Berliner
University of Missouri

R. Hendricks
Oak Ridge National Lab

Manfred Kopp
Oak Ridge National Laboratory

Michael Strauss
Argonne National Laboratory

J. M. Carpenter
Argonne National Laboratory

C. Borso
Argonne National Laboratory

LASL Attendees

T. A. Kitchens, P-8
J. L. Yarnell, P-8
R. G. Fluharty, P-8
P. A. Seeger, P-8
J. A. Goldstone, P-8
A. C. Larson, P-8 consultant
P. J. Vergamini, P-8
R. O. Nelson, P-9
D. E. McMillan, P-9
D. R. Machen, AT-4
David Brown, E-5

Gas-Filled Detectors (Coordinator: P. Seeger)

Present technology of neutron detectors in the United States is dominated by gas-filled proportional counters of the conventional as well as the position-sensitive type. Attention at this workshop was directed at position and time sensitive systems. Large single-vessel two-dimensional systems are almost invariably ^{3}He (rather than BF_3) in view of safety considerations. It appears that for the next several years our needs can be met fairly well by existing systems although they have certain shortcomings.

Desirable design features are:

1. High overall throughput including encoding

   Two parameters are significant: the dead time or minimum pulse-to-pulse recording time, which should be less than 0.25 μs, and the maximum rate at which data may be stored, which should be greater than 10^5 sec^{-1}.

2. Spatial and time resolution

   These requirements are strongly dependent on specific instruments. The highest spatial resolution is needed for single-crystal diffractometers and neutron radiography, and the highest time resolution for epithermal neutron detection.

3. Large area

4. Ability to cover arbitrary shapes and curved surfaces, and to encode in forms of spherical coordinates

5. High efficiency over an extended wavelength range

6. Uniformity of efficiency

   This requirement also reaches its extreme for single-crystal diffractometers.

7. Low cost, both for acquisition and for maintenance

   The complexity and cost of the encoding electronics are a major consideration.

8. Availability

Discussions concentrated on the ORNL design of the two-dimensional position-sensitive proportional counter (C. J. Borokowski and M. K. Kopp, Rev. Sci. Inst. 46, 951 (1975); J. Appl. Cryst. 11, 430 (1978)). This system represents about 10 years of development, indicating the lead-time necessary for future new systems. The upper limit of counting rate at high resolution is about 10,000 sec^{-1} in one space resolution element (continuous source), because of drift field distortions due to the positive ions. (Russell et al., ORNL technical memo.) These characteristics are probably adequate for WNR or IPNS-I but may be inadequate for future spallation sources. Several encoding schemes are possible (charge division and time analysis) and for neutrons there is no clear advantage except for local electronics expertise. The time needed to encode one event is a limitation in most present detectors, but can be improved, for instance, by direct time-to-digital encoding as at ANL (F. J. Lynch). Of the systems discussed, the multiwire area detector is most likely to achieve adequate uniformity. Various shapes can be considered, but only those for which anode wires are straight lines. These detectors are commercially available from at least two American sources.

An array of linear position-sensitive detectors should be considered as a cost-effective alternative to area detectors. Ron Berliner (Missouri University Reactor) has built such a system using charge-division encoding and a simple micro-computer. Throughput is obviously improved by parallel electronics. Individual detectors or preamps are easily replaceable. The resolution is good ($\sim$ 2 mm) in the axial direction but poor ($\sim$ 2 cm) perpendicular to the axes of the counters.

The other alternative mentioned is to use a large array of individual detectors. This allows arbitrary shape coverage and coordinate systems, but with limitations on the fraction of solid angle that can be covered. Individual electronics on each detector make encoding trivial, using simple inexpensive commerical components. The LASL small-angle detector uses a set of annular detector banks; each ring gives resolution in azimuth by recording individual detectors, and resolution in λ by time-of-flight.

Several minor research and development efforts could make substantial improvements upon gas-filled detectors for pulsed spallation neutron scattering experiments. These are:

1. Experimentation with composition of fill gases to improve efficiency for epithermal neutron detection and to improve time resolution.

2. Experimentation on ways of improving the detector efficiency for epithermal neutrons by increasing the density of detector gas without sacrificing time resolution. This might be accomplished by reducing the detector temperature to 100K or less.

3. Mechanical design of flatter and other novel detector windows to contain large detector gas pressures and be transparent to subthermal neutrons.

4. Mechanical design of flat-sided or other more convenient detector shapes.

5. Development of techniques to remove the difficulties of direct neutron beam irradiation of the detector.

Scintillation Detectors and Associated Encoding Schemes (Coordinator: J. Carpenter)

Scintillation detectors appear to offer advantages for low energy neutron detection in neutron scattering instruments.

The advantages of scintillation detectors are:

1. Speed (pulse resolution time $\lesssim$ 100 nsec)
2. Thinness (time resolution $\sim$1 mm/v; reduced parallax)
3. Flexibility of shape
4. Cost (advantage varies according to application)

At the present time, the only significant program of development of scintillation detectors of which we are aware is that pursued by H. Wroe and his colleagues at Rutherford Laboratory, U.K. in support of the U.K. Spallation Neutron Source program. These developments are summarized below. Further information is contained in an informal Rutherford Laboratory Document "Guidelines for Cost and Efficiency of Various Neutron Detectors for SNS Instruments"--SNS/UTL/N13/78.

RUTHERFORD LABORATORY SCINTILLATION DETECTOR DEVELOPMENTS

Scintillators

1. ZnS(Ag)Li^6F ("Stedman Detectors")
2. NE 900-Series Glasses

Detector Types

1. Large-Area Single Detectors
2. Linear Multidetectors
3. Area Multidetectors
4. Flexible Sizes and Shapes

Electronic Techniques

1. Coincidence Coding of Positions
2. Delayed-Gate Pulse Shape Discriminator ("Davidson Discriminator" for ZnS(Ag))

Special Developments

1. Sandwich Glass Detectors
2. Granular Glass Detectors
3. Fiber-Optic Connections

Applications (Detector Type)

1. Chopper Spectrometers (Glass)
2. Single Crystal Diffractometer (Glass)
3. Powder Diffractometer (Glass)
4. Backscattering Spectrometer (ZnS)
5. Small Angle Diffractometer (ZnS)

ARGONNE NEUTRON POSITION-SENSITIVE SCINTILLATION DETECTOR DEVELOPMENTS

(M. Strauss)

Development of a 2-dimensional Neutron Position-Sensitive Scintillation Detector (NPSSD) based on the principle of the Anger γ-ray camera has begun at ANL. The first experimental NPSSD will consist of a hexagonal array of seven 2" photomultipliers coupled to a 6" diameter, 1 mm thick, cerium activated Li glass scintillator. Two types of glasses supplied by Nuclear Enterprises are being evaluated, NE905 and NE912. Future detectors can have a larger area, a different shape, a thicker glass (for higher than thermal-energy neutrons), and possibly a different type of scintillator.

This position-sensitive scintillation detector will incorporate several specific features which make it attractive:

1. Li glass, 1 mm thick, has an efficiency of 80% for thermal neutrons (25 meV).

2. The Anger γ-ray camera with a 12.7 mm thick NaI(Tl) crystal has an intrinsic resolution at 140 keV of 3 mm. On the basis of the thermal-neutron pulse height in glass and the greatly reduced glass-scintillator thickness, we expect a spatial resolution of about 4 mm and virtually no parallax.

3. The detector window serves only as a light seal and hence need not be more than 1 mm thick Al. The housing of the photomultiplier assembly is a low mass Al structure just large enough to contain all the components. Thus neutron scattering in the window and the housing is minimized and so is the resulting γ background.

4. The count rate is limited only by the light pulse which decays (90-10%) in 100 ns.

5. By virtue of the pulse height resolution of the Li glass (-25%) background due to γ radiation below 1 MeV can be largely rejected by pulse amplitude discrimination. Above 1 MeV it can be reduced by the use of a sandwich scintillator consisting of alternate layers of Li glass and common glass. Background due to the natural α activity is low in NE912 glass. In a 6" diameter, 1 mm thick scintillator we expect 8 dpm.

6. Initial stability measurements of the Hamamatsu R878, 2" photomultiplier indicates a peak drift of 0.05-05% in 50-100 hrs of continuous operation. We expect this performance to improve in the future due to the considerable effort being made by PM manufacturers.

7. The detector enclosure consists of a cylindrical shell with a diameter just slightly larger than the scintillator. This design permits the placement of the detector very close to the beam.

RECOMMENDATIONS

Immediate Future

There is not sufficient time available to launch a development program in U.S., to provide detectors for the first instruments at IPNS-I or WNR. The only possibility seems to be to adopt Rutherford-developed detector designs, after careful consideration of their performance relative to gas tubes in light of detector specifications for IPNS-I and WNR instruments. Therefore the following steps are recommended:

1. Approach Rutherford Laboratory to ascertain feasibility of their providing design data, or of fabricating detectors.

2. Formulate detector specifications for IPNS and WNR instruments: detector area, efficiency for anticipated wavelength range, background rates, constancy of efficiency.

3. Evaluate existing Rutherford detectors relative to alternatives, according to these specifications.

Longer Term

Since there is no low energy neutron scintillation detector development program in U.S., and since these have significant prospects for supplanting gas detectors in many applications, such a program should be initiated and funded. Specific developments which should be pursued, whether such a program is established or not, are:

1. Develop U.S. supplier of scintillating glass (there is now only one supplier, world-wide)

2. Improved glass scintillators

3. Plastic or liquid scintillator detectors for low-energy neutrons (homogeneous Li^6 or B^{10} loading)

4. Scintillation detectors coupled to charge-coupled photosensing devices

5. Neutron Anger camera

Data Acquisition Electronic Systems (Coordinator: R. Hendricks)

Data acquisition systems for position-sensitive detectors must perform three functions: position-encoding and digitization, memory mapping, and memory incrementing. Position encoding is intimately linked to the detector design and the encoding methods vary among the several laboratories now developing position-sensitive x-ray and neutron detectors. It is generally agreed that position-sensitive detectors and their associated encoding electronics are capable of detecting 0.5-1.0 x 10^6 events per second. Experience at LASL (WNR), ORNL and elsewhere indicates that memory mapping and memory incrementing electronics capable of handling such data rates can readily be constructed with available commercial components.

Several procedures have been developed for memory mapping and incrementing. Among these are software-controlled minicomputer programs, dedicated hardware systems utilizing memory external to the minicomputer, and intelligent microprocessor or microcoded front-end hardware utilizing either external or minicomputer memory. It was the concensus of the participants of this meeting that microcoded intelligent front ends with external memory are the devices which should be employed. In such devices, memory mapping for 2 or 3 dimensions (parameters) and high speed memory incrementing are performed by programmable processors which access memory connected directly to it.

It appears to this group that a Bulk Memory Processor (BMP), currently under development at LASL, which has an 80-bit microcode instruction and up to 8 megawords of directly addressable 24-bit memory, meets all of the speed and memory criteria for foreseeable neutron scattering experiments at pulsed sources in the U.S. It also appears to meet most criteria for data acquisition systems now under consideration for continuous reactors and for synchrotron radiation x-ray sources. Its limitation is that its interface is specific to the ModComp I/O Bus. We strongly recommend that:

1. The interface be developed in a separate module so that it could be used with other computers simply by designing a new interface module, or

2. that the interface be made CAMAC compatible.

It is clear that the significant cost reductions which can be made by duplication of devices for use in numerous laboratories are possible only if such devices are machine-independent. The various laboratories, for historical and other reasons, seem to be committed to different data acquisition computers. Thus, we recommend that specific modules for position encoding and data manipulation should be implemented in CAMAC and its successors.

Finally, we observe that the data acquisition systems currently under consideration for pulsed sources and reactors are closely related to similar systems being developed for synchrotron radiation x-ray sources and continuous reactors. Therefore, we recommend that the committees considering such systems be enlarged to include representation from laboratories such as BNL, SSRL, and ORNL.

Advanced Neutron Detection Techniques

(Coordinator: Rex Fluharty)

Because of their availability in the U.S., ^{3}He gas proportional counters will probably be the major neutron detectors for the pulsed neutron sources in the near future (3-5 years). This is particularly true of position-sensitive detectors which have been developed in the U.S. for small-angle scattering and single crystal diffractometers. Similar devices are used for x rays and in particular will be useful for the synchrotron radiation sources. In addition to diffraction applications, they will be useful for radiographic purposes as well as others.

It is clear that neutron detector development has been neglected, and the most promising area of development, i.e. scintillation counters, is discussed elsewhere. Here we list some very speculative detector possibilities which could be examined. The list is not intended to be inclusive but instead to stimulate the imagination.

Resonance Detectors

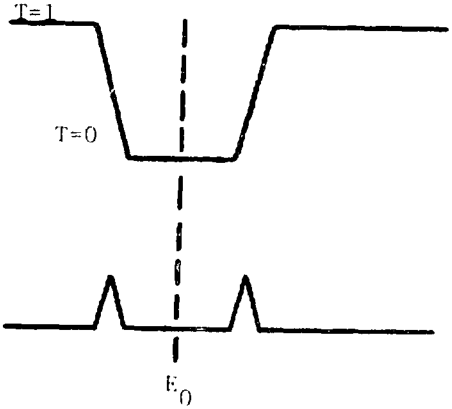
Pulsed neutron sources have high epithermal fluxes compared to reactors, and it has been proposed that this enhanced flux will allow measurements of materials in unexplored regions of ω-Q space. Higher energy electronic states in semiconductors and single particle magnetic states have been mentioned as important subjects for exploration in this energy region. However, plans for instruments and measurement programs in this area have not progressed much beyond the general discussion stage. This lack of real progress most probably reflects the neutron source strengths currently available at which elastic scattering measurements in the thermal neutron energy region are yielding quick and easy results. Because the signals are relatively large, the problems of backgrounds are less important. However, it is time to plan instruments and measurements in the epithermal region. Resonance detectors appear to provide a means of making exploratory measurements, and this subject is the major objective here.

The technique proposed by H. Mook of ORNL consists of a detector consisting of a foil which captures neutrons at some energy E_0 and a gamma ray detector foil to observe the nuclear capture γ rays. The detector is placed to observe the scattered radiation from a sample. The measurement is of $\sigma(E \rightarrow E_0, \theta)$ in downscattering where E is determined by TOF and E_0 by the nuclear resonance. So far, the most promising resonance appears to be that at 6.67 eV in ^{238}U where the nuclear width is $\sim$ 20 meV ($\Delta E/E = 0.003$). However, the initial motion of the absorbing nucleus increases the width at room temperature to 56 meV ($\Delta E/E = 0.008$).

Although the fractional energy resolution is not terrible, the solid state spectroscopist is used to $\sim$1 meV resolution; and the practical 56 meV resolution above is far from this desirable value. The obvious method of obtaining the intrinsic 20 meV width is by lowering the temperature. This cannot be completely realized because the target nuclei always have zero point motion. Many questions such as Mössbauer elastic interaction remain open here, and clearly a literature study and measurement program are called for to identify materials in which the Doppler broadening can be minimized.

Another technique, having similarities to the old "self indication" method needs to be explored. To illustrate this technique, a gamma detector is used to observe the capture γ rays from a thin foil at a distance ℓ in a TOF beam. And at another "good geometry" point in the beam various thicknesses of the same material are introduced in the beam as filters. Thus, the transmission of the filter resonances is measured using the same resonances in the detectors. This technique has been suggested to improve resolution by only observing the peak portion of the resonance.

However, let us assume that the transmission sample is thick and that no neutrons at the resonance peak are present. In this case the resonance detector response is shown in the following figure.



(a) Transmission through transmission filter

(b) Response of resonance detector

Figure 1

This shows two peaks which occur at the edges of the resonance. Now suppose that the filter in Fig. 1(a) is cooled and that the detector in Fig. 1(b) is heated. By controlling temperature the sizes and widths of the peaks in 1(b) can be varied. Calculations would be required to verify the effect and to optimize the widths. Width variations may not be as dramatic as desired or indicated above.

A better way seems to be that of changing E_0 in the laboratory by moving the detector or transmission filter. Thus, if the detector foil is moved toward the transmission filter the resonance will occur in the moving foil for a lower laboratory energy than that in the fixed foil. The following table shows the change in ΔE_0 as a function of the velocity of the moving foil.

ΔE_0	v (foil)
1 meV	2.7 m/sec
10 meV	27 m/sec
20 meV	56 m/sec
50 meV	135 m/sec

This approach has merit and will be tested. Unfortunately these velocities are a thousand times those used in Mössbauer spectroscopy and will probably require a design involving rapidly rotating components. By moving in one direction only, a single variable width peak can be obtained.

Carpenter pointed out that a fission foil with a solid state fission fragment detector is compatible with large peak cross sections. This would also increase the detection efficiency and eliminate background problems. In general fission levels are wider because the fission width is added to the capture. It appears that the transmission filter should be the moving foil in this detector configuration.

Acoustic Fission Detector

Large fission pulses can be heard acoustically. Use with wires as acoustic delay lines for position-sensitive detectors.

Boron-Based Solid State Detectors

Develop boron or boron compound semi-conductors. If not possible as boron or boron compounds, develop boron-diffuse junction silicon-layered counters. Such ideas could be applied to the fissionable isotopes and lithium compounds.

Absorbed ^{3}He Detectors

Vicor glasses can absorb large amounts of ^{3}He. Perhaps scintillation glasses could be developed having this property. Look for scintillating uranium glasses.

Cadmium Telluride Detectors

Cadmium telluride has been a candidate as a photon detector for many years, but large crystal size has not been accomplished. Small crystals should be examined as possible position-sensitive detectors.

Other Scintillator Techniques

Organic scintillators in combination with boron, lithium liquids, or particles should be examined. Hornyak buttons incorporating B_2O_3, ZnS and light transmitting media are old ideas which deserve a review with new materials.