ICANS XIV
14th Meeting of the International Collaboration on
Advanced Neutron Sources
June 14-19, 1998
Starved Rock Lodge, Utica, IL

BNL Activities in Advanced Neutron Source Development: Past and Present

J.B. Hastings, H. Ludewig, P. Montanez, M. Todosow, G. C. Smith, and J.Z. Larese
Brookhaven National Laboratory

Introduction

Brookhaven National Laboratory has been involved in advanced neutron sources almost from its inception in 1947. These efforts have mainly focused on steady state reactors beginning with the construction of the first research reactor for neutron beams, the Brookhaven Graphite Research Reactor. This was followed by the High Flux Beam Reactor that has served as the design standard for all the subsequent high flux reactors constructed worldwide. In parallel with the reactor developments BNL has focused on the construction and use of high energy proton accelerators. The first machine to operate over 1 GeV in the world was the Cosmotron. The machine that followed this, the AGS, is still operating and is the highest intensity proton machine in the world and has nucleated an international collaboration investigating liquid metal targets for next generation pulsed spallation sources. Early work using the Cosmotron focused on spallation product studies for both light and heavy elements into the several GeV proton energy region. These original studies are still important today.

In the sections below we discuss the facilities and activities at BNL focused on advanced neutron sources. BNL is involved in the proton source for the Spallation Neutron source, spectrometer development at LANSCE, target studies using the AGS and state-of-the-art neutron detector development.

Proton sources

BNL has a long and internationally recognized involvement in high intensity proton sources. The AGS which presently operates mainly for high energy physics can provide single pulse energies approaching those of the most intense spallation neutron sources that are now being planned. BNL is also specifically responsible for the compressor ring construction for the Spallation Neutron Source (SNS) at Oak Ridge TN.

The proton beam intensity in the AGS has increased steadily over the 35 year existence of the AGS, but the most dramatic increase occurred over the last few years with the addition of the new AGS Booster. The AGS Booster has one quarter the circumference of the AGS and therefore allows four Booster beam pulses to be stacked in the AGS at an injection energy of 1.5 GeV. At this energy, space charge forces are much reduced and this in turn allowed for the dramatic increase in the AGS beam intensity.

The beam intensity in the Booster has surpassed the design goal of 1.5×10^{13} protons per pulse and has already reached a peak value of 2.2×10^{13} protons per pulse. The AGS itself also had to be upgraded extensively to be able to cope with the higher beam intensity. The peak beam intensity reached at the AGS extraction energy of 24 GeV is 6.3 10^{13} protons per pulse, also exceeding the design goal for this latest round of intensity upgrades. This represents a world record beam intensity for a proton synchrotron. This level of performance was reached quite consistently during the last AGS experimental run of 24 weeks during which more than 10^{20} protons were accelerated in the AGS to 24 GeV.

This performance is ideally matched to the R&D needs of the neutron spallation source community for high power targets for the next generation sources. To take advantage of this an international collaboration was formed. The partners include

Forschungzentrum Jülich and Paul Scherrer Institut with interests directed toward the European Spallation Source, the Japan Atomic Energy Research Institute (JAERI) with a proposal for a 5 MW short pulse source and Oak Ridge National Laboratory and Brookhaven National Laboratory who are partners in the SNS to be located in Oak Ridge, TN.

The AGS Spallation Target Experiment (ASTE) has made preliminary measurements of neutron production, power deposition and pressure wave phenomena on a mercury target in the summer of 1997. Initial results of these efforts are reported at ICANS XIV by the various participants.

Spectrometer development

The Department of Energy is investing in upgrades at LANSCE in both the source and instrumentation. As a part of the instrumentation upgrade several Spectrometer Development Teams have formed to provide new instrumentation. J. Z. Larese, BNL Chemistry, is leading an SDT for a crystal backscattering spectrometer (CBS) to be built at BNL and installed at LANSCE.

There is a need in the United States for a state-of-the-art, cold-neutron CBS designed to investigate the structure and dynamics of condensed matter systems by the simultaneous utilization of long wavelength elastic diffraction and high-energy-resolution inelastic scattering. Cold neutron spectroscopy with CBS-type instruments has already made many important contributions to the study of atomic and molecular diffusion in biomaterials, polymers, semiconductors, liquid crystals, superionic conductors and the like. Such instruments have also been invaluable for ultra high resolution investigations of the low-lying quantum tunneling processes that provide direct insight into the dynamical response of solids at the lowest energies. Until relatively recently, however, all such instruments were located at steady-state reactors. This proposal describes HERMES I (High Energy Resolution Machines I) a CBS intended for installation at the LANSCE pulsed neutron facility of Los Alamos National Laboratory

The need for such an instrument was originally demonstrated by the success of the IRIS CBS at the ISIS pulsed neutron facility of the Rutherford Appleton Laboratory which made it clear that pulsed neutron and steady-state sources are equally effective for cold neutron spectroscopy. Intended originally as a quasielastic spectrometer for the study of diffusional motions, IRIS has had a major impact on the field of low energy inelastic spectroscopy as well by combining high resolution with a wide-enough energy transfer range to permit access to very-low-lying excitations in ground-state systems. (This Q,ω range is not accessible in equivalent, direct-geometry instruments because the energy transfer range is coupled to the incident neutron energy.) In fact so heavy is the demand for IRIS (it is currently oversubscribed by more than a factor of five) that only a few days per year are available to investigate new possible applications.

Including a white beam diffraction detector in a CBS adds to such instruments the capability of simultaneous diffraction and inelastic spectroscopy, thus - as recently demonstrated by experiments on IRIS - further enhancing their utility. And because IRIS-type instruments use neutrons with wavelengths as long as 25 Å, they have the attractive feature of extending the range of diffraction studies to long range magnetic periodicities and other types of large-scale structural ordering.

We propose to construct an updated, high-performance CBS which incorporates neutron techniques developed during the decade since IRIS was built, i.e. improved supermirror technology, a larger area crystal analyzer and high efficiency wire gas detectors. The instrument is designed in such a way as to be readily adaptable to future upgrades. HERMES I, we believe, will substantially expand the range and flexibility of neutron investigations in the United States and open new and potentially fruitful directions for condensed matter exploration. This document describes a implementation plan with a direct cost range between $4.5 to 5.6 M and scheduled duration of 39-45 months for identified alternatives.

Position sensitive thermal neutron detectors

Detector development for thermal neutron scattering experiments in the study of biological structures has been underway for some years at Brookhaven. The technology of choice has been the gas proportional detector, with ^{3}He as the neutron absorbing gas, because of several beneficial factors. These detectors offer superior efficiency to that of almost all other detectors, their maximum counting rate capability is adequate for that required in most reactor and spallation source applications, they can be built in a wide range of sizes, they are very insensitive to gamma radiation with appropriate choice of gas mixture, and their position stability is better than most other detectors. In single neutron counting mode, they offer infinite dynamic range for static experiments, while also offering the capability of performing dynamic studies with time frames below one second.

The reaction $^3He + n \rightarrow {}^3H + p + 0.764$ MeV represents the process by which neutrons interact with a helium three atom. The ionization centroid of the tracks of the two resultant particles is displaced from the interaction position because the proton is more heavily ionizing than the triton, and has a longer range. To a first approximation the FWHM position resolution is 0.8 times the proton range [1] and a quench gas such as propane is added the the helium in order to provide stopping power for the proton and triton. A resolution of about 1.5 mm FWHM can be achieved with 2.5 atm propane, a standard operating parameter in detectors with an active area of 20cm by 20cm. Combined with 4 or 5 atm ^{3}He, this results in a high resolution, high efficency detector which, with a suitable gas purification and circulating system [2], can operate for some years with no servicing. Other detectors of the same type that we have built are ones with a sensitive area of 50cm by 50cm, and one with 5cm by 5cm. The latter, because it is compact, can maintain a very high pressure. The propane in this device has a pressure of 6atm and the detector yields a resolution of less than 400 microns FWHM [3], the best resolution for a gas based neutron detector ever recorded.

Position information is obtained from the cross-wire cathodes that sandwich the anode plane. A readout has been developed in which the center of gravity of the induced cathode charge from a single event is determined from charge division between two, or at most three, closely spaced nodes [4]. Each cathode comprises about 20 nodes, providing a continuously sensitive readout, and permitting low readout noise with only a modest avalanche size, which is essential to the for the longevity of the detector.

A useful summary of operating characteristics of gas filled proportional chambers for thermal neutron detectors is given in table 1. It should be noted that not all the properties listed can necessarily be achieved in one detector at the same time. A set of detectors has been designed and fabricated which provide high resolution, stable, and reliable performance to a range of structural biology experiments. In this ongoing program, new devices and techniques are under development; for example, methods to minimize parallax errors in planar detectors for small angle experiments are being investigated, and large, curved detectors for crystallography experiments are being studied. Finally, it should be emphasized that the proportional detectors described here have one important advantage over competing devices such as image plates and phosphor/CCDs: the proportional detector, with sub-microsecond timing resolution, is the only device from these three with adequate timing resolution for white beam experiments at spallation sources.

Table 1: Performance Figures

Position Resolution (FWHM)	<0.4 - 2 mm
Number of Resolution Elements	from 128×128 to 1024×1024
Size	from 5×5 cm^2 to 50×50 cm^2
Wavelength Range	1 - 20 Å
Detection Efficiency	50 - 80 %
Counting Rate (total)	10^5 - 5×10^5 sec^{-1} (single readout)
Counting Rate (single peak)	5×10^4 sec^{-1}
Integral non-linearity	2×10^{-4} to 10^{-3}
Absolute Position Accuracy	30-100 μm
Stability of Origin	<50 μm
Stability of Response (efficiency)	<1%
Differential non-linearity	±3%
Dynamic Range	Single Neutron Detection
Timing Resolution	~ 1 μs

References:

1. Fischer, J., Radeka, V. and Boie, R.A., 1983, High Position Resolution and Accuracy in He^3 Two-dimensional Thermal Neutron Detectors. *Workshop on The Position-Sensitive Detection of Thermal Neutrons, ILL, Grenoble, France 11-12 October 1982. Proceedings edited by P. Convert and J.B. Forsyth (Academic Press, London)*, p129.

2. Boie, R.A., et al., 1982, Two-Dimensional High Precision Thermal Neutron Detectors, *Nucl. Instrum. & Meth.* 200: 533-545.

3. Radeka, V., Schaknowski, N.A., Smith, G.C. and Yu, B. 1996, High Precision Thermal Neutron Detectors. In "Neutrons in Biology", ed B.P. Schoenborn and R.B. Knott, Plenum Press, 1996, 57-67.

4. Radeka, V. and Boie, R.A., 1980, Centroid Finding Method for Position-Sensitive Detectors, *Nucl. Instrum. & Meth.* 178: 543-554.